Verification and Validation Activities for Embedded Systems
A Feasibility Study on a Reading Technique for SysML Models

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Abstract: Embedded Systems play an important role on today's interconnected world. However, there is a gap in relation to Verification and Validation (V&V) activities for Embedded Systems, particularly when they are designed with SysML models. Hence, the objective of this paper is to present a feasibility study on a Reading Techniques for detecting defects in SysML models. This technique is part of a family of reading techniques for inspecting Requirement Diagrams and State Machine Diagrams which are SysML models designed along the SYSMOD development process. The definition of these techniques required the establishment of a defects taxonomy, which was based on three sources: i) the certification standards for embedded systems UL-98 and DO-178C; ii) the Failure Mode and Effects Analysis (FMEA); and iii) the syntactic and semantic elements available in the formalism of the SysML language. A feasibility study was carried out to evaluate the effectiveness and efficiency of one of the techniques. From a total of 26 subjects, 50% have found an average of 72% of defects and spent an average of 48 minutes.

1 INTRODUCTION

The development process of Embedded Systems requires strict definition of functional and non-functional requirements such as, for example, time constraints (real-time), reliability and accurate requirements definition (Liggesmeyer and Trapp, 2009). In this context, the Embedded Systems Engineering aims to explore techniques and strategies largely used in the traditional software engineering to promote quality in the embedded systems development (Graaf, Lormans and Toetenel 2003). As a result, the modeling techniques and formal languages for the development of embedded systems have been pointed by the literature as promising approaches. As examples, we can cite the Unified Modeling Language (UML) and its extensions RT and MARTE (OMG, 2011); SysML (OMG, 2010) and Model-Driven Architecture (MDA) (Pastor and Molina, 2007). In terms of the software development process, there is the SYSMOD process which is a top-down process that uses the artifacts of the SysML language to model the functional and non-functional requirements (Weilkiens, 2008).

However, despite the adoption of a process, it is also important to apply software quality control activities to ensure that both the process and the artifacts generated during the execution of this process have the expected quality. Examples of software quality control activities are activities of Verification and Validation (V&V) such as inspection and testing. These types of activities have been considered as an essential practice for critical missions, especially for software that controls manned and unmanned aerial vehicles (UAV) (Albaker and Rahim, 2010). In addition, activities of V&V should be applied along all the process aiming to anticipate possible failures generated by the lack of formalism during the transcription of requirements to high level abstraction models.

The activities of V&V are considered as follows: static activity, as inspection; and dynamic activity, as the testing activity. The inspection activity was initially proposed by Fagan (1976). It is considered a static activity because it does not require the execution of the artifact under inspection. It is supported by reading techniques that provide to the inspector guidelines for reading the artifact. However, there is a lack of reading techniques for embedded systems, mainly comprised for UML/SysML and MATLAB/Simulink models.

Therefore, considering the importance of the software quality control activities, the contributions of this paper are: (*i*) to show that readings techniques can aid the identification of defects of SysML models; (*ii*) to present the family of reading techniques that was created to support the inspection of SysML and MATLAB/Simulink models generated by SYSMOD process; and (*iii*) to present the feasibility study that was carried out to explore the feasibility of using such type of technique.

This paper is organized as follows: in Section 2 related works are commented; Section 3 presents the family of reading techniques in the context of the SYSMOD process; Section 4 describes the feasibility study carried out for evaluating one of the techniques; and Section 5 presents the conclusion e future work.

2 RELATED WORK

Before starting the definition of the reading techniques addressed in this paper, we conducted a Systematic Mapping (SM) (Petersen et al., 2008) aiming to identify the main studies related to V&V activities in the context of embedded systems — specifically in the modeling level. Systematic Mappings are used, to detect literature evidence about a topic to be explored while Systematic Literature Reviews (SLR) (Kitchenham, 2004) are used to identify, evaluate and interpret all relevant research on a particular topic, aiming to establish the state of the art about it. Frequently, SMs precede SLRs.

