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

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ABSTRACT

The publication of the ECSS technical memorandum System Modelling and Simulation (ECSS-E-TM-10-21A) opened up the possibility of evaluating simulation tools developed in the context of space projects at INPE, the Brazilian Institute for Space Research, using an independent and unbiased assessment scheme. This evaluation was carried out with the objective of classifying INPE´s simulators as regards their scope for future re-using. In this article, we present the result of this evaluation for three simulators, currently under development at INPE. The effort needed to use these simulators for other space missions was taken as the main classification parameter. Moreover, we attempted to evaluate how the adoption of the Simulator Model Platform (SMP) standard could reduce development effort duplication. The assessment was carried out in the following 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 at assessing the degree of compliance of the evaluated simulators with the SMP standard. The results for the assessed simulators showed that the adoption of the SMP standard would reduce the development effort and would also increase flexibility, as regards use in other missions and mission phases.

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. The latter development is based on a Multi-Mission Platform which is planned to be reused in a family of satellites.

In order to support the development and verification activities of these satellites, a set of simulation tools is under development. INPE's experience in construction or customization of operational simulators and other particular tools for mission analysis can be found in Ambrosio et al., 2006 [1].

This paper presents an analysis of three simulation tools being developed at INPE, as regards their compliance with ECSS-E-TM-10-21A "Space engineering: system modelling and simulation" technical memorandum (TM) [2]. Table 1 presents the main features of the assessed simulation tools, here referred as SIM-A, SIM-B, SIM-C.

Table 1. Simulator Features

Feature	SIM-A	SIM-B	SIM-C
Development	In-house development.	Development carried out by Industry with the support of a government fostering agency (Finep).	Development carried out by Industry with the support of INPE.
Intended use	Operator training and validation of operational procedures.	System & Mission analysis, OBSW and OBC V&V, and V&V of associated equipment.	OBSW and OBC V&V and V&V of associated equipment.
HITL	No	Yes	Yes
Software technology	Qt; C++	C++	C; Web

In this article, we give the classification of the referred simulators according to the facility types defined in ECSS-E-TM-10-21A. The classification was accomplished by assessing the level of conformance of each simulator to the facility types defined in the technical memorandum, specifically by assessing the compliance with the standard requirements. The assessment was based on two criteria: (i) the absolute number of implemented requirements; (ii) the total number of implemented requirements from a sub-set of requirements, which are specific to the analysed facility class.

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

The paper is organised as follows: the first section briefly describes the ECSS standards used in the study; the next section presents the used methodology, whereas the following one gives the results; finally, the conclusion and a future work discussion are given.

ECSS STANDARDS USED IN THE STUDY

The work carried out in this article is based on two ECSS technical memoranda: ECSS-E-TM-10-21A and ECSS-E-TM-40-07.

ECSS-E-TM-10-21A, published in 2010, broadly describes the applicability of simulators across space mission phases. The main goals of this memorandum are: “(i) to maximise 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, independently 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 a set of simulation facilities aimed at supporting system engineering activities, in a space mission, is defined. The corresponding simulator classes and scope are given in Table 2.

In the memorandum, groups of requirements have been defined in order to categorize simulator features. They are organised by (i) Project level, (ii) Simulation facility, (iii) General Models and (iv) Facility Specific. The Simulation facility requirements are further decomposed into the following categories: functional, operational, interface, performance, maintenance, design, and verification & validation.

This detailed classification scheme has been applied to the evaluation of the level of compliance of INPE’s simulators to 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

The collection of memoranda ECSS-E-TM-40-07, first issued in 2011, introduces the Simulation Modelling Platform (SMP) standard, which delves into issues related to portability and reuse of simulation models. It is based in software engineering best practices and in two fundamental principles: common concepts and common types. While the first is related to the use of interfaces and inheritance in object oriented paradigm, the second is related to the definition of basic data types independent of language and platform [3].

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

On the 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, comprises four steps:

- first, we select and classify the requirements from ECSS-E-TM-10-21A into different sets, according to features relevant to our research;
- next, we classify INPE's simulators according to the ECSS-E-TM-10-21A sets, based on the level of compliance of each simulator to the requirements of each set;
- after, we assess the level of compliance of a hypothetical simulator environment implementing SMP interfaces and mechanisms with respect to infrastructure requirements;
- finally, we identify and quantify the duplicated effort in the implementation of requirements in the INPE's simulators.

In the following, each step is described with more details.

Requirements Selection and Classification

In the present work, we are concerned with the functional features of simulation tools under development at INPE. For this reason, only *Simulation Facility* and *Facility Specific* requirements have been considered. The other requirements (*Project level* and *General Models*), as well as the *Maintenance* and *Verification & Validation* categories of *Simulation facility* requirements have not been considered, since they are related to the product or project life cycle.

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

- decomposition of requirements which are related to more than one functionality into 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)*" was 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, a simulator may be compliant with one, both or none of them.

- elimination of requirements which are related to projects (i.e. development process, requirement specification or documentation) – for instance, SIM.OP.2 "*The basic MMI functionalities required shall be described*".

