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Alexis François, Antoine Lanthony, Antoine Brunner, Moncef Hammadi,  
Jean-Yves Choley, Stanislao Patalano, Ottorino Veneri

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# *PLACIS: Systems engineering through a project-based learning approach*

*General framework, debates and achievements through an overview and a concrete example*

Alexis François, Antoine Lanthony, Antoine Brunner  
ISMEP-Supméca  
Saint-Ouen, France  
[alexis.francois@supmeca.fr](mailto:alexis.francois@supmeca.fr), [antoine.lanthony@supmeca.fr](mailto:antoine.lanthony@supmeca.fr),  
[antoine.brunner@supmeca.fr](mailto:antoine.brunner@supmeca.fr)

Stanislao Patalano  
Università degli Studi di Napoli Federico II  
Naples, Italy  
[stanislao.patalano@unina.it](mailto:stanislao.patalano@unina.it)

Moncef Hammadi, Jean-Yves Choley  
Quartz –Supméca  
Saint-Ouen, France  
[moncef.hammadi@supmeca.fr](mailto:moncef.hammadi@supmeca.fr), [jean-yves.choley@supmeca.fr](mailto:jean-yves.choley@supmeca.fr)

Ottorino Veneri  
Istituto Motori – National Research Council of Italy  
Naples, Italy  
[o.veneri@im.cnr.it](mailto:o.veneri@im.cnr.it)

**Abstract—** PLACIS (Collaborative Platform for Systems Engineering) is a project funded by the French National Agency for Research under the “Investments for the future” program. PLACIS started in September 2012 and is run by Institut Polytechnique Grand Paris (IPGP, gathering ISMEP – Supméca, ENSEA and EISTI). In the framework of both a rapid change in engineering education and a need of young engineers able to think “systems”, PLACIS aims to promote active learning and teaching through industrial, international and at-a-distance collaborative projects, carried out by engineer students. The main general objectives of PLACIS are to develop or create the involvement of teachers and students into new teaching practice, but also to answer the needs of the industry. We train students not only to become classic engineers, but also to be able to understand multidisciplinary and industrial issues, to work in teams with people from different cultures, all these points giving them the ability to move easily in today’s and tomorrow’s industrial world and to think “systems”, to really understand a context and be able to propose adapted answers that are more than the old “think global, act local”. In order to illustrate concretely what is PLACIS, we can easily rely on the example of an industrial project started at the beginning of PLACIS in September 2012 and which is still in progress between Istituto Motori – CNR (IM-CNR), Università di Napoli Federico II (UNINA) and Institut Polytechnique Grand Paris (IPGP).

**Keywords—**systems engineering; project-based learning; multidisciplinary approach

## I. INTRODUCTION

Following different issues raised in the industry in the United States of America, the work done by INCOSE or the systemic approach of companies in aeronautics or software (like Dassault Systèmes), systems engineering became at the

same time a need in many companies, but also an issue, with many discussions around its meaning, its definition, the way to teach it and other aspects. In France and in most of the industrialized countries, it is admitted that companies face a lack of systems engineers. This profile is defined in the CarTesa report produced for the Paris Region Systems & ICT Cluster Systematic as follows: “an experienced systems engineer is someone who, in addition to a strong background in engineering, has a capacity for abstraction, communication with teams like the end customer, leadership, innovation and an understanding of the company’s business. He is someone who, having an overall vision of the project, “manages the system in all its complexity” [1]. This definition is a guideline but also led to discussions about systems engineering and what a PLACIS project should be. Nevertheless, all promoters of PLACIS agreed on the multidisciplinary aspect and on the fact that the recruitment flow of well-prepared young graduates to carry out these functions is promising, for example in aviation industry.

There are also discussions and actions in order to seek possible alternatives to traditional configuration courses / supervised work / practical classes notably through project-based learning (PtBL) and / or problem-based learning (PmBL). This progressive shift in engineering education meets the shift in what companies are looking for.

Higher education seeks to address these issues and prepare engineers in general and systems engineers in particular, assuming that the skills cannot be acquired only by learning knowledge or through the implementation of technical tools.

Based on this context and with a consolidated experience in PmBL and systems engineering, Institut Polytechnique Grand Paris (IPGP) answered a call for innovative learning schemes

(IDEFI - “Excellence initiatives for innovative training”) from the French National Agency for Research and was granted a special funding to develop PLACIS<sup>1</sup> in September 2012.

