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Hybrid simulation for complex manufacturing value-chain environments

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Abstract

Hybrid simulation is nowadays a valid alternative for studying complex manufacturing environments. Some challenges exist in this context, as the ambiguous use of terms and definitions in the literature; and the demanding skills required for developing hybrid models. A structured literature review provides an overview of the use of hybrid simulation in manufacturing business performance and its most important advantages and drawbacks. A classification scheme for the 51 analysed papers is presented, including interfaced, sequential, enrichment, and integrated taxonomies.

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Keywords: Agent-Based Simulation; Discrete Event Simulation; Hybrid Simulation; Manufacturing; System Dynamics; Taxonomy

1. Introduction

The complexity of modern manufacturing systems and the interactions in this context demand the use of simulation as an alternative to cumbersome mathematical models [1, 2]. Simulation is one of the most commonly used techniques in Operational Research (OR) [3]. It is very popular for modelling complex manufacturing systems

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[4, 5], assessing the impact of decisions [6], optimizing designs and operations, and assessing performance [7, 8]. There are many benefits in using simulation, as early insights on the behavior of complex systems [4], flexibility [2, 9], cost efficiency [10], easy development [2], few simplifying assumptions to the models [9], scaling-up of the models, quick running times, analysis of "what-if" scenarios, and ethical experimentation [2].

Recent demands from global business optimization, human decision making, and complexity of modern systems, push researchers for using hybrid simulation approaches, combining different simulation methods, for better understanding of complex interactions between processes of different nature [3, 8]. Adopting the definition in [3], hybrid approaches are those combining at least two of three simulation methods – System Dynamics (SD), Discrete Event Simulation (DES), and Agent Based Simulation (ABS).

Albeit there is a growing interest in hybrid simulation approaches, many questions remain unsolved. There is no unified use of terms and definitions in the literature [11], which introduces ambiguity. Literature in hybrid simulation is sparse, hampering the work of researchers interested in the topic. Also, many challenges arise when using more than one simulation method, as establishing information sharing between the models [12], converting time units [12, 13], and the skills required for building the models [14].

This work aims at providing insight on the use of hybrid simulation in manufacturing business performance; and the most important advantages and challenges of using hybrid simulation. We try to answer two research questions:

RQ1: Where and how has hybrid simulation been used in the context of manufacturing business performance analysis?

RQ2: Which are the key aspects and challenges for hybrid simulation approaches?

Particularly, focus is laid on exploring the different designs of hybrid simulation approaches which have been published in the context of manufacturing business performance (e.g. manufacturing supply chain, logistics), by following a structured literature review, focusing on the different combinations of methods (SD-DES, DES-ABS, SD-ABS, others). Furthermore, and focusing on the second research question, the key issues modelers should focus on when developing hybrid simulation models are explored.

The remaining of the paper is organized as follows. Section 2 includes a description of the three simulation methods. Section 3 highlights the steps in the structured literature review, the classification scheme for the different design approaches to hybrid simulation in the literature, and the challenges of hybrid simulation; and section 4 concludes the paper and provides guidance for future research.

2. Simulation methods

2.1. System Dynamics (SD)

SD was developed at the MIT, in the 1950s, by Jay W. Forrester [15, 16], and was initially called Industrial Dynamics [16]. It is a systems thinking approach [9], focusing on an aggregate view of the systems and emphasizes feedback mechanisms and their endogenous nature [12]. In SD, the structure of the real world determines behaviour over time [12, 15]. The endogenous behaviour results from feedback loops [16] creating dynamic complexity [17].

Processes are represented by stocks, flows between the stocks and feedback loops (balancing and reinforcing). SD focuses on policies instead of single events. All elements which influence the behaviour of the system have to be modelled endogenously [16]. SD models use finite differential equations to capture interactions between subsystems and the impact of delays [6]. Models are qualitative and quantitative: the qualitative aspect is related to developing the causal loop diagrams through discussion; variables must be quantified and the quantitative SD is used through stock-flow models. SD models are deterministic and do not require multiple iterations [15]. It is a "continuous" simulation method, in which time advances in small constant steps [18].

It is very important for understanding complex systems [19], in which time is an important factor [7]. It was primarily applied to supply chains (SCs), and later to economics, ecology, innovation, workforce management, software development, competition, and markets [17]. SD is adequate for representing the management environment, enabling practitioners to analyse strategic planning scenarios and simulation policies and operations [7]. Nonetheless, due to the continuous nature of SD, it is not capable of mapping discrete events which are common in many industries [20]. For a more comprehensive view of SD, please refer to Sterman [21].