ANALYSIS OF THE SIMULATION MODEL PLATFORM ADOPTION IN THE CONTEXT OF INPE SIMULATORS

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ABSTRACT

The publication of the System Modelling and Simulation (ECSS-E-TM-10-21A) allowed the evaluation of simulation tools developed in the context of space projects at INPE, the Brazilian Institute for Space Research. The main goals of this evaluation were to provide INPE simulators classification and to assess their scope for future re-using. Three simulators currently being developed at INPE were chosen to be evaluated.

Starting from the classification, it was measured the effort needed to use these simulators for other space mission's phases. Moreover, we have evaluated how the adoption of Simulator Model Platform (SMP) standard could reduce development effort duplication in INPE's simulators.

The analysis was conducted following these steps: (i) requirements analysis, in which metrics and weights for each ECSS-E-TM-10-21A requirement were defined in order to allow comparisons; (ii) simulator classification based on compliance or not with each requirement; (iii) SMP standard compliance evaluation, aiming to measure the intersection of its requirements with the requirements covered by the evaluated simulators.

The results showed that the adoption of SMP standard would reduce the effort employed in the development of the analysed simulators and would also increase their flexibility in covering various missions and various mission phases. For the evaluated simulators, this adoption would still facilitate the common models reuse which is an already recognized SMP adoption advantage.

INTRODUCTION

The Brazilian Institute for Space Research (INPE) has been developing two different remote sensing satellites: China-Brazil Earth Resource Satellite 3 (CBERS-3) and Amazonia-1. This last one is based on Multi-Mission Platform which is planned to be reused for a family of satellites.

In order to support different development and verification activities for these satellites, a set of simulation tools has been implemented. Traditionally, INPE's experiences have been centred in the construction or customization of operational simulators for missions such as SCD, CBERS-1 and FBM, in addition with other particular tools for mission analysis. A detailed history can be found in [1].

Recently, new kind of simulators are being constructed or acquired from the industry by INPE, envisaging other mission phases. Most of these tools represent a novelty in INPE's simulation expertise. This paper presents an analysis of three simulation tools being developed at INPE, regarding their compliance with ECSS-E-TM-10-21A "Space engineering: system modelling and simulation" technical memorandum [2]. Table 1 presents the main features of such simulation tools, named here as SIM-A, SIM-B, SIM-C.

Table 1. Simulator Features

Feature	SIM-A	SIM-B	SIM-C
Development	In-house	Industry supported by the Brazilian Government "Studies and Projects Finance Organization" (Finep)	Industry supported by the Brazilian space budget
Intended use	Operators training and operational procedures validation	System & Mission analysis, OBSW and OBC V&V and correlated equipment.	OBSW and OBC V&V and correlated equipment.
HITL	No	Yes	Yes
Software technology	Qt; C++	C++	C; Web

The main objective of this paper is to present the classification of the referred simulators according to the facility types defined by ECSS-E-TM-10-21A. The classification was done by assessing the conformance level of each simulator to these types, measuring their compliance with the technical memorandum requirements. The measurement was based on two approaches: (i) the absolute number of implemented requirements; (ii) the total number of implemented requirements from a sub-set, considered to be characteristic of the analysed facility class.

Furthermore, we also evaluated how the use of a common infrastructure implementing Simulation Modelling Platform (SMP) standard could increase the conformance level and reduce rework.

The remaining paper is organized as follows: the first section describes related ECSS standard; next the methodology is introduced; then the results are presented; and finally the conclusion and future works are discussed.

RELATED ECSS STANDARDS

This work is based on two Technical Memorandum (TM) related to simulation and printed by the European Cooperation for Space Standardization (ECSS) entity, ECSS-E-TM-10-21A e ECSS-E-TM-40-07.

The ECSS-E-TM-10-21A is a standard published in 2010 which broadly describes the applicability of simulators across space mission phases. The standard main goals are: "(i) to maximize the benefits of using M&S in support to the Systems Engineering function; (ii) to reduce effort in developing and maintaining simulators; (iii) to preserve investment in modelling a system, regardless of the tools; (iv) to improve collaboration between involved teams / communities by addressing distribution and interoperability aspects; and (v) to facilitate reuse from phase to phase, project to project." [2]

To address these objectives, this technical memorandum defines a set of simulation facilities to support the system engineering activities, in a space mission. Those simulators classes and their scope are described in Table 2.