In this SM a total of 411 studies were gathered and during the *screening phase* — i.e., the selection of relevant studies based on the inclusion and exclusion criteria, just 80 of them were accepted. After that, during the *keywording phase* — i.e., the definition of the classification scheme, some facets were defined. Among them, the three facets showed in Figure 1, highlighted a gap regarding inspection activities, particularly for detecting defects in SysML models and Simulink models. Besides, only 49 studies, from the total of 80 studies, satisfy the categories grouped in these facets. The other 31 studies address V&V activities for embedded system but are not related to these three facets specifically.

Figure 1 maps the 49 studies according to these facets. Observe from these 49 studies that 24 are related to facet (1) and facet (2); and 25 are related to facet (3) and facet (2). Hence, for example, there is one study that addresses both the categories: Reading Techniques and V&V Process; there are 8 studies that address Test Case Generation and V&V techniques. Also, it is important to notice that the same study can be included in more than one relationship.

Aiming to exemplify the initiatives that are being conducted, three studies will be commented. The first study refers to the static activity of inspection. Denger and Ciolkowski (2003) propose a Reading technique for inspecting Statecharts models inspired on *Perspective Based Reading* (PBR) (Basili et al., 1996). Hence, the authors propose a taxonomy that establishes quality criteria that should be present in Statechart specifications of embedded systems.

Another study refers to the use of certification standards for validating embedded system models. In this case the certification standard DO-178C is suggested as a V&V support activity in the context of the GENESYS architecture. Although the authors emphasize the importance of using UML/SysML in this architecture, they do not address the use of reading techniques. However, inspection has been pointed out as an effective way for detecting defects along a process and some reading techniques have been proposed. As example we can cite the following techniques: (i) PBR – Perspective Based Reading (Basili, Caldiera and Rombach, 1996), which is used to inspect requirement documents; (ii) UBR – Use Based Reading, which is used to detect anomalies in user interface (Zhang, Basili and Shneiderman, 1998); and (iii) OORTs – Object Oriented Reading Techniques (Travassos et al., 2000), which are used for inspecting UML models at project level; and (iv) OORTs/ProDES (Marucci et al., 2002), which are used for inspecting UML models that are constructed according to the ProDES process. Therefore, V&V activities have been widely investigated by researches from different points of view. However, no work was identified that explored inspection activities for SysML models, which are widely used for modeling embedded systems.

3 A FAMILY OF READING TECHNIQUES FOR SYSML MODELS

SysML/System Modelling (SysML/SYSMOD) (Weilkiens, 2008) is a top-down process of software development which has been highlighted in the community of embedded systems.

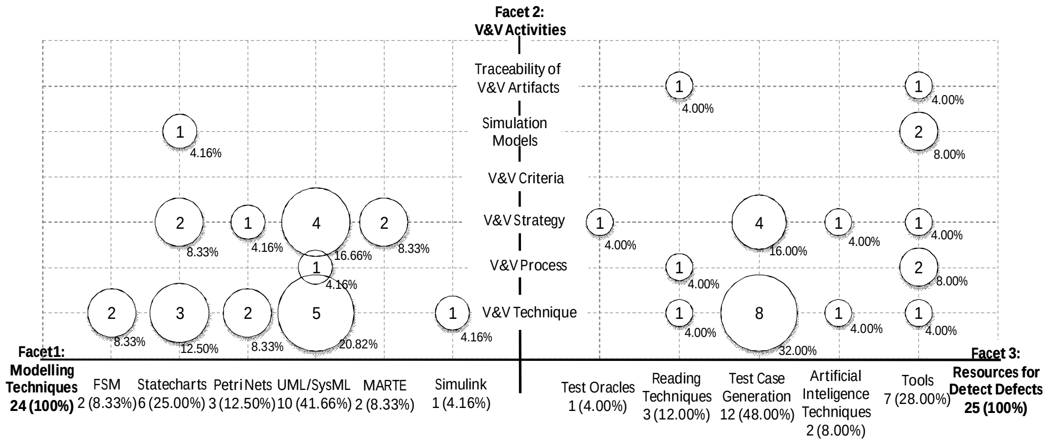


Figure 1: Systematic Mapping for V&V Activities.

