Simulation System for Earthmoving Operation with Traffic Flow

Kyoungmin Kim[1] , Kyong Ju Kim[2], Hyeon Jeong Cho[3], and Sang Kyu Lee[3]

[1.]PhD, Dept. of Civil & Environmental Engineering, Chung-Ang University, Seoul

[2.]Associate Professor, Dept. of Civil & Environmental Engineering, Chung-Ang University, Seoul

[3.]Graduate Student, Dept. of Civil & Environmental Engineering, Chung-Ang University, Seoul

Correspond to kjkim@cau.ac.kr

ABSTRACT: The object of this research is to develop a simulation system for earthmoving operations in consideration of the impact of congestion in-between equipment and existing traffic flow around the site. The congestion in-between equipment and traffic flow affect work productivity. The conventional discrete event simulation, however, has limitations in simulating the flow of construction equipment. To consider the impact of congestion in-between equipment and existing traffic flow, in this paper, a multi-agent based simulation model that can realize characteristics of truck behavior more accurately to consider the impact of congestion was proposed. In this simulation model, multiple agents can identify environmental changes and adapt themselves to the new environment. This modeling approach is a better choice for this problem since it describes behavioral characteristics of each agent by sensing changes in dynamic surroundings. This study suggests a detailed system design of the multi-agent based simulation system.

CE Database subject headings: Multi-agent-based simulation, Discrete event simulation, Simulation modeling approach, Traffic flow, Earthmoving operation

1. INTRODUCTION

This study aims to develop a multi-agent-based simulation system for planning and scheduling construction operations with traffic congestion. The conventional discrete event modeling simulation method cannot be used to implement this system because it has several limitations. Further, it is also known that traffic congestion adversely affects work efficiency and productivity. Therefore, to effectively simulate the behavior of construction equipment under traffic congestion, a new modeling approach that can describe continuous behaviors such as traffic flow is required. This study proposes a multi-agent-based simulation system for modeling a construction process. Large-scale construction projects such as those launched for the development of harbors and industry complex require many construction vehicles and machines. Therefore, Congestion and poor coordination of tasks during such a project could affect the efficiency of the overall operation. Furthermore, an increase in the number of construction vehicles can cause congestion around construction sites. In other words, the simultaneous use of many vehicles at a construction site could lead to traffic congestion and, in turn, decrease productivity. Because construction operations can be simulated and analyzed under various conditions by using a computer, a simulation system can be used to predict possible problems in advance and develop a cost-effective and quick construction process. The conventional discrete event modeling approach, however, has a limitation in simulating the impact of traffic congestion. Because this approach focuses on changes in the state of a system, it mainly describes (models) the relationships among events that occur due to an interaction between different parts of construction equipment. Continuous behaviors such as traffic flow are influenced by continual changes in both the vehicle speed and distance between vehicles. Therefore, the correlation and the model become substantially complicated. The scope of the conventional approach is limited to the simulation of the behavioral changes of each vehicle on an individual basis. The precise simulation of the behavior of construction vehicles by considering traffic congestion requires a new methodology for agent-based simulation modeling and a system that can describe continuous behaviors such as traffic flow and reflect the impact of other factors. To consider the traffic flow around a construction site and the congestion of construction vehicles, this study has developed a multi-agent-based simulation system for construction operations, and applied it to simulate earthmoving operations. The results of this study could be used by working-level construction engineers to assess the impact of traffic congestion during process planning. In addition, the results will also highlight the usefulness of multi-agent-based modeling for simulating construction operations.

2. MULTI-AGENT BASED SIMULATION MODELING FOR CONSTRUCTION OPERAT -IONS

A multi-agent-based simulation differs from other simulation approaches in that it is modeled and executed by an agent. Because the multi-agent-based simulation directly models individual objects, it is very different from macro simulation that is described using a mathematical model on the basis of common characteristics of the system. Parunak, Savit, and Riolo (1998) point out that a numerical model is useful in a central modeling system because it is governed by physical laws rather than data processing, while an agent-based model is effective in areas that are governed by discontinuous decision-making and specialized by distribution.

The agent modeling process consists of sampling, definition of attributes, domain knowledge setup, stipulation of behavioral characteristics, inter-agent relationship setup, and agent communication. Agents can be sampled after selecting targets for them and after setting their goal and role.

The agent class is organized after setting the basic characteristics and self-information of a sampled agent and classifying them according to attributes. The agent domain knowledge is defined by assigning knowledge, information, and resources that are necessary to fulfill tasks and setting action plans and roles for the agent so that it can perform the tasks in accordance with a specific goal. In the case of a truck agent that performs the hauling operations, for example, the basic characteristics of a transport vehicle are assigned to it and related attributes such as capacity, speed, and moving route are defined. Besides, major actions in which state change occurs (e.g., loading operation performed by a loader, job standby rules, unloading operation, awareness of traffic rules, left and right turns, and interaction with traffic flow) are set and information and resources that are necessary to fulfill tasks are assigned.