To specify the simulators features, groups of requirement have been defined by the standard. They are organized as following: (i) Project level; (ii) Simulation facility; (iii) General Models; and (iv) Facility Specific. The standard also classifies the *Simulation facility* requirements into categories: functional, operational, interface, performance, maintenance, design, and verification & validation.

Such detailed specification allowed the compliance evaluation of INPE's simulators products with different facility classes.

Table 2. Simulator Classes

Simulator		Scope
SCS	System Concept Simulator	System Concept Validation
MPS	Mission Performance Simulator	Mission Performance Validation
FES	Functional Engineering Simulator	System Performance Validation
FVT	Facility Validation Testbench	Critical Item Design Validation
SVF	Software Validation Facility	Critical System Software Validation
AIV	Spacecraft Assembly, Integration & Validation Simulator	Incremental Spacecraft AIV
GST	Ground System Test Simulator	Incremental low-level ground segment V&V
TOM	Training, Operations and Maintenance Simulator	Validation of Ground Segment & Operations Procedures

Recently, in 2011, the collection ECSS-E-TM-40-07 presented the Simulation Modelling Platform (SMP) standard, which addresses the issues related to portability and reuse of simulation models. It is based on well-known software engineering best practices and in two fundamental principles: common concepts (e.g. through the use of interfaces and inheritance in object-oriented paradigm); and common types (e.g. through the definition of basic data types not dependent on language and platform) [3].

The SMP architecture decouples simulation environment components from application models and specifies a collection of standard services and mechanisms.

On one hand, the fundamental concepts enable model interchange and their portability; on the other hand the architecture provides resources for a common infrastructure, to be used in several simulators across a space mission.

METHODOLOGY

The methodology adopted to classify the three INPE's simulators is comprised of four steps:

- First we had selected and classified the requirements from ECSS-E-TM-10-21A in order to create relevant universes to our research.
- Next we classified the INPE's simulators according to the ECSS-E-TM-10-21A types, based on the compliance level of simulators with the requirements of each set.
- After we assessed the compliance level of a hypothetical simulator environment implementing SMP interfaces and mechanisms regarding infrastructure requirements.
- Finally, we calculated duplicated effort on implemented requirements by the INPE's simulators.

In the following subsections, the processes are described in more details.

Requirements Selection and Classification

In this paper, we are evaluating the functional features of simulation tools that are being developed at INPE. For this reason, only *Simulation Facility* and *Facility Specific* requirements have been evaluated. We have not evaluated the *Project level* and *General Models* requirements, neither the *Maintenance* and *Verification & Validation* categories of *Simulation facility* requirements, since they are related to product or project life cycle.

Additionally, in order to normalize our simulators classification, we have adopted the following process:

- The decomposition of all requirements which seemed to be related to more than one functionality in several new requirements. For instance, the requirement SIM.AIT.5 "The spacecraft AIV simulator shall have the following configurations: Software only; SW + HITL (real equipment)", has been divided into two new requirements: SIM.AIT.5.a "The spacecraft AIV simulator shall have the following configuration: Software only"; and SIM.AIT.5.b "The spacecraft AIV simulator shall have the following configuration: SW + HITL (real equipment)". In this way, the analysed simulators can be compliant with one of them, both or none.

- Next the elimination of requirements which seemed to be related to the project (i.e. development process, requirement specification or documentation). For instance, SIM.OP.2 "The basic MMI functionalities required shall be described".

From the process above, we obtained two sets of requirements: F^* grouping the simulation facility requirements and G^* grouping the facility specific requirements. From the set G^*, we extracted a sub-set *G'* of requirements considered to be unique, with respect to its class of simulator. For instance, the requirement SIM.MPS.2-a "The facility shall include modelling of Instruments/payloads" is more typical of MPS class, and thus it was selected to represent it. On the other hand, the requirement SIM.AIT.4-a "The simulator shall be automatically configurable with data stored in the spacecraft database" is so common for all kinds of simulators that it was not picked for the set *G'*. In general, the criteria adopted to do this selection was to exclude requirements related to infrastructure, environment or general models, and to include those related to specific interfaces, models or analyses resources.

As a result, we found the summarized requirements described in Table 3, where the total number of each set of requirements can be compared against the original set from ECSS-E-TM-10-21A.

Assessing the Conformance Level: Existing Simulators

The classification process has been done using an empiric approach, based on simulator requirement documents and expert knowledge. For each simulator evaluated, a compliance score was given for all requirement belongings to sets F^*, G^* and *G'*. This score is expressed by a weight from 0 to 3, where 0 is *not compliance* (NC); 1 is *low compliance* (LC); 2 is *compliance* (C); and 3 is *high compliance* (HC).

