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Micro-motion level simulation for efficiency analysis and duration estimation of manual operations

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ABSTRACT

Due to the labour-intensiveness of the construction industry, accurate estimation of cycle time of manual activities is essential for reliable planning and scheduling of operations. Labour productivity study is used in current practice to obtain the required cycle time of manual tasks. However, the reliability of labour productivity study in estimating durations of manual activities is inhibited by its dependence on various factors which change with the different working conditions of construction jobsites and the difficulties associated with measuring productivity. This study thus investigates the use of a predetermined motion time system (PMTS) for modelling manual construction operations for cycle time estimation and efficiency evaluation. A motion-level simulation approach is developed by integrating PMTS into discrete-event simulation (DES) modelling, providing an automated and simple-to-use method of analysing manual tasks. As a case study, manual construction operations from a construction jobsite with different levels of repetitiveness are modelled, and the actual and simulated cycle times are compared and analysed. The results confirm the effectiveness of a PMTS-based simulation approach to modelling manual construction operations and its reliability in estimating the duration of manual tasks.

1. Introduction

Considering the labour-intensive nature of construction activities, the efficiency of the manual tasks carried out by workers has a significant impact on the success of projects [1]. Previous research has also shown that labour can account for more than half of the total cost of a project [2], and owners and contractors lose billions of dollars every year as a result of inefficiencies related to the deployment of labour resources [3]. Given that labour is considered to have the highest risk among the main project cost components of construction operations [4], accurate estimation of cycle time of manual activities is essential for reliable planning and scheduling of processes [5]. Furthermore, in the case of ongoing operations, reliable evaluation of the efficiency of the involved manual tasks is important in assessing and potentially improving productivity.

In current practice, labour productivity is commonly used in the construction industry in order to obtain the required cycle time of manual tasks for production planning and operational design. However, labour productivity may not always provide a precise estimation of duration of manual activities, as it depends on various factors that change based on the given working conditions [6–8]. Since there is no common productivity measurement standard due to the difficulties associated with quantifying it [9], productivity rates of the same activity are measured by different people using different methods, which results in incomparable values as well as in difficulty in defining and estimating productivity [10]. Furthermore, in the case of assessing the efficiency of ongoing manual operations, labour productivity cannot be reliably used as a benchmark for evaluation, since it merely represents an average figure and does not reflect the physical attributes of the manual tasks and the working environment. Due to the abovementioned reasons, using labour productivity for obtaining the duration of manual tasks might not result in accurate and reliable cycle time estimation and efficiency analysis. On the other hand, predetermined motion time systems (PMTSs) have been developed to provide a standard duration for manual activities by characterizing the working method in which a task is carried out. Thus, this study investigates the use of PMTS for estimating duration of non-existing manual construction tasks as well as for evaluating the efficiency of ongoing manual operations.

In order to investigate the effectiveness of a PMTS-based approach to estimating cycle time of manual construction activities, this study uses a motion-level simulation approach that integrates PMTS into discrete-event simulation (DES) modelling. By doing so, various manual activities can be modelled with minimal time and effort and with higher

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Table 1
MODAPTS code and duration for a sample task.

Action	Attribute	MODAPTS motion	MODAPTS code
Move hand to reach a concrete block	Hand is moved 30 cm	Move	M4
Grasp the concrete block	Grasp requires visual feedback	Get	G3
Walk while holding the block	Distance is 2 steps	Walk	W10
Put concrete block on table	Put requires visual feedback	Put	P2
Handle block	Block weighs 5 kg	Load	L1
		MODAPTS code:	M4G3W10P2L1
		Total MODs:	20
		Total duration:	$20 * 0.129 = 2.58$ s

reliability compared to manual analysis. After developing the motion-level simulation platform, this approach is implemented to model manual operations from an actual construction jobsite, in order to study the suitability of the proposed approach in modelling construction tasks for cycle time estimation and efficiency evaluation. Manual tasks with different degrees of repetitiveness are selected to examine the reliability of this approach for different types of construction activities.

