



HAL
open science

Modelling cyber-physical systems using data-driven patterns

Concetta Semeraro, Mario Lezoche, Hervé Panetto, Michele Dassisti

► **To cite this version:**

Concetta Semeraro, Mario Lezoche, Hervé Panetto, Michele Dassisti. Modelling cyber-physical systems using data-driven patterns. INSIGHT - International Council on Systems Engineering (INCOSE), 2021, New challenges and Advances in Systems Engineering at French Universities, 24 (4), pp.12-15. 10.1002/inst.12354 . hal-03507207

HAL Id: hal-03507207

<https://hal.science/hal-03507207>

Submitted on 3 Jan 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Modelling Cyber-Physical Systems using Data-driven Patterns

Concetta Semeraro^{*1,2,3}, Mario Lezoche³, Hervé Panetto³, Michele Dassisti²

¹ Department of Industrial and Management Engineering, University of Sharjah, Sharjah, United Arab Emirates (e-mail: csemeraro@sharjah.ac.ae)

² Department of Mechanics, Management & Mathematics (DMMM), Polytechnic University of Bari, Bari, Italy E-mail: michele.dassisti@poliba.it

³ Université de Lorraine, CNRS, CRAN, Nancy, France (e-mail: mario.lezoche@univ-lorraine.fr; herve.panetto@incose.org)

The Smart Factory paradigm represents the "fourth industrial revolution" in the field of manufacturing industry, through the implementation of "intelligent systems" consisting of physical systems and software to control and improve manufacturing processes (Zuehlke 2010). These intelligent systems typically include various components, such as sensors for signal acquisition, communication units for data transmission between components, control units for components, control and management units for decision making, and actuators to perform appropriate actions (Lezoche and Panetto 2018). In recent years, the emergence of cyber-physical systems (CPSs) has amplified the ability to sense the world through a network of connected devices using the existing network infrastructure. Cyber-physical system (CPS) aims at embedding computing, communication and controlling capabilities (3C) into physical assets to converge the physical space with the virtual space (Monostori et al. 2016). The combination of intelligent systems and sensing systems forming a large-scale distributed cyber-physical system is a key element in the development of the distributed cyber-physical system. However, they suffer from a lack of modelling techniques that take into account not only their technological parameters but also their high degree of information and functional interrelationships. As the complexity of these systems continues to grow, the challenge of developing intelligent and sensing systems has exceeded the design complexity of their individual components (Lee, Bagheri, and Kao 2015). The main problem in developing intelligent systems is the complexity of integrating and managing these different components, technologies, and objectives across a broad spectrum. In this sense, the concepts defined in the field of Systems Engineering are relevant to the challenge of shared knowledge formalization. It is necessary to define a modelling method that helps to analyse a new form of intelligent systems (smart) and detection in a sustainable perspective. The representation of shared knowledge is a branch of artificial intelligence that studies the way human reasoning occurs and defines symbols or languages. This representation allows the formalisation of knowledge to make it understandable to machines, aligned with reference models. An important prerequisite for the cyber-physical integration is a proper and highly-accurate digital model (Semeraro et al. 2021a). Considering the complexity of digital modelling, this work aims to identify and formalise elements that contribute to the construction of informational and functional models of systems to improve and simplify the modelling of manufacturing processes and products, based on networked components.

The idea is to propose a series of modelling patterns aimed at identifying automatically, in the masses of data, invariant behaviours that can be modelled for the emulation of these cyber-physical systems and thus contribute to the digital transformation of industrial production companies. This work aims to define an approach to formalize data-driven patterns for improving the smartness of manufacturing processes and products, involving networked components. Firstly, the use formal concept analysis (FCA) (Valtchev, Missaoui, and Godin 2004) allows the extraction of tacit knowledge included in the masses of data, as shown in Figures 1-3. Formal Concept Analysis (FCA) is a mathematical theory oriented at applications in knowledge representation and data analysis. It provides tools to group the data and to discover formal patterns by representing it as a hierarchy of formal concepts organized in a semi-ordered set named lattice. The discovered patterns are concretised through the modelling of systems and procedures in system modelling language (SysML) (Figure 4). The idea behind data-driven patterns is to permit the re-use of predefined functional patterns for designing digital models based on the specific application. The approach makes the shared knowledge more easily reusable, and it is the basis of some standardization efforts.



