A Microscopic Simulation Model for Earthmoving Operations

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Heavy construction is one of the largest industries in the world. Examples of common heavy construction include highway and road construction, mining, etc. Construction in general is a complex industry and heavy construction projects in particular are comparatively larger in scope. Earthmoving is an important part of major construction projects involving especially designed heavy equipment with significant purchasing/leasing prices and high operating and maintenance costs. Apart from the high purchasing/leasing and operating cost of equipment, the cost of manpower is also of considerable amount due to reasons like rough working conditions, the training process of the equipment operators, etc.

The prime function of construction management is to plan, procure, organize and control the activities of the plant and equipment resources [1]. It is often challenged in making "the right decisions" on both strategic and tactical levels before and throughout a project. Strategic decisions include what equipment to purchase or lease and the quantity of equipment so that the project will be completed within the targeted timetable and budget. At the strategic planning stage, the long-term decisions are made with the entire project as the target; while at the tactical level, management focuses on short-term operating issues and resolution of issues that come up due to the uncertainty of the operating environment.

Thus, both strategic and tactical productivity estimations are indispensable for planning and operating purposes. Nevertheless, there are number of difficulties to overcome due to the uniqueness of construction operations: (1) complex system where many resources collaborate to carry out tasks; (2) operations are frequently impacted by uncertainties; (3) ever-changing environment at construction site. It is therefore important to use methods for total cost estimation at different levels of details and appropriate for the targeted applications. The concept of "Total Cost of Ownership (TCO)" is frequently used in construction business. A TCO analysis includes total cost of acquisition, the operating cost and productivity of a project, and gives the management a clear picture of the profitability over time.

Simulation is a widely used tool in operation research and system analysis [2]. The popularity of simulation is its ability to model complex systems with realistic representations of interactions among their various components taken into account the important uncertainties in the operating environment. Discrete-event simulation has been used for modeling cyclic processes and used for quantitative analysis of complex construction operations. In the past three decades, several simulation systems have been developed specially for modeling construction operations. In the early 1970s Halpin [3] introduced the CYClic Operations NEtwork (CYCLONE) modeling methodology which modified the conventional Activity Cycle Diagram (ACD) to signify various activities that take place in construction operations. A further development was the creation of the software tool MicroCYCLONE [4] in 1980s. Many improvements have been made after MicroCYCLONE. Martinez extended CYCLONE and created an advanced graphical simulation software State- and ResOurce-Based Simulation of COstruction ProcEsses (STROBOSCOPE) [5] and EZStrobe [6]. SIMPHONY [7] is another example of a successful simulation tool that provided more flexible user interfaces and facilitated more complex model development. These tools have been applied on project-level simulations such as productivity measurement, resource planning [8], design and analysis of construction methods [9] and site planning [10].

However, the above-mentioned simulation systems are all macroscopic designed for productivity analysis at the strategic level. They are a number of limitations, especially for uses related to productivity estimation at the operational level. Examples of limitations include:

- Durations of activities are either deterministic or drawn from stochastic distributions estimated from historical data or field measurements. They are hence not sensible to a fast-changing construction environment or simply not available for new operating conditions. In reality, it might be impossible to collect data due to reasons such as the uniqueness of a project, regulations or lack of time or personnel for data collection.
- Fuel costs have become a substantial part of operating costs in recent years due to the scarcity of fossil resources and to stricter environmental policies, but this respect was never taken into account by the previous works. A good estimation of fuel consumption will improve the estimation of productivity and total cost of ownership.
- The fleet at construction sites often consists of vehicles of different types and models with various capacities which result in different duration and fuel consumption for carrying out an activity, but most of the existing simulation programs do not characterize certain features such as the model of a piece of construction equipment.

In this paper, a microscopic discrete-event simulation system is proposed for modeling construction operations and conducting productivity estimations on an operational level in terms of TCO. Earthmoving operations are selected as the specific application area since it is the most fundamental operation in construction. The logistics of the physical earthmoving system are represented using the CYCLONE modeling elements. Discrete-event simulation techniques used to capture the interaction between the resources and the randomness of each of the activities. Figure 1 illustrates the framework of the proposed simulation model.

