STSM Report: Systematic literature review on multi-paradigm modeling for CPS Systems

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I. Purpose of the Visit

Short Term Scientific Mission (STSM), was carried out in period of 14 till 30 of April 2018 at Faculty of Organisational sciences (FON), together with prof. Dusan Savic, in the context of the MPM4CPS COST Action IC1404.

This report contributes to WG4, by defineing in extensively and in a systematic fashion the current state of the art on the topic of MPM4CPS. In order to provide a balanced and objective summary of research evidence, a systematic literature review process is considered as an appropriate method to carry out such a review in software engineering.

A. Technique

Systematic Literature Review (SLR) is a research method to obtain, evaluate, and interpret information related to a research question. A SLR provides an objective reliable, rigorous, and methodological manner to conduct some study. In this report a SLR of sustainability in modelling of Cyber-Physical Systems (CPS) is conducted. This research aim requires accumulating a body of knowledge for various reasons: justifying the basis for future research, learning as much as possible from other domains related to the topic, and providing a basis for other researchers as well as students who consider learning about and contributing to this area.

The research objective of this SLR is to Identify and analyse multi-paradigm modelling approaches for CPS. We expect to give an overview of the current state of the art in supporting multi-paradigm modeling of CPS. With this objective, we systematically investigate the research literature of modelling of CPS in the period between 2011-2017. The quest is to identify models, and implementations in a model-driven formal way that lends itself to a more systematic development of CPSs. Next is to summarize the State-of-the-art research trends, as well as to categorize proposed approaches, techniques, tools and methods for assessing and improving a multi-paradigm modelling of CPS.

B. Research Questions

A main research questions are the following:

- **RQ1** Which modeling approaches exist for building CPS?
- **RQ2** Which modelling approaches for addressing multi-paradigm modelling of CPS exist?
- **RQ3** Which application domains have been considered?
- **RQ4** Which modelling approaches for addressing multi-paradigm modelling of CPS exist?
- **RQ5** What is profile of person which perform modelling of CPS?

Further we define PICOC analysis which specified in detail our search for evidence:

Population: The population is composed by studies in which we found reports about works for modeling CPS and/or approaches for multi paradigm modelling. No specific industry, system or application domain were considered.

Intervention: The review searches for reports of methodologies for multi paradigm modelling, namely focusing on 2 important factors; Reported for CPS; Reported for software products and applicable to CPS. We also search for the methodology/tool/technology/procedure that support the modelling of CPS.

Comparison: Not applicable

Outcomes: Outcomes should point to tehniques, methods and metrics that can be used to address the multi paradigm modelling of CPS.

Context: All practitioners: Academy and Industry

II. Description of work

In the context of this SLR, we planned our SLR process as suggested by Kitchenham [2]. In the planning phase the review protocol is developed as well as research strategy. Following the initial step of definition of the research question, an initial list of studies is taken from the SLR previously executed by author, where the papers reporting modelling of CPS were identified. The list will be used as a starting point in the primary study selection step. Each article will be examined to select studies which answer the original research question. This required the definition of selection criteria that will be the objective guidance in selecting primary studies. We record all inclusion and exclusion rules to determine if one study can be a candidate for primary study. Primary studies are the output of the SLR method and the input for further analysis and discussion. Further, primary studies reporting on multi-paradigm modelling were identify by the research quarry.

There are systematic literature reviews on different topics in software engineering, but so far none has been conducted

that investigates the multi-paradigm modeling of CPS. An original contribution of our effort is that for the first time in this research field, we have followed an SLR method to be as objective as possible in our selection of primary studies. However, we examine in detail SLR protocol from related work. Related studies provide the necessary instruments to replicate the study, or in our case to extend them to cover new research.

