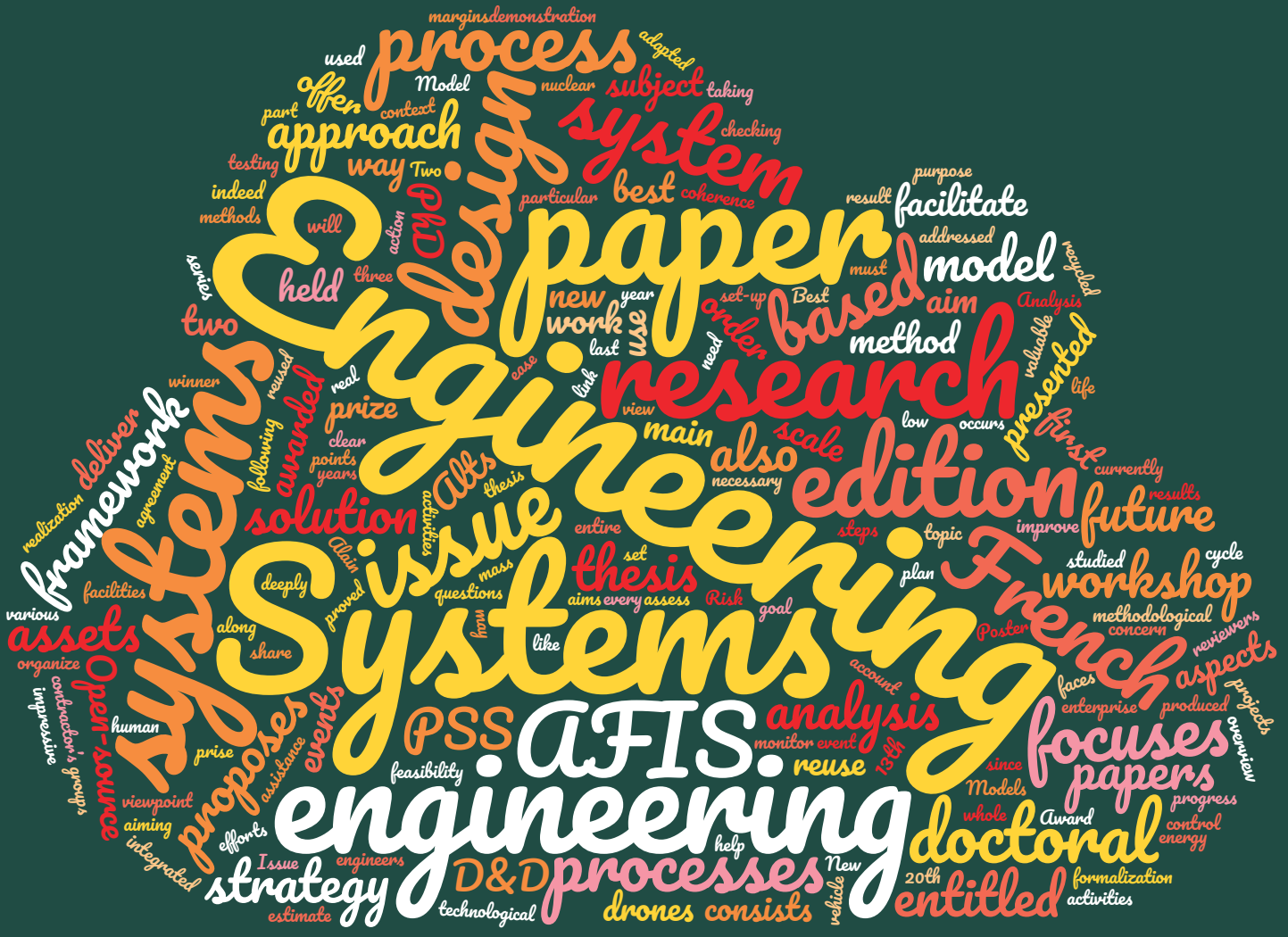
INSIGHT

This Issue's Feature:

AFIS Doctoral Symposium: New Challenges and Advances in Systems Engineering at French Universities



DECEMBER 2019
VOLUME 22 / ISSUE 4

A PUBLICATION OF THE INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING

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INSIGHT

A PUBLICATION OF THE INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING

DECEMBER 2019 VOLUME 22 / ISSUE 4

Inside this issue

About This Publication

INFORMATION ABOUT INCOSE

INCOSE's membership extends to over 17, 000 individual members and almost 100 corporations, government entities, and academic institutions. Its mission is to share, promote, and advance the best of systems engineering from across the globe for the benefit of humanity and the planet. INCOSE charters chapters worldwide, includes a corporate advisory board, and is led by elected officers and directors.

For more information, click here:
The International Council on Systems Engineering
(www.incose.org)

OVERVIEW

INSIGHT is the magazine of the International Council on Systems Engineering. It is published four times per year and features informative articles dedicated to advancing the state of practice in systems engineering and to close the gap with the state of the art. ***INSIGHT*** delivers practical information on current hot topics, implementations, and best practices, written in applications-driven style. There is an emphasis on practical applications, tutorials, guides, and case studies that result in successful outcomes. Explicitly identified opinion pieces, book reviews, and technology roadmapping complement articles to stimulate advancing the state of practice. ***INSIGHT*** is dedicated to advancing the INCOSE objectives of impactful products and accelerating the transformation of systems engineering to a model-based discipline.
Topics to be covered include resilient systems, model-based systems engineering, commercial-driven transformational systems engineering, natural systems, agile security, systems of systems, and cyber-physical systems across disciplines and domains of interest to the constituent groups in the systems engineering community: industry, government, and academia. Advances in practice often come from lateral connections of information dissemination across disciplines and domains. ***INSIGHT*** will track advances in the state of the art with follow-up, practically written articles to more rapidly disseminate knowledge to stimulate practice throughout the community.

ARTICLE SUBMISSION

INSIGHT@incose.org

Publication Schedule. ***INSIGHT*** is published four times per year. Issue and article submission deadlines are as follows:

- March 2020 issue – 2 January
- June 2020 issue – 2 April
- September 2020 issue – 1 July
- December 2020 issue – 1 October

For further information on submissions and issue themes, visit the INCOSE website: www.incose.org

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ADVERTISE

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INSIGHT reaches over 10, 000 individual members and uncounted employees and students of almost 100 CAB organizations worldwide. Readership includes engineers, manufacturers/purchasers, scientists, research & development processionals, presidents and CEOs, students and other professionals in systems engineering.

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INSIGHT EDITOR-IN-CHIEF

William Miller, insight@incose.org

We are pleased to publish the December 2019 issue of *INSIGHT* published in cooperation with John Wiley & Sons as a magazine for systems engineering practitioners. The *INSIGHT* mission is to provide informative articles for advancing the state of the practice of systems engineering. The intent is to accelerate the dissemination of knowledge to close the gap between the state of practice and the state of the art as captured in *Systems Engineering*, the Journal of INCOSE, also published by Wiley.

The focus of the December issue of *INSIGHT* is the French Chapter of INCOSE, Association Française d'Ingénierie Système (AFIS) Doctoral Symposium: New challenges and Advances in Systems Engineering at French Universities. This is our sixth issue devoted to doctoral research in France. The previous issues were July 2008 (Volume 11, Issue 3), December 2011 (Volume 14, Issue 4), December 2013 (Volume 16, Issue 4), December 2015 (Volume 18, Issue 4), and December 2017 (Volume 20, Issue 4). Articles were selected after peer reviews from a larger set of doctoral presentations in collaboration with French universities and industry. Articles from theme editors David Gouyon and Hervé Panetto, and authors address the following topics:

1. Theme Editorial
2. Review of AFIS 2018 Academy-Industry Meetings in Nancy – The Celebration of the 20th Anniversary of AFIS!
3. RobAFIS Student Competition Actuality: Safety & Security Interactions Between Operators and with the System
4. Extended Enterprise Model for PSS within a Systems Engineering Perspective
5. Management of the Design Process: Human Resource Allocation and Project Selection in Factories of the Future
6. A Monitoring Strategy for Industry 4.0: Master Italy s.r.l Case Study
7. Challenges for Autonomous Vehicles (AVs) Engineering Safety Validation of Functional Performance Limitations
8. System Engineering and Dependability: Methodology of Model Synchronization between System Architecture Models and Risk Analysis
9. A Model-Based Approach to Design, Organize, and Monitor Dismantling and Decommissioning of Nuclear Facilities
10. On the Mastering of Modelling Activities Development in Engineering
11. Towards a Maturity Assessment Scale for the Systems Engineering Assets Valorization to Facilitate Model-Based Systems Engineering Adoption
12. Evaluation of Systems Contractor's Ability to Deliver a Solution to Offer During an Engineer-to-Order Bidding Process
13. Coordination of Multi-Underwater Drones: Towards an Integrated Object-Oriented Methodology in an Open-Source Environment.

The editors of *INSIGHT* would be pleased to accept proposals from other INCOSE chapters, working groups, and affiliated bodies for themed issues centered on systems engineering practices beginning in 2021. The 2020 *INSIGHT* themes and articles are already committed: 1) Artificial Intelligence in Systems Engineering from the US Systems Engineering Research Center (SERC), 2) Critical Infrastructure Protection and Recovery II follow-on to the December 2016 issue from the working group of the same name, 3) Loss-Driven Systems Engineering from the Resilient Systems Working Group, and 4) Security in Product Line Engineering from the Systems Security Engineering Group.

I thank assistant editor Lisa Hoverman and her team, Chuck Eng for layout and design, our theme editors in 2019, associate director for INCOSE publications Ken Zemrowski, Holly Witte in the publications office, and the staff at Wiley.

Feedback from readers is critical to the quality of *INSIGHT*. We encourage letters to the editor at insight@incose.org. Please include "letter to the editor" in the subject line. We hope you continue to find *INSIGHT*, the practitioners' magazine for systems engineers, informative and relevant. ■

Editorial of *INSIGHT* Special Feature

AFIS Doctoral Symposium: New Challenges and Advances in Systems Engineering at French Universities

David Gouyon, david.gouyon@incose.org; and **Hervé Panetto,** herve.panetto@incose.org

This *INSIGHT* special issue section focuses on the eighth edition of the French Systems Engineering Academia-Industry meetings, organized by AFIS (Association Française d'Ingénierie Système), the French chapter of INCOSE, and supported by French universities as a regular series, usually every two years. This edition transpired in Nancy in December 2018.

These meetings, which consist of workshops and plenary lectures, provide the opportunity for both academics and industrials to:

- debate on systems engineering practices, education, and competences development for professional situations
- develop and promote research in systems engineering.

The first article of this special section, by Eric Levrat, Eric Bonjour, David Gouyon, Pascale Marangé, Frédérique Mayer, Hervé Panetto, and Jean-Claude Tucoulou, presents the events that occurred during the meetings: a pre-forum, a forum, conferences, workshops, a doctoral workshop, the AFIS thesis prize, and the celebration of the 20th anniversary of AFIS.

One event, a major one for AFIS, is the RobAFIS Challenge which occurs each year since 2006. The article by Jean-Claude Tucoulou and David Gouyon aims at presenting the 13th edition of RobAFIS, and results. An originality of this edition is the solution's footprint consideration: the system platform must focus on material or product with a low ecological footprint, reused or recycled, and must be recyclable itself. Among other novelties of this edition, the Alain Faisandier prize was initiated for the best development document quality and systems engineering processes implementation.

The other special issue articles concern the main contributions presented in another major forum event, the meetings' doctoral workshop, providing an overview of French research in the systems engineering domain. For this *INSIGHT* issue, doctoral students and their supervisors submitted an extended version of their presentations to emphasize the research aspects of systems engineering. This edition selected eleven research papers to promote research on systems engineering approaches.

The first research paper, by Mourad Harrat, Elaheh Maleki, Farouk Belkadi, and Alain Bernard, entitled "Extended Enterprise Model for PSS Within a Systems Engineering Perspective" addresses the representation of organizational capabilities as part of the Product-Service Systems (PSS) enabling systems. Two UML diagrams propose to clarify the structure and to characterize the collaborative processes behind this virtual organization. The proposed modeling framework is a background for the design and management of collaborations along the PSS life cycle.

In the second paper, entitled "Management of the Design Process: Human Resource Allocation and Project Selection in Factories of the Future," the authors, Guangying Jin, Séverine Sperandio, and Philippe Girard, propose a human resource allocation methodology and project selection methodology to help project managers effectively manage the design process in future factories, especially for the collaboration and communication problem in candidate design groups.

Future factories are also the subject in "A Monitoring Strategy for Industry 4.0: Master Italy s.r.l Case Study," the paper by Concetta Semeraro, Hervé Panetto, Mario Lezoche, Michele Dassisti, and Stefano Cafagna. This paper's goal is to present and to analyse the monitoring strategy adopted in a design for a real Italian SME company's digital transformation . The monitoring strategy is a hybrid approach between the life cycle analysis and the exergetic analysis based on the mass balance evaluation and the energy balance.

Various papers consider safety aspects. The first one, by Tchoya Florence Koné, Eric Bonjour, Eric Levrat, Frédérique Mayer, and Stéphane Géronimi, focuses on

the "Challenges for Autonomous Vehicles (AVs) Engineering: Safety Validation of Functional Performance Limitations." AVs engineering cannot limit itself to the classical safety validation issue, which ensures the vehicle's functional safety. It faces a new safety validation challenge in the functional performance guarantee of these new vehicle types. This paper presents some validation issue reflections and concludes with some important questions.

In particular, the systems engineering and dependability link is the subject of the paper by Anthony Legendre, Agnès Lanusse, and Anthoine Rauzy: "System Engineering and Dependability: Methodology of Model Synchronization Between System Architecture Models and Risk Analysis." It proposes a collaborative approach to set-up adapted modelling and methodological practices in the enterprise, taking into account the studied system context, applied processes, applied methods, and viewpoint produced by engineers.

Model-based systems engineering is currently a main research topic, as proved by the following papers. Maxence Lafon, Vincent Chapurlat, Jean-François Milot, and Cyril Moitrier propose "A Model Based Approach to Design, Organize, and Monitor Dismantling and Decommissioning of Nuclear Facilities." The method involves three steps: first, formalization and specification of the entire set of requirements; second, structure, checking, and demonstration of the project's coherence and feasibility from both the technological and organizational view points; third, re-evaluation of the dismantling and decommissioning (D&D) strategy and the product's management, depending on the D&D projects' possible evolution.

As these modelling activies must result in clear and traceable models to benefit from model advantages like communications improvement, system understanding, and knowledge sharing and reuse, Freddy Kamdem Simo, Dominique Ernadote, and Dominique Lenne focus "On the Mastering of Modelling Activities Development in Engineering." The contribution of the authors is the introduction of a MODEL-based Federation of Systems of Modelling (MODEF) and its supporting framework with its principles, theoretical and practical arguments for understanding, modelling, analysis, monitoring, and ease of modelling activities (MA) development and operation considered as a project-product system. Freddy Kamdem Simo received the prize for the best PhD thesis work in systems engineering 2017-2018.

Model-Based Systems Engineering adoption is Quentin Wu, David Gouyon, Sophie Boudau, and Éric Levrat's focus in "Towards a Maturity Assessment Scale for the Systems Engineering Assets Valorization to Facilitate Model-Based Systems Engineering Adoption." The paper's main hypothesis is, to facilitate MBSE adoption, a prerequisite is the capture of engineering assets and their valorization through reuse. The article aims to propose a scale to evaluate the systems engineering assets' valorization maturity. In this way, it will be possible to assess the margins for progress and therefore to estimate the necessary efforts to improve their maturity through a corresponding action plan. This work won Best Poster Award during the meetings' doctoral workshop.

Abdourahim Sylla, Elise Vareilles, Thierry Coudert, Michel Aldanondo, and Laurent Geneste focus on agreement processes. They propose an "Evaluation of Systems Contractor's Ability to Deliver a Solution to Offer During an Engineer-To-Order Bidding Process," by using two confidence indicators and their evaluation method. These indicators aim at evaluating a company's future ability to deliver a solution to offer during a bidding process. Also presented is a way to use these confidence indicators during a design process. Abdourahim Sylla also received awards for his PhD thesis.

The last paper, entitled "Coordination of Multi-Underwater Drones: Towards an Integrated Object Oriented Methodology in an Open-source Environment," proposed by Hoang Anh Pham, Thierry Soriano, and Hien Van Ngo, presents a framework for studying the coordination of multi-underwater drones, specifically the formation control, that depends on real-time object-oriented paradigms in an open-source environment. The objective is to capture the system's whole development life cycle, from the requirements specification to testing the simulation and realization models.

We are grateful for the authors' impressive contribution and for the reviewer's valuable assistance to this *INSIGHT* issue's scientific relevance. ■

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THE EDITORS

Dr. David Gouyon is a Systems Engineering associate professor at the University of Lorraine. There he oversees work-linked training within a master's degree on Complex Systems Engineering. He is within the Nancy Research Centre for Automatic Control (CRAN), and his research interests are Systems and Automation Engineering, mainly with models (MBSE). He is a member of the French chapter of the International Council of Systems Engineering, an Associated Systems Engineering Professional (ASEP).

Dr. Hervé Panetto is a Professor of Enterprise Information Systems at the University of Lorraine, TELECOM Nancy. He teaches Information Systems modelling and development, and conducts research at CRAN (Research Centre for Automatic Control), Joint Research Unit with CNRS where he is managing a research project on ontology use for formalising models related to the interoperability of production systems, and many enterprise information systems. He is an elected member of the Academia Europaea in 2018.

He received his PhD in production engineering in 1991. He has strong experience in information systems modelling, semantics modelling and discovery, and database development. His research field is based on information systems modelling for enterprise applications and processes interoperability, with applications in enterprise modelling, manufacturing processes modelling, and furniture data modelling. He is working in ERP and MES integration from a Business to manufacturing perspective. He is expert at AFNOR (French National standardisation body), CEN TC310 and ISO TC184/SC4 and SC5. He participated in many European projects including IMS FP5-IST Smart-fm project (awarded by IMS) and the FP6 INTEROP NoE (Interoperability Research for Networked Enterprises Applications and Software). He is editor or guest editor of books and special issues of international journals. He is author or co-author of more than 150 papers in the field of Automation Engineering, Enterprise Modelling and Enterprise Systems Integration and Interoperability. He is a member of INCOSE and the AFIS French Chapter on Systems Engineering. He is Chair of the IFAC Coordinating Committee 5 on "Manufacturing and Logistics Systems" since 2014. He received the IFAC France Award 2013, the INCOSE 2015 Outstanding Service Award and the IFAC 2017 Outstanding Service Award. He is a co-organiser of the yearly OTM/IFAC/IFIP EI2N workshop on "Enterprise Integration, Interoperability and Networking" and General Co-chair of the OTM Federated conferences.

DECEMBER 2019
VOLUME 22/ ISSUE 4

Review of the AFIS 2018 Academy-Industry Meetings in Nancy - The Celebration of the 20th Anniversary of AFIS!

Eric Levrat, eric.levrat@univ-lorraine.fr; **Eric Bonjour,** eric.bonjour@univ-lorraine.fr; **David Gouyon,** david.gouyon@univ-lorraine.fr; **Pascale Marangé,** pascale.marange@univ-lorraine.fr; **Frédérique Mayer,** frederique.mayer@univ-lorraine.fr; **Hervé Panetto,** herve.panetto@univ-lorraine.fr; and **Jean-Claude Tucoulou,** jeanclaude.tucoulou@incose.org (*president of the French Chapter of INCOSE*)

The AFIS Academy-Industry meetings commenced 4-6 December 2018 in Nancy at the University of Lorraine. Six complementary events brought together 165 participants: the LF2L-ENSGSI Preforum, the Faculty of Science and Technology RobAFIS 2018 competition, the 8th AFIS Academy-Industry Forum 2018, the Doctoral Seminar 2018, the AFIS Thesis Prize 2018, the 20th Anniversary of AFIS celebration, and the Forum Gala Dinner with the theme "AFIS celebrates its 20th anniversary!"