Following 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', containing requirements considered to be unique with respect to a class of simulators. For instance, the requirement SIM.MPS.2-a "*The facility shall include modelling of Instruments/payloads*" is most typical of a MPS class, and thus it was selected to represent it. The requirement SIM.AIT.4-a "*The simulator shall be automatically configurable with data stored in the spacecraft database*", in turn, is common for all types of simulators, as such it was not included in the set G'. As regards the elimination of requirements, requirements related to infrastructure, environment or general models were, in general, not considered. Requirements related to specific interfaces, models or analyses resources were, in general, maintained.

As the result of this decomposition and selection process, we arrived at the categories and requirements described in Table 3. The table also compares the number of requirements in each set against the original number of requirements in the corresponding set from ECSS-E-TM-10-21A.

Assessing the Conformance Level: Existing Simulators

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

From these scores, a conformance level was calculated for each facility specific type and simulation facility category, according to the following function: let *A* be a requirement set, the *conformance level* Γ of a simulator *k* is given by the equation (1)

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

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

Presuming the existence of a simulator environment implementing all SMP interfaces and mechanisms, we then carried out the classification of each simulator according to ECSS-E-TM-10-21A. In this assessment, we employed the same approach as we used before, giving each requirement a score from 0 to 3, according to its level of compliance. From this classification, the number of requirements that could have been inherited by INPE's simulators, if they had been developed from a common infrastructure, could be computed.

Computing the Duplicated Effort

In the last step, we compute the number of requirements which are implemented by more than one of INPE's simulators. This process has been applied to *simulation facility* and *facility specific* requirements from sets F^* and G^*, considering as implemented the requirement whose score is equal 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.

As a result of the foregoing assessment, we obtain the total number of reworked requirements that could have been implemented only once, if a common infrastructure had been used.

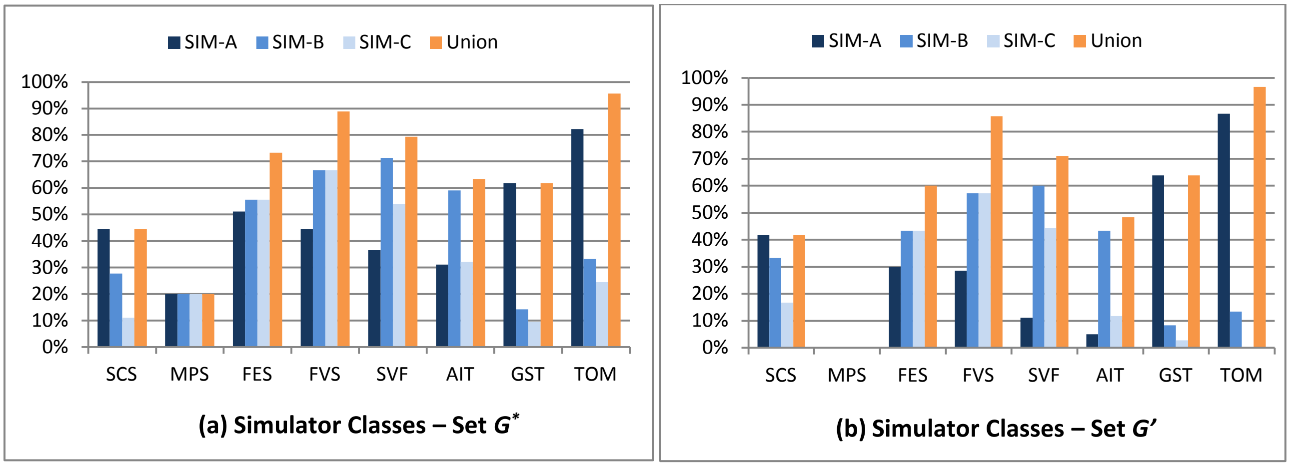
RESULTS & DISCUSSIONS

From the scoring process above described, 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 sets G^* and G', respectively. The Fig. 1 (b) gives a more realistic view of how close a simulator is to a facility class, since it does not consider requirements related to either infrastructure or general models.

It can be seen that the highest compliance levels were obtained for 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') in the case of 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^*) and 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 result may be explained by INPE experience in operational simulators and due to the particular application of MPS's.

Another analysis given in Fig. 1 (a) and Fig. 1 (b) (orange column) is related to the level of complementarity existing between the simulators. The compliance level computed considering the requirements implemented by at least one simulator has been taken as a measure of the level of complementarity between simulators. It represents a union scenario, in which model interchanging and infrastructure reuse would have been adopted by a development strategy.



(a) Simulator Classes – Set *G**

(b) Simulator Classes – Set *G'*

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

As seen from the figures, this scenario could benefit classes FES, FVS, SVF and TOM. Specifically 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 show 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 is also observed that there would be no significant gain with respect to the number of implemented requirements, in a union scenario. This result suggests 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 compliance of the interface category requirements', as can be seen from the "SMP-union" (red column) in Fig. 2.