Considering the importance of the application of verification and validation activities for quality in software development and also that the SYSMOD process uses SysML diagrams, we define a family of reading techniques to be used with the SYSMOD process.

The goal of these techniques is to establish a quality control activity to ensure that the information is correctly transcribed from a diagram to another diagram. Thus, any defects unintentionally inserted during the development process can be identified and corrected before being transferred to later stages and propagated in various other defects, probably increasing the cost of development. Figure 2 illustrates the SYSMOD process with the readings techniques. This figure highlights the phases of this process: Requirements, System Context, Use Cases, Domain Knowledge, System Structure and Dynamic System. Each SYSMOD phase defines the SysML diagrams necessary for the specification of the embedded system. For example, in the Requirements phase, the system requirements are specified into a Requirements Diagram (REQ), and in the System Context phase, system requirements are detailed in Internal Block Diagram (IBD) and Block Definition Diagrams (BDD). The reading techniques have been established between pairs of diagrams where the information of one diagram is used to build the other one. As an example, T1 technique is applied to the pair of diagrams: Requirements Diagram (REQ) and Internal Block Diagram (IBD) (Figure 2). According to the nomenclature used by Travassos, Shull and Carver (2000) for UML, we named vertical reading technique the one that uses the Requirements Diagram and horizontal reading technique the ones that do not involve the Requirements Diagram.

Thus, aiming to verify, during the system development evolution, if the transcription of information from one diagram to another diagram is correct, a taxonomy of defects was defined. This taxonomy is based on the Std1044 IEEE-2009 (IEEE, 2010) standard, and classifies a set of defects inspired in three sources. One of these sources are the UL-98 standard (Desai, 1998; UL, 1998) for embedded systems and the DO-178C standard (Daniels, 2011) for aircraft certification. The goal of using these standards is to anticipate the identification of defects for the modeling level, once these standards are focused in identifying defects only when the code of the embedded system is already built. The second source is the Failure Mode and Effects Analysis (FMEA) methodology (Pentti and Atte, 2002). In this case, the goal is to identify hardware elements susceptible to defects in the diagrams addressed by the reading technique. The third source are the syntactic and semantic elements available in the formalism of the SysML language. The goal is to verify whether the diagrams are consistent to each other in terms of adequacy of elements transcription. To exemplify the reading techniques, we selected an excerpt of the reading technique $T4_{comp}$. Figure 3(a) shows an excerpt of this technique in the textual format and Figure 3(b) shows the same excerpt of this technique in the flowchart format. Observe that parts (A) and (B) of Figures 3(a) and 3(b) are exactly equals, and part (C) describes the steps of the technique in the formats previously mentioned.