The University of Lorraine, the university organizing these meetings, has, since 2005, two pioneering courses teaching Systems Engineering in France and referenced in the "Worldwide Directory of Systems Engineering & Industrial Engineering Academic Programs 2017:"

- the Master's Degree in Complex Systems Engineering and
- the National Higher School of Engineers in Systems Engineering and Innovation (ENSGSI).

Research activities involving the Systems Engineering theme in two University of Lorraine laboratories: CRAN (Centre de Recherche en Automatique de Nancy, UMR CNRS 7039) and ERPI (Research team on innovative processes) support these training courses.

A COMPLETE AGENDA

These meetings provide academic and industrial communities exchange opportunities on the systems engineering theme, its industrial implementation, teaching, and related research issues. This edition's unifying theme was: From the systems' complexity to their acceptance and ease of use. Linking expertise, teaching, and systems engineering research, developed by the University of Lorraine teachers-researchers the theme forms a paradox; a challenge manufacturers faced, contextualizing change from a product economy to a service or experience economy. How to design systems to control their complexity and ensure simplicity/acceptance of uses, how are systems engineering processes and methods impacted by this rationale, how can systems engineering facilitate this transition within companies?

Five conferences and eight workshops led by 20 facilitators (half industrialists and academics), the participants discussed the forum's unifying theme. Participation found a good industry and academy balance, contributing to the Forum's mission: being a place to share and exchange systems engineering knowledge and practices in business, education, and research.

ACKNOWLEDGEMENTS

We thank Paul Schreinmakers, Director of INCOSE's EMEA Sector, for his warm testimony on AFIS' significant INCOSE work contributions. This took place with Jean-Claude Roussel, commanding the AFIS and INCOSE International Relations missions, during the 20th Anniversary Celebration Jean-Claude Tucoulou led.

We also thank the speakers for the high quality of their presentations.

Laurence Kujawa and Valérie Castel (Nexter Group - Nexter Systems). "Ergonomics at the Heart of User Centered Design at Nexter Systems."

Catherine Devic (EDF). "Digital Twins for the Performance of Nuclear Power Plants... or How to Bring Models to Life."

Christophe Ducamp (AIRBUS). "Virtual Simulators and Digital Twins: How to Check & Validate Usage as Soon as Possible."

Damien Trentesaux (Deputy Director of GDR MACS – University of Valenciennes). "Challenges of Civil Autonomous Systems. Ethics, and Humanity."

Eric Levrat and Eric Bonjour (University of Lorraine). "Complexity of Systems and Simplicity/Acceptance of Uses."

Finally, 70 forum participants took the gala dinner opportunity to extend these exchanges during another convivial moment.

AFIS PREFORUM 2018 – AFIS SEMINAR

The preforum is an event organized the day before the forum, aiming to promote systems engineering in the forum's region. The 2018 theme addresses many SMEs concerns about improving the value of their products and services: "Connected Objects and Innovation: What Opportunities and Challenges for SMEs?"

The Lorraine Fab Living Lab (LF2L®–http://lf2l.fr/fr/), a co-design prospective platform evaluating uses and acceptability of innovation developed by the ERPI laboratory in Nancy, hosted the AFIS Preforum. It brought together industrialists from SMEs in the Greater East Region; students, lecturers, and researchers. AFIS invested industrialists, experienced in systems engineering, also came to complete the feedback. We thank the speakers who provided rich feedback and interesting exchanges with the participants.

AFIS PRIZE FOR THE BEST PHD THESIS WORK IN SYSTEMS ENGINEERING 2017-2018

The prize for the best PhD thesis work in Systems Engineering 2017-2018, the third edition, collaborating with the GIS S-MART, was co-chaired by Frédérique Mayer (University of Lorraine) and Dominique Luzeaux (Habilité à Diriger des Recherches, Ministère des Armées). On 6 December 2018, during the AFIS meetings, the jury announced the results. Doctors who graduated between November 2016 and November 2018 submitted eight high quality applications. The evaluation criteria were both academic (originality, publications) and industrial (systems approach, impact on systems engineering practices). Winners are as follows. The 2018 winner was Freddy Kamdem Simo, for his thesis work entitled "Model-based federation of systems of modelling." Thesis supervised by Dominique Lenne, UTC, HeuDiaSyc, and Dominique Ernadote, Airbus Defence & Space. The other winners were Abdourahim Sylla (ENI Tarbes, IMT Mines Albi), Sonia Ben Hamida (CentraleSupelec) and Li Zheng (INSA Toulouse). (See photo 3). Congratulations to these winners!

DOCTORAL SEMINAR AND BEST AFIS 2018 POSTER AWARD

This year presented 17 posters for the best AFIS 2018 poster award. This great success for AFIS demonstrates the Meetings' interest for young researchers and the French systems engineering research dynamism. We congratulate the organizers, David Gouyon and Hervé Panetto (University of Lorraine), for the event's high quality. The 17 participants who submitted a poster took advantage of free AFIS 2018 forum registration. Thus, promoting their PhD thesis work supported by their poster and forum participant exchange.

The 2018 Best Poster Award winner is Quentin Wu, University of Lorraine, CRAN / SAFRAN Aerosystems. Modeling and reuse of know-how in an MBSE approach: application to aircraft electrical distribution systems. (See photo 4).

INCOSE invited the participants in the seminar, as well as the winners of the PhD thesis prize, to write a paper summarizing and enhancing their work and published these papers in this *INSIGHT* special issue. ■

Emmanuel Caillaud (Co-Chair of AFIS), Damien Trentesaux, Abdourahim Sylla, Frédérique Mayer, Freddy Kamdem Simo, Alain Roussel (former president of AFIS)

David Gouyon, Emmanuel Caillaud, Frédérique Mayer, Anthony Legendre, Florence Koné, Maxence Lafon, Quentin Wu, Alain Roussel

RobAFIS Student Competition Actuality: Safety & Security Interactions Between Operators and with the System

Jean-Claude Tucoulou, jeanclaude.tucoulou@incose.org; and **David Gouyon,** david.gouyon@incose.org

This paper presents the RobAFIS competition which AFIS, the French chapter of INCOSE, organizes yearly since 2006. Previous editions of *INSIGHT* presented this competition alongside its pedagogical objectives (Tucoulou Gouyon and Bonjour 2011) (Tucoulou and Gouyon 2013) (Tucoulou and Gouyon 2015) (Tucoulou Bonjour and Gouyon 2017). RobAFIS enhances AFIS action, offering educational and research institutions an operation to better understand and develop systems engineering uses and best practices, as recommended and formalized by AFIS. Two reference documents recommended for RobAFIS are:

- the book "To discover and understand Systems Engineering" (Fiorèse and Meinadier 2012)
- the book "Thinking System" (Tucoulou Daniel-Allegro and Le Put 2014).

Since 2007, students and their supervising teachers may exchange with the jury AFIS expert members, working in industry or teaching systems engineering. During development, these experts answer, via a FAQ page RobAFIS dedicated as collaborative space (RobAFIS 2019), questions including technical or methodological issues related to stakeholder requirements or to the development document.

RobAFIS' main objective is highlighting the benefits of basing systems engineering education on a project life cycle realization: a full life cycle including the implementation of an operational system, deployed by a client, in a real environment.

1. A DEVELOPMENT IN TWO PHASES

To enhance the system architectural choices and technology choices distinction, since 2015 we proposed a model of development in two phases:

- Phase 1: an upstream study phase where a preliminary development document (§2) addresses possible solution identification (at least 3 candidate solutions) and the justified choice of the selected solution, based on studied solutions drafts;
- Phase 2: a full development phase where a detailed development document (§3) and an operational prototype correspond to the solution selected in the first phase.

The aim is to highlight both phases specific nature and contribution, using a progressive definition, the first one encompassing a system vision; the second one a product-oriented vision.

2. PRELIMINARY DEVELOPMENT DOCUMENT ARCHITECTURE (ROBAFIS 2019)

Concluding Phase 1 requires student teams to supply a preliminary development document, structured into 3 deliverables (more details on www.robafis.fr):

1. Preliminary version of requirement referential (Deliverable 10)
2. Presentation of possible architectural designs (Deliverable 20)
3. Justification of architecture choice (Deliverable 40).

3. DEVELOPMENT DOCUMENT ARCHITECTURE (ROBAFIS 2019)

Full development Phase 2 results, supplied under the form of a detailed development document, require an 8 deliverables structure (more details on www.robafis.fr):

1. Final requirement referential (Deliverable 10)
2. Final architectural design (Deliverable 20)
3. Reference configuration (Deliverable 30)
4. Justification of definition (Deliverable 40)
5. Integration, Verification, Validation Plan (Deliverable 50)
6. Maintainability study and maintenance definition (Deliverable 60)
7. Project management (Deliverable 70)
8. Assembly and verification instructions (Deliverable 80).

4. RECENT TECHNICAL SUBJECTS

Previous years have seen various evolutions in the case studies' technical aspects:

- 2015-2016-2017-2018: Operators and technical systems interactions

Equipes RobAFIS 2018
IMT – Mines d'Alès
Institut National des Sciences Appliquées Toulouse – INSATOMIQUE
Institut National des Sciences Appliquées Toulouse – RED PANDA
Ecole Internationale des Sciences du traitement de l'Information
ITESCIA (CNAM)
Université de Reims Champagne Ardenne – Master EEAII
Université Technologique de Troyes – Départment EAA
Université de Bordeaux – Master GILOG
Université de Lorraine – Master ISG
Sigma – Clermont
Ecole Nationale de l'Aviation Civile – SITA option ISI
Université de Bourgogne Franche-Comté – Master on Green Mechatronics
Université de Technologie de Compiègne – Master ISC
UTC ESIEE – Master ISC

Figure 1. Teams

- 2017: Evolution of the two systems deployed simultaneously in a common environment
- 2018: Evolution of the system in an environment imposing high operational safety constraints and introduction of environmental requirements with a low ecological footprint and recyclability.

5. 2018: "13TH EDITION" ORGANIZED AS PART OF THE 20TH ANNIVERSARY OF AFIS

This year broke record participation. 14 teams participated in the competition (Figure 1) and 100 teachers and students presented for the final on 4 and 5 December 2018, an event hosted in Nancy by the University of Lorraine, at the Faculty of Science and Technology.

The proposed subject concerned a robot for handling and transporting radioactive packages in the environment of a nuclear waste reprocessing center (Figure 2).

The system sequences could operate either automatic mode maximizing operational safety and security requirements, or remote mode from a monitoring and control console (Figure 3, next page), served by two separate operators depending on the performed operation.

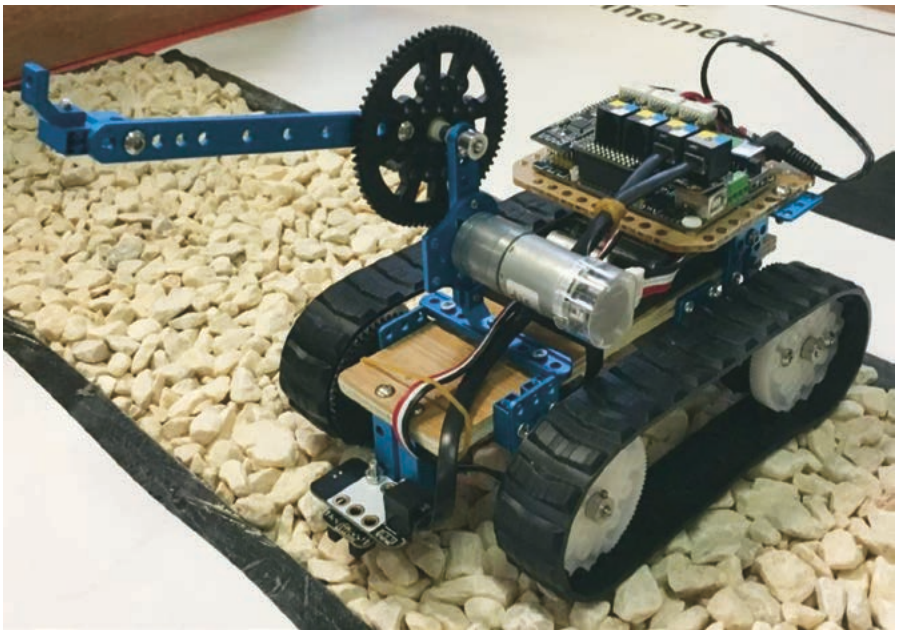

Figure 2. Deployment phase

Each edition required all components necessary for the operation of the solution come from the AFIS provided kit. This year, the exception was the bare platform of the system (Figure 4, next page) constructed of material or product with a low ecological footprint, reused or recycled, and the solution itself being easily recyclable at the end of its life. The evaluation of the engineering file and the project audit integrated these requirements' satisfaction. AFIS awarded a special prize to the most innovative and eco-responsible solution.

In the overall ranking, the three best teams received the AFIS Prizes. Ranked 1st ex-aequo were the EISTI of Cergy Pontoise and the INSATOMIQUE team of INSA Toulouse. Ranked 3rd was the PANDA team of INSA Toulouse.

Ecole Nationale de l'Aviation Civile de Toulouse received the Best Human Factor Approach to System Engineering and Best Usability of the System NEXTER SYSTEM Award.

The Master ISC of the University of Lorraine received the best engineering and demonstration of maintenance aptitude AIRBUS Maintainability Award.

SIGMA CLERMONT received the best project audit for the innovative nature of the bare platform and the satisfaction of design and end-of-life disposal requirements AFIS Prize.

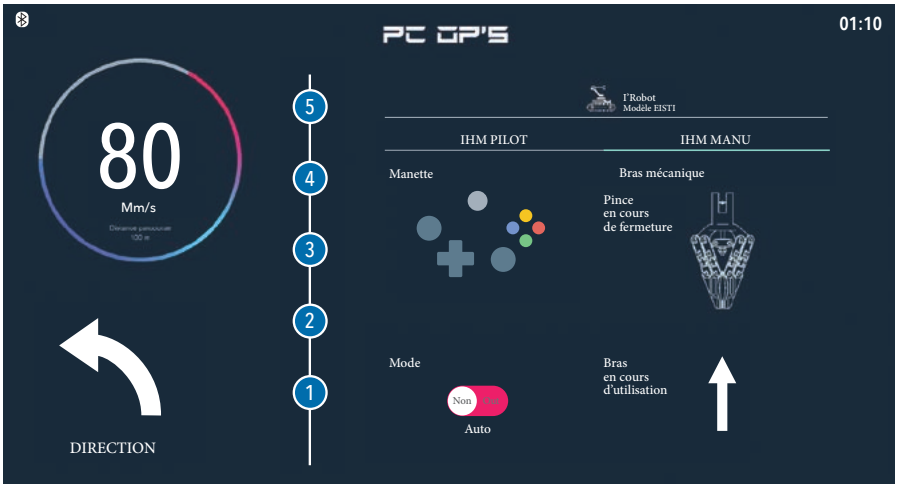

Figure 3. HMI for the handling operator

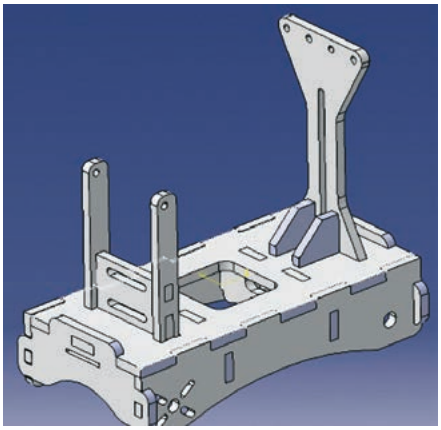

Figure 4. Platform design example

Master ISC of the University of Lorraine, for the development document quality and the systems engineering technical processes implimentation, received the first time Alain Faisandier System Engineering Prize. ■

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Extended Enterprise Model for PSS Within a Systems Engineering Perspective

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■ **ABSTRACT**
Today, firms are adopting Product-Service Systems (PSS) business models requiring new designing, producing, and consuming methods. Systems engineering is a promising solution addressing the PSS development and life cycle management complexity. Following this perspective, this paper focuses on organizational capabilities representation as part of the PSS enabling systems. Two UML diagrams propose to clarify the structure and to characterize the collaborative processes behind this virtual organization. The proposed systems engineering based modeling framework functions as a background for the design and management of collaborations along the PSS life cycle.

1. INTRODUCTION

Product-Service Systems (PSS) strategically proposes new value for the customers through a long-term relationship that increases their loyalty. Literature defines it as a combination of tangible and intangible components to provide original offers and to fulfill specific customers' needs (Tukker and Tischner 2006; Pawar, Beltagui, and Riedel 2009; Meier, Roy, and Seliger 2010) institutes and programs in the EU paid attention to product-service systems (PSS).

Previous works (Maleki, Belkadi, Bonjour, and Bernard 2018) OEMs (Original Equipment Manufacturers) demonstrate based on a systems engineering approach, that PSS can function as an integrated system composed of two main sub-systems: system of interest and enabling systems (Maleki, Belkadi, Bonjour, and Bernard 2018) OEMs (Figure 1). The final solution provided to the customer who pays for its usage (or its consumption) is the system of interest. This system's components are:

- Products whose components can be electronical, mechanical, and/or cybernetic.
- Service components, including service processing, software, and the embedded system.

The Enabling Systems are all other support resources for PSS delivery and operation. They apply several capabilities and competences from the company to support the PSS business model realization. These systems components are:

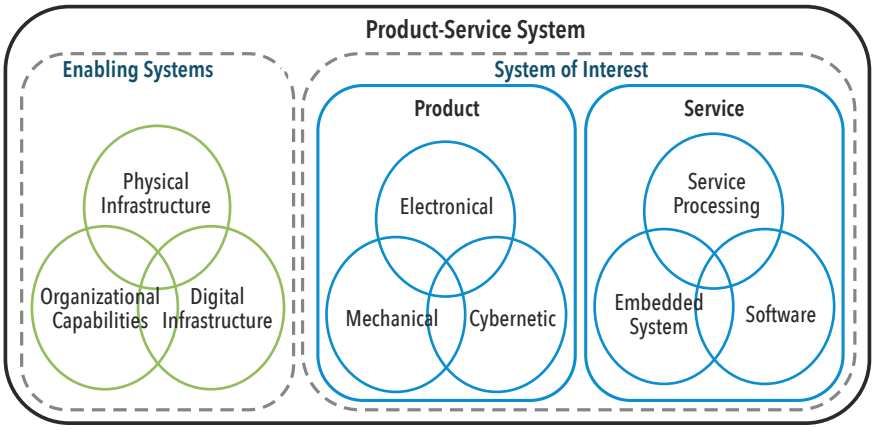

Figure 1. A systems engineering perspective of PSS (Maleki Belkadi Bonjour and Bernard 2018) OEMs (Original Equipment Manufacturers)

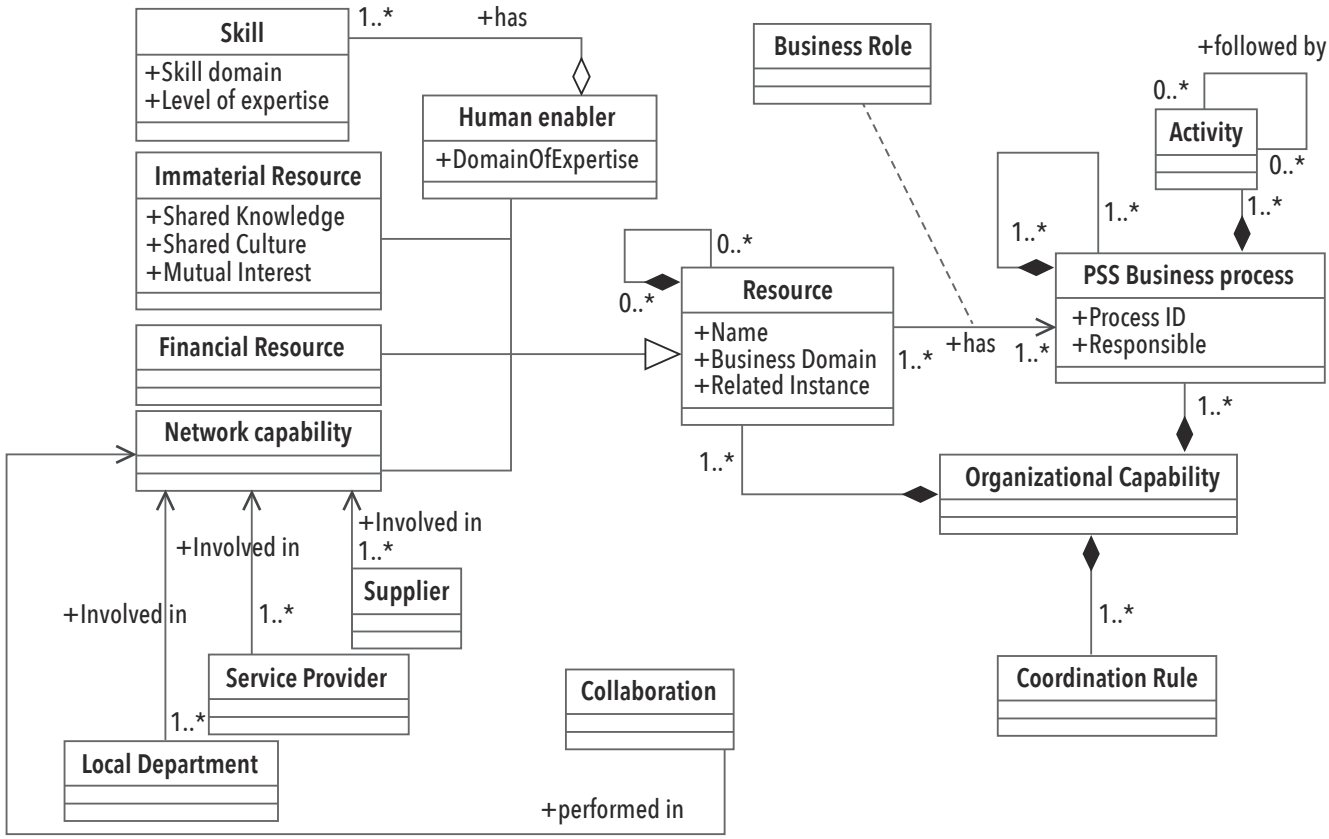

Figure 2. Organizational Capabilities Model (Maleki Belkadi Bonjour and Bernard 2018) OEMs (Original Equipment Manufacturers)

- Physical and digital infrastructures, which exist within and assist the stakeholders' network. The PSS owner or another partner could buy or rent these infrastructures. Physical infrastructure examples are buildings, distribution network and stations. Digital infrastructures include informatics network, servers, information systems, and more.
- Organizational capabilities, defined as the necessary resources and operational processes for added value creation and maintenance during the PSS life cycle.