Lun et al. [3], published Cyber-Physical Systems Security: a Systematic Mapping Study. This study aim at identifying, classifying, and analyzing existing research on CPS security in order to better understand how security is actually addressed when dealing with CPS. Authors empirically define a comparison framework for classifying methods or techniques for CPS security. From the collected data authors observe that even if solutions for CPS security has emerged only recently, in the last years they are gaining a sharply increasing scientific interest across heterogeneous publication venues. The systematic map of research on CPS security provided here is based on, for instance, application fields, various system components, related algorithms and models, attacks characteristics and defense strategies. Following string was used to obtain a primary studies: ((“cyber physical” OR “cyber-physical” OR cyberphysical OR “networked control”) AND system*) OR CPS OR NCS) AND (attack* OR secur* OR protect*))

Gunes et al. [1], presents A Survey on Concepts, Applications, and Challenges in Cyber-Physical Systems. In order to shed some light on the origins, the terminology, relatively similar concepts, and today’s challenges in CPS, authors presented survey on related literature discussing practical applications and dominant research domains. Since CPS is a very broad research area, CPSs span diverse applications in different scales. Therefore, each application necessitates strong reasoning capabilities with respect to unique system-level requirements/challenges, the integration of cutting-edge technologies into the related application, and overall impact on the real world. Authors conclude that existing legacy systems have limited awareness of the CPS requirements, and that revolutionary design approaches are necessary to achieve the overall system objectives.

III. Result

Main result of this STSM is the protocol defined to address research questions presented in Section 1. The additional details about protocol and research results can be found in online Excel file [1].

A. Data sources and search strategy

It is specified that our SLR will address the period from **2011-2017** as it is indicated within related research that interested on topic of CPS development boosted from 2011.

Data sources were selected in order to include the most relevant journal, conferences and international peer-reviewed workshops that are concerned with the topic of mulitiparadigm modelling or CPS. For the automated scan of the Search Process we selected the following digital libraries:

1) ACM Digital Library (ACM)
2) IEEExplore (IEEE)
3) Science Direct (SD)
4) Springer Link (SL)
5) Scopus

[1]protocol: https://goo.gl/DJx9wa

TABLE I
Primary studies

Database	Q1	Q2	Q3
ACM	44	4	200
IEEE	42	0	48
SD	80	8	25
SL	294	25	39
SCOPUS	66	97	33
	526	**134**	**345**

B. Search query

In this SLR the author obtained the results from search sources [1-5] based on following research quarrys:

Q1 - ”(””cyber physical”” OR ””cyber-physical”” OR CPS OR cyberphysical OR smart OR critical) AND ((””integrate model*”” OR ””composable model*””) OR (””integrate simulation”” OR ””composable simulation””)) AND (””model driven”” OR model-driven OR ””model based”” OR model-based)”

Q2 - (”multi-paradigm” OR ”multi-formalism” OR ”heterogeneous formalism” OR ”unified modelling formalism” OR ”multi-model language”) AND ((“cyber physical” OR “cyber-physical” OR cyberphysical OR smart) AND system*) AND (”modelling approach” OR ”modeling approach” OR ”integrate modelling” OR ”integrate modeling” OR ”model driven” OR ”model-driven”) AND (”software engineering” OR ”software system”)

Q3 - ”(“multi-paradigm” OR “multi-formalism” OR ””heterogeneous formalism””) AND (””Modeling and Simulation”” OR ””Integrate modeling””) AND (””cyber-physical system ”” OR ””hybrid system”” OR ””embedded system”” OR ””real-time system”” OR ””smart system””)”

In Table I we report on primary studies which are obtained using research quarries. From Q1 based on abstract review there was obtained

C. Study selection criteria

The studies that were included are the ones that report modelling of CPS and are reported from the 2011-2017. The studies that are part of informal literature, present duplicated work or its extension and ones that are not in English are not also considered (see Table II for detail criteria).

