An Approach: SysML-based Automated Consistency Evaluation of the System Requirements Specification

Jovita Bankauskaite
Department of Information Systems
Kaunas University of Technology
Kaunas, Lithuania
jovita.bankauskaite@ktu.lt

Aurelijus Morkevicius
Department of Information Systems
Kaunas University of Technology
Kaunas, Lithuania
aurelijus.morkevicius@ktu.lt

***Abstract*— Systems Modeling Language (SysML) is used for specifying, analyzing, designing and verifying complex systems, and is designed to provide simple but powerful constructs for modeling a wide range of Systems. SysML is not a methodology, nor a method and there are thousands of different ways to describe the using it. In this case, there cannot be a single, universal approach to evaluate the consistency of the requirements specification. It is necessary to choose a specific method in combination with SysML to accurately and comprehensively evaluate the consistency of requirements specification. The consistency evaluation of requirements specification in model-based system engineering (MBSE), depending on the modeling language and method is quite a new practice. This opens up discussions of how to utilize SysML provided infrastructure to evaluate the System Requirements Specification (SRS) and achieve a high-quality of the SRS. In this paper, a new approach of how requirements specification, expressed with sufficient precision in SysML can be used for automated consistency evaluation.**

Keywords—SysML, MBSE Grid, Consistency Metrics, System Requirements Specification, Requirements Engineering, MBSE

I. INTRODUCTION

Due to model-based engineering progress in recent years, system engineering slowly but surely moves from document-based system engineering to model-based system engineering. Nowadays, MBSE is enabled by Systems Modeling Language.

SysML is a general-purpose graphical modeling language that supports the analysis, specification, design, verification, and validation of complex systems. The language is intended to create cohesive and consistent models of structure, behavior including their interconnections. SysML introduces requirement diagrams, which represent requirements and their relationships to other requirements, design elements and test cases [1].

Requirements engineering is one of the most important and critical phases in MBSE which consists of two main processes: specification and management. Generally, for systems engineers are more important requirements specification process than requirements management process. While managers focus is on the requirements management process, but they have a poor understanding of the benefits of MBSE. According to PMI's study, poor requirements management is the second most common reason for project failure [4].

In order to reduce the risk of mistakes detection and correction in the late stage of development, it is desirable and important to identify the inconsistencies in a requirements specification in the early stages of systems engineering. The mistakes due to incompleteness, inconsistency, and ambiguity introduced at the stage of requirements engineering are difficult and more expensive to correct than those introduced in later stages of system development [5]. Mistakes in requirements specification may arise if the consistency of the specification is violated or the stakeholder requirements are misrepresented by the specification. Completeness and correctness (C&C) analysis of requirements specification aims to eliminate occurred mistakes.

In this paper, we focus on a subset of the C&C task – correctness analysis only. We understand the correctness of SRS as the nonexistence of inappropriate relationships between requirements and model elements. The question is how to utilize SysML provided infrastructure to successfully achieve a high quality of the requirements specification: what method to use in combination with SysML.

In this paper, we propose a new approach of how requirements specification that is expressed in SysML in combination with MBSE Grid method can be used for automated consistency evaluation of the system requirements specification.

The MBSE Grid method guides how to specify principal areas of the system model and how to manage different layers of abstraction [7].

The MBSE Grid is organized in a matrix view. Columns represent four main aspects of systems engineering (requirements, system structure, system behavior and parameters). Rows represent two main viewpoints: one to define the problem in order to understand it, other to provide one or several alternative solutions to solve it. Cells of the grid (Fig. 1) represent different views of model-based systems engineering [8]. Specified traceability among view specifications is a very important aspect of the MBSE Grid method. The method helps to organize and maintain the model.

This research is carried out using MagicDraw toolset, which supports SysML. It was chosen because of several published studies, e.g. [9], [2], [10], [11].

The rest of this paper is structured as follows: in section 2, the related works are analyzed; in section 3, the proposed approach for automated consistency evaluation of the requirements specification is presented; in section 4, evaluation of the proposed approach is described; in section 5, the achieved results, conclusions, and future work directions are indicated.

II. Related Works

There is a large number of research papers on the consistency analysis of requirements specification. Most of them are applied to the small area of the domain or a specific tool, e.g. [12], [13], [3].

Several authors proposed methodologies for evaluation of consistency within the UML models which are applicable to SysML, as SysML is the extension of UML. Methods defined in [14], [15], [16], [17], [18] use formal techniques for consistency evaluation, e.g. Object-Z in [14], algebra in [15], attributed graph grammars in [16] focusing mainly on class diagrams and behavior diagrams. [17] describes an algorithmic approach for consistency evaluation between UML sequence and state machine diagrams while [18] proposes a declarative approach using process algebra CSP for consistency evaluation between sequence and state machine diagrams.