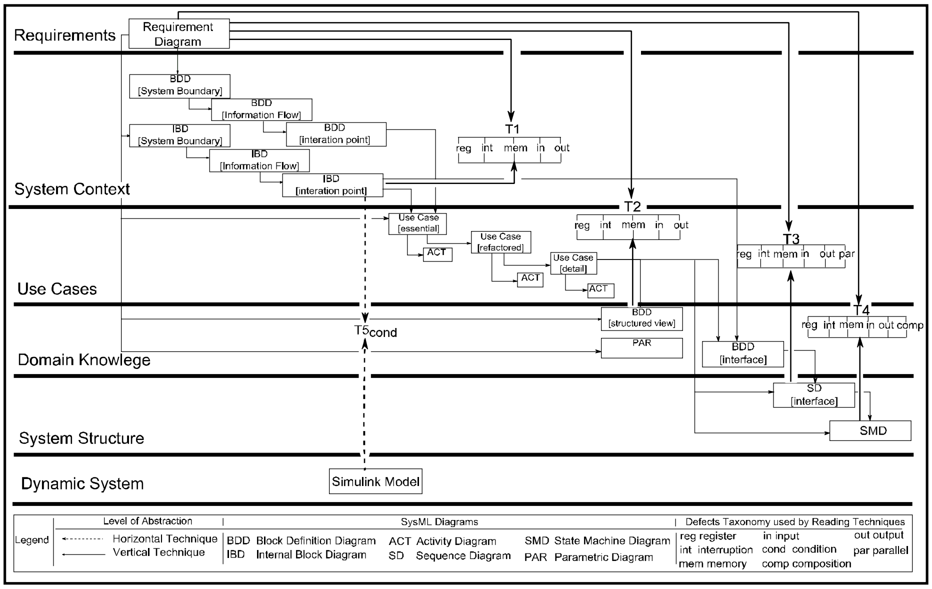


Figure 2: SYSMOD Process with Family of Reading Techniques.

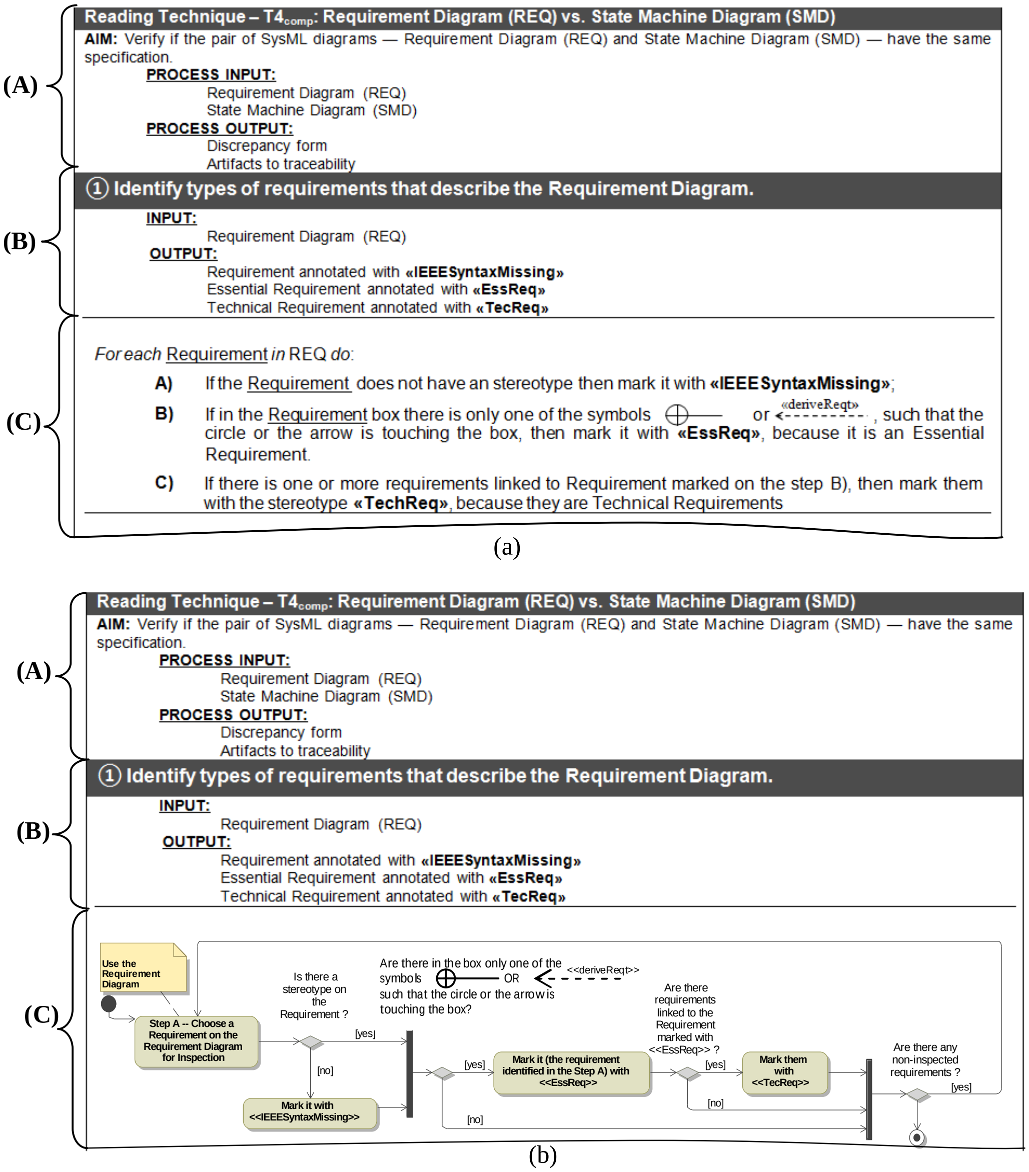
See that part (A) specifies the objective of the technique, the diagrams that are inspected and the inputs and outputs of the technique as a whole. Similarly, part (B) specifies the diagram that will be prepared to be used in the consistency comparison. Finally, part (C) specifies the steps of the technique in the textual format (Figure 3(a)) and in the flowchart format (Figure 3(b)).