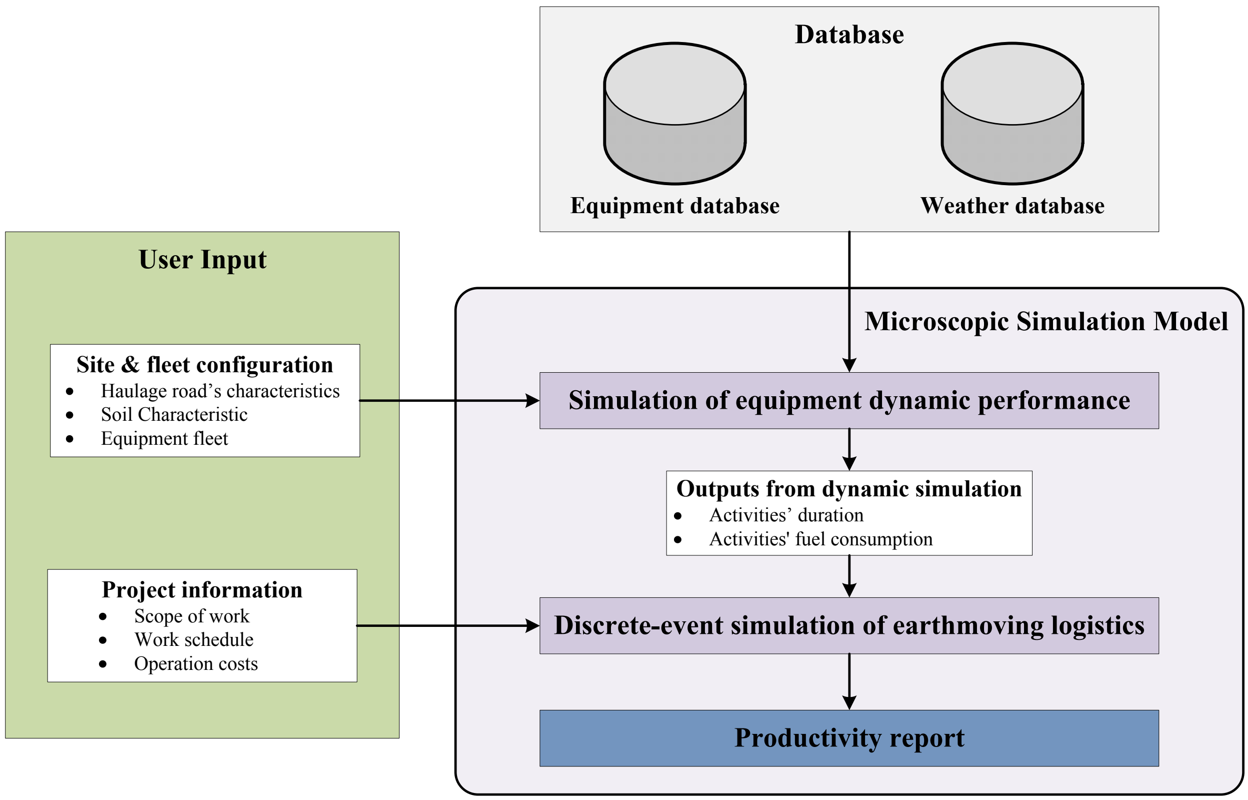

Figure 1 Framework of the microscopic simulation model

Compared to previous works, this microscopic model represents individual equipment at a very detailed level and comprehensive vehicle dynamics are employed to obtain the duration and fuel consumption of each activity. The included comprehensive models of vehicle dynamics incorporate the impact on performance of several factors such as road geometry, payload, weather, and provide accurate estimations of activity duration and fuel consumption. These estimations are then used as the input into the simulation. Subsequently, suitable probability distributions from previous studies of the duration and fuel usage are used to describe the randomness of these two respects. In addition, this simulation module also includes the flexibility to characterize resources.

A prototype has been developed to demonstrate the applicability of the proposed framework. The model is capable of evaluating alternative operating strategies and resource development at a very detailed level. It supports a better understanding of the interactions between resources, and the impact of improvement in the operating characteristics of equipment, operator behavior, etc.

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