The IDEFI PLACIS, which was presented at the WEEF2014 [2], has two main objectives. Firstly, it is an approach to educational research, preparing students to systems engineering and to the professional world they will meet when they are in the industry. Secondly, it allows developing and testing the tools and collaborative and / or digital methods to achieve in a PtBL or PmBL framework, involving both teachers and students.

Concretely, the main idea is to develop several tools and collaborative at-a-distance industrial and / or international projects in order that the students become able to work as systems engineers in a changing globalized world, in which working in international teams, distributed over many locations, composed of members having different cultures and working habits becomes the norm.

Members of IPGP are working on the development of tools and models. Academic institutions like Università di Napoli Federico II (UNINA), Politecnico di Torino or Hochschule Esslingen are PLACIS partners, with an involvement of both students and teachers. Many companies are also PLACIS partners in various ways: engineering system software providers like Dassault Systemes or providers of industrial research project subjects like Bosch, Hutchinson or Istituto Motori – CNR (IM-CNR). Most of these projects are confidential, as it is most of the time the case in the industrial world, but we can for example present one project (focused on electric powertrains) that started at the beginning of PLACIS in September 2012 and which is still in progress between Istituto Motori – CNR (IM-CNR), Università di Napoli Federico II (UNINA) and Institut Polytechnique Grand Paris (IPGP, mainly through ISMEP-Supméca).

We will explain PLACIS in detail and then focus on the IM-CNR – UNINA – IPGP project. All along the paper, we will also point out the different links and discussions related to systems engineering.

## II. PLACIS PROJECTS AND SYSTEMS ENGINEERING

### A. What do PLACIS projects look like ?

PLACIS places students in realistic situations and makes them feel the reality of an industrial project. The main framework of PLACIS project is for Master students, with different kinds of formats to involve them. In all cases, the projects are collaborative, multidisciplinary, industrial and, most of the time, international with a foreign academic partner and / or a foreign company. So, there are bilateral as well as trilateral levels of interaction between stakeholders.

We choose to place PLACIS projects for Master students in a PtBL framework, according to Prince and Felder [3]. It means that they are broader and present more elements than classical PmBL or capstone projects, for example as defined by

<sup>1</sup> The PLACIS project is managed by the French National Agency for Research under “Investments for the future” program with the reference ANR-11-IDFI-0029.

Ward in [4]: PmBL being for him “pedagogy in which students learn about subjects by solving complex, multidisciplinary and realistic design problems” [4]. PLACIS projects for Master students go beyond that, with their multi-location and multi-actor dimension, but also with their systems engineering approach, making not only complexity mandatory, but also industrial context, use of specific tools and consideration of specific approaches in systems engineering education.

Apart from these approaches, PLACIS projects share common semester organization schemes and the possibility to use different formats.

The organization scheme of a semester is the following:

- A company proposes a project (a new one or the continuation of an ongoing one) requiring expertise from different engineering fields,
- Industrial and academic partners discuss in order to better define and validate the subject,
- Groups of students are formed in one or both universities in order to create a team,
- A kick-off meeting (in-person or by video-conference) is organized with all the people involved in the project, in the industrial company,
- Then, students carry out their project while staying in their home university and using the tools of collaborative engineering. They are tutored by teachers and by a person from the industrial company providing the subject,
- The performance is assessed by the industrial partner and the teachers.

The different formats of involvement for IPGP students are the following:

- Master 1, from April to June, 100 hours / student, groups of 3 students,
- Master 2, from September to February, 300 hours / student or from December to February, 150 hours / student, groups of 2 to 4 students.

The foreign academic partners define their own rules for the involvement of their students, respecting their schedules, so that students can collaborative, keeping a real flexibility.

Some interns from Supméca (from Master 1 and Master 2 levels) can also take part in PLACIS projects, for example in parallel to the involvements of groups of students in the formats presented above.

### B. Tools used and assessment of the work of the students

The students use the last engineering and collaborative tools. These tools are mainly: Catia V6, Dymola, SysML, ANSYS tools, Simulia, Matlab, Abaqus, Artisan Studio, WebEx, Skype, SharePoint and the new 3.0 platform.

The 3.0 platform has been developed in the framework of PLACIS. Being adaptive, collaborative, semantic and social, this platform will allow two main results, which will become

tools for users: each project will have a real community place online; each student will be able to follow his individual learning path through a real learning management system. The first tests of this platform will take place in autumn 2015.

Assessment issues are also important issues for PLACIS. There are two kinds of assessments:

- Assessment of the work done in each project, i.e. assessment of students,
- Assessment of PLACIS itself.