Hence, in this example, observe that $T4_{comp}$ technique aims to identify defects associated to relevant syntactic and semantic properties of the SysML language formalism. As showed in part (C) of Figures 3(a) and 3(b), the inspector should use the stereotype «IEEESyntaxMissing» to mark syntactic defects in the Requirements Diagram. Also, the stereotypes «EssReq» and «TecReq» should be used to mark blocks that contain essential requirements and technical requirement, respectively, of the SysML language. Analogously to the excerpt of $T4_{comp}$, showed in Figure 3, the other reading techniques were constructed.

4 THE FEASIBILITY STUDY

According to Shull, Carver and Travassos (2001), a feasibility study must be used to evaluate if a new process fulfilled the overall goal for which it was created. Hence, in this case, one of the reading techniques was evaluated in the feasibility study aiming to verify if it was worthwhile and provided usable results. In this feasibility study, two questions were evaluated: **(Q1)** The main question aimed to evaluate if the Reading Technique $T4_{comp}$ is feasible to be used to inspect SysML models in terms of *effectiveness* and *efficiency*; and **(Q2)** The secondary question aimed to evaluate if the format the technique is written (Text or Flowchart) can interfere on the performance for identifying defects (*effectiveness* and *efficiency*). To answer these questions, we used a SysML model of a hybrid gas/electric powered Sport Utility Vehicle (HSUV). Some defects were inserted in this model and an oracle version was created for the comparison and summarization of the final results. The study was based on the main steps suggested by the Wohlin's experimental process (Wohlin et al., 2000) and they are presented in following subsections. The main objective of the feasibility study is presented as follows:

Analyze *the Reading Technique* $T4_{comp}$
For the purpose of *evaluation*
With respect to *effectiveness and efficiency*
From the point of view of *the developer*
In the context of *undergraduate students*



Reading Technique – T4$_{comp}$: Requirement Diagram (REQ) vs. State Machine Diagram (SMD)

AIM: Verify if the pair of SysML diagrams — Requirement Diagram (REQ) and State Machine Diagram (SMD) — have the same specification.

PROCESS INPUT:
Requirement Diagram (REQ)
State Machine Diagram (SMD)

PROCESS OUTPUT:
Discrepancy form
Artifacts to traceability

① Identify types of requirements that describe the Requirement Diagram.