Fig.1 Data Table

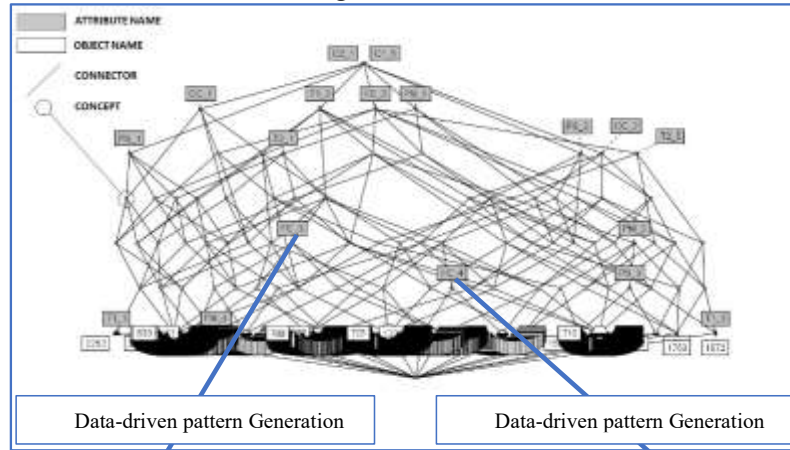


Fig.2. FCA Lattice

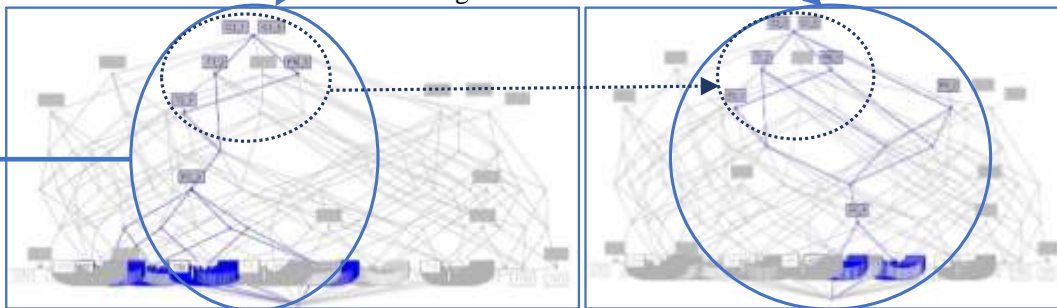


Fig.3a) Clamping Pattern

Fig.3b) Pression Control Pattern

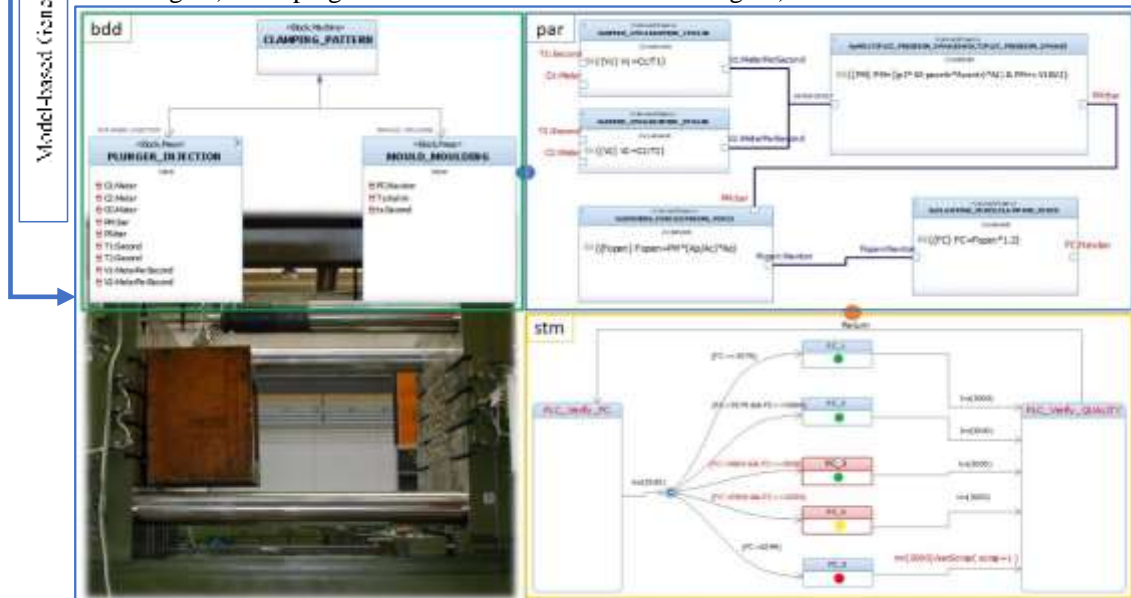


Fig.4: SysML Representation (Semeraro et al. 2019a)

In view of the above, a list of data-driven patterns has been presented in (Semeraro 2020) according to the methodology described in (Semeraro et al. 2019a). The detected data-driven patterns are listed as follow: Filling pattern (P1); Re-start machine pattern (P2); Clamping force pattern (P3); Pression control pattern (P4); State pattern (P5). The filling pattern (P1) can be used whenever it is necessary to model the behaviour of a plunger or an injection

system. The re-start machine pattern (P2) can be applied for describing the machine restart after machine downtimes. The clamping force pattern (P3) can be instantiated for describing the behaviour of a clamping system (e.g., the clamping of a mould) or for describing and preventing mechanical breakdowns. The pression control pattern (P4) can be useful for modelling hydraulic systems (e.g., the clamping of a mould) and related problems. The state pattern (P5) can be instantiated for simulating different states of the machine based on the evaluation of a set of parameters (Semeraro et al. 2021b).