Therefore, designing a PSS implies the need to consider its whole life cycle, integrating all stakeholders involved in the different PSS life phases: Need clarification, solution seeking, and solution development (Wallin et al. 2015). The resulting network suggests a higher complexity regarding the multidisciplinary and the variety of partners and their roles. To deal with this complexity, modelling the organizational capabilities should classify the resource and process variety and highlight the network member relationships.

Consequently, the organizational capability within the value network should be consistently managed as an Extended Enterprise. This paper aims to propose collaboration meta-model as a backbone of the PSS organizational capabilities.

2. ORGANIZATIONAL CAPABILITY AS AN EXTENDED ENTERPRISE

In project development, the term organization refers to the functional (the design process structure) and the organic architectures (the collaborative teams' members and their interactions) (Bonjour, 2008). Several works on organizational architecture in product design dealt with topics such as design processes optimization, decomposition into design teams, minimization of coordination efforts on the project, and more (Braha 2002; Sosa, Eppinger and Rowles 2003; Whitfield, Duffy, and Kortabarria 2005) are some examples. In PSS, the systems' complexity is increasing, creating an aligned view of the involved enterprises' strategies and processes. This could be possible through the concept of "Extended Enterprise" which implies a System of Systems perspective. According to the definition of Sachs, Post, and Preston (2002), Extended Enterprise is "the nodal element within a network of interrelated stakeholders that create, sustain, and enhance its value-creating capacity." A long-term business contract between partners as an inter-enterprise collaboration with the necessity of high trust, knowledge sharing, and resource investments (Mohr and Spekman 1994; Dyer 2000; Browne and Zhang 2002) characterizes Extended Enterprise. These characteristics are at the heart of PSS organizational capability making viewing it as an Extended Enterprise possible. Figure 2 shows the UML diagram proposing an organization capabilities model for PSS, based on this definition.

This model includes several concepts: coordination rules, PSS business processes, and typology of resources. The different classes inheriting resources are human enabler (some skills assigned), immaterial resource, financial resource, and network capability. Network capability is the necessary condition for each stakeholder as it allows value creation for the customer (Berghman, Matthyssens, and Vandenbempt 2006) changing the rules of the market while moving from a producer to a collaborative process (Vargo and Lusch 2008). Network capability classes involve: Supplier, who deals with physical parts; Service Provider; and Local Department, one of the company's units localized in different geographical positions. Finally, Network Capability properly functions through a collaboration process.

Looking to the Extended Enterprise as an organization, a critical aspect to reach the performance remains the way

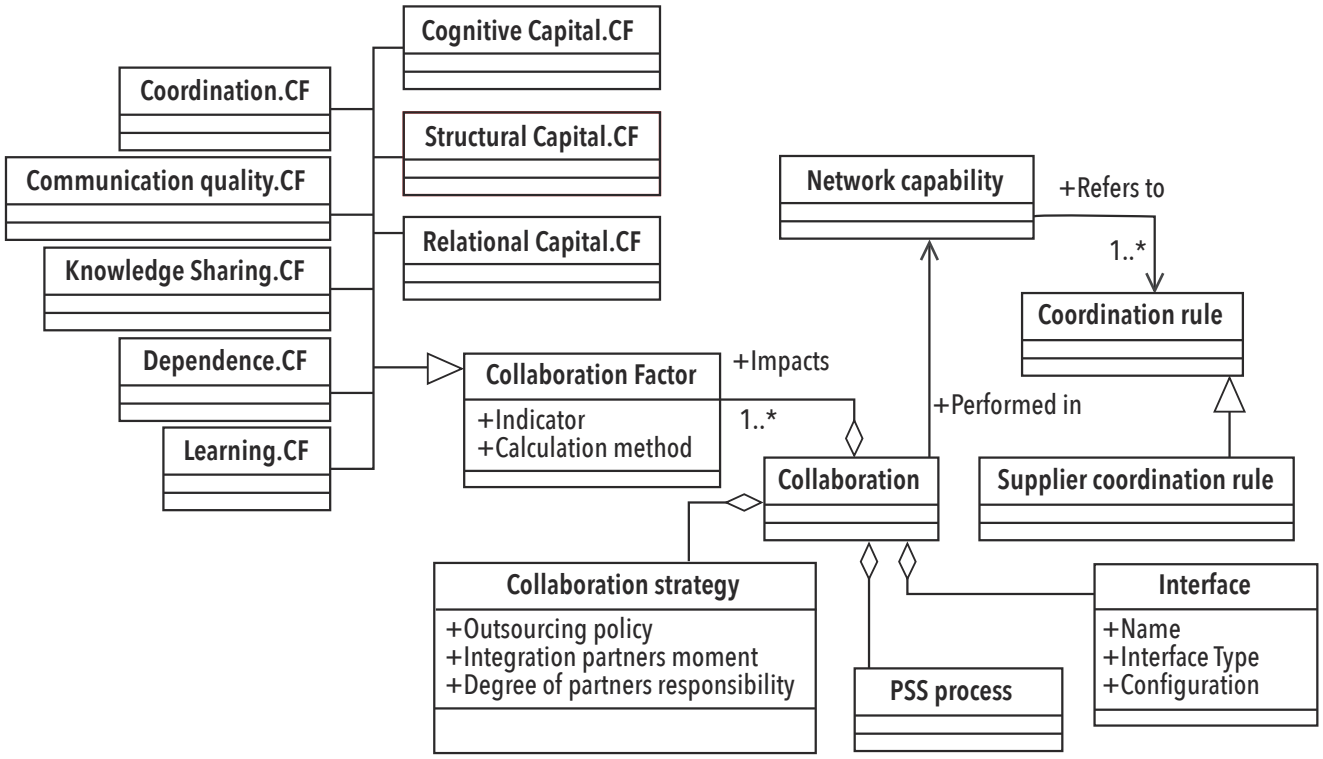

Figure 3. Proposed collaboration model

of all stakeholders working together. The successful collaboration among the PSS organization is dependent on several factors like the commitment of partners, resources shared, coordination mechanisms, and more. Requiring a global model detailing the above concept of collaboration through various points of view helps design and manage such complexity. The following Figure 3 proposes a second UML diagram is as a specification of the class "Collaboration" cited in Figure 2.

According to this model, collaboration process implements a collaboration strategy involving the critical long term decisions in a given network capability. Outsourcing policy (develop, co-develop or buy decisions), partners' integration moment, and the degree of partners' responsibility (Petersen, Handfield, and Ragatz 2005) are strategic choice examples PSS providers (OEM) face. In addition, different factors impact collaboration. We mention social capital dimensions (cognitive, structural, and relational) (Nahapiet and Ghoshal 1998), Coordination, communication quality, knowledge sharing, dependence, and learning. Indicators associate each factor for measure and assessment by using calculation methods. In systems engineering vocabulary terms, value network collaboration conducts different organizational and operational interfaces, which conduct other physical and informational interfaces between tangible components, separately owned by the Extended Enterprise members. Maleki, Belkadi, Bonjour, and Bernard explain a detailed classification of interfaces within PSS context (Maleki, Belkadi, Bonjour, and Bernard 2018). The interface concept definition is "shared boundary between two functional units, defined by various characteristics about the functions, physical interconnections, signal exchanges, and other characteristics, as appropriate" (ISO/IEC 2015).

3. CONCLUSION

This work extends previous research on the application of systems engineering approach as a foundation to represent PSS characteristics. It explores collaboration model as a foundation to support the organizational capabilities, key enabling systems of PSS. This model is a starting point of the characterization of the collaboration management framework, assisting industrial actors for choosing the appropriate collaboration strategy when engaging in a new PSS based business. To realize this collaboration management framework, ongoing work is addressing the identification of collaboration performance assessment methods, using the factors mentioned as criteria. ■

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> continued on page 22

Management of the Design Process: Human Resource Allocation and Project Selection in Factories of the Future

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With the Internet of Things' rapid development, many new challenges such as global collaboration, scarcity of resources, and more shape the designers' project relationships. The engineering design depends on actor communication efficiency in the design process. This leads to increased human resource allocation and project selection process complexity. Therefore, we propose human resource allocation methodology and project selection methodology to help project managers to effectively manage the design process in future factories.

Design is a human activity, related to human needs, addressing the necessity to change the present environmental state (Rosenman and Gero 1998). Design actors must collaborate closer to enhance design efficiency due to global competitive pressure and development process complexity increasing and product development cycle decreasing (Robin Rose and Girard 2007).

Meanwhile the Internet of Things' (IOT) development (Osseiran, Elloumi, Song, and Monserrat 2017) changed the different designers' (those involved in the design process) relationship organization. The designers can communicate and collaborate easier and frequently without any design process intermediary (Figure 1).

They can establish a virtual team to work together and simultaneously control one design process encompassing different IOT. Therefore, the future design process organization structure will be the point-to-point structure without any intermediary.

The challenge of resource allocation is a corporate strategy fundamental feature (Levinthal 2016). Any organization has limited resources: it requires the most efficient and optimum improvement plan to achieve the highest possible overall readiness (Ahmadi, Yeh, Martin, and Papageorgiou 2015).

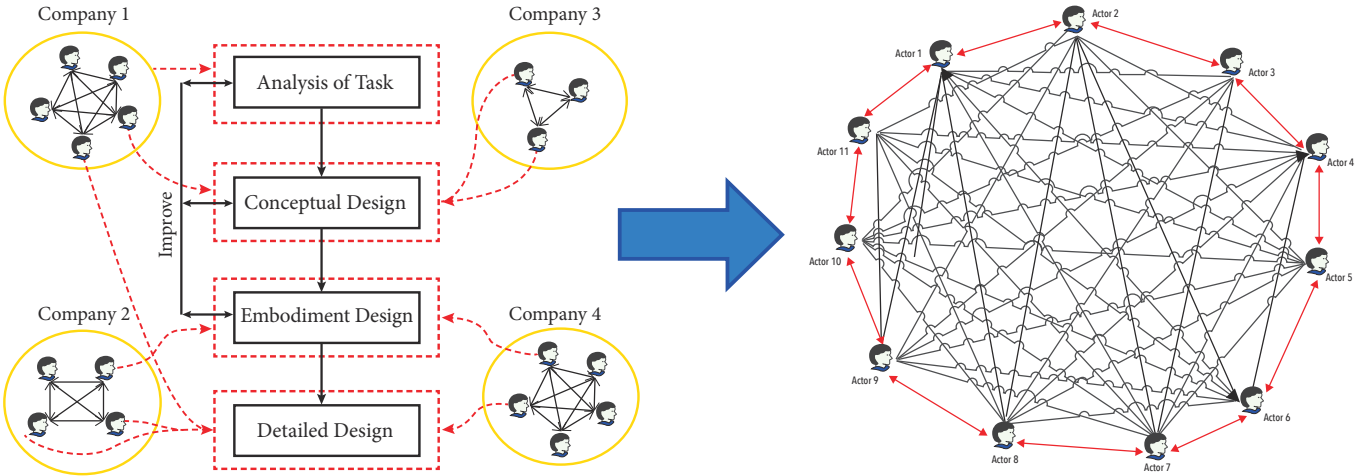


Figure 1. Internet of Things to the future horizontal organization structure (Schoenthaler et al. 2015)

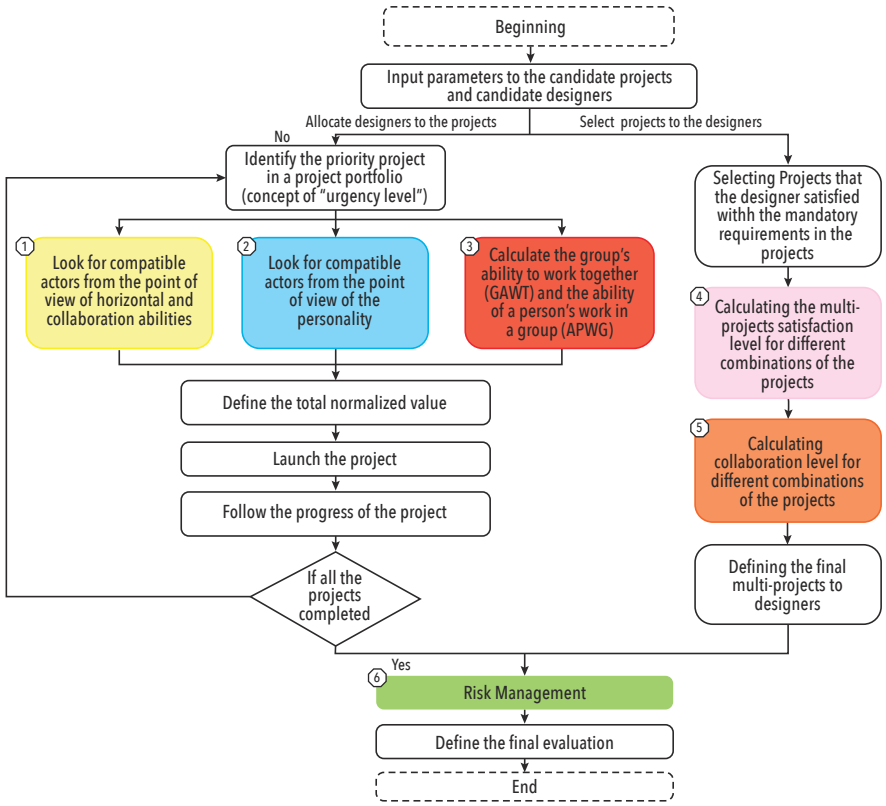


Figure 2. Whole process human resources allocation and project selection methodology

An efficient resource allocation problem's influence is important for a company considering the growing investment decisions' decentralization around the world (Francis Huang Khurana and Pereira 2009).

The Project Management Triangle (Haughey 2011, Thorne 2016); quality of work constrained by the project's budget, deadlines, and scope; is a project management constraints' model used to analyze projects. However, the triangle is insufficient for a project's success because it omits crucial success dimensions including; impact on the project team members, such as position project satisfaction; and other positioned project team member communication and collaboration ability. Therefore, managers require additional attention to the different actors combinations' collaboration and communication ability.

Due to flexible and frequent designer collaboration and communication in future organization structures, technical issues and designers' behavioral problems will affect other co-workers depending on the relationships' intricacy. Therefore, managing the human risk becomes an essential condition for future design process success.

Based on the problems discussed above, the first objective of this research is to approach the multi-project human resources allocation problem while considering horizontal ability (skill, availability, occupancy rate, education, age, and so on), personality analysis and cooperation ability for the design process in future factories. The second objective is considering designers' satisfaction. Finally, the third objective is considering personal and interdependent effects.

Figure 2 shows the whole process of human resources.

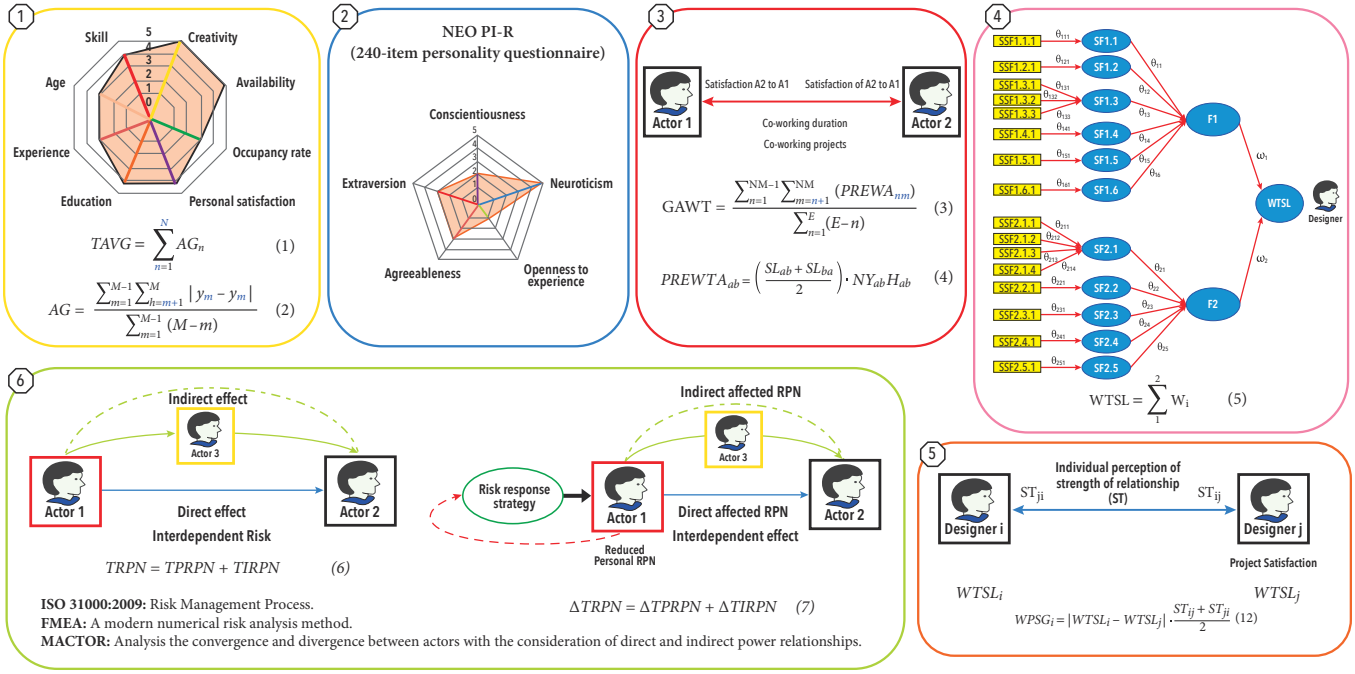
Describing the needs, such as required skills, occupation time, and more, precedes the two branch processes. The left branch allocates designers to projects, and the right branch selects projects for designers. When scheduling several projects along the left branch, priority projects need identifying to promptly, solve the human allocation problem of this project. This allows a project manager, allocating candidate actors, to understand which project is the most urgent project. After that, the project manager locates priority project compatible actors, addressing the project's mandatory needs and requirements.