D. Study quality assessment

To have means to reflect a confidence of reviewer, we defined two self-assessment points (see Table III). In a case that a reviewer is not very confident about the paper, the

TABLE II
INCLUSION AND EXCLUSION CRITERIA

Id	Type	Criteria
E1	Exclusion	Informal literature (power point slides, conference reviews, informal reports) and secondary/tertiary studies (reviews, editorials, abstracts, keynotes, posters, surveys, books).
E2	Exclusion	Duplicated papers.
E3	Exclusion	Papers that did not apply to research questions i.e. did not report the method for sustainability or modeling approach for CPS
E4	Exclusion	Papers with the same content in different paper versions.
E5	Exclusion	Papers written in other than English language.
E6	Exclusion	Purely hardware, or electrical engineering perspective papers
E7	Exclusion	Purely application of sustainability in environmental domains (e.g. agricultural papers)
E8	Exclusion	Secondary study
I1	Inclusion	Publication date from 1/1/2011
I2	Inclusion	Relevance with respect to research questions
I3	Inclusion	Explicit mentioning of cyber-physical system
I4	Inclusion	Papers that report a methodology, metric or model for multi-paradigm modelling
I5	Inclusion	Papers that report a methodology, metric or model for CPS
I6	Inclusion	Analysis of relevant application domains for MPM4CPS

TABLE III
SELF ASSESSMENT CRITERIA

Id	Self-Assessment Criteria	Score		
SA1	Reviewers confidence about content of the study	1 = Very confident	0.5 = Confident	0 = Not very confident
SA2	Reviewers confidence about quality of the study	1 = Very confident	0.5 = Confident	0 = Not very confident

additional reviewer will be asked to make revision and the assessment scores will be discussed.

In order to access the quality of selected studies the criteria was defined in order to rank the quality of each paper (see Table IV). To characterize a first criteria (relevance of journal or conference), we decided to use **CORE2017** [2] conference ranks list. For the second criteria * apply for paper published before 2014; while ** for paper published 2014 and after. We did not define any exclusion criteria regarding the quality of study, but we find it meaningful to present a statistics on the end and observe if it does make any impact.

E. Data Extraction Form

Data Extraction Form is created from four parts (See Table V);

First part giving us the general information about the selected study, like who are authors and how many citations paper had. We will take a number of citations reported by

[2]http://portal.core.edu.au/conf-ranks/

TABLE IV
QUALITY ASSESSMENT CRITERIA

Id	Assessment Criteria	Score			
QA1	What is the relevance of the paper according to the conference/journal where it was published?	1 = Very relevant (A)	0.5 = Relevant (B)	0 = Not so relevant	
QA2	What is the relevance of the citation according to its related citations?	1 = High (*>5; **>0)	0.5 = Medium (*>0; **=0)	0 = Low (*=0)	
QA3	How clearly is the problem of study described?	1 = Explicitly	0.5 = Vaguely	0 = No description	
QA4	How clearly is the research context stated?	1 = With references	0.5 = Generally	0 = Vaguely	
QA5	How rigorously is the method evaluated?	1 = Empirical foundation	0.66 = Case study	0.33 = Lessons Learned	0 = No evaluation
QA6	How explicitly are the contributions presented?	1 = Explicitly	0.5 = Generally	0 = No presentation	
QA7	How explicitly are the insights and issues for future work stated?	1 = With recommendations	0.5 = Generally	0 = No statement	

Google Schoolar [3]. In this part we register who reviewed the given paper.

Second part is meant to collect information's that will help us to address the research questions . For RQ1, we are identifying if the paper report modeling approach for building CPS, and if it does we register if it report a model/meta-model, a tool or a process. For RQ2, we identify if the paper report approach for addressing multi paradigm modelling. For RQ3, we register if the approach is domain- specific, and if it is we want to know which application domain is addressed. Finally, for RQ4 we explicitly register if paper report who is involved in modelling of CPS and what is the profile.

Third part of extraction form address the quality of the paper itself and is described in Quality Assessment Study (see Table IV).

Finally, fourth part define self-assessment which reflect the confidence of the reviewer (Likert scale from Not very confident 0, Confident 0.5 to Very confident 1) (see TableIII):

Confidence about content of the study where the reviewer gives its confidence about if the content of the paper really report the modelling of CPS or a sustainability assessment (Part 2 of the form).