The idea has been explored and validated on a real case study Master Italy s.r.l by using a set of patterns to create a digital twin model prototype to control and optimize a die casting aluminium process (Semeraro et al. 2019b). A Digital Twin (DT) is a “virtual” image of the reality constantly synchronized with the real operating scenario (Negri, Fumagalli, and Macchi 2017). The digital twin has received strong interests from researchers and industries since it allows the predictive manufacturing by integrating the cyber and the physical space. The digital twin requires the building and the applying digital models representing the set of resources and processes knowledge. A generic DT can be thought as consisting of several components organised into three main layers above recognised:

1. The physical layer, consisting of entities identified based on the stage of the product life cycle.
2. The network layer, connecting the physical domain to the virtual one. It shares data and information.
3. The computing layer, consisting of virtual entities emulating the corresponding real entities, including data-driven models and analytics, physic-based models, application, and user.

The design criteria of a Digital Twin are not well assessed or even standardised. In our approach, the digital twin prototype is implemented as shown Figure 5 applying three data-driven patterns: filling pattern (P1), re-start machine pattern (P2) and the clamping force pattern (P3) to create the digital model of the die casting process. The resulting tool can exploit the existing knowledge and the information from the real process to emulate its behaviour and thus diagnose and even predict problems and propose potential improvements. The prototype can analyse the online data collected from the physical line for searching the optimal solution to the physical line. It can evaluate the production line real-time and optimize the resource allocation autonomously (Rosen et al. 2015). With our approach, the physical settings interact with the digital space, according to specific properties and rules, to understand the behaviour of the process and the correlations between technological parameters. The digital twin has been designed to support the employees in decision-making process to identify autonomously the several quality problems of the components, compared to the standards (dimensions, tolerances, finishes, quantity), alert operators through proper alarm systems about abnormal or out of tolerance situations and support the choice of corrective actions to eliminate the detected failures and defects. It is currently being used by the company, which now wants to extend it to other manufacturing systems in its plant. Compared with existing approaches with a barrier of high design complexity, this study proposes a modular solution for designing cyber-physical systems.

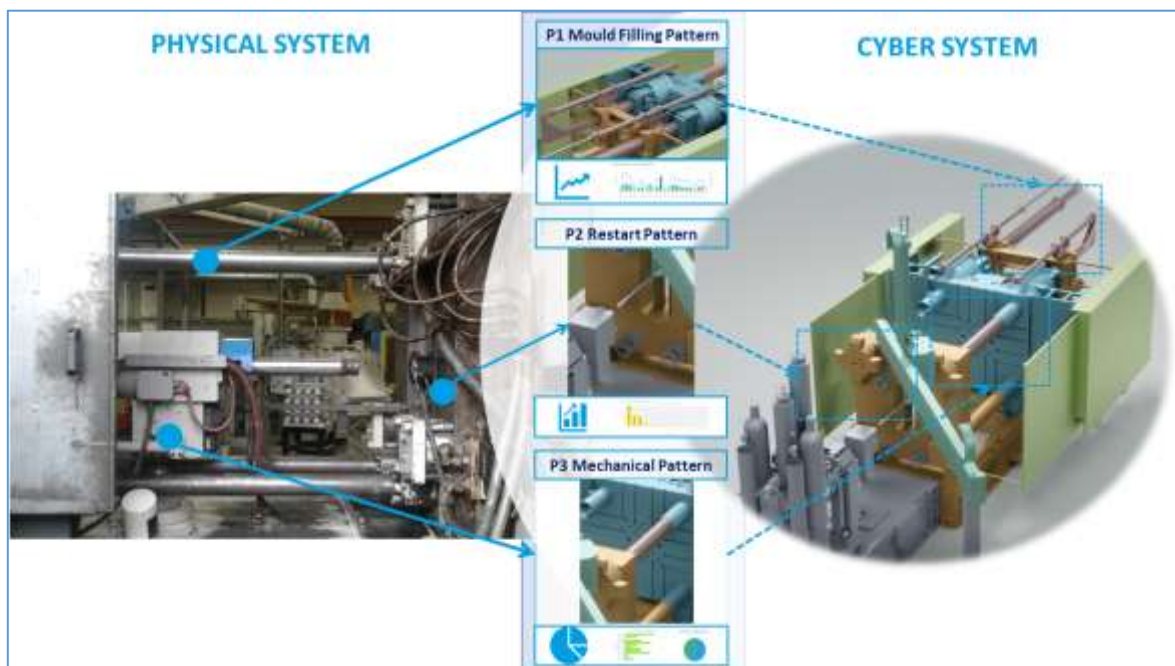


Fig.5: Digital Twin Prototype (Semeraro 2020)