INPUT:
Requirement Diagram (REQ)

OUTPUT:
Requirement annotated with **«IEEESyntaxMissing»**
Essential Requirement annotated with **«EssReq»**
Technical Requirement annotated with **«TecReq»**

For each Requirement in REQ do:

A) If the Requirement does not have an stereotype then mark it with **«IEEESyntaxMissing»**;

B) If in the Requirement box there is only one of the symbols ⊕—— or ←- - - - - - «deriveReqt», such that the circle or the arrow is touching the box, then mark it with **«EssReq»**, because it is an Essential Requirement.

C) If there is one or more requirements linked to Requirement marked on the step B), then mark them with the stereotype **«TechReq»**, because they are Technical Requirements

(a)

Reading Technique – T4$_{comp}$: Requirement Diagram (REQ) vs. State Machine Diagram (SMD)

AIM: Verify if the pair of SysML diagrams — Requirement Diagram (REQ) and State Machine Diagram (SMD) — have the same specification.

PROCESS INPUT:
Requirement Diagram (REQ)
State Machine Diagram (SMD)

PROCESS OUTPUT:
Discrepancy form
Artifacts to traceability

① Identify types of requirements that describe the Requirement Diagram.

INPUT:
Requirement Diagram (REQ)

OUTPUT:
Requirement annotated with **«IEEESyntaxMissing»**
Essential Requirement annotated with **«EssReq»**
Technical Requirement annotated with **«TecReq»**

(A)
(B)
(C)
Use the Requirement Diagram
Step A -- Choose a Requirement on the Requirement Diagram for Inspection
Is there a stereotype on the Requirement ?
[yes]
[no]
Mark it with <<IEEESyntaxMissing>>
Are there in the box only one of the symbols ⊕—— OR ←- - - - <<deriveReqt>> such that the circle or the arrow is touching the box?
[yes]
[no]
Mark it (the requirement identified in the Step A) with <<EssReq>>
Are there requirements linked to the Requirement marked with <<EssReq>> ?
[yes]
[no]
Mark them with <<TecReq>>
Are there any non-inspected requirements ?
[yes]

(b)

Figure 3: Reading Technique T4$_{comp}$ – (a) text notation; (b) flowchart notation.

To answer the research question Q1 the hypotheses 1a and 1b were formulated as follows:

- **Hypothesis 1a:**

  H$_{0|1a}$: T4$_{comp}$.is not effective, i.e., there is not at least 50% of subjects that found at least 50% of defects.

  H$_{1|1a}$: T4$_{comp}$.is effective, i.e., there is at least 50% of subjects that found at least 50% of defects.

Table 1: Specification of Hypothesis 1a.

#subjects	#defects	hypotheses	description
>50%	<50%	**H$_{0|1a}$**	T4$_{comp}$is not feasible
<50%	<50%		
<50%	>50%		
≥50%	≥50%	**H$_{1|1a}$**	T4$_{comp}$ is feasible

- **Hypothesis 1b:**

$H_{0|1b}$: $T4_{comp}$ is not efficient, i.e., there is not at least 50% of subjects that finished the inspection before 60 minutes.

$H_{1|1b}$: $T4_{comp}$ is efficient, i.e., there is at least 50% of subjects that finished the inspection before 60 minutes.

To answer the research question Q2 the hypothesis 2a and hypothesis 2b were formulated as follows:

- **Hypothesis 2a:**

$H_{0|2a}$: There is no significant difference between the effectiveness of $T4_{comp}$(Text) and $T4_{comp}$(Flowchart), i.e., *Effectiveness* [$T4_{comp}$(Text)] = *Effectiveness* [$T4_{comp}$(Flowchart)].