To help the decision making process, we calculate their analysis:

- Actors' horizontal ability and collaboration ability (① in Figure 2 and Figure 3). The horizontal ability means overall factors (skill, creativity, availability), which can impact project quality and completion time delay. Collaboration ability corresponds to conflict communication and design team harmony. These two steps aim to find the most efficient collaboration and communication of different actors combinations to increase the project completion speed and quality.
- Actors personality (② in Figure 2 and Figure 3). Analyzing the candidate actors' personalities requires the Five Factor Model (FFM) (Neuroticism, Extraversion, Openness, Agreeableness and Conscientiousness) (McCrae and Costa 2013), the most widely accepted solution to describing trait structure problems (McCrae and Costa 2013), and reveals individual differences in personality. Meanwhile, the Revised NEO Personality Inventory (NEO-PI-R) measures the FFM (Costa and McCrae 1992) to release the total personality ability.
- A group's ability to work together and a person's (individual) ability to work in a group (③ in Figure 2 and Figure 3). It considers mutual cooperation, satisfaction, years of experience, and project experience to calculate the Groups Ability to Work Together (GAWT) value and identify different candidate combination groups.

The right branch prioritizes the projects which the designer can satisfy the project's minimum skill requirement. Skill requirement for design projects can be UI (User Interface) design, graphic design basics, design software, and more. We then prioritize multi-projects which the designer can satisfy different project combinations' occupation time follow. Afterwards, we calculate the multi-projects satisfaction level (④ in Figure 2 and Figure 3) and designer collaboration level (⑤ in Figure 2 and Figure 3) for different project combinations. Finally, we define the final multi-project to designer.

After completing the two branch processes, we can manage the risk for designers (⑥ in Figure 2 and Figure 3) and define the final evaluation. According to the previous steps (designer selection considering their profile, personality, collaboration ability, and project selection addressing designers' satisfaction), a project manager must brainstorm potential candidate designer errors and/or shortcomings and determine corresponding error impacts. Then, the project manager assigns a personal severity, detection, and occurrence rank for each designer, depending on the FMEA (Failure Mode and Effect Analysis) methodology (Mikulak McDermott and Beauregard 2008). Calculating the Risk Priority



Note. TAVG = Total Average Gap. AG= Average Gap of one property of the horizontal ability for the entire group. GAWT = Group's Ability to Work Together. = Pair Experience Working Together Ability between actor 'a' and actor 'b'. SLab = Satisfaction Level for actor 'a' to actor 'b'. NYab = the number of years worked together between actor 'a' and actor 'b'. Hab = the number of projects worked together between actor 'a' and actor 'b'. NM = Number of Members in the group. . . . WTSL = Weighted Total Satisfaction Level for the designer. TRPN = Total RPN. TPRPN = Total Personal RPN. TIRPN = Total interdependent RPN. ΔTRPN = Total reduced RPN. ΔTPRPN = Total Personal reduced RPN. ΔTIRPN = Total reduced Interdependent RPN. ST = Strength of social relationship between two designers.

Figure 3. Important parts of human resource allocation and project selection methodology

Number (RPN) defining the designer's risk to the design process happens before, finally, the risk treatment part. We can propose a methodology reducing the error actor risk, and check if the remaining risk is tolerable. If the risk is tolerable, we complete the organization and launch the project. Otherwise, the project manager should eliminate the actor, and redefine its organization.

Using this methodology, a project manager can approach the human resource allocation, project selection, and risk management problem in future factories, especially for the candidate design group collaboration and communication problem.

Although the methodology approaches the problems above, limitations and difficulties remain. One limitation is the method is for measuring designer abilities before the company launches projects. Another is the missing temporal actor compatibility and social interaction evolution during the project's life analysis. Therefore, the methodology cannot ensure the measuring results' continued stability, possible improvements, or degradation. ■

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A Monitoring Strategy for Industry 4.0: Master Italy s.r.l Case Study

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Manufacturing enterprises are presently facing an array of industry 4.0 (I4.0) challenges. "Digital requirements" require accurate analysis and deep understanding of the manufacturing operations' operational and technological criticalities.

Structuring a monitoring strategy for industry 4.0 must contain:

1. Measuring Parameter definitions
2. Sensor Application
3. Measurement execution.

The goal is to present and to analyse the monitoring strategy adopted in a design for Master Italy s.r.l.'s, a real Italian company with subject matter expertise (SME) in digital transformation.

Master Italy s.r.l. produces small accessories for civil window frames and has implemented a monitoring strategy.

The monitoring strategy is a hybrid approach combining Life cycle analysis (LCA) and exergetic analysis (EA) based on mass balance (Figure 1) and energy balance (Figure 2) evaluation.

LCA is an analytical tool quantifying and interpreting flows to-and-from the environment through the product's, process', or service's whole life cycle. LCA appreciates quantities of elements flowing in the processes (energy, materials, and more) but it depends on standard databases.

The exergetic analysis is a thermodynamic method (Bakshi, Gutowski, and Sekulic 2011) that permits:

- Energy usage evaluation.
- Process energy inefficiency identification and quantification.

LCA identifies the critical manufacturing process and the company's critical product in terms of resource consumption and pollutions (green line). The critical process and the critical product in analysis are, respectively, die casting aluminium and steel corner (Figure 1 and Figure 2).

The exergetic analysis allows:

1. Split manufacturing process in different sub-systems.
2. Critical sub-system evaluating the exergy loss contribution identification.
3. Critical parameters to control definition.

Die casting is a metal casting process characterized by forcing molten metal under high pressure into a mould cavity. The die casting aluminium injection cycle encompasses four different phases:

1. Melting: the aluminium enters at the solid state and exits at the molten state.
2. Injection: a plunger transfers the molten aluminium into a chamber to inject it into the mould.
3. Moulding: the molten aluminium solidifies in the mould cavity.

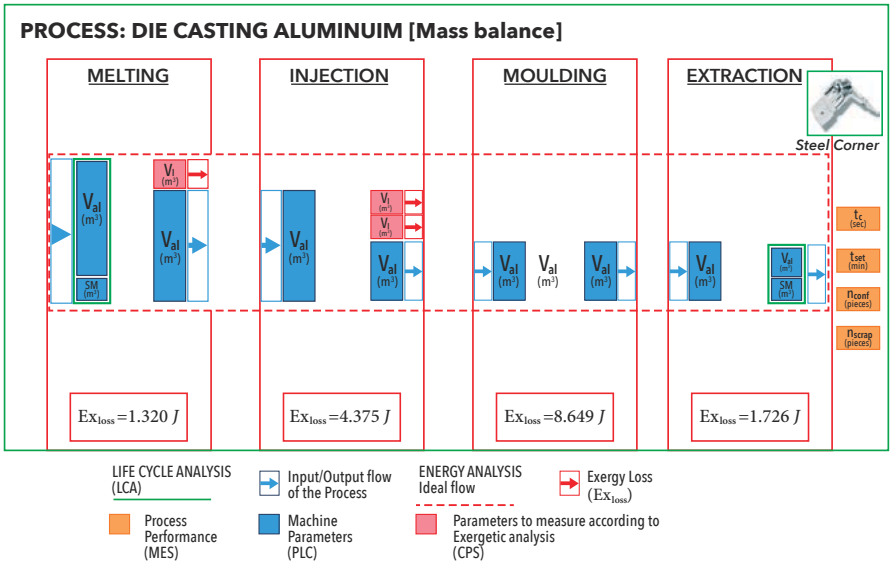

Figure 1. Mass balance

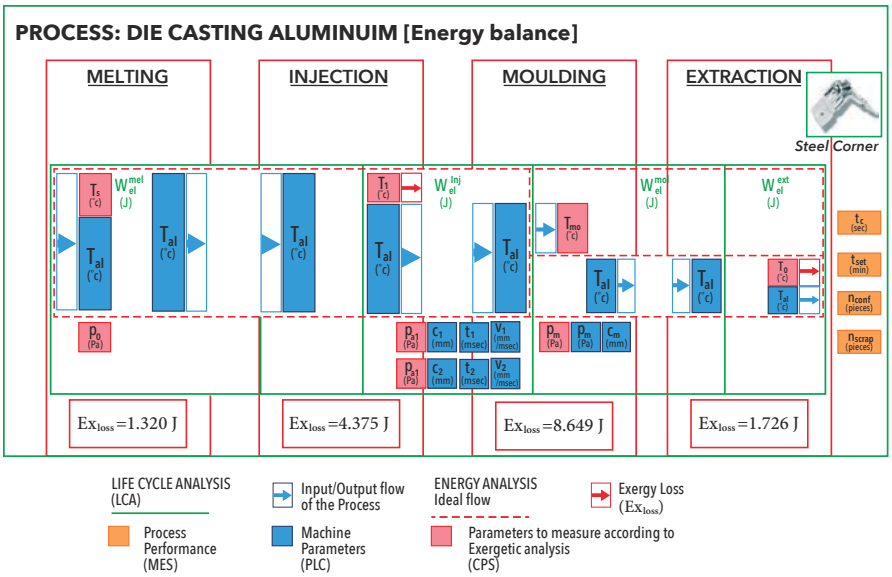

Figure 2. Energy balance

4. Extraction: an ejection mechanism pushes the casting out of the mould cavity.

The monitoring strategy optimization criterion requires minimizing **Exloss**, since exergy loss is proportional to the generated entropy and this one is responsible for the less-than-theoretical system efficiency. Exergetic analysis application shows the moulding phase (Subsystem 3) is the critical subsystem because the exergy loss is higher than other subsystems (Figure 1 and Figure 2). The first monitoring strategy goal, for Industry 4.0 implementations, is selecting and defining where, what, and why to sensorize (red rectangle).

Exergy loss depends on material exergy (**Ex, M**), work exergy (**Ex, W**), and heat exergy (**Ex, Q**) input and output variation. Reducing the exergy loss means predicting process behaviour: it is thus necessary to identify and classify the parameters to monitor within the main, derived, and non-controllable areas.

Data is an important element for monitoring and modelling complex systems. Data contains information assisting modelling, simulation, optimization, and prediction. With New Information Technologies' developments, physical and virtual data volume, richness, and fidelity increased. This stage's monitoring strategy integrates and fuses data from different sources, obtaining and extracting more accurate and useful information from data (Figure 3).

This way, operational, technological, and environmental data from the physical space can simulate results and predict states in the virtual space.

It requires access to realistic models of the process' current state. These models are typically digital twin (Figure 3) (Rosen, Von Wichert, Lo, and Bettenhausen 2015).

Defining the digital twin is a set of models emulating physical properties, behaviours, and manufacturing process constrains. It receives real time data to update itself along the product constraints (Grieves and Vickers 2017). The digital twin is the physical process' digital mirror (Glaessgen and Stargel 2012).

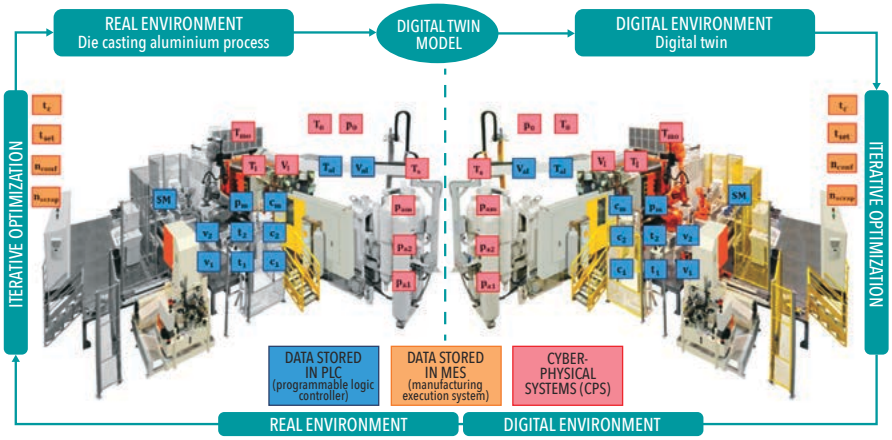

Figure 3. The digital twin

The architecture proposed comprises five layers (Tao and Zhang 2017, Ponomarev, Kudryashov, Popelnukha, and Potekhin 2017):

1. Physical layer (PL): production factors including human, equipment, materials, and environment.
2. Data layer (DL): production data, tooling data, equipment data, material data, quality data, cost data, human data, environmental data, forming the cyber layer's base.
3. Network layer (NL): through which the cyber and physical layer can communicate real time. It is critical to build the physical and virtual entities' connection for data exchange.
4. Cyber layer (CL): the physical layer's digital model. The cyber layer compares simulated results with known information represented by mathematical or physical equations. It focuses on a set of different models to represent a physical system's structure, behaviour, and interactions needing monitored or predicted. Systems Modelling Language (SysML) is the modelling language for building physical, behavioural, and parametric models. SysML provides nine interrelated diagram types to describe function, structure, behaviour, and system requirements while supporting the systems' models specification, analysis, and verification. By modelling subsystems as blocks and parameters as value properties, using the Block Definition Diagram (bdd), the behaviour becomes an action set to describe how the inputs transform into outputs. In particular, the state diagram (stm) models the behaviour defining states and an object's events during its lifetime. Stm simulates how the states change based on internal or external events. A parametric diagram (par) models the exergetic constraint equations. Constraints represent physical laws or mathematical and logical operators or decisions that evaluate input parameters to return a result.
5. Application and user interface layer: provides service to support the physical layer's management and control through the cyber layer. It tries to make the PL work as expected through real-time regulation and sustains high CL fidelity through model parameters calibration.

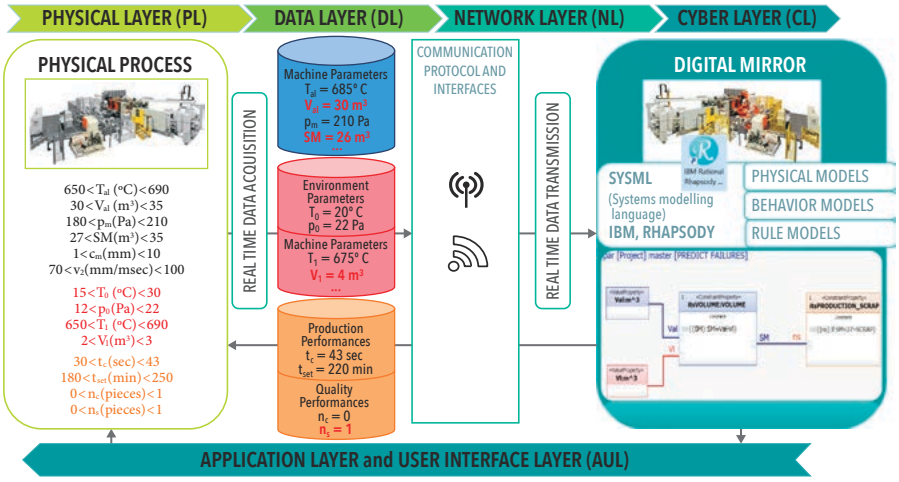

Fig. 4. The architecture for monitoring strategy

The proposed architecture applies to manufacturing process for (Lee, Lapira, Yang, and Kao 2013):

- Geometry assurance – The digital twin accelerates the correct design product developing.
- Remote monitoring – The digital twin allows large interconnected systems, such as manufacturing systems, operational remote visibility which allows virtual monitoring systems and validation of the production systems' current status (energy monitoring and fault monitoring).
- Predictive analytics – Digital twin future state prediction can predict errors and problems in manufacturing facilities before they occur, therefore preventing downtime, failures, and more.
- Simulating future behaviour – The digital twin can virtually simulate manufacturing processes to plan process and system reconfiguration in response to external changes.
- Optimization and validation – Validate and optimize the system's operation using simulation and real-time sensor feedback. ■

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Challenges for Autonomous Vehicles (AVs) Engineering: Safety Validation of Functional Performance Limitations

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■ **ABSTRACT**
AVs engineering cannot limit itself to the classical safety validation issue, which ensures the vehicle's functional safety. It faces a new safety validation challenge, in the functional performace guarantee of these new vehicle types. This paper presents some validation issue reflections and concludes with some important questions.

INTRODUCTION

Seen as the technological solution, the automated vehicles' arrival and benefits address several problems: safety benefit regarding lives saved or injury reduction, economic and societal benefit, traffic efficiency and convenience, and mobility (NHTSA 2005) improvement. To manage this technology's deployment, the Society of Automotive Engineers (SAE) defined six Automation levels: level 0 (No Automation) to level 5 (Full Automation). This classification means, the more advanced the Automation level, the less involved the human driver. In other words, the automated vehicle, as the vehicle control guarantor, bares the driving responsibility importance.

Traditional engineering (manual vehicle) manufacturers do not consider the road user behavioral deviations (other vehicles, pedestrians.) the vehicle can encounter. Instead manufacturers transfer this responsibility to the driver. Safety requirement validation thus consists of demonstrating vehicle failures cannot generate critical hazardous events.

Thus to guarantee the vehicle is safe and aligned with the ISO 26262 automotive standard, manufacturers focus on the electrical and electronic malfunctions which can occur.

In the autonomous vehicle engineering context (Hellestran 2013), vehicle safety demonstrations and certifications become critical. The vehicle control responsibility comes back totally or in part (according to autonomy level) to the manufacturer, who must demonstrate safety performance at least equal to human control.

To manage the responsibility manufacturers, investigate many solutions. One addresses the AVs optimized functional architecture definition. Ulbrich et al. (2017) proposed a modular architecture characterized by a functional and hierarchical separation of different blocks included in the AV. Matthaei and Maurer (2015) also incorporated modularity but they used a top down approach covering: human operated aspects, mission accomplishment, map data, localization, environmental and self-perception, and cooperation. Furthermore, other architectures explicitly include dedicated safety aspect modules (Thorn, Kimmel, and Chaka 2018). Finally, after different AV architecture examination and the comparison, Tas, Kuhnt, Zöllner, and Stiller (2016) outlined some main characteristics: distributed architecture, included monitoring systems, redundant and complementary sensors observing the vehicle's surrounding environment, considered sensor information uncertainty, incorporated feedback from controller for motion planning, separation and module redundancy, predicted software function degradation, and map-based map sensor information to know the system's status.

These considerations are good solutions made to develop a safe AV. However, they engender other difficulties such as the increase of complexity and multidisciplinary engineering. Thus, Smaoui et al., propose an MBSE approach may facilitate communications involved in the AV conception during the design phase. Manufacturers already realize complex systems improve when jointly using Model-Based Systems

Engineering (MBSE) and Model-Based Safety Assessment (MBSA). With this logic in mind, Mauborgne, Deniaud, Levrat, Bonjour, Micaëlli, and Loise (2016) propose a definition of high-level (or vehicle-level) safety requirements (called safety goals in ISO 26262) based on a model-based safe systems engineering process.

Beyond the functional architecture, the AV faces issues. Emerging studies focus on specific technology-related safety like ADAS (Advanced Driver Assistance Systems)(Godoy Pérez Onieva Villagrá Milanés and Haver 2015) which are automated function parts.

One challenge is the difficulty defining the environment and considering it a potentially chaotic behavior for the AVs perception and interpretation modules. This occurs on a situation basis, thus requiring the AV to either request the co-driver control, or develop real time strategy respecting the safety constraints (according to the Autonomy level). Thus, the safety validation process must consider some performance limitations occurring even if the AV is free from electrical or electronic failures affecting the AVs safety. According to Koné, Bonjour, Levrat, Mayer, and Géronimi (2019), the safety validation process must include manufacturers ensuring AVs can correctly detect their surrounding environment, detect nearby or distant objects, and ensure that they will perform successfully in poor weather conditions or degraded environment configurations. This means verifying their situational awareness ability (with or without foreseeable misuse), the ways they react to dynamic environment, and make decisions. The observable safety breaches, due to AV performance limitations, when facing these situations are under a new standard: the Safety Of Intended Functionality (SOTIF)(ISO/PAS 21448 2019). Therefore, what is this standard looking for? How do manufacturers perform AV safety validation regarding its potential performance limitations?