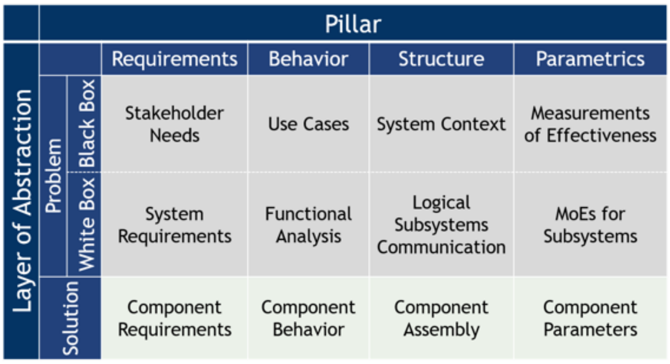

Fig. 1. MBSE Grid

Use of traceability relationships to evaluate the consistency of the requirements specification has been defined in [19], [20], [21], [22]. [20] proposes consistency analysis method to identify the inconsistencies in the requirements. This method checks requirements consistency in forward and backward directions. The inconsistencies found between requirements and structural elements are logged into configuration inconsistency matrix. A method in [22] uses traceability and manages fuzzy relationships between high-level software artifacts (requirements), uses case models and black box test plans.

In [23] publication is proposed set of metrics based on requirements and UML design models for an object-oriented system to measure the degree of consistency of design models with respect to requirements. The metrics defined in this method are based on the linking of two different types of elements, e. g. class and activity.

In conclusion, all the analyzed methods to evaluate the consistency of requirements specification encounter several common issues: (i) unclear traceability relationships between requirements and design elements, (ii) unsupported consistency evaluation at all stages of the requirements specification, (iii) it is difficult to interpret the results of consistency evaluation.

Overall, researches carried out in this area have very little proof of its successful application on real-industry cases or is very specific to a small area of application and specific tools dependent. We are proposing a more generic, easy to use approach, applicable to the majority of SysML modeling tools for different systems engineering domains. The proposed approach in combination with MBSE Grid will evaluate the consistency of each stage of requirements specification. This will help to monitor the quality of SRS and make the necessary decisions in the early stage of requirements specification process.

III. An Approach for Consistency Evaluation of System Requirements Specifications

This section describes the proposed approach in detail.

The approach consists of the following metric groups that are defined on the basis of the principles of MBSE Grid method:

A. Requirements Refinement Metrics

B. Requirements Satisfaction Metrics

C. Requirements Verification Metric

The metric groups mentioned above compute only atomic model elements that are linked to the atomic requirements (child requirement). The relation between atomic requirements and atomic model elements eliminates the ambiguities that may occur having relations between higher level elements.

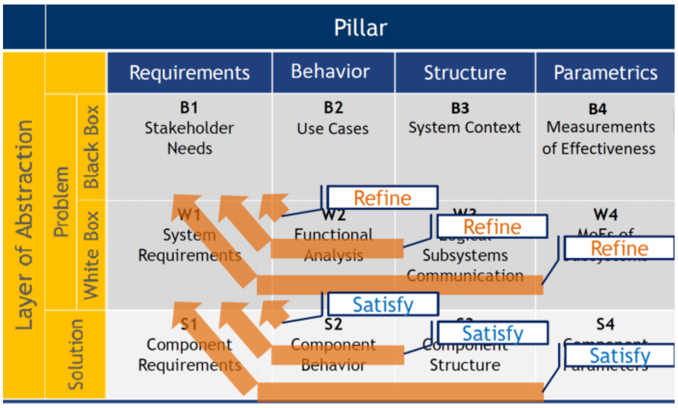

Fig. 2. MBSE Grid Traceability

The approach is based on specified traceability relationships in MBSE Grid [Fig. 2]. Requirements Refinement Metrics compute the consistency of requirements specification at problem layer. This metrics group evaluates the refinement of stakeholder needs by elements that are specified at stages of functional analysis, logical subsystems communication and measurements of effectiveness of Subsystems (MoES). Requirements Satisfaction Metrics compute the consistency of requirements specification at solution layer. This metrics group evaluates system requirements satisfaction by elements that are specified at stages of component behavior, structure and parameters. Requirements Verification Metric evaluates the consistency between system requirements and test cases.

The proposed method concerns the consistency evaluation of the system requirements specifications. An approach is implemented in the MagicDraw modeling tool.