From these scores, a conformance level was calculated for each facility specific type and simulation facility categories. Let *A* be a requirement set, the *conformance level Γ* of a simulator *k* is given by the equation (1):

$$\Gamma^k = \frac{1}{3N}\sum_{i=1}^{N} s_i^k \qquad (1)$$

where, *s* is the score of requirement *i* of simulator *k* and $N = |A|$ is elements number of set *A*.

Table 3. Sets of Requirements

		Total Number of requirements	
		Original	Set F^*
Simulation Facility	FU	22	32
	OP	9	8
	IF	6	4
	PE	6	0
	DE	13	8
	MO	14	0
	VV	2	0

		Total Number of requirements		
		Original	Set G^*	Set *G'*
Facility Specific	SCS	6	6	4
	MPS	2	5	4
	FES	6	15	10
	FVS	3	9	7
	SVF	6	21	15
	AIT	21	31	20
	GST	8	14	12
	TOM	7	15	10

Assessing the Conformance: Requirements Inherited from a SMP Infrastructure

Assuming there was a simulator environment implementing all SMP interfaces and mechanisms, several simulation facility requirements from ECSS-E-TM-10-21A (i.e. functional, operational, interface and design requirements) would be already covered. In this analysis, we have employed the same approach used before to classify simulators, giving each requirement a score from 0 to 3, according to their level of compliance. In this way, we could count the number of covered requirements that could have been inherited by INPE's simulators, if they had used a common infrastructure.

Calculating Duplicated Effort

In the last step we have counted the number of requirements which had been implemented by more than one INPE's simulator. This process has been applied to simulation facility and facility specific requirements from sets F^* and G^*, assuming as implemented the requirements whose scores were equal to or greater than 2 (C or HC).

The duplicated effort was considered to be the re-implemented requirements whose scope could be directly reused or quickly adapted from one simulator to another, avoiding over-estimated reuse events.

As a result, we obtained the total number of reworked requirements that could have been implemented only once, if there was a common infrastructure.

RESULTS & DISCUSSIONS

From the process of compliance level scoring, we obtained INPE's simulators classification into specific facility types. The result of this classification is shown in Fig. 1 (a) and Fig. 1 (b), for the set G^* and G', respectively. It is important to note that the Fig. 1 (b) gives a more realistic view of how close a simulator is conform to a facility class since it does not consider requirement related to infrastructure neither general models.

It can be seen that the highest compliance levels were obtained in the specific facilities for which the simulators had been originally specified. In short, the GST levels (62% for set $G^*$and 64% set G') and TOM levels (82% for set $G^*$and 87% for set G') refer to SIM-A, which is an operational simulator. Similarly, SIM-B and SIM-C both scored 67% (G^*) and 57% (set G') for FVS, while SIM-B scored 71% (G^*) 60% (G') for SVF.

From the specific facility classes perspective, we can observe two extremes from MPS and TOM. MPS is not properly covered by any simulator, since the only implemented requirement in set G^* does not belong to G' (Req. SIM.MPS.2-c "The facility shall include modelling of Orbit and attitude" is not a characteristic requirement for MPS class). By contrast, TOM is the best covered, reaching at least 82% by SIM-A. This can be explained by INPE experience in operational simulators and due to the particular application of MPS's.

Another analysis presented in the Fig. 1 (orange column) is the complementary characteristic between the simulators, where the compliance level is computed considering the requirements implemented by at least one simulator. It represents a union scenario, in which model interchanging and infrastructure reuse would have been adopted by a development strategy.

