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An approach to determine simulation model complexity

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Abstract

Discrete event simulation (DES) is an essential tool for planning, operating and evaluating manufacturing systems. Estimation of simulation model complexity provides several advantages in the planning phase of a simulation project. For this purpose some measures of the simulation model's complexity are indispensable. The paper presents an approach to determine the complexity of DES models by combining several parameters describing simulation models. The potentials of the proposed approach are examined via industrial cases.

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Keywords: manufacturing; simulation; complexity

1. Introduction

In the last couple of decades manufacturing systems are becoming complex to fulfil the requirements of the increasing production quality and flexibility demands. Determining the complexity of manufacturing systems supports to understand and control the non-linear behavior of them and conclusively makes them more productive and predictive [1]. Analysis and evaluation of manufacturing systems' behavior and their performance became essential in the recent years. Digital enterprise technologies helps decision and in structure or performance analysis of manufacturing systems. One of most effective tools of these technologies is discrete event simulation (DES) [2]. A simulation model is a digital representation of an actual system [3]. DES is applied to model a system as it changes over time by representing the changes of the state variables at separate points in time [4]. Manufacturing simulation imitates several aspects of the real system such as the behavior and the layout of it. Simulation model complexity affects heavily the model building phase of a simulation project. Moreover preliminary estimation of simulation model complexity provides several advantages in the planning phase of a simulation project. For this purpose some measures of the simulation model's complexity are indispensable.

1.1. Complexity generally and in manufacturing systems

There is no universal and absolute definition for the word "complexity" and does not exist a widely accepted definition of it either [5], however the expression "complex" is used in several scientific fields. "Complexity" is typically used in association with systems. A system which consists of partly interacting and partly interdependent components is more complex if more component exist in it, and if more connections represented among the components.

In the field of production systems the complexity can be classified by physical and the functional domains. Physical complexity is divided to static and dynamic complexity. Static complexity is also named as structural complexity and related to the system's physical configuration that is not modified in time. It also refers to the interconnections and interdependencies of the static components. Dynamic complexity is also termed operational complexity and refers to the uncertainty of the system's behavior [5], [7].

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In the classification of the functional domain two groups are distinguished: time-independent and time-dependent complexity. In this domain complexity is defined as a measure of uncertainty in achieving the functional requirements.

1.2. Simulation model complexity

The correct association between digital and the physical world is essential to design and control a production system by digital technologies [6]. DES models consist of similar components and logical connections as the real system does, hence approaches determining the complexity of manufacturing systems are applicable for creating also various measures for simulation model complexity. Several approaches are published for measuring manufacturing system complexity. Section “Literature review” presents a selection of the existing manufacturing complexity modelling and measuring approaches.

1.3. Granularity, complexity

The representation of the real world in a DES model is heavily affected by the aims of the simulation experiment. Huge amount of information describe a production system completely and this information is inherently kept in the production system itself. The components of the system, the information of their attributes and the interactions and the interdependencies of them are available, measurable or calculable. The modelling objectives determine the set of data used to create a conceptual model that is a base of the simulation model construction and is formal description of the observed attributes of the production system. In this exposition simulation objectives filter data of the production system, see Fig. 1.

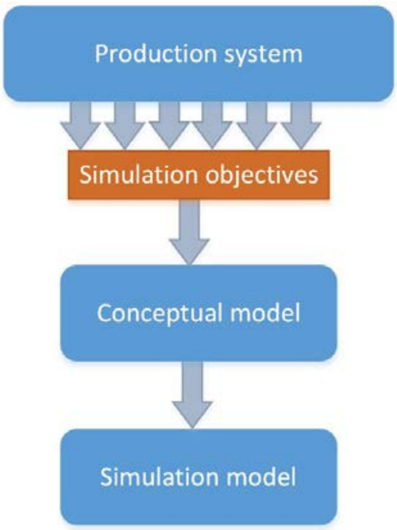

Fig. 1.: Considered information flow to simulation model construction

Simulation objectives also determine the required granularity of the model. In [14] granularity is defined as the varying levels of detail of the system. In terms of simulation granularity is related to the volume of information provided by the conceptual model.

2. Literature review

In the past years several approaches applying different methods have been published for determining and modelling manufacturing model complexity. Majority of them apply methods from axiomatic design theory, information theory, non-linear dynamics, or the combination of them [5], [7] [8].

In the domain of manufacturing several approaches based on “Axiomatic design theory” define complexity as a measure of uncertainty of fulfilling the aims of the functional requirements of the system [9], [10]. According to this approach the main goal of the design and control of manufacturing systems is the optimization of the productivity alongside reduced system complexity, following the philosophy of the “Design-Centric Complexity” (DCC) theory.

Shannon’s notion of entropy is related to the uncertainty of the occurrence of an event in the series of events [11]. Information entropy is applied by several approaches in manufacturing in order to determine the complexity of a production system. In [12] the proposed method targets to measure the static complexity of a production system by considering the sum of individual entropies across the different states. Kolmogorov’s complexity measure and the Lempel-Ziv complexity measure are also applied for manufacturing domain in [8].

In [13] Alfaro presents a methodology derived from non-linear dynamic systems (NLDS) theory to describe the system’s sensitivity to its initial conditions applying Lyapunov exponents and the bifurcation diagrams.

3. Novel approach

In the proposed approach simulation model complexity is divided to three different measures according to the classification of manufacturing complexity in the physical domain in [5].

In the domain of static complexity structural and software (computational & algorithmic) complexity are considered. Regarding the two main domains of structural and software complexity two main categories of measures are defined in the novel approach:

1. Structural complexity measure.
2. Software complexity measure.

3.1. Structural complexity

Structural complexity in simulation models refers to the complexity of the physical layout of the modelled system and the existing physical connection among the represented elements, practically the possible material transportation routes. Regarding the number of the modelled objects and the connections two measures of the layout were defined:

1. M_1: highlights the number of the modelled objects,
2. M_2: determines the number of the connections among the modelled objects.