This short article will present some reflections about these questions.

THE SAFETY OF THE INTENDED FUNCTIONALITY (SOTIF) STANDARD

To assign the AV the ability to perform its driving task, manufacturers use specific technologies such as sensors and localization systems, communication systems, and intelligent control systems, which electrical and/or electronic (E/E) architecture implements. These embedded technologies are new and difficult to specify. Although, the electrical and electronic malfunctions they may face, which can affect the vehicle's safety, fall under automotive functional safety standard scope: ISO 26262, some performance limitations may occur (even if the AV is free from electrical or electronic failures).

The ISO 26262 standard does not recommend limitation mitigation, so they are developing a complementary standard called SOTIF.

However, the Advanced Driver Assistance Systems (ADAS) introduced this standard's need. ADAS are the first systems that initiated the autonomous driving project. They belong to automation levels 1 and 2, according to the SAE classification. Their usefulness, especially for road user protection and driver comfort, quickly attracted increased interest. Utility importance required these systems be robust, reliable, not affecting the general vehicle safety which is the manufacturer's responsibility (Raffaëlli, Vallée, Fayolle, De Souza, Rouah, Pfeiffer, Géronimi, Pétrot, and Ahiad 2016). Unfortunately, relying on detection systems and the numerous parameters identified during a mission profile proves conventional methods insufficient or obsolete for the ADAS validation.

Preliminary versions of this future standard are available under the name: PAS 21448 (Publicly Available Specification 21448). This reference provides a complement to the ISO 26262 by focusing on AV functional performance safety. It targets specific characteristics such as sensing, complex algorithm processing, and actuation dysfunctions linked to desired function performance limitations. In different road situations, with unpredictable events, it studies the embedded systems' behavioral influence on AV safety. SOTIF's purpose is reducing known dangerous scenarios and showing residual risk due to unknown dangerous scenarios is acceptable. The actual future reference's edition focuses on emergency intervention systems (emergency braking systems) and Advanced Driver Assistance Systems (ADAS), but can progress to higher automation levels with additional measures (ISO/PAS 21448 2019).

SAFETY VALIDATION OF THE AV RESPECTING PERFORMANCE LIMITATIONS

The last version of the PAS 21448 (2019) proposed some combinable methods to help with the specification and validation activities. Among the proposed approaches, we can find environmental condition analysis and operational use cases(ISO/PAS 21448 2019). AVs will face many real situations, due to environmental condition variations, related to traffic conditions, weather, infrastructure, or other road users' behavior. Since it is difficult to predict all these situations, manufacturers must consider new approaches.

The first identification strategy concerns experience use. This approach aids manufacturers in avoiding starting from scratch. The idea uses previous driving function based experiences, like ADAS systems or manual driving systems, to identify a relevant scenario list. Driver returns can complete this list, they inform the manufacturers about events or misuses during driving. In the same way, accident databases are helpful for identifying critical situations that may be a challenge for AV.

Due to AV complexity, previous experiences cannot depict all scenarios; manufacturers need other strategies. One strategy uses specific driving to collect information and target specific scenarios. Another one, refers to expert knowledge on AV implemented technologies. Note governments are busy revising regulations and defining procedures manufacturers must follow to validate and deploy their AVs, and identifying scenarios manufacturers need to test.

Added to previous approaches, due to the difficulties in validating AVs, all AV actors (customers and suppliers) collaborate to share knowledge and define common generic scenarios.

The chaotic situation's combinatorial explosion makes physical test completeness difficult to conceive in an experimental way (Kalra and Paddock 2014). It becomes necessary to explore the universe of critical situations with other strategies, and by simulation. Generating the numerous test cases makes simulation difficult to use (Raffaëlli, Vallée, Fayolle, De Souza, Rouah, Pfeiffer, Géronimi, Pétrot, and Ahiad 2016). However, it remains the most promising method and this is obvious given the difficulty of carrying out experiments, especially in urban areas. To handle scenario identification and generatio n, as well as the AV validation by simulation-based method, manufacturers must address particular issues. Firstly, they must define what a scenario is, what composes it, and how to model it. From combinatorial approaches(Xia, Duan, Gao, Hu, and He 2018) to ontology-based approaches (Geng, Liang, Yu, Zhao, He, and Huang 2017; Bagschik, Menzel, and Maurer 2017; Geyer, Baltzer, Franz, Hakuli, Kauer, Kienle, Meier, et al. 2013) through the concept of maneuvers (Bach, Otten, and Sax 2016) and simulation approach (Hallerbach, Xia, Eberle, and Koester 2018), methods are multiplying to bring answers to this issue. Secondly, the situations an AV encounters during driving scenarios are unpredictable and due to their combinatorial explosion, Industrials need to generate a finite situation sample (a mission profile containing different situation class representations) and use it to evaluate each

situation class' safety. Finally, each situation class contains uncertainty influencing its safety assessments. Therefore, we also need to model the uncertainties and compose evaluations in a metric representing the confidence level granted by AV safety.

CONCLUSION

We addressed the AV safety validation challenge focusing on its potential performance limitations. We first presented the future reference (SOTIF) which addressed such limitations. Then, we explored one possible approach recommended to handle the AV validation regarding these performance limitations, ending with existing issues, which need investigating to complete the simulation-based validation approach. However, one central question remains: how to set up a simulation architecture able to handle scenario generation while managing the AV safety validation by evaluating, based on the simulated scenario results, the AV safety level?

Future work will help address the identified issues and this central question. ■

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System Engineering and Dependability: Methodology of Model Synchronization between System Architecture Models and Risk Analysis

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■ **ABSTRACT**
Modern industry faces new challenges making classical organization in "disciplinary silos" ill-adapted to demands for complex and evolving systems. We advocate promoting inter-team communication in a "Multidisciplinary Organization" can manage complexity better: it allows early problem discovery, offers solutions to more complex issues, and favors early solution emergence. Indeed the transition to such organization requires new collaborative processes and methods to integrate various engineering fields earlier and along the development cycle. In this paper, we propose a collaborative approach to set-up adapted modeling and methodological practices in the enterprise. It leverages the rising interest for Model-Based Systems Engineering and related modeling technologies to offer a new approach to different engineering discipline model synchronization to support their collaboration. This approach considers the studied system context (under several viewpoints), applied processes, applied methods, and viewpoints produced by engineers. We illustrate it by creating a collaboration framework between two particular engineering fields: system architecture design and avionics applicative safety analysis at different life cycle stages.

■ **KEYWORDS:** Models Synchronization, Integration in multi-disciplinary processes, Model-Based Safety Assessment, Model-driven engineering, Systems engineering.

INTRODUCTION

In a moving world where innovation and new technologies constantly progress, and where constraints coming from standards grow; engineers' solicitation to assess new critical system proposals (particularly new architectures) in safety performance terms becomes increasingly important. Demands for fast design choice feedback comes from upstream development cycle stages, without providing them reliable or accurate information sources, needed for specific context assessment.

Moreover, with a classical organization in disciplinary silos, problems discovered too late and experts lacking communication prevent early solution emergence. Such practices reach their limits to manage and control system complexity and project management. Therefore, to face the growing industrial complexity, the different engineering disciplines (mechanic, thermic, electric and electronic, software, architecture) virtualize their contents, they design models. However, these models are generally specific to their viewpoints and it is difficult to share them to support collaborative analysis and solution emergence. This is why it is urgent to provide new collaborative methods and interaction opportunities for various engineering fields to establish agreement on goals and consistencies earlier and along the development cycle.

Theoretically, these interactions should rely on a common system understanding, but different discipline engineers generally reason on different system representations (models). These models come from different teams working with different languages at different abstraction levels for different purposes. Consequently, engineers have difficulties sharing, understanding, or questioning others' models. To reach a common understanding for all these views, if we consider all the life cycle (design/production/operation/decommissioning), it is inconceivable through a common modeling language (it would become too complex to represent all problem dimensions). Such modeling involves dozens or hundreds of model designs. Additionally, any direct model subset comparison is inconceivable. Therefore, we propose means to compare models (views) for particular tasks at given exchange points directed by enterprise reference processes, facilitating decision point agreements along the development cycle according to enterprise practices.

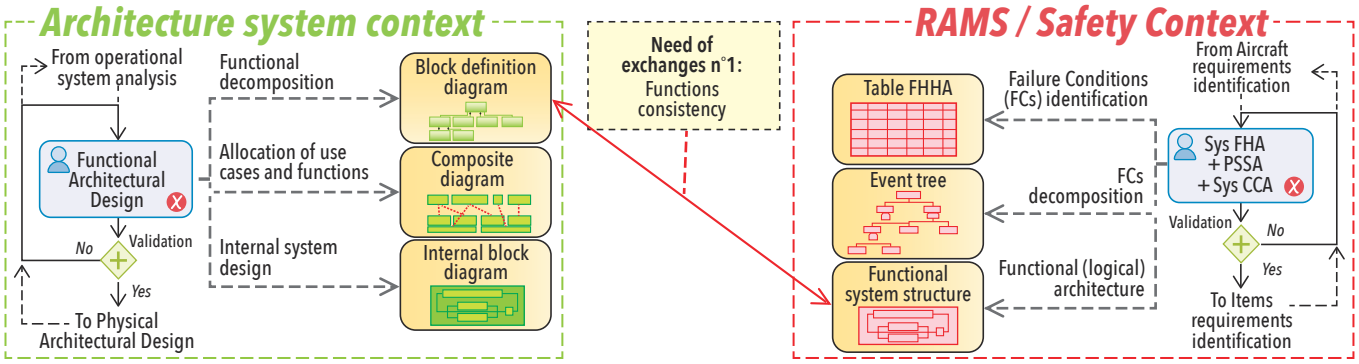

Figure 1. Synchronisation point between architecture system and safety analysis contexts

This results in a model synchronization methodology and dedicated mechanisms. In this paper, we consider, as a motivating example, two particular engineering fields' possible exchanges playing major roles in a critical system development cycle: system architecture design and safety analysis. In the following we present the method and its implementation.

TOWARDS A NEW PROCESS BASED MODELS SYNCHRONIZATION PARADIGM

The approach proposed is twofold. It proposes: 1) a conceptual framework for model comparison and synchronization and 2) a methodology for model synchronization enactment in the enterprise along the development process.

Main principles

The approach is to see a synchronization process as a synchronization point sequence where both disciplines' engineers make model alignment decisions (agreement, change requests, and related rationale). To support engineers, we provide engineer specialized comparison mechanisms. Thus, each synchronization point coincides with dedicated comparison mechanisms used ***where*** they need decisions. The local synchronization is generally obtained after several expert exchange iterations (traced).

The current processes guide synchronization point identification while observed by the enterprise or by domain specific standards if the company wants to improve its international standard compliance (ISO 61508, ARP 4761, ISO 15 288, EIA 632 or IEE 1220).

Concepts and mechanisms (Legendre Lanusse and Rauzy 2017)

We identify synchronization points as exchange and/or decision stages involving several disciplines (2 in the example addressed). In each one, we characterize the artefacts used and specify the exchanges' and related information goal, nature, and scope. Such information will provide the abstracted model core dedicated to this exchange (for each participant), as shown in figure 1. Then we define dedicated comparison and traceability rules. These concepts permit experts to share information, propose changes, reach agreements, and trace decisions and rationale. If we consider other approaches, like model federation, we differ by not simply defining an information exchange map, but we define a process dedicated to reach an agreement (or a non-agreement and the related rationale).

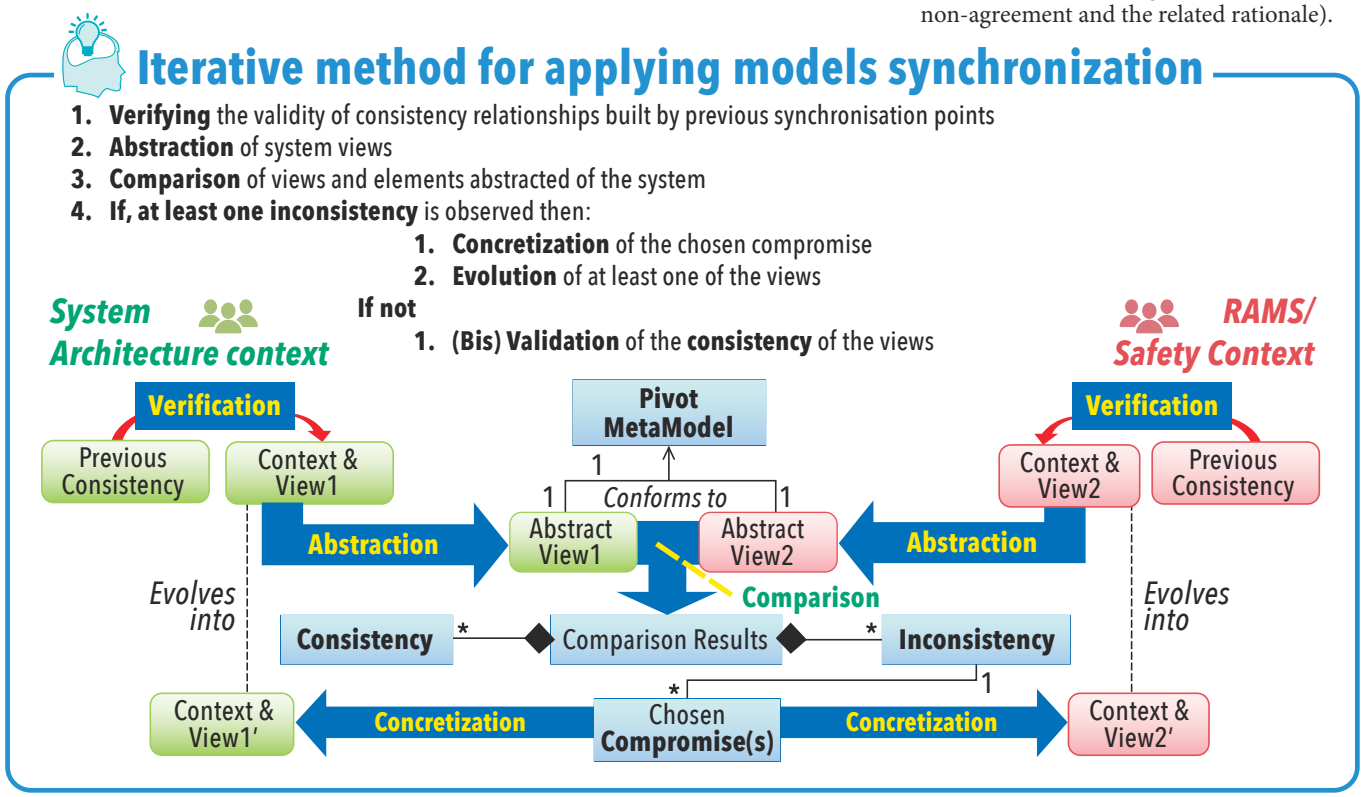

Figure 2. Synchronizing models: an Iterative method

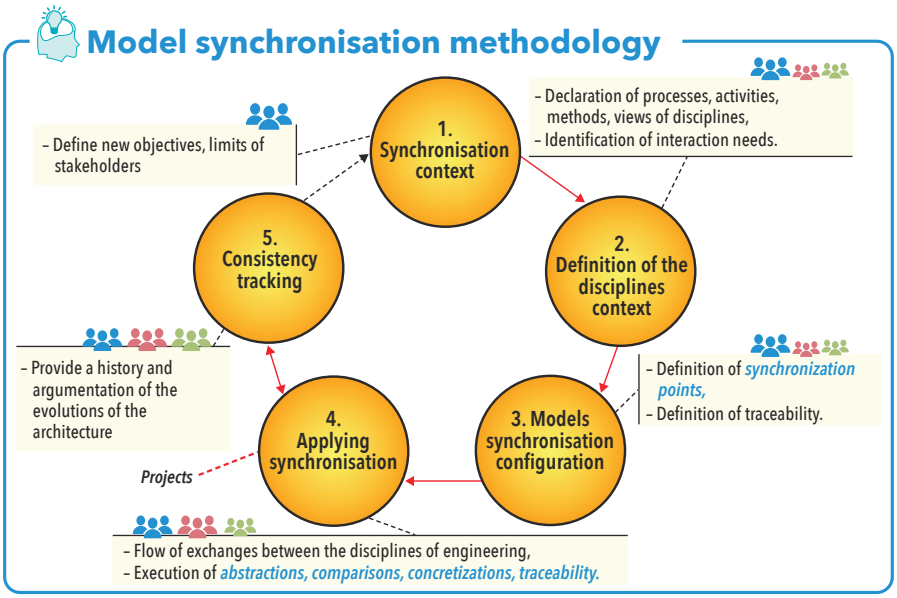

Figure 3. Global model synchronization methodology

The synchronization mechanism itself follows three-steps. First, abstraction step to extract relevant information from the models considered. Second, a system knowledge comparison step caught by the abstractions to set or edit the consistency. Third, a concretization step allowing improved proposals in the original models, coming from the comparison results. Figure 2 illustrates the model synchronization principle.

Methodology enactment

The approach described imposes the accompanying process definition to help engineers adapt it to their particular context. This is why we defined a methodology to implement the approach. Figure 3 illustrates the methodology following a change management process inspired by TOGAF. Based on the enterprise's process analysis (we propose an iterative method), framework uses process modeling and definition standards, such as ISO 42010 and OMG BPMN, to model processes and describe related views.

Through this iterative cycle we determine the involved processes steps for each discipline and characterize artefacts used. Then we identify which steps from the different processes must interact; which leads to the identification of *needs for exchange*. From these *needs for exchange* we configure model synchronization mechanisms.

RESULTS

A representative case study from the defense and aeronautics sectors implemented the methodology. The studied system is a fire detection system onboard a fighting helicopter assigned to detect fire events in three specific areas in the helicopter. Five synchronization moments dimensioned and then applied at several development cycle stages reflect the information gained during model synchronization: 57 coherence relations drawn and 27 inconsistencies identified (including 8 corrected inconsistencies and 19 assumed by the engineers). This experimentation showed the approach brings targeted and formalized dialogue.

This work resulted in:

- a conceptual framework, which brings all the required concepts to the model synchronization;
- a proposal for an iterative methodology, inspired by architectural frameworks such as TOGAF 9.1, to apply model synchronizations in a specific industrial context (Figure 3);
- Demonstrations of technical feasibility in tooling and application on a concrete case study.

The proposed approach is both pragmatic and original. It required raising several important scientific and technological locks:

- To understand each discipline's processes throughout the system's development cycle. Mainly, integrate the local visions into a global vision, particularly industrial work.
- To precisely define and decline the 3 model synchronization mechanisms in a particular industrial context.

RELATED WORK

This work is in the continuity of recent research directions targeting multi-disciplinary co-operative design. We explored more particularly the domain of MBSE-MBSA interaction trying to overcome systems engineering and RAMS (Reliability, Availability, Maintainability, and Safety) study isolation from different technical and methodological cultures.

To reduce these field gaps, two main research directions developed in the last decade: 1) automatic artefacts generation from annotated systems engineering models (Bozzano NuSMV, Papadopoulos with Hip-Hops); 2) Higher level modeling of RAMS aspects leading to Model Based Safety Analysis (MBSA) and MBSE and MBSA model transformation + information exchange. In this context, researchers explored several clues to address the multidisciplinary interaction problems. A conceptual model proposed by P. Mauborgne (2016) enriched the concepts used during system architect activities to consider the dysfunctional qualitative aspects provided by the safety engineers. This removed ambiguities about the terms used by these two engineering fields. The model federation, (Guychard, Guerin, Koudri, Beugnard, and Dagnat 2013) is a tooled technique to ensure strict consistency relations, traceability and intersectoral view creation. MOISE project (Prosvirnova, Saez, Seguin, and Virelizier 2017), IRT Saint Exupéry (Toulouse), proposes a collaborative process between the system architecture and safety analysis based on an aeronautical case study's experimentation conducted by two specialist teams.