These two issues were detailed in WEEF2014 [1] and CFM2015 [5]. Assessment issue is also a key point to be developed and discussed in EPICES<sup>2</sup> (European Platform for Innovation and Collaboration between Engineer Students), a new project started in September 2014 and funded in the framework of the Erasmus+ program. EPICES will allow developing a European collaborative at-a-distance PtBL framework and method, and one of its intellectual outputs focuses on assessment issues.

Nevertheless, the point related to the assessment of PLACIS itself, in link with systems engineering definition and perception, will be underlined in next section.

### C. PLACIS debates on systems engineering definition and education

From the writing of the draft of PLACIS till now, there have been debates on what is systems engineering.

The definition of the International Council on Systems Engineering (INCOSE) stands the following [6]:

“Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Cost & Schedule
- Performance
- Training & Support
- Test
- Disposal
- Manufacturing

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.”

This broad definition was in mind since the beginning of PLACIS, but PLACIS started to run with a definition a bit

more centered on both methods and software, for example with the use of Catia V6.

There have been many discussions between stakeholders inside PLACIS and a balance was found between views, especially with the development of projects not using Catia V6.

### D. Stakeholders' feedbacks on systems engineering in the framework of PLACIS

Taking into account the latter, we more and more wanted to have a feedback from the users about systems engineering. For this reason, questions on that topic were included in the surveys conducted with academic tutors, industrial tutors and students.

Hereafter are the results from the survey of the first semester of the academic year 2013-2014.

One question, whose results are in table 1 was common to all types of stakeholders, whereas a second question (results in table 2) was designed for teachers about the practice of systems engineering and a third question (results in table 3) was designed for students about the understanding of systems engineering.

TABLE I. DID THE PLACIS CONTEXT, ACCORDING TO ITS DIFFERENT AXES, WELL MEET YOUR EXPECTATIONS IN TERMS OF SYSTEMS ENGINEERING APPROACH?

Answer	Industrial tutors		Academic tutors		Students	
	Count	%	Count	%	Count	%
Yes	4	80.00%	6	85.71%	17	80.95%
No	0	0.00%	1	14.29%	0	0.00%
Uncertain	1	20.00%	0	0.00%	4	19.05%
No answer	0	0.00%	0	0.00%	0	0.00%

TABLE II. DO YOU THINK THAT THE PLACIS PROJECT(S) YOU WERE INVOLVED IN ALLOWED YOU TO PUT INTO PRACTICE SYSTEMS ENGINEERING?

Answer	Academic tutors	
	Count	%
Yes	6	85.71%
Partially	0	0.00%
No	1	14.29%
No answer	0	0.00%

TABLE III. DO YOU THINK THAT PLACIS HELPED YOU TO BETTER UNDERSTAND WHAT IS SYSTEMS ENGINEERING?

Answer	Academic tutors	
	Count	%
Yes	11	52.38%
Partially	9	42.86%
No	1	4.76%
No answer	0	0.00%

<sup>2</sup> With the following reference: 2014-1-FR01-KA203-008560.

These results are positive, but also reflect the issues raised about the definition, and consequently understanding, of what is systems engineering.

The results of the surveys conducted after the first semester 2014-2015 are not fully available but we see a positive trend and a better feedback from students towards the comprehension of systems engineering.

One element is that new projects were set up in various fields and the most relevant projects in terms of approach have been kept active.

Among them, the project started in September 2012 and still in progress between Istituto Motori – CNR (IM-CNR), Università di Napoli Federico II (UNINA) and Institut Polytechnique Grand Paris (IPGP) is an example, both in terms of content with for example a huge work on Modelica models and in terms of positive feedback and consequences, from students in both institution learning and also from academic and research collaboration between institutions, with visiting professors and joint published papers [7].

This project presents a very good overview of what PLACIS brings to its actors.

### III. AN EXAMPLE OF PLACIS PROJECT AND ITS DIRECT AND INDIRECT ACHIEVEMENTS

#### A. Description and objectives

Students involved in PLACIS project experiment the systems engineering approach called Requirement-Functional-Logical-Physical (RFLP), which is proposed by Dassault Systems in CATIA V6. In this study, we will limit the scope to the modeling and simulation of mechatronic systems performed in the logical level (L). Mechatronic systems are special engineering systems requiring a high level of design integration in order to evaluate the performance of the overall system. The logical level (L) in the RFLP approach allows designers to define several system architectures or concepts that could be candidate solutions, generated after a functional (F) study and a requirement (R) analysis. The selected solution is therefore detailed in the physical level (P).