Confidence about quality of the study where the reviewer gives self assessment of the confidence regarding answering the Quality Assessment questions (Part 3 of the form)

IV. FUTURE COLLABORATION

We presented our work to COST network participants at Cost network meeting. We invited all members to participate

[3]https://scholar.google.com/

TABLE V
DATA EXTRACTION FORM

1 Paper	
Id	1
Author	
Title	
Year	
Venue	
Country	
CitaionKey	
Citations	
URL	
Library	
Reviewer	
2 RQ	*default answer to Questions (Q) is Yes/No if not defined differently
RQ1	Which modeling approaches exist for building CPS?
Q1	Does the paper report modeling approache for building CPS?
Q1.1	Does paper report a model/meta-model?
Q1.2	Does paper report a tool?
Q1.3	Does paper report a process?
RQ2	Which modelling approaches for addressing multi-paradigm modellig of CPS exist?
Q2	Does the paper report multi-paradigm modelling approach?
Q2.1	Which part of CPS paper report to model?
Q2.2	Which formalizam is used for modelling of CPS?
	1- Acausal Modeling of Physical Systems with Bond Graphs (theory)
	2- Equation-Based Acausal Modeling With Modellica
	3- Causal Block Diagrams
	4- Discrete Event Modeling
	5- Statecharts
	6- Modelling and Verifying Complex Non-Deterministics Systems
	7- Architecture Analysis and Design Language (AADL)
	8- MPM process FTGPM
	9 - Other
Q2.3	How it is possible to integrated this formalizms?
RQ3	Which application domains have been considered?
Q3	Is approach domain specific?
Q3.1	Which application domain is addressed?
	1 - Smart Manufacturing
	2 - Emergency Response
	3 - Air Transportation
	4 - Critical Infrastructure
	5 - Health Care and Medicine
	6 - Intelligent Transportation
	7 - Robotic for Service
	8 - Building automotation
	9 - Other
RQ4	What is profile of person which perform modelling of the CPS?
Q4	Does paper report who is a person/s which are involved in modelling of the CPS?
	1 - CPS engineer
	2 - CPS user
	3 - Domain expert
	4 - Evaluation expert
	5 - Other
Q4.1	Does paper report on modellers background knowladge?

in protocol revision and invited them to participate in SLR execution using online questionnaire [4]. After receiving answers, our first step is to apply the feedback to proposed protocol. Also, the survey will help us to decide which research strings we should use, and eventual other research sources to consider.

After having the final version of the protocol, it will be necessary to obtain the primary studies and input them into an online library (e.g. Mendeley). Primary studies will be assigned to participants of COST network, for which we expect to collect the revisions until August 2018. Further, we will perform the analysis of obtained data and produce journal article with other SLR participants. The article is expected to be submitted to international venues (e.g. Software Systems Modeling (SoSym) journal or IEEE Transactions on Emerging Topics in Computing (TETCSI)). We expect to obtain data which will support the classifications which make part of the work plan of group W1 Also, it is expected to have a support for the facts presented as part of WG4, especially related to a definition of modellers profile.

REFERENCES

[1] Volkan Gunes, Steffen Peter, Tony Givargis, and Frank Vahid. A Survey on Concepts, Applications, and Challenges in Cyber-Physical Systems. *TIIS*, 2014.

[2] Barbara Kitchenham. Guidelines for performing Systematic Literature Reviews in Software Engineering. Technical Report EBSE 2007-001, Keele University and Durham University Joint Report, 7 2007.

[3] Yuriy Zacchia Lun, Alessandro D'Innocenzo, Ivano Malavolta, and Maria Domenica Di Benedetto. Cyber-Physical Systems Security: a Systematic Mapping Study. pages 1–32, 2016.

[4] https://goo.gl/forms/E1HNz0feAQTmitN53