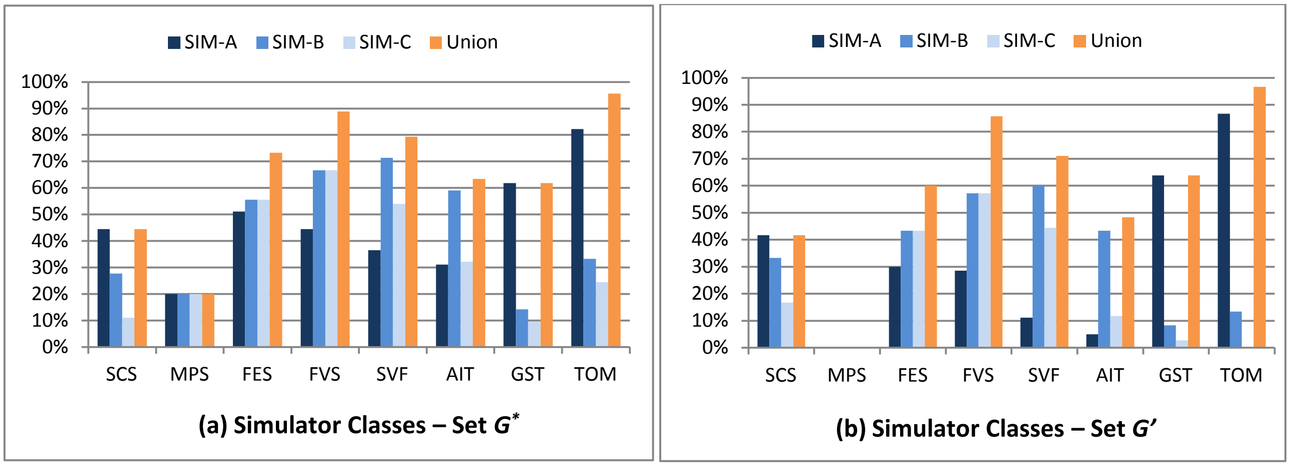

Fig. 1. Simulator Classes – *Conformance Level*.

This scenario could benefit the classes FES, FVS, SVF and TOM. Especially in the case of FVS, the most benefited class, 29% new requirements were implemented, which corresponds to a 50% gain. For the TOM simulator, the compliance level could be increased to 97%.

In addition, Fig. 2 summarizes an analogue analysis for the simulation facility requirements (set F^*), in the functional, operational, interface and design categories.

The analysis results have shown that the SIM-C has the lower level of compliance in all categories when compared to the others INPE's simulators, reflecting the fact that this simulator has been specified as a tool for a very specific satellite mission.

Precisely, by being specified to supporting many space missions, the flexible infrastructure of SIM-B covered a broader number of simulation facility requirements. However, the interface category requirements could be better tailored, envisaging integration with existing tools.

It could be also observed that there was no significant gain with respect to the number of implemented requirements, in a union scenario. It points the idea that infrastructure is an important player for communality in spacecraft simulators.

As expected, the adoption of a simulation environment implementing SMP would increase the level of interface category requirements' compliance, as it can be seen from the "SMP-union" (red column) in Fig. 2.

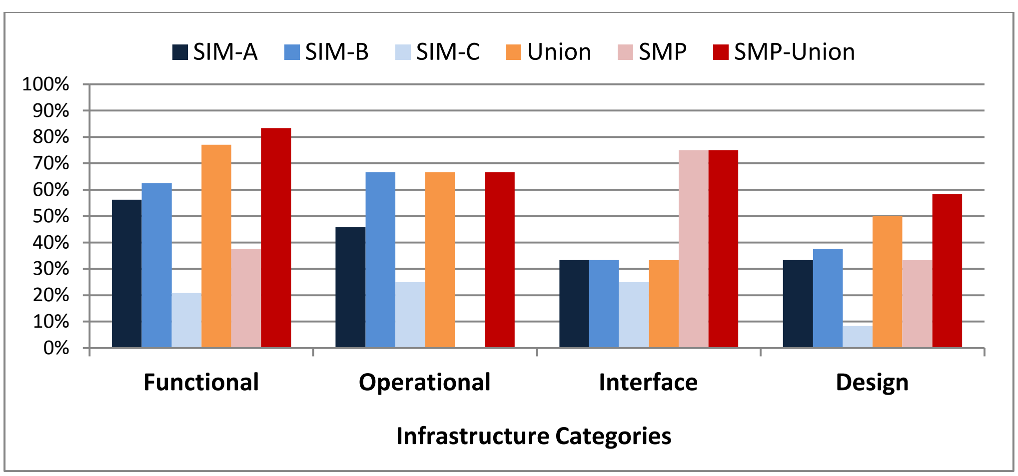

Fig. 2. Infrastructure Categories – *Conformance Level*.

Regarding duplicate effort, the results are presented in Table 4 and Fig. 3. Table 4 is organized as follows:

- *Total:* represents the requirements of set F^* and G^*,
- *Implemented:* is the number of requirements implemented at least by one simulator,
- *Reworked:* is the number of requirements where there was rework, that is, it could be implemented only once (required effort), but that was implemented by two or three simulators, and
- *Rework:* express rework in number of requirements implemented more than once.[1]

The actual rework is summarized in the last two columns of Table 4 and it may be better observed in the plot of Fig. 3. For instance, the AIT class has 20 implemented requirements, of which 11 (eleven) have been reworked at least once (blue column) and the calculated rework was 17 (seventeen) (red column). In case of simulation facility requirements, the remarkable level of rework reinforces the concept of infrastructure reuse.