Istituto Motori (IM-CNR) focuses its research activity in the field of energy conversion and environmental protection. The research team in IM-CNR, working on conversion and storage systems of the electric energy for propulsion and charge of full electric and hybrid vehicles, is involved in PLACIS project since September 2012. Several studies were performed until today in this domain within PLACIS project.

The objective of this study is to compare the performance and the environmental impacts of two hybrid electric configurations of busses: series and parallel configurations. In the next sections we will describe the modeling methods and the simulation results found by the students who have worked on this subject.

#### B. Modeling method

Modelica is an object-oriented modeling-language for the simulation of multi-domain and multiphysics systems [8].

Modelica is suitable for modeling hybrid (discrete/continuous systems). Continuous systems, modeled with differential algebraic equations (DAE), can therefore be simulated with Modelica.

Several previous works were based on Modelica language for the modeling, simulation and multi-disciplinary optimization of electric and hybrid electric vehicles [9]. The advantage of Modelica is the high level of modeling integration for the system level evaluation and validation. However, the drawback of Modelica is that it does not support the resolution of problems modeled with partial differential equations (PDE). Other techniques, in that case, such as finite element method (FEM), are more suitable. Some works in literature proposes to use multi-agent approach for the multi-level modeling of mechatronic systems to couple detailed multi-physics modeling based on FEM method with the system level modeling based on differential algebraic equations [10].

Returning to the case of modeling of hybrid electric busses, figures 1 and 2 show Modelica models for both series and parallel hybrid electric busses.

The students involved in this work combined both forward and backward modeling approaches to be able to simulate all the dynamic variables required in the study [11].

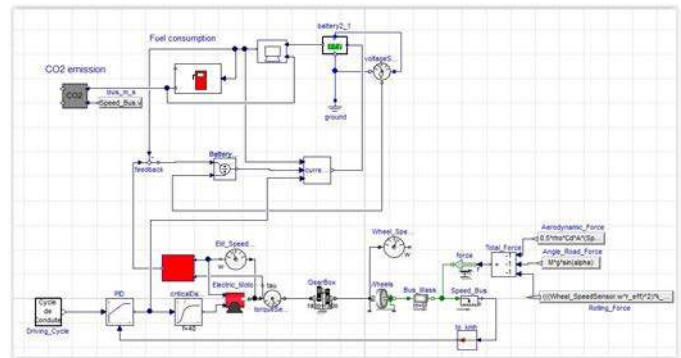


Fig. 1. Modelica model of a series hybrid configuration of a Bus

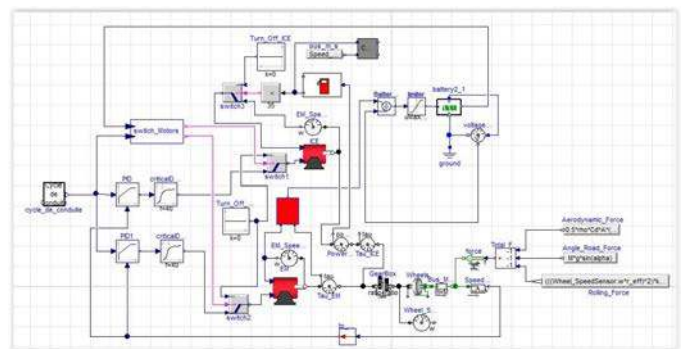


Fig. 2. Modelica model of a parallel hybrid configuration of a Bus

In particular the models can calculate the mechanical and electrical variables (velocity, forces, motor speed, toques, current, voltage and power) in the system and in its components. The state of charge of the battery (SoC) can also be simulated and other performance characteristics, such as

fuel consumption and CO<sub>2</sub> emission, are similarly determined with these models.

### C. Case-study results

As an example of simulated results we choose to make a comparison between the state of charge in the battery for the series and parallel configurations of the hybrid electric busses.

The component parameters used for the simulation are summarized in table IV.