The core idea of the present work is to extract patterns automatically from data and model these to design CPSs. The contribution has been tested through a real implementation on an industrial case-study. A web platform and a digital twin prototype have been presented for showing how to instantiate and use a pattern. The future research direction is to enrich the pattern's semantics to create a comprehensive library of formalized data-driven patterns. It means to select different production lines to apply the same patterns for designing digital models for different applications and scopes. Other sets of data need to be selected such as logistic data, product data, customers' data to extract new data-driven constructs. In this way it is possible to create a consistent library of patterns.

Acknowledgement

This research has been funded by the company "Master Italy s.r.l."

References

- Lee, Jay, Behrad Bagheri, and Hung-An Kao. 2015. 'A Cyber-Physical Systems Architecture for Industry 4.0-Based Manufacturing Systems'. *Manufacturing Letters* 3: 18–23.
- Lezoche, Mario, and Hervé Panetto. 2018. 'Cyber-Physical Systems, a New Formal Paradigm to Model Redundancy and Resiliency'. *Enterprise Information Systems*, Taylor & Francis, 2020, 14 (8), pp.1150-1171. (10.1080/17517575.2018.1536807)
- Monostori, László, Botond Kádár, T. Bauernhansl, S. Kondoh, S. Kumara, G. Reinhart, O. Sauer, G. Schuh, W. Sihn, and K. Ueda. 2016. 'Cyber-Physical Systems in Manufacturing'. *Cirp Annals* 65 (2): 621–41.
- Negri, Elisa, Luca Fumagalli, and Marco Macchi. 2017. 'A Review of the Roles of Digital Twin in CPS-Based Production Systems'. *Procedia Manufacturing*, 27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy, 11 (January): 939–48. <https://doi.org/10.1016/j.promfg.2017.07.198>.
- Rosen, Roland, Georg von Wichert, George Lo, and Kurt D. Bettenhausen. 2015. 'About the Importance of Autonomy and Digital Twins for the Future of Manufacturing'. *IFAC-PapersOnLine* 48 (3): 567–72.
- Semeraro. 2020. 'Contribution to the Formalization of Data-Driven Invariant Modelling Constructs of Cyber-Physical Systems, Co-Mentorship Phd of the Université de Lorraine (France) and of the Politecnico Di Bari (Italy)'.
- Semeraro, Concetta, Mario Lezoche, Hervé Panetto, and Michele Dassisti. 2021a. 'Digital Twin Paradigm: A Systematic Literature Review'. *Computers in Industry* 130:103469. (10.1016/j.compind.2021.103469)
- Semeraro, Concetta, Mario Lezoche, Hervé Panetto, and Michele Dassisti. 2021b. 'Pattern-Based Digital Twin for Optimizing Manufacturing Systems: A Real Industrial-Case Application'. In *17th IFAC Symposium on Information Control Problems in Manufacturing, Budapest, Hungary, June 2021*.
- Semeraro, Concetta, Mario Lezoche, Hervé Panetto, Michele Dassisti, and Stefano Cafagna. 2019a. 'Data-Driven Pattern-Based Constructs Definition for the Digital Transformation Modelling of Collaborative Networked Manufacturing Enterprises'. In *IFIP Working Conference on Virtual Enterprises*, 507–15. Springer. Turin, Italy. Sep 2019, pp.507-515, (10.1007/978-3-030-28464-0_44).
- Semeraro Concetta, Hervé Panetto, Mario Lezoche, Michele Dassisti, and Stefano Cafagna. 2019b. A monitoring strategy for industry 4.0: Master italy s.r.l case study. INSIGHT - International Council on Systems Engineering (INCOSE), Wiley, 2019, Systems engineering research at French Universities, 22 (4), pp.20-22. (10.1002/inst.12269)
- Valtchev, Petko, Rokia Missaoui, and Robert Godin. 2004. 'Formal Concept Analysis for Knowledge Discovery and Data Mining: The New Challenges'. In *International Conference on Formal Concept Analysis*, 352–71. Springer.
- Zuehlke, Detlef. 2010. 'SmartFactory—Towards a Factory-of-Things'. *Annual Reviews in Control* 34 (1): 129–38.