$H_{1|2a}$: There is significant difference between the effectiveness of $T4_{comp}$(Text) and $T4_{comp}$(Flowchart), i.e., *Effectiveness* [$T4_{comp}$(Text)] ≠ *Effectiveness* [$T4_{comp}$(Flowchart)]

- **Hypothesis 2b:**

$H_{0|2b}$: There is no significant difference between the efficiency of $T4_{comp}$(Text) and $T4_{comp}$(Flowchart), i.e., *Efficiency* [$T4_{comp}$(Text)] = *Efficiency* [$T4_{comp}$(Flowchart)]

$H_{1|2b}$: There is significant difference between the efficiency of $T4_{comp}$(Text) and $T4_{comp}$(Flowchart), i.e., *Efficiency*[$T4_{comp}$(Text)] ≠*Efficiency*[$T4_{comp}$(Flowchart)]

4.1 Variable Selection

The following independent and dependent variables were considered in this study:

- **Independent variable:** the reading technique $T4_{comp}$ is the independent variable in the context of this study; besides, considering the question Q2, $T4_{comp}$ is explored in text and diagram formats.

- **Dependent variable:** the *effectiveness* and *efficiency* are the dependent variables of this study and they are defined as follows:

effectiveness	Number of detected defects per total of discrepancies.
efficiency	Percentage of detected defects in relation to inspection time.

After the variable definition, the subjects were selected according to convenience and they were a group of undergraduate students of the System Engineering. Since it is a feasibility study with the primary objective of determining whether the use of the reading technique $T4_{comp}$ really helps to find defects and the application time is feasible, all subjects applied the same technique.

However, due to the secondary objective of evaluating the format (notation) used to write the technique, subjects were divided into two groups: G1 applying $T4_{comp}$(Text) and G2 applying $T4_{comp}$(Flowchart).

4.2 Descriptive Analysis of Research Question Q1 and Q2

Table 2 summarizes the collected data of the study and Figure 4 represents, via box-plot, the results of effectiveness and efficiency. The results of the feasibility study are presented in Table 2 as follows: The first column depicts the treatment groups G1 and G2. The second column represents the subjects through the identifiers S_1 to S_{26}. The third column shows the format the technique was used (text and flowchart). In the fourth column it is indicated the project used as example. The fifth column presents the total number of defects identified by each subject. The sixth column shows the time spent, in minutes, by each subject during the inspection activity. Finally, in the seventh and eighth columns there are the effectiveness and efficiency, respectively. At the bottom line of the table, average values (μ) are presented.

Aiming to totalize defects found by each subject, the discrepancy form was compared with an oracle version previously developed by the authors. This oracle had 20 defects and it was used to decide whether discrepancies were real defects.

The box-plot of Figures 4 and 5 summarize the results of effectiveness and efficiency, respectively.

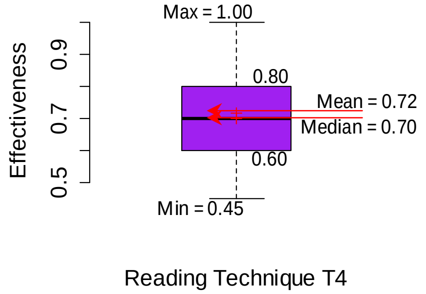


Figure 4: *Effectiveness* of $T4_{comp.}$

According to Figure 4 the following regions can be observed: (i) the first region corresponding to the first quartile, which represents 25% of data, where (0.45 ≤ *effectiveness*< 0.60);

Table 2: Collected data of the discrepancy form.

