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VIRTUAL ENGINEERING TO DESIGN ADVANCED MANUFACTURING SYSTEMS

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ABSTRACT

Designing advanced manufacturing systems (AMS) is a complex task needing to consider the re-configurability requirements, how these should be controlled to protect the system's productivity and the consistency of a guaranteed product quality. Virtual Engineering (VE) multi-disciplinary simulation provides insights to explore design options and evaluate different scenarios whilst considering multiple criteria. This paper presents how VE can be used in the design of AMS to meet the objectives for productivity, re-configurability and process quality. Commercial case studies relevant to various industries are presented, including personal care formulation, pharmaceuticals, material handling and packing. The main contribution is the demonstration of how system design and VE work together to effectively support the design challenges. The steps and key considerations are presented.

1 INTRODUCTION & PROBLEM DESCRIPTION

VE is increasingly used in the design and development of AMS. The typical approach starts with defining the stakeholder requirements, moving onto evaluating the extent to which the generated concepts and / or initial designs meet the requirements. This can be an intricate and time-consuming task, due to the multi-disciplinary nature of these evaluations. It is often considered to be crucial to ensure full alignment with the requirements to avoid costly engineering changes later in the project. VE analysis provides insights into performance metrics and allows the evaluation of a systems behaviour for different scenarios. The latter is becoming more important as AMS are expected to rapidly reconfigure to address changes in customer-needs, such as in the Fast Moving Consumer Goods sector. Also, efficient evaluation can contribute to identifying innovative concepts and de-risking less-conventional designs. The following challenges with VE at the initial stages of system design have, however, been identified: (1) how to deal with unknowns and uncertainty; and (2) how to avoid outdated models, version control of models and data. Initial concepts and designs change frequently and significantly in the early conceptualisation stages, making it a challenge to keep models up to date with the latest concepts and designs, which in turn results in additional time and effort obligations

2 PROPOSED VIRTUAL ENGINEERING METHODOLOGY

A five-step VE methodology to handle the two aforementioned challenges is proposed:

- STEP 1: Approximate the analyses objective and scope, assessing which system design aspects require VE support and where most impact can be delivered. During this, reviewing lessons learnt from previous projects is highly recommended.

- STEP 2: Identify and map models to the analyses objectives and scope. For each model, it is necessary to decide how to develop these in order to analyse different candidate solutions along the timeline for the design changes and updates to support decision making. Three different approaches can be used for this: (1) develop a model iteratively, continuously reconfigure and update the model as the concepts and designs are refined; (2) develop the model as sprints when analysis is required; (3) implement a batch of modifications at waypoints. The choice of approach should consider when the model will be out of date and the effort required to update the model. It is important to note that for all approaches, following a systematic approach for requirement and data capture will expedite analyses delivery.
- STEP 3: As analyses are performed in the initial stages of the system design, there is typically uncertainty around the system to be modelled. Therefore, it is necessary to handle this uncertainty in an explicit way to generate meaningful results. To do this, the following can be used: (1) simplifications; (2) additional assumptions; (3) relative analysis. Whilst the first way is to simplify the model to exclude the unknown / uncertain elements, including additional assumptions are useful when considering best- or worst-case scenarios. The third option, relative analysis, gains insights into emergent system behaviour.
- STEP 4: Deliver the VE analysis using the developed models. It is suggested to store results, input data, assumptions, and the model with the analysis to keep a complete configured record to be able to revisit the analysis at a later point in time.
- STEP 5: Maintaining and updating the model; it is important to adhere to one of the above approaches for implementing future updates to the model, as it is ineffective (in long term) to change and mix multiple approaches.

3 COMMERCIAL CASE STUDIES

A first commercial case study looks at an AMS for shampoo production system that includes dosing, mixing, bottle filling, labelling and packing operations. The key requirement was rapid re-configurability so as to allow changing between product variants as a responds to market trends. The consequence of this was to balance the trade-offs between flexibility, cost and productivity. The VE method included discrete event simulations (DES) and cost benefit analyses (CBA), which were continuously updated with new functionality and datasets during design iterations. The insights into guiding equipment selection were gained from identifying feasible time-budgets for production versus changeover, and also highlighted the (pre)mixing processes to be the bottlenecks during both production and changeover. Through VE, the design team was able to analyse the system's productivity with different mixing process technologies as well as changeover strategies, considering the respective costs for both. These VE explorations suggested switching from inline to offline ingredient premixing to improve the productivity (>37%) to avoid delays in the pre-mixing stage, with only small cost for increased effluent waste (<5%). Note, that being able to identify the optimal concept (i.e. offline instead of inline) during early design phases is also highly valuable from an engineering point of view.

A second commercial case study looks at the development of an AMS for packing pharmaceutical tablets. The key innovation was reducing the amount of work-in-progress (WIP) that is scrapped during changeovers. The VE method included thermal modelling (physics-based heat transfer analyses), DES and CBA, where: the thermal modelling estimated part temperature during the different processes within the system; DES estimated the throughput, the work-in-progress, and changeover time; CBA compared the value of different designs against a baseline. Through initial relative analyses, the relationship between WIP, productivity and temperature was characterised, which showed that active cooling can be avoided for certain product types. These insights led to an innovative adaptive system design to deploy active cooling only when / where necessary, and thereby increasing productivity (>2%) and reducing scrap rates (>15%). Further exploration through VE showed an increased productivity can be realised (>10%) if a system reconfigures with WIP in place, i.e. without having to empty the line, resulting in a relatively low cost increment for more complex changeover automation.