These works bring answer elements on several scales: conceptual, tooling, and operational techniques. However, few contribute to: co-conception driven approaches, integrating an interaction process throughout the development cycle, or a model-based interaction method. We can cite Fabien Bouffaron's (2016) important work on the co-specification system-based executable models.

CONCLUSION

Models serve as communication supports, calculation statements, or software generations. They also strongly link to the nature of activities implied by processes. The work described in this paper facilitated an adaptive methodological proposal capable of defining, organizing, and conducting the multidisciplinary interactions required to maintain model consistency describing the same system throughout the development cycle. This required defining a conceptual framework to support the model synchronization enactment alongside existing processes within the enterprise. Its practical implementation within an industrial context in an instrumented form is still a challenge but the principles can act as methodological guidelines while progressing the process' instrumentation through significant early stage points. ■

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A Model-Based Approach to Design, Organize, and Monitor Dismantling and Decommissioning of Nuclear Facilities

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■ **ABSTRACT**

Dismantling and Decommissioning (D&D) of nuclear facilities involves complex operations, requiring various activities' many stakeholders to collaborate, and must address numerous significant constraints. The CEA (French Alternative Energies and Atomic Energy Commission), is conducting research to better pilot these operations, reduce their costs and timeframes, and improve overall performance. However, many issues remain, leading to studying and implementing, in the form of a method with appropriate tools, systemic principles and complex project and systems engineering. This method first formalizes and specifies the entire requirement set to consider. Second, based on these requirements, the method will enable the project team to structure, check, and demonstrate the project's coherence and feasibility from both the technological and organizational viewpoints. Lastly, the method should permit a constant D&D strategy and product management re-evaluation, depending on the possible D&D project evolution. Developing demonstration software aims to provide the functionalities requested for the design, and future enterprise software implementation and maintenance, which should provide a complete D&D project Digital Mock-Up being interoperable and connected to the tools and databases of the stakeholders' information systems.

INTRODUCTION

Today, nuclear facilities of various types are reaching their Dismantling and Decommissioning (D&D) phase. Managers must pay particular attention to D&D project design and management. They have to consider the inherent complexity and history of each nuclear facility, especially because it is difficult to generalize elements to all D&D projects despite significant capitalization and valorization of feedback.

ISSUES

D&D meets numerous complexity factors such as:

- the many activities D&D operations require
- the many stakeholders involved, and their various roles and responsibilities
- the many varied element interactions
- the significant amount of data, information, and knowledge to handle
- the strict requirements based on a strong risk culture
- the project evolutions that require model flexibility and adaptability.

Firstly, incidents during a nuclear facility's lengthy operation phase may have modified or impacted the facility. D&D projects should thus know and consider these changes during design and performance, focusing on ensuring safety at all times. In addition, designing a D&D project requires considering the variety of stakeholders and businesses involved: nuclear physics, nuclear chemistry, mechanics, robotics, nuclear instrumentation, computer science, and more. Indeed, they could express various requirements relating to their knowledge field while relating to other fields. This improves the collaborative work and exchanges. Moreover, to meet the requirements, the D&D project life cycle manages a large amount of data from different detail levels, and needs several documents and different deliverables, involving skills from several businesses (OECD-NEA 2012) (IAEA 2013). Their creation, provisioning, and updating are

major stakes for managers. However, data quality and availability, collected from different facility life cycle phases (records, plans), represent a recurring issue for D&D projects. It is, therefore, important to define the relevant raw data types to collect and trace for D&D projects as early as possible (IAEA 2014).

TOWARDS A NEW METHOD

Therefore, we adopted a Model-Based Systems Engineering (MBSE) approach and principles (ISO, IEC, IEEE 2015) (NASA 2016)(Estefan 2008) to propose and promote a new method for D&D project engineering and monitoring, equipped with necessary tools and based on a systemic modeling framework. This must support nuclear facility description and characterization, with a sufficient detail level and data consideration, and project description at a detailed level enabling first design and validation before deployment, then monitoring and adaptation in real time when in progress (Nastov, Chapurlat, Dony, and Pfister 2016).

The modeling framework addresses stakeholders perspective descriptions, aiming for understanding and sharing, by guiding them through classical, functional, physical, requirements, behavioral, and risks management viewpoints. This framework, based on a systems approach, integrates the D&D existing vocabulary or emerges when requesting a new common vocabulary. To support stakeholder collaboration while considering D&D projects' technical and organizational, this framework must be unambiguous.

Current existing standards or methods remain limited when considering various viewpoints, detail levels, and modeling languages. Models use neither the same modeling language (conventionally denoted Domain Specific Modeling language DSML in MBSE context) nor interoperable languages nor the same media over time. We may mention the maps case, which today are evolving on digital media. Models' federation is however requested for validation, monitoring, and involving decision-making strategies more broadly for all activities (Project Management Institute 2017). The new method's goal is procuring a D&D project "whole model" built step by step from the design phase. This results from current model federation or composition in each view point. The framework must integrate and enable the analysis of the interfaces, dependency relations (both from semantic or pragmatic aspects), and related links between all D&D models. This allows whole project description to gain relevance and accuracy when managers want to assess the project's global safety, security, and performance to test and assess alternative solutions, to trace some unforeseen event's impact on the whole project's behavior, and to validate the project in part or as a whole.

PROGRESS

Currently, CEA (Lafon, Chapurlat, Milot, and Moitrier 2018) is studying the proposed method. Each D&D project first formalizes and specifies all needed requirements to bring the project to a successful end. Second, based on these requirements, the method should enable project structure, verification, and validation while demonstrating its coherence and feasibility both from a technical and an organizational view point (Pesola 2010). Finally, the method should permit a continuous dismantling plan and product (waste) reassessment, depending on the possible project evolution (new stakeholders, unforeseen events).

The method, thanks to MBSE, enables a formal D&D system representation construction related to each project. Such a D&D system is "a set of elements of various and heterogeneous nature that interact in order to decommission a nuclear facility." It implements a basic concept set through some viewpoints, including the classical viewpoints previously mentioned.

First, a generic timeless metamodel collects and syntactically and semantically describes these concepts and relationships and therefore adapts to various nuclear facilities and project evolutions.

Each viewpoint defines DSML. Project managers will be able to model D&D systems and share their models all along the projects. These DSML must therefore be ergonomic and understandable by experts, not modeling experts, from various businesses.

The proposed method, to enforce, includes two important concepts:

- From the modeling side: D&D System formalization as a system of systems including the properties described by Maier (1998)
- From the management side: during project piloting, process management implementation based on adaptive workflow principle proposed by Samiri, Najib, El Fazziki, and Boukachhour (2017).

The D&D life cycle uses and needs these two concepts.

Finally, in the method, we have implemented the modeling patterns concept, describing elements common to a project set (several scenarios use such a dismantling technique and its different features, or a waste outlet, including technical specifications for a given waste type found in several D&D projects). Stakeholders can make and share modeling patterns thus facilitating metamodel handling to cope with this decommissioned facility heterogeneity. They compel managers to draw from past experiences. In addition, we can ensure through a few features, flexibility (adaptation to evolution) and dynamism (automatic feedback or model verification and the validation) in D&D organization and monitoring. Model pattern use aims to catalyze experienced project element reproducibility and reuse to justify their use and thereby to facilitate decision-making steps to achieve and improve in real time the dismantling solution, the D&D system as a whole, with a multi-point of view and multidisciplinary approach.

Defined users make and validate these patterns and are often experts in the various D&D involved businesses: nuclear measurement and instrumentation, transportation, regulation, and more. A database stores these patterns and each project manager can use them to feed his specific model, or other experts can create new patterns.

The patterns can evolve over time, consequently it is necessary to guarantee modification traceability and to manage the impacts on each project.

PROSPECTS

Today, the partially equipped method has developed a demo software based on use cases proving the meeting of conceptual, methodological, technical, economic, and human challenges identified at the project's beginning. Results provide features requested to handle the proposed design and monitoring framework, helpful for future enterprise software design, implementation, and maintenance. The last tool should provide a complete interoperable D&D project Digital Mock-Up connected to the tools and databases of the stakeholders' information systems (Chapurlat, Nastov and Lafon 2018). This should be useful for D&D project management and should catalyze collaborative work in D&D projects. ■

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On the Mastering of Modelling Activities Development in Engineering

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■ **ABSTRACT**
This paper summarizes programmatic work challenges, propositions, and its components aiming to master modelling activities development in systems engineering.

INTRODUCTION

Many systems are difficult to engineer (conceptualise, build, operate, and retrieve) because of their uniqueness – that is not easy to define *a priori* – and the means and obstacles (environment) contributing to and hampering their engineering. While well-mastered means addressing specific system aspects exist, systems engineering attempts to network and guide those means to achieve programmatically and functionally expected systems.

Modelling activities (MA) are transversal to and used by various engineering activities. Despite the potential advantages – communication improvement, system understanding, and knowledge share and reuse – offered by models and modelling, one might encounter the same problems – clarity, traceability, and reasoning – as with informal documents. This is the case when MA are concurrently performed by various people and on various fields over long and different life cycles. In this situation, MA development should become subject to mastering global understanding and provable reasoning. Possessing computational supports fostering data, storage, use, and analysis is insufficient. The underlined data and transformation procedure principles and architectures related to MA operation must be available in such a way that it becomes possible to locally and globally reason on MA operation. As a result, mastering MA development can be a strategic endeavour to model-based systems engineering.

This paper summarizes a programmatic work toward that goal – building on the doctoral thesis of the first author (Simo 2017). Throughout the paper, whenever details will be necessary, the reader may refer to that thesis and references therein.

PROBLEM AT ISSUE

Given the aforementioned situation, a key problem is understanding MA impacts on model life cycles they produce; models which in turn influence MA operation. Accordingly, the following questions arise. Is it possible to master, in a disciplined and systematic way, MA development to foresee a direction MA should take? A direction might differentiate from another one by expectation satisfaction level on the system under engineering and resource use. But, is it, in the first place, possible to enter and measure MA? Thus, defining desirable and undesirable directions is necessary.

In this paper, the system under study is MA development and operation. By mentioning the system we refer, unless otherwise specified, to the studied system. This (product-project) system comprises project system parts – related to MA – and the product system or the system-of-interest as usually understood in systems engineering – related to MA produced models. Therefore, the overriding interplay between both systems is important to seize.

RELATED WORK

By leveraging numerous systems engineering standards, best practices, and related scientific techniques (INCOSE 2015, Sage and Rouse 2009), helpful tools for mastering MA are available. Unfortunately, those tools are either what-oriented (not how-oriented), overly verbose, or lacking unifying capabilities. This creates gaps and difficulties during implementation – especially in new contexts – leading to informal practices and uninformed decisions. Among the six main identified current systems engineering challenges (Beihoff, Friedenthal, Kemp, Nichols, Oster, Peredis, Stoewer, and Wade 2015), "Technical and programmatic sides of projects are poorly coupled… hampering effective project risk-based decision making." The problem addressed in this paper relates to this challenge by considering MA operation as a project-product system.

Several approaches – (Sharon, De Weck, and Dori 2011; Vareilles, Coudert, Aldanondo, Geneste, and Abeille 2015; Wynn and Clarkson 2017; Eckert, Wynn Maier, Albers, Bursac, Chen, Clarkson, Gericke, Gladysz, and Shapiro 2017) – from

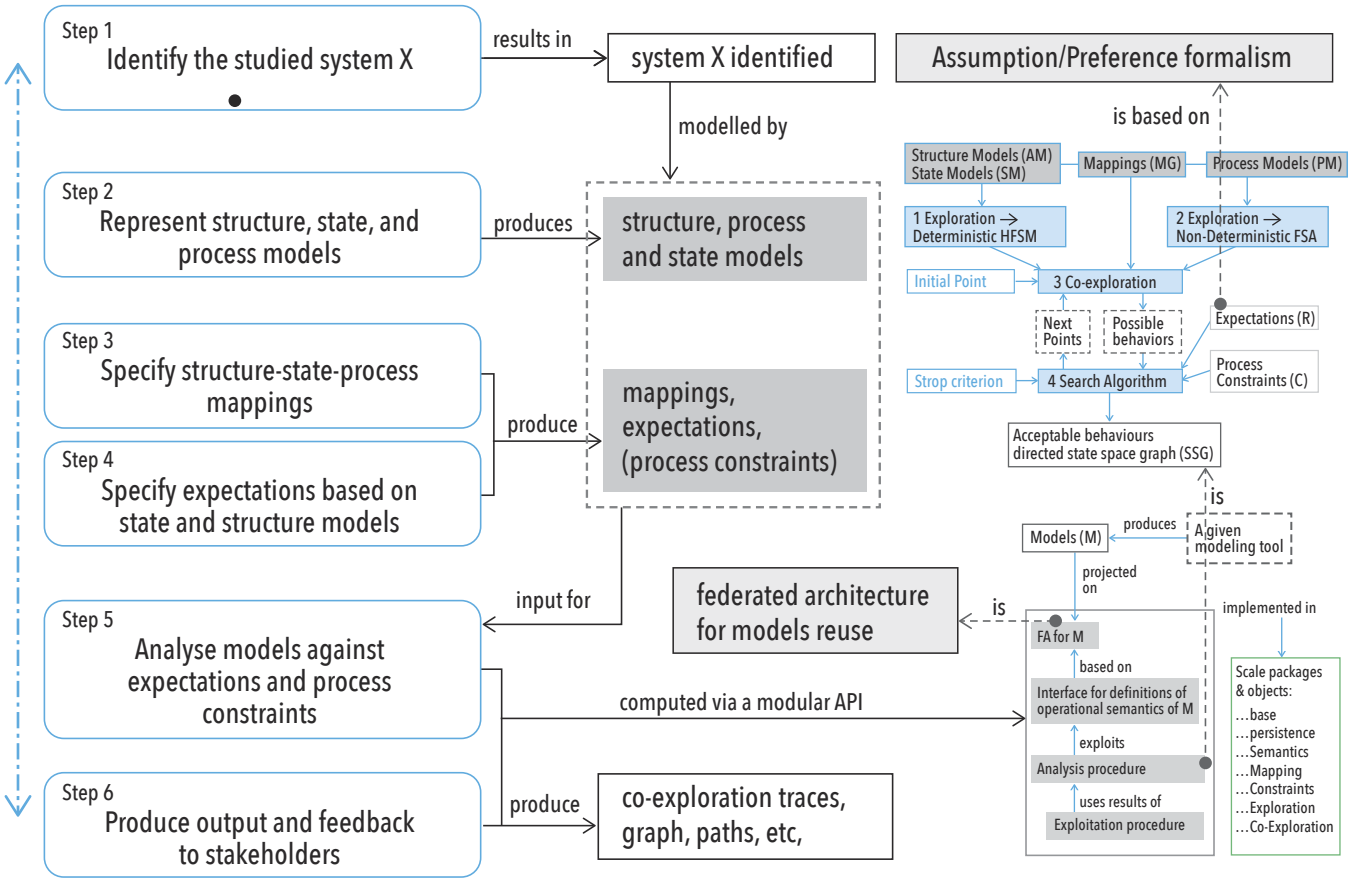

Figure 1. MODEF's main steps and supporting artefacts and their relations

systems engineering, engineering, and system design have addressed the association, integration, or coupling (explicitly or not) of the product and project systems by different means and for different purposes. Software development projects (Steward and Tate 2000) introduce a necessity: a product's functional requirements and design parameters fall into tasks of a Gantt chart project plan following an axiomatic design paradigm. We refer the reader to (Simo 2017) for more information.

Some lessons drawn from those approaches are: methods from project management seldom handle project-product dimension, exceptions are Systems Dynamics and Design Structure Matrix and their variants (Sharon, De Weck, and Dori 2011). There is a vital need to make explicit and formalise product and project domain interactions – demonstrated by an empirical survey after 2 large projects' failures (Vareilles, Coudert, Aldanondo, Geneste, and Abeille 2015). Additionally, few works expound these interactions. The coupling might happen at different abstraction levels, considering different model kinds with three coupling degrees (isolated, coupled, and integrated) (Eckert, Wynn, Maier, Albers, Bursac, Chen, Clarkson, Gericke, Gladysz, and Shapiro 2017; Wynn and Clarkson 2017). Model use for product and project domains modelling leads to tooling issues: modelling notations and tools, development, visualization, and model analyses (Eckert, Wynn, Maier, Albers, Bursac, Chen, Clarkson, Gericke, Gladysz, and Shapiro 2017).

PROPOSITIONS

The basic need to master MA development and current approaches' limitations –highlighted hereinafter – have led to building and using MODEF which stands for Model-based Federation of Systems of Modelling.

Figure 1 is an overarching logical structure and description of MODEF's main steps and supporting artefacts and their relations.

This work's contribution is the introduction of MODEF and its supporting framework with its principles, theoretical and practical arguments for understanding, modelling, analysis, monitoring, and ease of MA development and operation considered as a project-product system. MODEF has four main axes. We discuss and compare these 4 axes to specific related works (Simo 2017). Holistically MODEF ought to interact with upper- and lower-focus approaches – micro- meso- or macro-level approaches (Wynn and Clarkson 2017). Macro level could consider enterprise architecture and engineering which address a wider perimeter and permanent issues beyond the aim of systems engineering.

1. Abstraction of the system

We characterized MA operation locally as a system and globally as a federation, and set up the latter's modelling hypothesis. System and Federation concepts allow recognizing MA's nature and context, considering them as proper systems and delimiting future studied systems relevant elements. These approaches do not explicitly account for autonomy, asynchrony, and concurrency. Furthermore, the system is non-deterministic and should be continuously reworked. We focus on MA operating system-to-be-made models, the system-to-be-made models themselves with their life cycles; and MA's effects on these life cycles. No hypothesis on specific methodologies for technical activities, for the system-to-be-made engineering exists. In fact, many domain-specific methods characterize systems engineering. It would be, therefore, awkward to generally assume a specific methodology. We believe a bijective link (Vareilles, Coudert, Aldanondo, Geneste, and Abeille 2015) between the product and

project systems is a strong assumption because it might not always apply given both systems structure and granularity.

2. Modelling of the system

We introduced a delimited system's modelling framework to modelling architecture. Due to architecture being a system's fundamental organisation (carried by components, relationships, and environment) governing its design and evolution, we studied the system at an architectural level. Without adding a modelling language or tool we relied on existing formalisms and considered discrete event systems and hierarchical finite state machines for modelling MA and models life cycles. Mappings specify MA's (events) effects on model life cycles (transitions), allowing observing reasoning on MA's nature. This general modelling choice does not consider particular techniques and factors such as Critical Path Method, Program Evaluation and Reviewing Technique, budget measurement, and schedule tracking. Model life cycles ought to derive from models (Sharon, De Weck, and Dori 2011) or act as model constraints. Specific approaches focusing on quantitative insights and indicators could help determine system constraints. Nonetheless, we believe they should function in conjunction with qualitative models that provide procedural insights.

3. Analysis carried out with models of the system

3.1 We introduced an Assumption/Preference formalism or A/P expectations for specifying expected system behaviours. Assumption/Guarantee contracts (Benveniste, Caillaud, Nickovic, Passerone, Raclet, Reinkemeier, Sangiovanni-Vincentelli, Damm, Henzinger, and Larsen 2012) form this formalism's base. Instead of a guarantee (G) (proposition), we defined a Preference as a pre-order – a transitive and reflexive relation. Our A/P expectations use is close to the first contract uses in programming where programs (system models) define preconditions (A) and postconditions (P) (Hoare 1969; Meyer 1992). Both A and P build on the form's atomic propositions: the component C is in the state S. The pre-order structure enables describing different preference levels on the system's states instead of the (too stringent) binary case: true or false. Additionally, there might be several foreseeable states, some more preferable and expected than others.