Group	Subjects	Reading Technique $T4_{comp}$	Defects (a)	Time (b)	Effectiveness (a/20)	Efficiency (a/b)
G1	S_1	Text	16	68	0.80	0.24
	S_2		15	58	0.75	0.26
	S_3		16	50	0.80	0.32
	S_4		14	50	0.70	0.28
	S_5		15	41	0.75	0.37
	S_6		17	45	0.85	0.38
	S_7		9	43	0.45	0.21
	S_8		12	46	0.60	0.26
	S_9		12	45	0.60	0.27
	S_{10}		17	37	0.85	0.46
	S_{11}		10	40	0.50	0.25
	S_{12}		12	40	0.60	0.30
	S_{13}		18	50	0.90	0.36
	S_{14}		15	47	0.75	0.32
G1 Average (μ)			**14.1**	**47.15**	**0.70**	**0.30**
G2	S_{15}	Flowchart	14	73	0.70	0.19
	S_{16}		14	65	0.70	0.22
	S_{17}		17	62	0.85	0.27
	S_{18}		15	60	0.75	0.25
	S_{19}		12	55	0.60	0.22
	S_{20}		20	49	1.00	0.43
	S_{21}		11	60	0.55	0.18
	S_{22}		18	50	0.90	0.36
	S_{23}		14	46	0.70	0.30
	S_{24}		11	35	0.55	0.31
	S_{25}		14	40	0.70	0.35
	S_{26}		14	45	0.70	0.31
G2 Average (μ)			**14.5**	**53,33**	**0.72**	**0.28**
Average (μ) of the G1 and G2			**μ= 14**	**μ = 50**	**μ = 0.72**	**μ = 0.30**

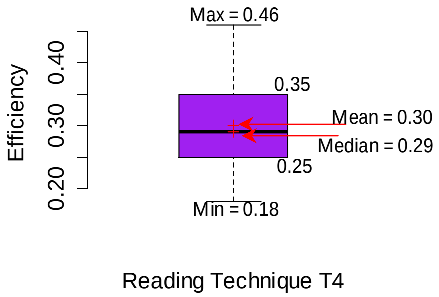


Figure 5: *Efficiency* of $T4_{comp}$.

(ii) the second region corresponding to the second and third quartiles, which represents 50% of data, where (0.60 ≤ *effectiveness* ≤ 0.80); and (iii) the third region corresponding to the fourth quartile, which represents the greatest 25% of data, where (0.80 <*effectiveness* ≤ 1.00). From second region it can be observed that one half of subjects have got at least 50% of effectiveness.

As the mean and median were very close — 0.72 and 0.70, respectively, we can consider that the data distribution is symmetric, i.e., the effectiveness data has a normal distribution. In relation to efficiency (Figure 5), the data can be interpreted in a similar way. It is important to notice that at least at least 50% of subjects detected from 0.25 to 0.35 defects per minutes, on the other hand, them have spent from 46 up to 48 minutes to conclude the inspection — it has been calculated using the relation between the effectiveness, efficiency and total number of defects existing in the oracle (*time spent* = 20**effectiveness/efficiency*).

In summary, in relation to effectiveness, we can say that $H_{0|1a}$ can be rejected because more than 50% of subjects have found more than 50% of defects. The same occurs for efficiency, i.e., $H_{0|1b}$ can be rejected because more than 50% of subjects have spent less than one hour to finish the inspection activity.

Based on Table 2, was calculated the total of the G1 and G2 groups, separately, i.e., it was summarized the means of groups using flowchart and text reading technique. Applying F-test statistic test, both failed to reveal a significant effect for the G1 (p = 0.9853) and G2 group (p = 0.8290). In these conditions, we must not reject null hypothesis $H_{0|2a}$ and $H_{0|2b}$.Finally, in both cases there was no statistical significance. Therefore, we can say that there is no significant difference in applying T4 in text format or flowchart format.

5 CONCLUSIONS

This paper described, by means of a feasibility study, the contribution of a reading technique ($T4_{comp}$) for detecting defects in SysML models. Based on the results of this study, families of similar techniques were defined taking into account some SysML models generated through the application of the software development process SYSMOD. The goal of this family of techniques is to identify defects throughout the process as soon as they occur.

This feasibility study has assessed the effectiveness in detecting defects and the time required to do this. As presented in this paper the results indicated that more than 70% of the defects were identified by at least 50% of the subjects. Furthermore, the feasibility study allowed assessing the format to write the techniques, suggesting that there is no difference in the effectiveness and efficiency for defects identification, independently of the format used (text or flowchart). As this study was performed as soon as the first technique was defined, the other techniques were defined in a similar way and nowadays other experimental studies are being conducted to evaluate the other techniques.

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