In order to obtain the more precise evaluation results of requirements specification, metrics are categorized by three aspects of system engineering: Behavior, Structure, and Parameters.

The following subsections describe in detail each consistency metric of requirements specification.

A. Requirements Refinement Metrics

This metric group evaluates the consistent use of model elements to refine stakeholder needs. The stakeholder needs are refined by the behavior elements specified in the functional analysis, by the structure elements specified in the logical subsystem communication and by the parameters specified at the measurements of effectiveness.

The metric group of requirements refinement consists of the following metrics:

- *Functional Requirements Refinement by Behavior Elements Metric*

This metric evaluates the utilization of behavior elements to refine requirements. The atomic activity elements defined in the functional analysis have to refine the atomic functional requirements of stakeholder. Below is provided the metric formula.

$$MER_{BE} = \frac{BE_{RFR}}{BE} \times 100\% \tag{1}$$

MER_{BE} - functional requirements refinement by behavior elements metric

BE_{RFR} – quantity of behavior elements used to refine functional requirements

BE – quantity of behavior elements defined in the functional analysis

- *Physical Requirements Refinement by Structure Elements metric*

This metric evaluates the utilization of structure elements to refine requirements. The atomic block or part elements defined in the logical subsystem communication have to refine the atomic physical requirements of stakeholder. Below is provided the metric formula.

$$MER_{SE} = \frac{SE_{RPhR}}{SE} \times 100\% \tag{2}$$

MER_{SE} - physical requirements refinement by structure elements metric

SE_{RPhR} – quantity of structure elements used to refine physical requirements

SE – quantity of structure elements defined in the logical subsystem communication analysis

- *Interface Requirements Refinement by Proxy Elements metric*

This metric evaluates the utilization of proxy elements to refine requirements. Proxy ports defined in the logical subsystem communication have to refine the atomic interface requirements of stakeholder. Below is provided the metric formula.

$$MER_{PPE} = \frac{PPE_{RIR}}{PPE} \times 100\% \tag{3}$$

MER_{PPE} – interface requirements refinement by proxy elements metric

PPE_{RIR} – quantity of proxy port elements used to refine interface requirements

PPE – quantity of proxy port elements defined in the logical subsystem communication analysis

- *Performance Requirements Refinement by Parameters Elements metric*

This metric evaluates the utilization of value property elements to refine requirements. The value property elements defined in the measurements of effectiveness have to refine the atomic performance requirements of stakeholder. Below is provided the metric formula.

$$MER_{PE} = \frac{PE_{RPR}}{PE} \times 100\% \tag{4}$$

MER_{PE} - performance requirements refinement by parameters elements metric

PE_{RPR} – quantity of parameters elements used to refine performance requirements

PE – quantity of behavior elements defined in the measurements of effectiveness analysis

B. Requirements Satisfaction Metrics

This metric group evaluates the consistent use of model elements to satisfy system requirements.

The metric group of model elements usage for requirements satisfaction consists of the following metrics:

- *Functional Requirements Satisfaction by Behavior Elements metric*

This metric evaluates the utilization of behavior elements to satisfy requirements. The atomic activity elements defined in the component behavior have to satisfy the atomic functional requirements of the system. Below is provided the metric formula.

$$MES_{BE} = \frac{BE_{SFR}}{BE} \times 100\% \tag{5}$$

MES_{BE} - functional requirements satisfaction by behavior elements metric

BE_{SFR} – quantity of behavior elements used to satisfy functional requirements

BE – quantity of behavior elements defined in the component behavior analysis

- *Physical Requirements Satisfaction by Structure Elements metric*

The metric evaluates the utilization of structure elements to satisfy requirements. The atomic block or part elements defined in the component assembly have to satisfy the atomic physical requirements of the system. Below is provided the metric formula.

$$MES_{SE} = \frac{SE_{SPhR}}{SE} \times 100\% \qquad (6)$$

MES_{SE} - physical requirements satisfaction by structure elements metric

SE_{SPhR} – quantity of structure elements used to satisfy physical requirements

SE – quantity of structure elements defined in the component assembly analysis

- *Interface Requirements Satisfaction by Proxy Elements metric*

This metric evaluates the utilization of proxy elements to satisfy requirements. Proxy ports defined in the component assembly have to satisfy the atomic interface requirements of the system. Below is provided the metric formula.

$$MES_{PPE} = \frac{PPE_{SIR}}{PPE} \times 100\% \qquad (7)$$

MES_{PPE} – Interface Requirements Satisfaction by Proxy Elements metric

PPE_{SIR} – quantity of proxy port elements used to satisfy functional requirements