3.2 We built procedures for analyzing system models and for providing feedback to stakeholders. The analysis procedure applies, on-the-fly, a search (Uniform-Cost Search – UCS) algorithm in the co-exploration of the state space described by models (discrete event systems and hierarchical finite state machines). Aside from expectations, checked during the co-exploration, it is possible to specify and address specific constraints (time, cost) related to MA: this is a novel application of UCS. This search algorithm can therefore substitute for another one from operations research or artificial intelligence. We devised ad hoc procedures to provide synthetic and simple data on foreseeable states – useful to informed decisions. In comparable approaches, it is rare to rely on formal requirements (expectations) for analyzing, using standard algorithms, the system's description. Model-checking becomes a useful analysing technique when analytical approach are difficult or impossible to apply in practice.

The analysis procedure's exponential complexity corroborates previous results on design process difficulties and system design problems. They appear as NP (Non-deterministic Polynomial-time)-hard (Braha and Maimon 2013, Chapter 6) and NP-Complete (Chapman, Rozenblit, and Bahill 2001) respectively. This means no known fast procedure exists to solve those problems; in the first case, the problem could prove not decidable.

4. Tooling of approaches and model reuse

MODEF does not include a specific modelling tool or language, instead we added all principles, foundations, and algorithms. But an issue remains: how to implement and integrate the computation routines and model reuse outside of a (modelling) tool. Therefore, we implemented MODEF computation routines under a modular Application Programming Interface – fostering flexibility and openness. To address model reuse, for analysis concerns, we specified a federated architecture (FA) and means, such as data structures and base algorithms, for its implementation. Such means function as projecting models coming from a modelling tool to independent data structures. FA follows FMI (Functional Mockup Interface, https://fmi-standard.org) on condern separation (model structure and function). FA targets descriptive models while FMI targets simulation models. The model structure in FA acts as composite components. Furthermore, we did not impose a pre-defined interface for the function's implementation – the FMI case considers the target interface's semantics as a timed Mealy machine (Tripakis 2015). We argued such an implementation must derive from an model structure interpretation. Lastly, we define FA within a category-theoretic framework promoting structural and relational viewpoints.

BEYOND MODEF'S MAIN OBJECTIVE

We reviewed a systems engineering challenge and related works to product-project-systems mastering through MA operation. These systems are a twosome, pivotal for modern systems engineering. However, they might lose control in some (concurrent) engineering environments operating over long life cycles. Hence the need for appropriate handlings grounded on provable-by-construction foundations. MODEF components and their principles might deepen independently of MODEF's main aim. For instance, the A/P formalism, the analysis procedure, and the Federated Architecture might prove useful for expectation, product-project, and model engineering. This work yielded several perspectives related to modelling framework, MA resource allocation, analysis algorithms, and FA. ■

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Towards a Maturity Assessment Scale for the Systems Engineering Assets Valorization to Facilitate Model-Based Systems Engineering Adoption

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CONTEXT AND OBJECTIVES

Regarding engineering practices' transition from a document-based approach towards Model-Based Systems Engineering (MBSE) approaches, it is necessary to demonstrate to end-users how MBSE will help them design their system, even during routine disruption. However, unlike changing engineering practices, engineering knowledge is sustainable and remains key to good system development. Previous works show pattern relevance for engineering asset capture and valorization through reuse (Wu, Gouyon, Levrat, and Boudau 2018). Unfortunately, it appears the current trend to adopt MBSE methodologies (Figure 1) does not entice engineers to leap towards these new approaches (Huldt and Stenius 2018), as the gap with engineering practices is too significant.

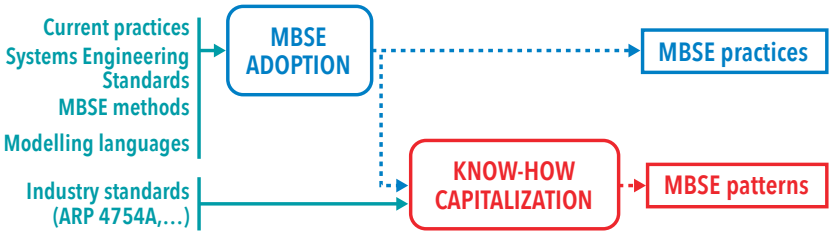

Figure 1. Current trend for the adoption of MBSE methodologies

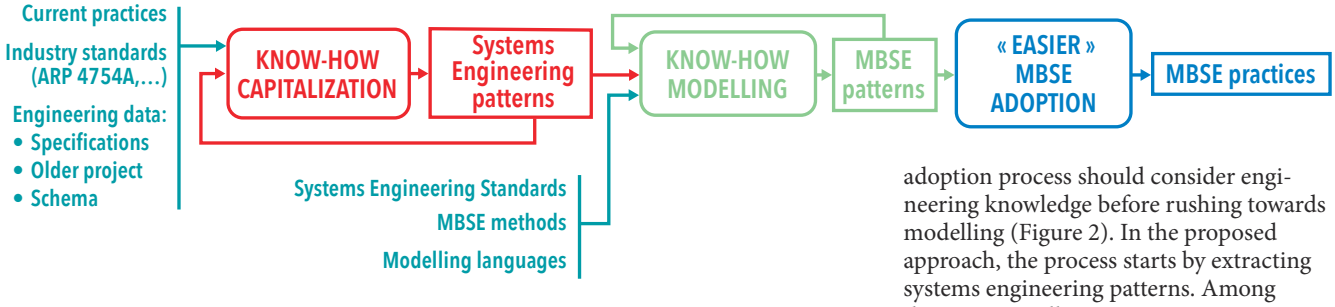

Figure 2. Proposed approach for the adoption of MBSE methodologies

Unlike the current trend capitalizing knowledge after an MBSE development, the adoption process should consider engineering knowledge before rushing towards modelling (Figure 2). In the proposed approach, the process starts by extracting systems engineering patterns. Among them, some will meet engineering team needs more than others. It is, therefore, these patterns which an MBSE approach will model and integrate. This approach allows engineering teams to choose the patterns that will have the most added value for them, and thus facilitate MBSE methodology adoption.

This article proposes a scale to evaluate systems engineering asset valorization maturity, assuming the valorization process includes highlighting valuable engineers' knowledge to distribute to other engineers at the needed time and comprehension level. It means that, if the final goal is to reuse systems engineering assets, other processes are necessary to achieve these expectations. As promoted in the software community, systematic reuse will allow significant gains in development productivity and quality (Garcia, Lucrédio, Alvaro, De Almeida, De Mattos, Fortes, and De Lemos Meira 2007). Thus, to develop reuse strategy, a maturity scale will facilitate determining the maturity level at which a company operates. In this way, it will be possible to assess the progress margins and therefore estimate necessary efforts to improve their maturity through a corresponding action plan.

STATE OF THE ART

A maturity scale provides a systematic framework to assess organization developed product maturity. Unfortunately, many maturity models propose different issues related to development and reuse processes. Research works done in the software community propose various practices and models to mature reuse activities. For example, the Reuse Capability Model (RCM) provides a method for determining an organization's software reuse capability (Rine and Sonnemann 1998) by defining five levels to evaluate and plan organization reuse capability improvements. However, as assessment concerning development and reuse process must operate in multiple dimensions it appears a complete maturity model requires multiple criteria coverage. Accordingly, the RiSE Maturity Model (Garcia, Lucrédio, Alvaro, De Almeida, De Mattos, Fortes, and De Lemos Meira 2007) includes four perspectives addressing organizational, business, technological, and process issues. The RiSE Maturity Model's main purpose is supporting an incremental software reuse practice adoption and implementation. Recent work (Younoussi and Roudies 2016) compiled and compared these and other software maturity models to provide each model a classification depending on criteria and parameters to help a company choose the right approach.

The systems engineering community developed maturity models for deploying systems engineering processes (Cornu, Chapurlat, Quiot, and Irigoin 2012) or measuring MBSE use but have not yet studied in detail valorization and systems engineering asset reuse assessments. A Systems Engineering Capability Maturity Model (SE-CMM) (Software Engineering Institute 1995) developed before CMMI (Software Engineering Institute 2010) did not consider reuse aspects. CMMI, however, establishes high level reuse practices but lacks instructions on the operational side. Thus, companies require assistance assessing their current reuse process performances and guidelines to improve them. The answer to this is through defining a systems

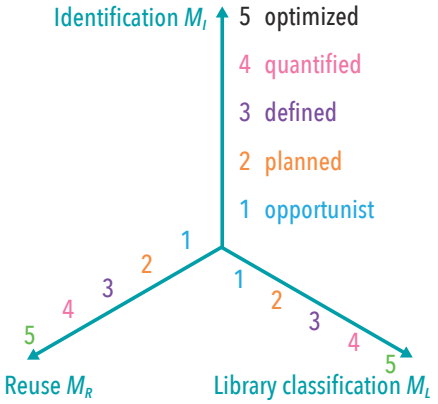

Figure 3. Proposed maturity scale

Table 1. Detailed maturity level description

Identification		AXIS		
		Library classification	**Reuse**	
MATURITY LEVEL	0	No identification of reusable elements	No library classification	No reuse from previous projects
	1	**Opportunistic** identification of reusable elements from previous projects, without method (uncomplete vision)	**Awareness**: "I already saw something like this"; **Opportunistic** oral sharing of reusable elements: "we already did it this way," use of paper board…	**Opportunistic** reuse by copy/paste from previous projects, without method; manual adaptation
	2	**Planned** identification of reusable elements, without method (uncomplete vision)	**Planned** sharing of formalized elements (communication, archiving…) identified as reusable (texts, models…)	**Planned** reuse by copy/paste from previous projects, without method; manual planned adaptation
	3	**Defined** identification method: classification in function of defined abstraction levels	**Defined** capitalization method: sharing organized around a sharing structure	**Defined** reuse method: defined selection of reusable elements and transitions between defined abstraction levels
	4	**Quantified** measure of defined identification method efficiency (identification time, costs…)	**Quantified** measure of defined capitalization method efficiency (classification time…)	**Quantified** measure of defined reuse method efficiency (direct reuse or adaptation time…)
	5	**Optimization**: continuous improvement of identification method	**Optimization**: continuous improvement of classification method	**Optimization**: continuous improvement of reuse method

engineering asset valorization maturity scale, proposed in the next section.

MATURITY SCALE

This article proposes a multiaxial scale which includes five maturity levels by axis, to cover the different systems engineering asset valorization process aspects (Figure 3). This allows both quantifying maturity degrees (***MI, ML, MR***) specific to some activities (Identification, Library classification, Reuse) and an overall maturity level (***MVSEA***) depending on each axis level. This scale leans on the CMMI and proposes adapting its maturity level definition to specific systems engineering asset needs.

The scale's peculiarity is axis dependency links. Indeed, the final goal is asset to reuse assets to disseminate know-how and future development ease and speed. However, this is not possible without first identifying those assets. Also, reuse is more efficient if libraries classify assets. This means the identification axis is the start to every process, and its maturity level constrains other axes. Thus, this scale assumes:

$$MR \leq MI$$
$$ML \leq MI$$

After setting these conditions, it is possible to define the overall systems engineering asset valorization maturity level (***MVSEA***) as follows:

$$MVSEA = \min(MI, ML, MR)$$

Table 1 describes each maturity level in detail.

Systems engineering assets vary depending on maturity level. In the context presented in the first section, patterns are systems engineering assets, but systems engineering assets should function as patterns from maturity level 3 (defined) and above.

CONCLUSION & PERSPECTIVES

This first maturity scale version for systems engineering asset valorization and reuse allows current practice assessment. It also guides action plan elaboration to improve current maturity.

In future works, the maturity scale axes will refine and consider MBSE assets: model identity card, model maturity assessment (for example depending on various metrics such as version number and number of instantiations), tools supporting model reuse, and more. ■

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Evaluation of Systems Contractor's Ability to Deliver a Solution to Offer During an Engineer-To-Order Bidding Process

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■ **ABSTRACT**
To increase their business volume and remain competitive, systems contractors must propose competitive and feasible solutions to customers. However, Engineer-To-Order industrial situations become challenged by the lack of relevant information. This article, to help companies to overcome this problem, presents two confidence indicators, their evaluation methods, and a way to use them during a design process. These indicators allow evaluating a company's future ability to offer a solution during a bidding process.

INTRODUCTION

In the bidding process context, to transmit a commercial offer to a customer, a systems contractor (or a bidder) must design a technical bid solution which complies with the customer's requirements. In general, the technical bid solution contains two interconnected parts (see Figure 1). The first part is the technical system (TS) which corresponds to the customer's technical and functional requirements and includes sub-systems (SS) which the system architecture helps integrate (Sauser, Ramirez-Marquez, Henry, and Dimarzio 2008). The second part is the technical system's delivery process (DP) which incorporates activities and resources (ACT) necessary to develop, assemble (or manufacture), and deliver the technical system once the customer accepts the offer. Offers include only the technical system solutions. However, it is crucial to design and evaluate both parts to perform a realistic solution evaluation, especially their cost, delivery date, and feasibility (or associated risks).

In an Engineer-To-Order (ETO) bidding process, the customer's requirements exceed the range of available technical bid solutions within the supplier company. Hence, to propose a relevant offer, it is necessary to design a solution which covers all the customer's requirements (Zheng Xu, Yu, and Liu 2017). However, in general, customers allow limited time to submit an offer. In addition, as customers cannot guarantee the offer's acceptance, optimizing resources and time during the bidding process is crucial when customers do not accept the offers (Kromker 1998). Consequently, at the bidding phase, several companies perform a pre-design of the potential solutions instead of a detailed design reducing the resources and time used during offer elaboration. However, these partially designed solutions contain uncertainty and risks regarding the companies' future abilities to develop and deliver the proposed solutions after the customers accept their offers (Chapman, Ward, and Bennell 2000)(Sylla, Vareilles, Coudert, Kirytopoulos, Aldanondo, and Geneste 2017). In some companies, experienced designers provide subjective judgments to estimate the company's ability to deliver a solution. These judgments, human dependent, lead to inaccurate or inexact estimations and result in cost growth and schedule slippage during solution realization and delivery. This article focuses on evaluating a company's ability to develop and deliver a solution offered during a bidding process. The ability acts as a measure of the risks associated with a specific offer (a technical

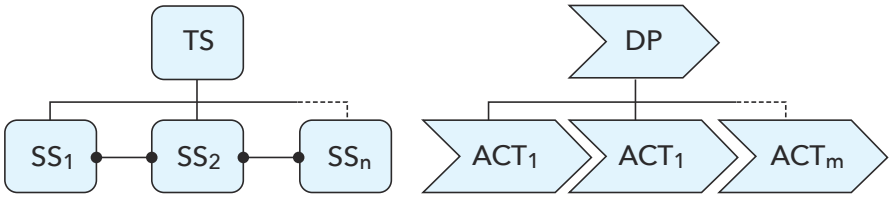

Figure 1. Technical bid solution

system and delivery process pair). Thus, its assessment enables bidders to anticipate risks related to the technical system's development and delivery after the customer accepts the offer. Therefore, this article assists the risks management process, as defined in the ISO/IEC/IEEE 15288:2015 standards, by presenting two confidence indicators, their evaluation methods, and how to use them during a design process. Overall Confidence in System (OCS) is the technical system indicator and Overall Confidence in Process (OCP) is the delivery process indicator. Our previous work (Sylla, Vareilles, Coudert, Kirytopoulos, Aldanondo, and Geneste 2017) proposes both indicators and allows bidders to assess their ability to deliver a solution offered during a bidding process.

THE CONFIDENCE INDICATORS AND THEIR EVALUATION METHOD

In the proposed method, two different indicators characterize each technical bid solution part (technical system and delivery process). The first indicator is factual and intrinsic to the elements (sub-systems, sub-system integrations, and activities) which compose the technical bid solution. They provide an objective evaluation of the technical system's maturity and the delivery process' feasibility. The second indicator, based on the designer's subjective feeling, allows considering the designer's expert feeling about the solution's success.

As shown in Figure 2, to compute the technical OCS, the factual indicators *Technology Readiness Level* (TRL_i) and *Integration Readiness Level* (IRL_{ij}) characterize each sub-system and each sub-system integration (i and j). The TRL and IRL indicators assess the sub-systems and their integrations developmental maturity (Mankins 1995) (Sauser, Ramirez-Marquez, Henry, and Dimarzio 2008) and measure on a nine-level scale. The subjective indicators *Confidence In Sub-system* (CIS_i) and *Confidence In the integration of Sub-systems* i and j (CIS_{ij}) further characterize each sub-system (i) and each sub-system integration (i and j). They assess the designer's expert feeling about the sub-systems and their integrations success and measure on a five-level scale. Then, an aggregation method (Sauser, Ramirez-Marquez, Henry, and Dimarzio 2008) computes the technical system's factual and subjective (System Readiness Level (SRL) and the Confidence In System (CIS)). SRL and CIS indicators measure on a five-level scale. Finally, a method computes the technical system's OCS using the SRL and CIS indicators (see Figure 2), measured on a nine-level scale.

To compute the delivery process' overall confidence (OCP), the factual indicator

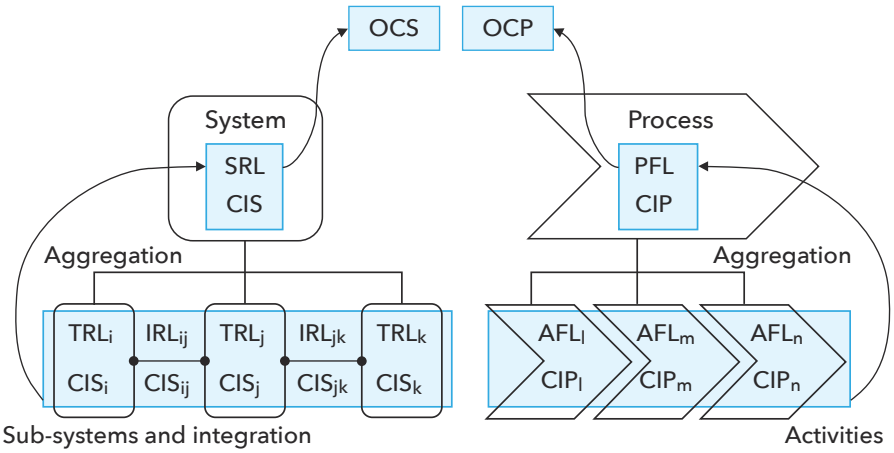

Figure 2. OCS and OCP indicators

Activity Feasibility Level (AFL_l) characterizes each activity 1 (see Figure 2). The AFL indicator measures the activities' feasibility by aggregating three dimensions: (i) the resource competence, (ii) the resource availability, and (iii) the activity risk. AFL measures on a five-level scale. The subjective indicator *Confidence In a delivery Process* activity (CIP_k) further characterizes each activity. It assesses the designer's expert feeling about the activity's success and measures on a five-level scale. Then, a weighted average aggregation method computes the two delivery process indicators (*Process Feasibility Level* (PFL) and *Confidence In Process* (CIP)). PFL and CIP indicators measure on a five-level scale. The same method used to compute the technical system's OCS computes the delivery process' OCP based on the PFL and CIP indicators (see Figure 3). The OCP indicator measures on a nine-level scale.

With these two confidence indicators (OCS and OCP), a bidder will have a powerful tool that can propose an attractive and feasible solution to a customer during a bidding process. A bidding process' or engineering design process' design phase obtains several potential solutions (Renzi, Leali, and Di Angelo 2017). In this situation, the most critical task in a bidding process is selecting the most interesting solution to offer while maintaining feasibility and realism. The solutions attractiveness relies on the evaluation criteria values such as cost, delivery date, and technical performances. Its feasibility relies on the company's future ability to develop and deliver it according to the expectations. This feasibility can consider the confidence indicators presented in the previous section. Thus, a good solution has good values for both the evaluation criteria and the confidence indicators. Therefore, in addition to the standard criteria (cost, delivery date, and technical performances), the two confidence indicators (OCS and OCP) can act as decision criteria in a design process to select the most interesting design solution. Following is an example of confidence indicator use.