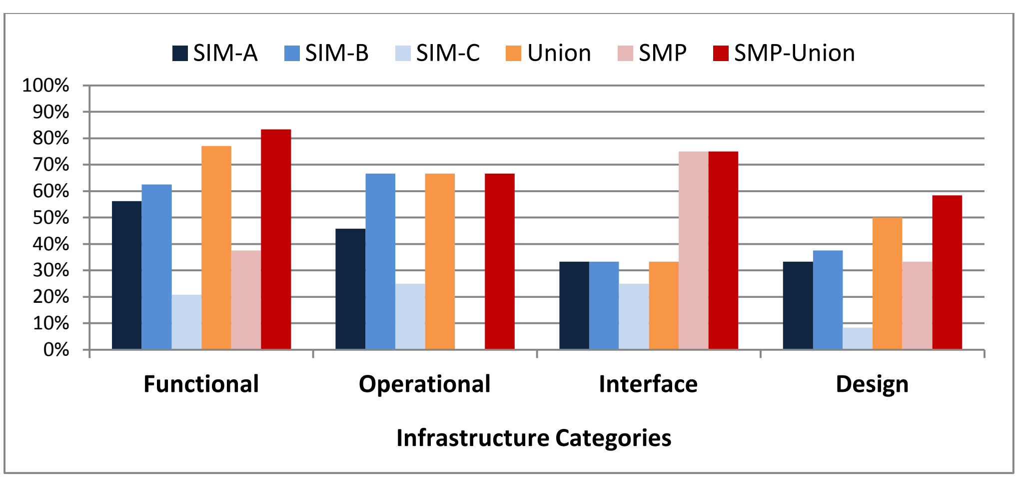


Fig. 2. Infrastructure Categories – *Conformance Level*.

The results regarding duplicated effort are presented in Table 4 and Fig. 3. The columns in Table 4 have the following definition:

- *Total:* gives the number of requirements in sets F^* and G^*,
- *Implemented:* gives the total number of requirements implemented by at least one simulator,
- *Reworked:* gives the number of requirements for which there was rework, that is, requirements that could, in principle, be implemented only once (required effort), but that were independently implemented by two or three simulators, and
- *Rework:* gives the 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. From these, 11 (eleven) have been reworked at least once (blue column) and the computed total 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%

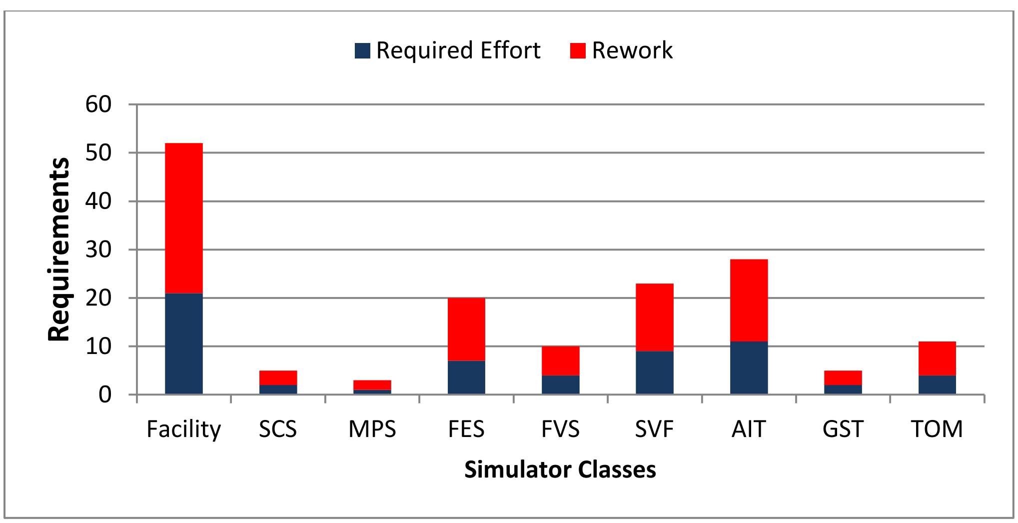


Fig. 3. Required Effort and Rework.

[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 compliance level of satellite simulators being developed at INPE, envisaging their assessment as regards ECSS M&S technical memoranda, tools communality and how they could take advantage of a common infrastructure like SMP.

The results show that the studied simulators conform well to the classes for which they have 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). Despite the fact that none of them has fully implemented the ECSS-E-TM-10-21A requirements, the very good conformance level of operational simulators may be explained by INPE's experience with operational simulators.

As a general result, we observed that a higher conformance level would be reached if there were a policy 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 excels for model reuse, it should be considered for INPE's projects, aiming at reducing rework and aggregating complementary efforts.

This study may contribute to the definition of a software development policy at INPE aimed at increasing reuse and decreasing rework in the development of Satellite Simulators for future missions. In this direction, as future work, we plan: (i) to evaluate the required effort to adapt 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 may fulfill current needs of INPE's missions.

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

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