TABLE IV. SIMULATION PARAMETERS FOR THE COMPARATIVE STUDY

	Modeling/Simulation parameters		
	Parameter name	Value	Unit
$M$	Vehicle mass	3514	kg
$\rho$	Air density	1.2	kg/m <sup>3</sup>
$A_{front}$	Vehicle frontal area	5.4	m <sup>2</sup>
$C_{ro}$	Rolling coefficient	0.3	-
$C_d$	Aerodynamic drag coefficient	0.6	-
$\alpha$	Grade angle	0	-
$g$	Gravitational acceleration constant	9.8	m/s <sup>2</sup>
$rw$	Wheel radius	0.34	m
$N_s$	Number of series cells in battery	100	-
$N_p$	Number of parallel strings in battery	1	-
$SoC_{init}$	Initial state of charge	80%	-
$P_m$	Nominal power of the electric motor	64	kW
$T_{max}$	Maximum torque of the electric motor	540	N.m
$N_m$	Nominal speed of the electric motor	2600	rpm

In addition to the parameters indicated in table IV, the thermal engine has the following characteristics:

- Max power: 41 kW @ 5700 rpm
- Peak torque : 81 N.m @ 3470 rpm
- Tank capacity 20 L.

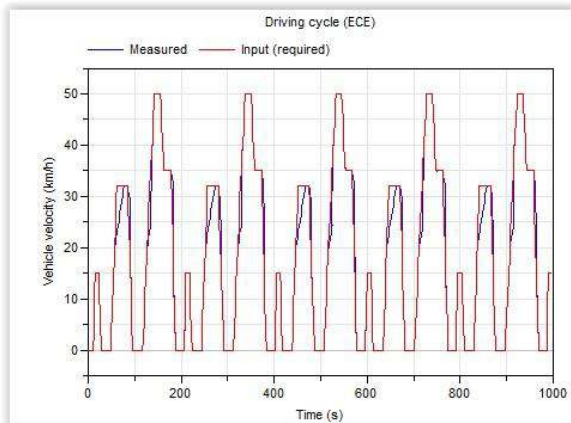


Fig. 3. Urban European driving cycle (ECE) used for hybrid buss simulations

The results are generated for the same urban European driven cycle. Figure 3 shows a comparison between the input and the measured vehicle velocity in the case of a parallel configuration.

Results show a slight difference between the two curves due to the simple and not optimized power management strategy adopted to switch between electric and thermal engines. However, a good agreement between the two curves was found for the case of series configuration, because of easiest power management strategy.

Figure 4 shows a comparison of state of charge (SoC) of the battery in both series and parallel configurations.

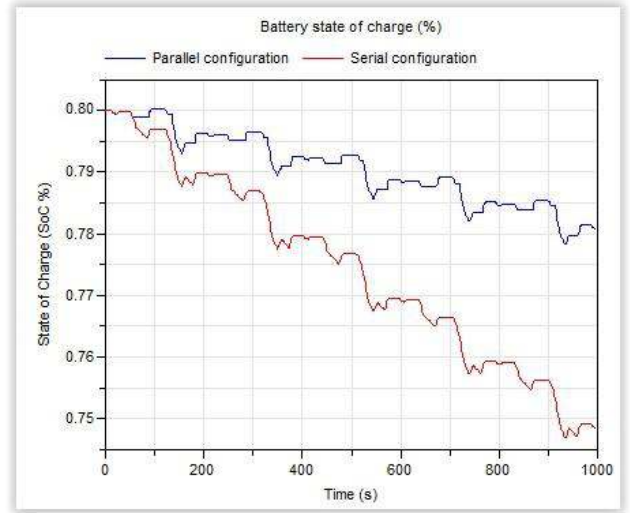


Fig. 4. Results of simulation: Battery state-of-charge for both series and parallel hybrid bus configurations

Results indicate that the final value of SoC in the series configuration is less than in the parallel configuration. Because in the parallel configuration the power management strategy used allows the propulsion of the system using both thermal and electric sources. While in the series configuration, only the battery is used as a source of power.

For both configurations, results show that the developed models allow the simulation of the effect of regenerative braking due to decelerations on the SoC during the driving cycle.

This activity is still under development with experimental validations performed on test-benches, located in the IM-CNR laboratories. Once these models find a validation, they can be added to the other Modelica libraries and then used by IM-CNR and other academic institutions involved in future projects.

## IV. CONCLUSION

In this paper we presented the PLACIS (Collaborative Platform for Systems Engineering) project. The general framework of PLACIS, its impact on learning systems engineering and the outcomes were also detailed.

As an example of studies performed within PLACIS project, the case of modeling and simulation of two hybrid electric

configurations of busses were presented. Some results about the battery-state-of-charge in both configurations were compared and some conclusions were drawn.

Based on the experience gained in PLACIS project, a new project, called EPICES (European Platform for Innovation and Collaboration between Engineer Students), has been funded in the framework of the Erasmus+ program. EPICES was launched on September 2014, with the main objective of developing a European collaborative at-a-distance PtBL framework and method, based on already existing and still developing technical platforms, i.e. collaborative and engineering tools.

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