Table 4. Rework

		Requirements			Rework	%	
		Total	**Implemented**	**Reworked**		**Reworked / Total**	**Reworked / Implemented**
Simulator Classes	**Facility**	52	36	21	31	40%	58%
	SCS	6	3	2	3	33%	67%
	MPS	5	1	1	2	20%	100%
	FES	15	12	7	13	47%	58%
	FVS	9	8	4	6	44%	50%
	SVF	21	17	9	14	43%	53%
	AIT	31	20	11	17	35%	55%
	GST	14	9	2	3	14%	22%
	TOM	15	15	4	7	27%	27%

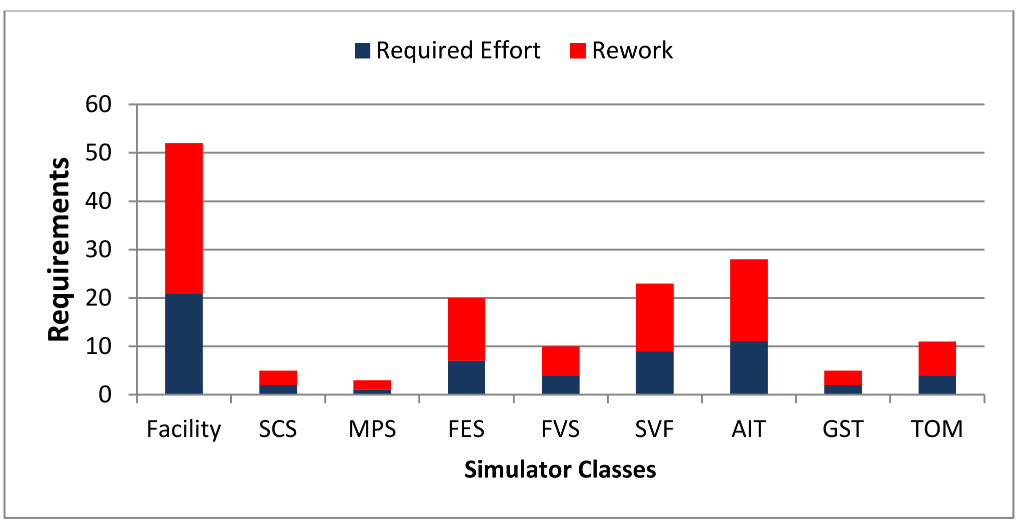

Fig. 3. Required Effort and Rework.

[1] If the requirement SIM.AIT.4-a were implemented by 2 simulators, thus it would count +1 for *reworked column* and +1 for *rework column*. Likewise, if the requirement SIM.MPS.2-c were implemented by 3 simulators, so it would count +1 for *reworked column* and +2 for *rework column*.

CONCLUSIONS

This work has evaluated the conformance level of satellite simulators being developed at INPE, envisaging their classification according to ECSS M&S technical memorandum, the tools communality and how they could take advantage of a common infrastructure like SMP.

The results have shown that the simulators are conformed to the classes for which they had been designed: (i) SIM-A, as an operational simulator, pertaining to GST and TOM classes; (ii) SIM-B and SIMC-C aiming V&V of OBC and OBSW, pertaining to FVS and SVF (this last one only SIM-B). Nevertheless, none of them has fully implemented the ECSS-E-TM-10-21A requirements; the conformance level of operational simulators is a reflection of INPE's past experiences.

In general, a higher conformance level could be reached if there was a strategy for resources exchange between the simulation tools. In most cases, this could increase the number of implemented requirements and reduce the rework at least 50%. Since SMP standard covers infrastructure requirements and proved to be a lot more satisfactory for model reuse, it should be considered for INPE's projects, aiming to reduce rework and aggregate complementary efforts.

This study will contribute to the definition of a policy to INPE which allows to increase reuse and decrease rework in the Satellite Simulators development for future missions. In this direction, as future works, we plan: (i) to evaluate the required effort to adapt the existing simulation tools to comply with SMP, using as reference the work [4]; and (ii) to formulate a development strategy to construct a FES from existing models and infrastructure, since this type of facility has already a relevant conformance level and it would contribute for current needs of INPE's missions.

Furthermore, as improvement of the present work, we suggest enhancing the expert universe involved in simulators evaluation and the inclusion of the assessment of INPE's simulators specific requirements, which were not covered by the technical memorandum scope. A methodology for this assessment may be found in [5].

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