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A non-queue-based paradigm in Discrete-Event-Simulation modelling for construction operations

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ABSTRACT

Discrete-Event Simulation (DES) is an event-driven simulation approach in which a real dynamic process is imitated as it progresses over time. It has been recognized as a powerful technique for the quantitative analysis of complex construction operations. However, current DES modelling strategies/frameworks implicitly rely on queuing structures which are too rigid to easily describe systems with complex behaviour common in construction, e.g., multi-tasking resources and/or role changes of entities. Queuing networks are one of the most common elements of DES systems and have been used to model a wide range of problems, but they lack the generality to easily model the complex decision mechanisms required to, e.g., efficiently multi-task or dynamically determine the best role for an entity. This research proposes a new modelling approach for construction that replaces Queue-Based (QB) DES, with its implicit queuing network control, with Non-Queue-Based (NQB) DES that explicitly defines the decision mechanisms of a model. It utilises a new conceptual modelling paradigm for simulation, Hierarchical Control Conceptual Modelling, which was developed to address similar issues with control mechanisms in health care simulation. This new approach is especially beneficial for the construction industry where determining effective decision making mechanisms is of significant importance for optimising, e.g., logistics and resource utilisation. This research investigates the benefits of the proposed approach for DES models in construction by investigating three earthmoving case studies. Although the scope of this research is limited to DES modelling in construction, the outcomes of the proposed NQB paradigm in construction translate to other domains that utilise DES for solving complex problems.

1. Introduction

Traditional management in construction is dominated by decision mechanisms that are based on the intuition and experience of construction engineers and project decision makers [16]. Prevalent decision mechanisms tend to predict con-

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struction operations performance using deterministic and linear functions, so they ignore the dynamism and uncertainty found in production processes [7]. This leads to weak planning, poor performance, delays and other drawbacks [6,17,27,53]. In fact, traditional decision making mechanisms stifle construction productivity so that the construction industry lags far behind other industries (such as manufacturing) when it comes to applying analytics to make decisions [53]. Transforming the construction industry into a more productive and competitive industry requires new decision making mechanisms that are supported by advanced management technologies. In this regard, DES has proved to be a valuable analytical technology [2,21,55]. In a DES model, the operation of a real system is represented as a sequence of discrete events that occur over a period of time. Each event occurs at a particular instant in time and marks a change of state in the system. The early developments in DES were largely founded on the manufacturing industry [66]. DES has since been implemented in other industries including (but not limited to) chemical, food, health care and construction [3,9,13,14,26,65]. However, its adoption by the construction industry has only been partially successful and mostly limited to the academic community [1,2]. In the next section, one of the main problems that prevents the widespread use of DES in construction is discussed. The objective of the research is explained thereafter in Section 3. This is followed by a literature review (Section 4), the research methodology (Section 5) and three working examples as case studies (Sections 6, 7 and 8) that clarify the significance of this research.

2. Problem statement

One of the main reasons for the prevention of widespread use of DES in construction is that modelling strategies have been adopted from manufacturing, where early developments in DES originated [58,66]. Most manufacturing operations follow a queuing network of activities so that processes can be simulated as queues and analysed in terms of: the source of queued items; how frequently items arrive; how long they wait; whether an item should jump ahead; how multiple queues might be formed/managed; and the rules by which items are enqueued/dequeued [54]. We call this Queue-Based (QB) control. However, construction operations have a different dynamic and higher level of complexity in terms of resources that perform multiple tasks and components that change roles (e.g., from an entity to a resource and back again). Representing such construction operations with a queuing network structure requires either a significant degree of simplification or non-standard queuing structures being embedded within the queuing network. Construction operations include interdependent components that are subject to activity start-up conditions and produce unpredictable outcomes [2]. For example, in the traditional DES sense, the dynamic roles of multi-tasking construction machinery/labourers require both machines and labourers to switch between acting as entities (that are being served) and resources (that serve) as they perform different tasks. This dynamic behaviour may significantly change the sequence of activities/processes/events for entity movements and so, cannot be modelled easily by queues. Representing operations which do not naturally fit into a queuing network structure results in modelling workarounds. For instance, if a machine which is acting as a resource needs refuelling, that resource can be ‘failed’ and a new ‘clone’ for that entity created. In such a case, the cloned machine entity moves to the fuel depot and queues until it is refuelled. The entity returns to its original working area at which point the entity leaves the model and the resource is restored back to ‘working’. In this example we could model the refuelling as a simple stochastic delay, but this would not accurately account for any queuing behaviour when two machines need refuelling over the same period. Thus, modelling complex construction scenarios in which entities can engage in activities in an unanticipated sequence (such as scenarios that can occur when optimising activities in real time) and dynamically change roles (such as in the previous refuelling example) requires more general, Non-Queue-Based (NQB) control. Since queuing networks are ubiquitous in DES conceptual modelling (hence QB control is also, implicitly, ubiquitous), we utilise a very recent conceptual modelling framework, Hierarchical Control Conceptual Modelling – HCCM [13], that replaces implicit queuing networks with an explicit non-queuing control structure. NQB DES not only provides a straightforward approach for modelling and, hence, evaluating decision making (due to the explicit modelling of the decision making), but also results in: (1) simplicity (defined in this research as a reduced number of modelling components), (2) generalization (defined in this research as the ability to use some or all of the model for operations of a similar nature) and (3) flexibility (defined in this research as the ease with which changes to the decision mechanisms can occur). These definitions are derived from research conducted by Abourizk [1], and Martinez and Ioannou [42]. Based on their perspective, simplicity is embodied by simulation strategies that shorten the model development process; generality is measured via application breadth (e.g., is the modelling approach general or tailored for a special purpose); and flexibility is synonymous with programmability (which admits succinct, detailed representation of resource interactions, activity relationships, and decision logic). In this paper we investigate how the choice of QB or NQB modelling approaches affects the simplicity, generality, and/or flexibility of the modelling process. We particularly focus on the flexibility of these two modelling approaches when evaluating the decision making mechanisms, e.g., how easy is it to move from a Decentralised Decision Making (DDM) mechanism to a Centralised Decision Making (CDM) mechanism. This key focal point is in recognition of the need for improved decision making in construction operations (as discussed in Section 1). Our case studies (see Sections 6–8) demonstrate that QB control can suitably model DDM mechanisms; but when moving to CDM mechanisms significant workarounds are required (e.g., there is poor flexibility) and simplicity and generality are also compromised. These workarounds essentially replace the individual QB control mechanisms with a NQB control mechanism. This critical observation gives rise to the question ‘is the implicit reliance on queuing networks in DES modelling appropriate for evaluating different control/decision mechanisms in construction simulation