PPE – quantity of proxy port elements defined in the component assembly analysis

- *Performance Requirements Satisfaction by Parameters Elements metric*

The metric evaluates the utilization of value property elements to satisfy requirements. The value property elements defined in the component parameters analysis have to satisfy the atomic performance requirements of the system. Below is provided the metric formula.

$$MES_{PE} = \frac{PE_{SPR}}{PE} \times 100\% \qquad (8)$$

MES_{PE} - performance requirements satisfaction by parameters elements metric

PE_{SPR} – quantity of parameters elements used to satisfy functional requirements

PE – quantity of parameters elements defined in the component parameters analysis

C. *Systems Requirements Verification metrics*

This metric evaluates the consistent use of test cases to verify the system requirements. Defined test cases have to verify atomic system requirements. Below is provided the metric formula.

$$TCV = \frac{TC_{SR}}{TC} \times 100\% \qquad (9)$$

TCV – system requirements verification metric

TC_{SR} – quantity of test cases used to verify system requirements

TC – quantity of test cases

D. *Refinement Evaluation of Stakeholder Needs*

This subsection describes in detail the principles of the refinement evaluation of stakeholder needs applying the requirements refinement by behavior elements metric (1).

The figure below (Fig. 3) represents the stakeholder needs refinement by atomic activity element.

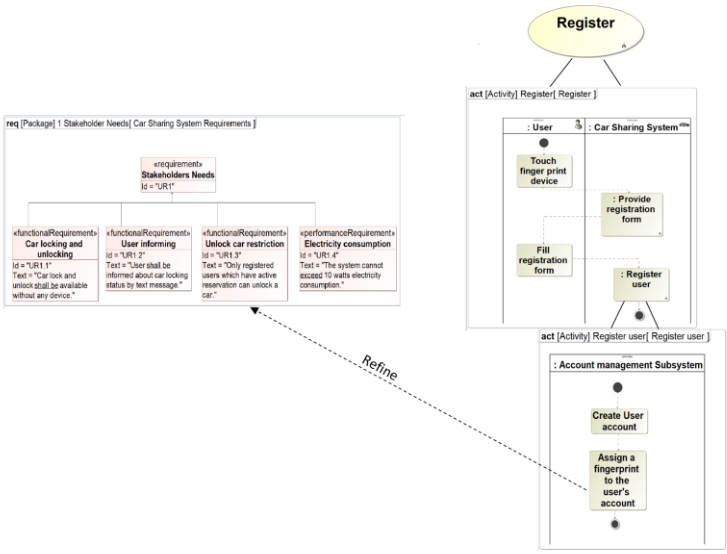

Fig. 3. Refinements of stakeholder requirements

First, we calculate the quantity of atomic activity elements that are defined in the functional analysis. Activities have to represent the behavior of the system.

Second, we calculate the quantity of atomic activity elements that are used to refine the atomic functional requirements of stakeholder.

Third, we calculate the evaluation of requirement refinement by behavior elements using the particular metric.

Below is provided the result of the evaluation of stakeholder need refinement according to Fig. 3.

$BE_{RFR} = 1$

$BE = 2$

$$MER_{BE} = \frac{1}{2} \times 100\% = 50\% \qquad (10)$$

This indicates that 50% of the activities which are specified at the stage of function analysis are used to refine the stakeholder needs.

IV. Case Study

This section describes the case study of the proposed approach. This is a case study of a commercial project to evaluate the consistency of the requirements specification.

The following is a detailed description of the consistency analysis of requirements specification. The commercial project is based on SysML and is modeled in the MagicDraw toolset. The modeling carried out in accordance with the principles of MBSE grid.

Requirements specifications Consistency metrics have been computed over the entire period of SRS. After each metric calculation, the responsible persons have been analyzed the metrics data and made appropriate decisions to ensure a high quality of the SRS.

Fig. 4 shows the part of requirements satisfaction metric table that is computed in the MagicDraw tool. For effective analysis, metrics data was exported to the excel and the visual charts were created according to the metrics data.

#	Date	Systems Functional Requirements	Satisfied By Behavior	Satisfied By Behavior Percentage	Systems Physical Requirements	Satisfied By Design	Satisfied By Design Percentage
1	2017.10.19 09.10	67	47	70.15	44	0	0.00
2	2017.10.27 11.14	67	55	82.09	44	0	0.00
3	2017.11.10 12.22	67	63	94.03	44	13	29.55
4	2017.11.22 14.33	67	66	98.50	44	37	84.09
5	2017.12.07 15.02	67	67	100.00	44	40	90.90
6	2017.12.18 18.09	67	67	100.00	44	42	95.45

Fig. 4. Metric Table

Below is provided a detailed analysis of each metric groups that are presented in the charts.