THE USE OF THE CONFIDENCE INDICATORS IN A DESIGN PROCESS

We assume a configuration software designs and evaluates the potential solutions (Sylla, Guillon, Vareilles, Aldanondo, Coudert, and Geneste 2018). A configuration software is a knowledge-based design tool based on a generic model. A generic model contains relevant knowledge characterizing the technical bid solution diversity offered by a supplier company. This generic model associated with a relevant decision aiding tool allows the designer to instantiate relevant solutions according to the

OCS/OCP		CIS/CIP				
		level 1	level 2	level 3	level 4	level 5
SRL/PFL	level 1	1	2	3	4	5
	level 2	2	3	4	5	6
	level 3	3	4	5	6	7
	level 4	4	5	6	7	8
	level 5	5	6	7	8	9

Figure 3. OCS and OCP computation matrix

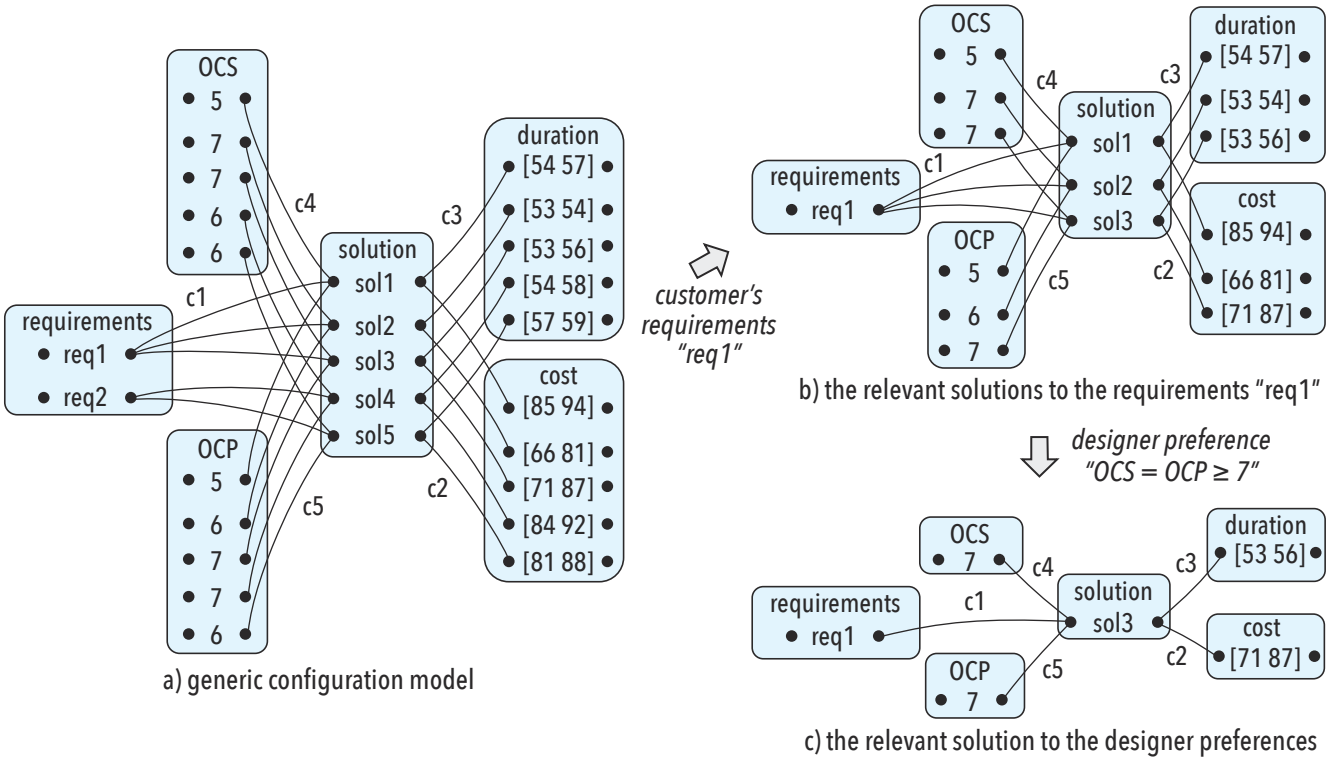

Figure 4. An example of confidence indicator use

customer's requirements.

Consider the simple generic configuration model presented Figure 4, developed using a *Constraint Satisfaction Problem* (CSP) framework. A CSP framework's configuration problem model uses three elements: (i) a variable set, (ii) a finite domain for each variable, and (iii) constraints linking the variables. In this model, the requirements, the solution, the cost, the duration, and each confidence indicator (OCS and OCS) associates to a variable. Their possible values represent the corresponding variable's domain. Therefore, technical bid solutions link to the variable "solution." Five possible solutions ("sol1" to "sol5") represent this variable's domain. Constraint "c1" defines the solutions relevant to specific customer's requirements (sol1, sol2 and sol3 are relevant to the requirements "req1"). Constraints "c2" and "c3" define each solution's cost and duration whereas constraints "c4" and "c5" define each solution's OCS and OCP. For instance, for the technical bid solution "sol3": duration = [53 56], cost = [71 87], OCS = OCP = 7.

Considering a design or a configuration problem as a CSP allows constraint filtering mechanisms to act as an aiding tool. Each customer's requirement or designer's preference triggers constraints to propagate this decision and prune variable values for the solutions, cost, and duration while automatically updating the confidence indicators (Aldanondo and Vareilles 2008). As an example, consider the customer's requirements correspond to "req1." Then, only the three solutions "sol1," "sol2," and "sol3" are relevant (see Figure 4). Now, the designer must select one solution to propose to the customer. To consider the company's future ability to deliver the solutions, the designer can define required OCS and OCP values for selecting a solution. Let us consider the designer has selected "7" as the required OCS and OCP values. Then, only the solution "Sol3" corresponds to the designer preference (see Figure 4). Consequently, the commercial offer considers this solution "sol3." Note in a more practical or complex case, one could optimize several criteria (cost, OCS, and OCP). In such a situation, a multicriteria decision support approach could determine each criterion's appropriate weight and select the most interesting solution (Zheng, Xu, Yu, and Liu 2017).

CONCLUSION

We have presented two confidence indicators (OCS and OCP) and their evaluation method for evaluating a company's ability to develop and deliver a solution offered during an Engineer-To-Order bidding process. Two different metrics (factual and subjective) characterize the OCS and OCP indicators. We have also shown how to use them as a decision criterion to select a feasible solution in an engineering design process. This represents a first step in the validation process of the proposed indicators and their evaluation method. However, proving their applicability and effectiveness requires performing a more realistic case study, considered as future research. Future research should also consider developing a method for a more factual evaluation of the subjective indicators CIS and CIP. ■

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Coordination of Multi-Underwater Drones: Towards an Integrated Object-Oriented Methodology in an Open-Source Environment

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■ **ABSTRACT**

This paper's goal is to present a framework for studying multi-underwater drone coordination, specifically formation control, based on a real-time object-oriented paradigms in an open-source environment (the Operating Robot System Environment). This framework will capture the system's whole development life cycle, from the requirements specification to testing out the simulation and realization models. Based on this specialized framework, we can easily and quickly develop and verify the control algorithms while meeting future input requirements or manageable changes.

I. INTRODUCTION

In recent years, there has been increasing interest in control cooperation for multiple Autonomous Underwater Drones (AUD) due to many achievable advantages such as robustness, adaptivity, and flexibility for exploration tasks.

According to Oh and Park (2015), some approaches to coordination control include: the position-based control, displacement-based control, and distance-based control. However, AUD's rapid development and the numerous different approaches have made the AUD controller's algorithms more complex. Also, AUD failures may occur unexpectedly in autonomous operation mode in harsh environments. Therefore, system analysis must predict and understand its capabilities and operational quality attributes (its performance, reliability, or security) to avoid costly rework late in development and maintenance.

Object Management Group (OMG) standardized Model-Driven Architecture (MDA) (OMG 2003) through Unified Modeling Language/Systems Modeling Language (UML/SysML) (OMG 2007, OMG 2012), which started with separating system operation specifications from how the system uses its platform capabilities. MDA provides an approach and tools to: specify a system independently of the supporting platform, specify platforms, choose a particular platform for the system, and transform the system specification for a particular platform. In addition, the Object-Oriented Methodology (OOM) is a common approach to system development encouraging and facilitating software component reusability with four main principles: abstraction, encapsulation, modularity, and hierarchy. OOM's purpose is to break down the software into objects. Architecture Analysis & Design Language (AADL), standardized by the Society of Automotive Engineers (SAE) (SAE 2017), addresses specific industrial control system platform-oriented and physical aspects (Feiler et al. 2004; Akdur et al. 2018). However, the AADL focuses on modeling real-time embedded systems and includes a comprehensive catalogue of standard hardware and software elements in such systems and their characteristics, allowing relatively precise and dependable analyses of different system properties such as performance, schedulability, reliability, or power consumption (Kordon et al. 2013; Grolleau et al. 2018). This ecosystem brings methodologies and tools to address the industrial realization of a robot software project.

In this paper, we develop a framework

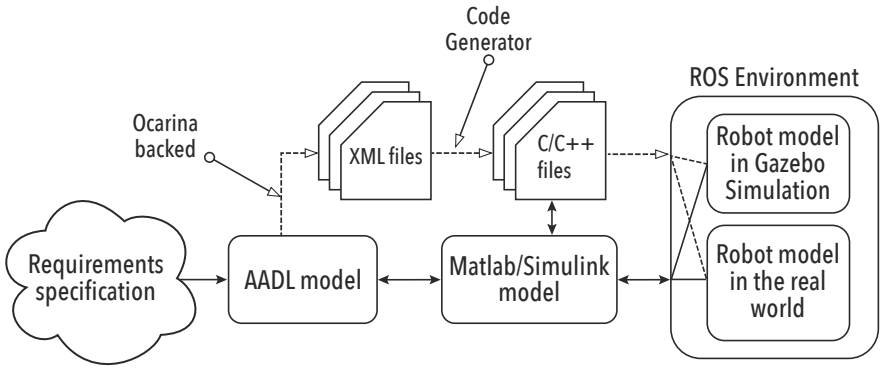

Figure 1. A toolchain for coordination of multiple UUVs

for studying the multiple AUD coordination by applying AADL based on OOM. The AUD control system, considered as an embedded system, can consist of hybrid hardware and software components. This embedded system can process a signal data stream from sensors and/or communication modules through actuators with the influence of the external environment disturbances.

II. PROPOSAL OF A FRAMEWORK FOR DEVELOPING THE COORDINATION OF MULTIPLE AUD

We propose a framework for studying multiple AUD coordination in figure 1. The AADL models can describe the requirements specification and analyze end-to-end latency including processing time and delay. Four factors affect it: processing time by tasks in the end-to-end flow, processing delay due to queuing or sampling, information timing concurrency between tasks along connections, and timing delay due to queuing or waiting for time slots in the transferring protocol.

In addition to the AADL model, we can define the error components, which correspond to the ARP4761 standard. By using the guidelines and methods for conducting the Safety Assessment Process on Civil Airborne Systems and Equipment (SAE 1996), AADL provides general guidance on evaluating design safety aspects and identifies processes, methods, and tools supporting the evaluation (Delange et al. 2014).

By using AADL models to specify the input requirements specification, we can precisely determine system component requirements and binding constraints, described at abstraction and generalization levels. From the defined AADL models, two approaches test AUD model simulation and realization. Firstly, the AADL models convert to XML files. Then XML files, through round-trip engineering, generate in C/C++ libraries, implemented by using the ROS environment. However, Python must manually create this method's code generator. Semprebon (2017) and Bardaro et al. (2017) provide more details about this approach. In the scope of this study using available platforms, we have chosen the second approach. We use the transformation rules applied to the AADL model to have the models on Matlab/Simulink. Moreover, the model on Matlab/Simulink can directly connect to Gazebo simulator (Manhães et al. 2016) to fit in virtual robots and with actual ROS-enabled robots; or from models on Matlab/Simulink, we can generate C ++ libraries, which can function as a library in ROS environment.

Figure 2 shows Matlab/Simulink and ROS environment relationship details. From the AADL models through the transformation rules, we could get the models on Matlab/Simulink. Then, the model on Matlab/Simulink can directly connect to Gazebo simulator or maybe from models on Matlab/Simulink we can generate C++ libraries, which can act as a library in ROS environment. The Gazebo simulator receives and sends messages on the following topics. It receives velocity commands from Matlab/Simulink, as messages of type "*geometry_msgs/Twist*" on the "*/commands/velocity*" topic. It sends odometry information to Matlab/Simulink, as messages of type "*nav_msgs/Odometry*" to the "*/odom*" topic. Using algorithm models in Matlab/Simulink will quickly help test and verify the requirements. In the following section, we detail a case study using this framework to study.

III. CASE STUDY: COORDINATION OF TWO UNDERWATER DRONES – BLUEROVS

Figure 3 (on the following page) presents an example using the framework focused on coordinating two underwater drones BlueROV. ArduSub open-source software and the Pixhawk autopilot form this AUD's basis. AADL models BlueROV components by using open-source AADL tool environment – (OSATE 2016) which includes sensors, microcontroller, and actuators with its characteristics. Threads form the microcontroller blocks (number 1) details. Thus, this case's algorithms are *consensus algorithms, image processing, avoidance obstacle algorithm, and avoidance collision algorithm*. This paper only presented consensus algorithms. By using transformation rules (Lukas 2015), the *consensus algorithms* (number 2) thread can convert to the model on Matlab/Simulink (number 3). With the consensus algorithms threads, we can define the input values and output values which will function in the same way as the Matlab/Simulink model. Using the Matlab/Simulink model, we can verify algorithms for simulation models or realization model with communication support between Matlab/Simulink and ROS environment (number 4). In a synthetic way, the AADL model deals with response time and reliability, the Simulink model deals with behavior, and the ROS/Gazebo model deals with 3D simulation and implementation. The author's previous presents consensus algorithm details (Pham et al. 2018) and the conference OCEANS (Pham et al. 2019) presents AADL development.

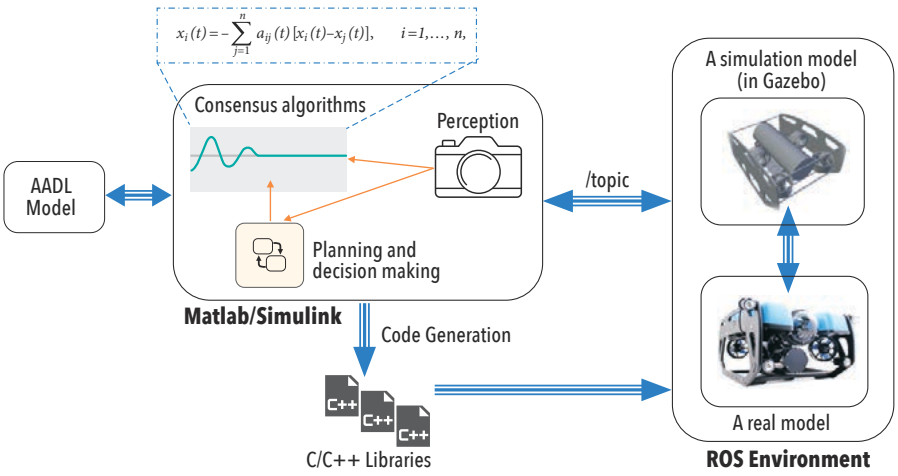

Figure 2. Framework based on Matlab/Simulink and ROS/Gazebo

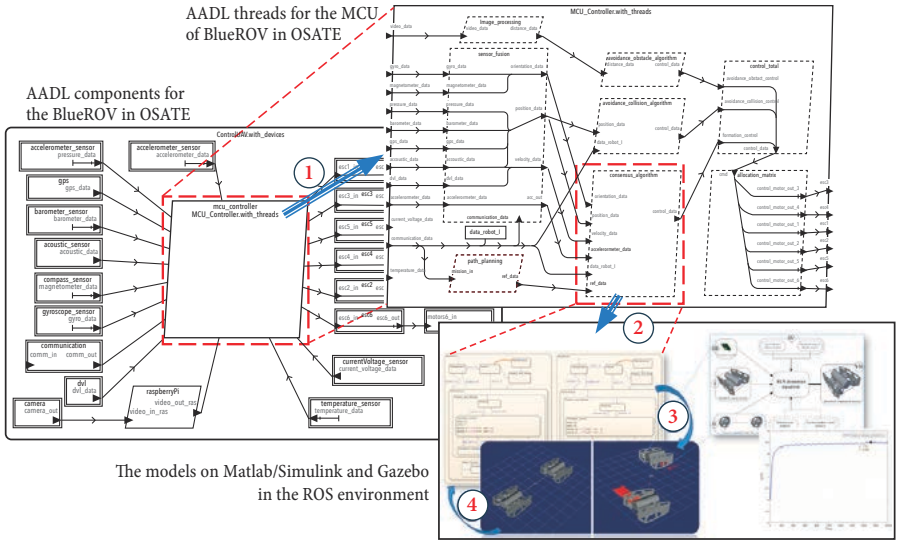

Figure 3. An example of using the proposed framework for a coordination multi-robots

CONCLUSION

In this study, we proposed a framework to study multiple AUD coordination in different environments. Thanks to AADL, various hypothetical conditions verify the end-to-end flow latency and faults for an AUD embedded system. Using ROS environment or Matlab/Simulink tools supports real-time status visualization, control parameters, and 3D simulation. In future works, we will study a complete framework, so we can verify more algorithms (the application of the algorithms of neural network for control), and will also study more rules to automatically trace between AADL models and Matlab/Simulink models. ■

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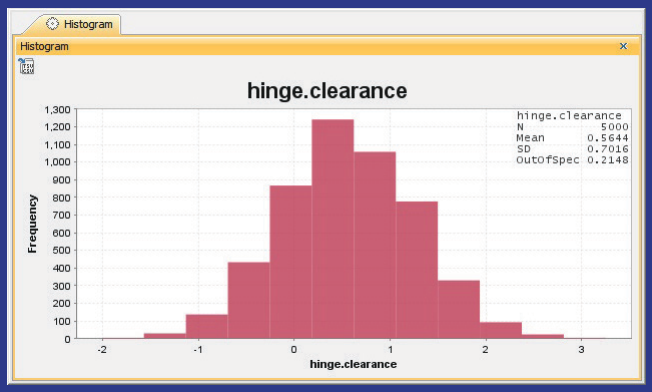

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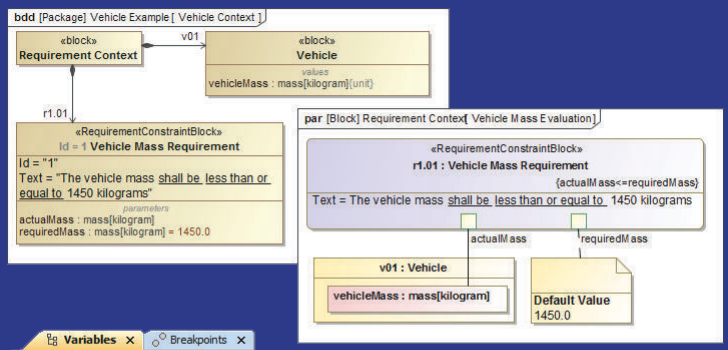

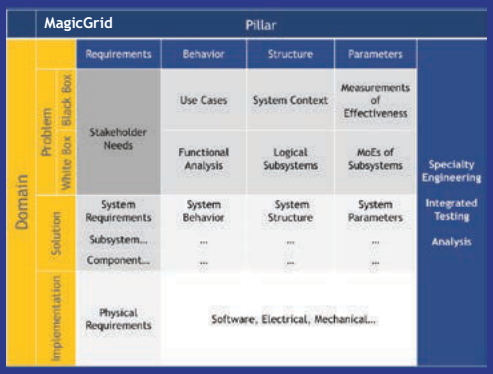

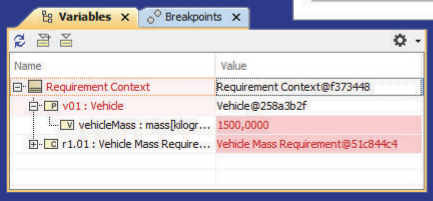

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