2. Related work

This section reviews the challenges inherent in estimating the cycle time of manual activities using labour productivity in order to evaluate its reliability and effectiveness and investigate the potential need for a more accurate and efficient approach. The techniques currently used in the construction industry for evaluating duration of manual tasks are also introduced. Issues related to measuring labour productivity and using it for estimation of activity durations, as well as the effectiveness of traditional estimation approaches, are discussed as informed by the existing literature on the subject.

2.1. Challenges in activity duration estimation by labour productivity

In estimating the duration of activities, productivity performance from ongoing or past projects is a key input commonly used in practice, allowing for predicting the amount of resources (e.g., man-hours) needed to complete a given task [11]. This relationship can be intuitively explained using Eq. (1), which expresses the most common and widely accepted definition of labour productivity in construction [12,13].

$$\text{Labour Productivity} = \frac{\text{Total Output}}{\text{Total Man-hours}} \quad (1)$$

In this equation, the total man-hours can be calculated simply when total output (e.g., amount of work) and labour productivity are known, and thus the activity durations can be estimated by determining the number of labourers to input. In practice, however, accurate measurement and estimation of labour productivity is not easily achieved, since the efficiency of manual tasks performed by labourers is affected by various factors. For instance, Hwang and Soh [14] introduced the common challenges of measuring productivity in the construction industry and categorized them as industry-related challenges, firm-related challenges, and trade-related challenges. Some of the challenges include the absence of standard productivity measurement method, lack of clear definition of productivity, difficulty in obtaining accurate benchmarks for productivity comparisons, low reliability of data recorded, and difficulty in measuring work hours. Previous studies have also attempted to identify the different productivity-influencing factors. For example, Dai et al. [6] examined 83 factors affecting productivity and found that those involving tools and consumables, material, engineering drawing management, and construction equipment are the factors which contribute most to productivity, based on craft workers' perception of productivity. Jarkas and Bitar [15] identified 45 factors, including clarity of technical specifications, labour supervision, design complexity, and construction manager's leadership. Kheirieh and Heravi [16] sorted various factors into four main categories (i.e., external, management, human, and technical), and concluded that weather,

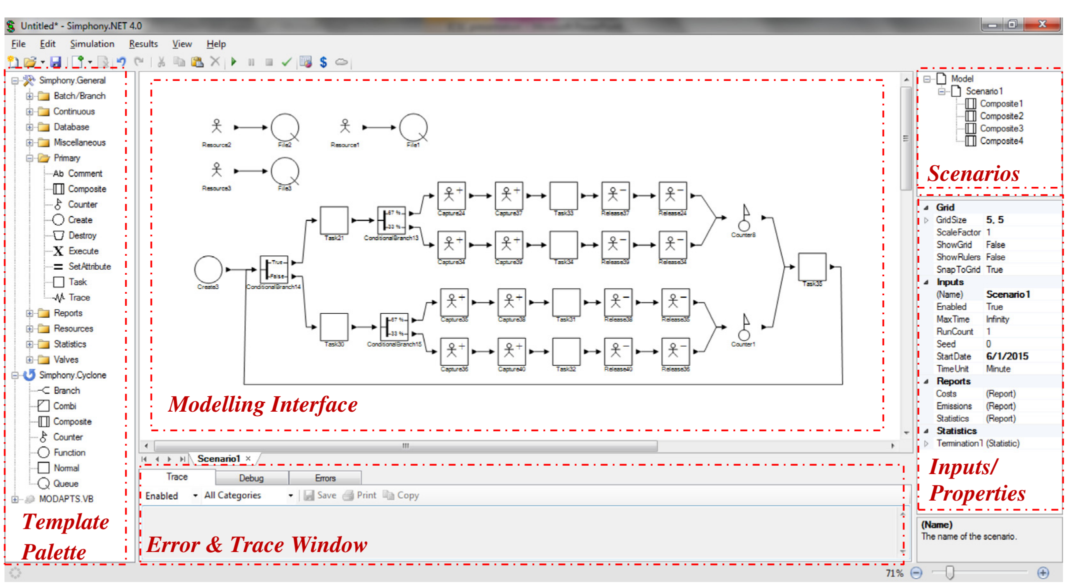

Fig. 1. Simphony's user interface.

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