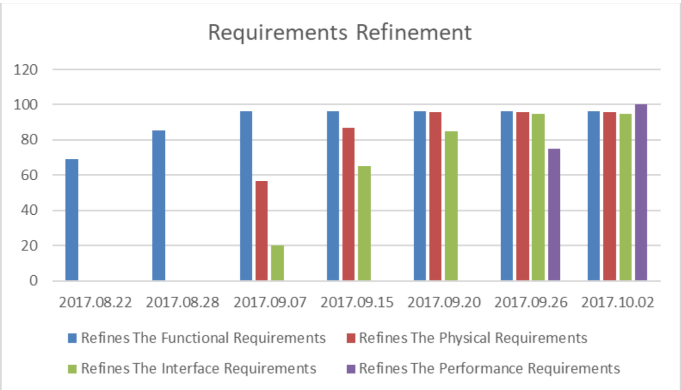

Fig. 5. Requirements Refinement Diagram

In Fig. 5 is displayed refinement analysis diagram of requirements specification. Requirements refinement metrics have been computed over a period specifying the problem layer of requirements specification. First, the functional requirements of stakeholder have been refined by behavior elements. Reaching the 85% of behavior elements usage for refining functional requirements of stakeholder has been started another stage, the refinement of physical and interface requirements. Reaching over the 80% of proxy ports usage for refining interface requirements of stakeholder and structure elements usage for refining physical requirements of stakeholder has been started the refinement of performance requirements stage. When all metrics reached over 90%, it was decided that the refinement of requirements specification is sufficient.

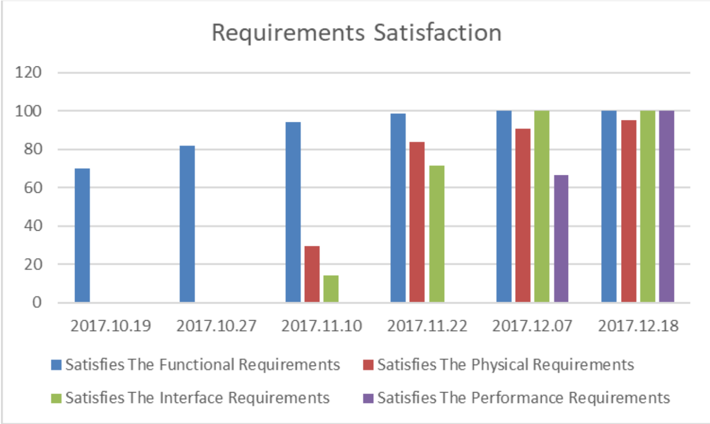

Fig. 6. Requirements Satisfaction Diagram

In Fig. 6 is displayed satisfaction analysis diagram of requirements specifications over a period specifying the solution layer of requirements specification. First, the functional requirements of the system have been satisfied by behavior elements. Reaching the 82% of behavior elements usage for satisfying the functional requirements of the system has been started another stage, the satisfaction of physical and interface requirements. Reaching over the 85% of proxy ports usage for satisfying the interface requirements and structure elements usage for satisfying the physical requirements has been started other stage, the satisfaction of performance requirements. When all metrics reached over 90%, it was decided that the satisfaction of requirements specification is sufficient.

V. Conclusion and Future Works

The analysis of existing consistency evaluations methods for the requirements specification disclosed that there are multiple different methods available. The majority of them cannot be used in combination with systems modeling techniques, such as SysML, in practice. We found a need to propose a more generic, easy to use approach, applicable to the majority of SysML modeling tools for different system engineering domains.

In this paper, we proposed a new approach of how requirements specification, expressed with sufficient precision in SysML, can be used for automated consistency evaluation. The approach consists three metric groups that are defined on the basis of the principles of MBSE Grid method: Requirements Refinement Metrics, Requirements Satisfaction Metrics, Requirements Verification Metric.

We have implemented the proposed approach in the MagicDraw CASE tool and demonstrated an example case study. After analyzing the case study, it was determined that calculation of the consistency metrics over a period contributes to ensure a high quality of each stage of requirements specification.

Currently, the approach is oriented to automated consistency evaluation of requirements specification. However, we plan to extend the approach in the near future, to evaluate the completeness of requirements specification and, finally, we seek to combine both to evaluate more precisely the requirements specification in model-based systems engineering.

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