The behavioral characteristics of the agent stipulate action rules by state change and a plan that can modify the action to respond to the external environmental change in a suitable manner. Besides, defining the behavioral characteristics of agents implies that the agent stipulates intelligent behaviors such as responsiveness and preliminary behavior. Action rules are as follows. When the truck agent arrives at a loading site, it checks if there is no any truck waiting for loading and loader available, and then, the loading operation to the truck is performed by a loader. If the truck agent is operated on the road, its impact on traffic flow should be considered. Therefore, the complexity of the behavioral characteristics increases. In fact, it is not possible to program all agent actions under various conditions that could prevail on the road (e.g., moving from a construction site road to a general road, speed change and lane change, and awareness of traffic rules by means of traffic signal). Therefore, it is effective to set action rules under particular conditions in advance and make an agent respond to the change suitably. For example, in order to define the speed change of the truck and other vehicles on the road, acceleration and deceleration rules are set in advance on the basis of inter-vehicle space. Then, an agent sets the speed by calculating the distance between the truck and the front vehicle.

To describe the movement of individual vehicles and inter-vehicle interaction clearly, a microscopic traffic simulation model is required. To simulate the speed change caused by changes in inter-vehicle distances and the behavioral characteristics of lane change, this study has implemented a car-following model known as the IDM (intelligent driver model) (Treiber, Hennecke, and Helbing, 2007) and a lane change model known as MOBIL (minimizing overall braking decelerations induced by lane changes) (Treiber and Helbing, 2002). The IDM represents the movement of individual vehicles by describing traffic conditions using the position, speed, and lane index of all vehicles. The acceleration or deceleration of a vehicle depends on its distance from the vehicle in front of it, speed of the vehicle, and speed of the front vehicle.

The decision to change lanes is made on the basis of inter-vehicle distance. Therefore, to simulate a decision-making process for changing lanes, many variables should be considered. In this study, the lane change model, MOBIL, proposed by Treiber and Helbing (2002) is adopted to simulate lane changes. In the case of MOBIL, a lane change occurs when incentive criterion and safety criteria are satisfied on the basis of accelerations on the current and new lanes, which are calculated using the IDM.

3. DESIGN OF MULTI-AGENT-BASED SIMULATION SYSTEM

As shown in <Fig. 1>, the simulation system consists of the “main module” and “processing module.” The former receives data from a user and sends them to the latter. After performing and controlling the simulation, the main module sends the result to the user. The processing module is a logical component in which the actual simulation is performed. It estimates the distance between car agents, speed change, and work hours.

As the UI (user interface) for simulation, “SimConUI” receives input data from a user, displays the results of the simulation, and illustrates the state of each agent. As a part that executes a program and receives input data from a user, “SimApp” presents an environment for actual simulation and connects simulation logic with the UI. “SimConBB (Blackboard),” which has the actual simulation logic, performs the actual simulation depending on the user-defined value from “SimApp” and sends the result to the UI. In addition, SimConBB functions as a data bus that sends and receives data and as a data storage device that stores all simulation data. It checks environmental changes after each agent performs the simulation and supports the determination of the behavioral characteristics.

“Lane” class contains general vehicles and the truck agent, creates as many agents as the number of lanes, calculates the distance between agents in the lane, and controls the agents. “State update” updates the agent state by considering the speed change, lane change, and work state. “Agent” assigns basic attributes to actual agents such as “Truck agent,” “Car agent,” and “Loader agent,” and connects the “Moveable” module to each agent.

The Moveable module, which handles “DriveModel,” consists of the following components:

- LaneChangeModel: A class used for lane change by a car or truck
- RampModel: A model used when a truck enters the general road from the construction site road. When a car enters the general road using LaneChangeModel, priority is given.
- DriveModel: A car-following model class that calculates the speed of cars and trucks

Agent information is stored in Blackboard (SimConBB) through agent initialization and creation after basic system information is entered. Then, simulation is performed depending on the total amount of remaining work. Blackboard is a data storage space in which data exchange occurs between agents. Agents update their actions using the information on the blackboard and reupload the updated data on the blackboard to allow other agents to use it. Once the simulation is begun, the agents are lined up along the moving section by the lane agent and the position information of each agent is analyzed. Then, the information is stored in Blackboard. Using its own position information, each agent selects an operation (dumping, loading, or moving). The agents on the general road decide their own moving state depending on traffic rules (e.g., traffic signal) and their distance from other vehicles. The simulation continues until all work is completed (common goal of the system) and all agents perform their own work.

4. DEVELOPMENT OF MULTI-AGENT-BASED SIMULATION SYSTEM

<Fig. 5> shows the default display and configuration of simulation system that implemented multi-agent-based simulation perspectives. The display shows earthmoving operations from a loading site to a dumping site. In this simulation system, the action objects such as the truck, loader, and general vehicles are modeled from a multi-agent perspective and the operation is performed through interactions among agents. This prototype system consists of route setup, truck setup, loader setup, traffic light setup, and SIM control.

(1) Route setup: A “Route” implies a path along which resources are delivered from a loading site to a dumping site by a truck. The positions of the loading and dumping sites are also included in the route. The lengths of the general road, the road that leads to the loading site, and the road that leads to the dumping site can be expressed in meters. The traffic volume on the general road can be expressed as the average traffic per hour (number of vehicles/hr). The routes are created by lane class.

(2) Truck setup: A truck is an agent that transports resources from a loading site to a dumping site along the route. The number of available trucks, speed limit (km/hr) on the general road, speed limit (km/hr) on the construction site road, and truck capacity (m3) can be set. Work hours (s) at the dumping site can also be set.

(3) Loader setup: A loader is used to load resources onto the truck at a loading site. The number of loaders available to the loading site and the bucket capacity (m3) can be set. The loading time per cycle can be expressed in sec/cycle. Loading continues until the maximum truck capacity is achieved. The loading time per truck can be estimated by multiplying the number of operations by the loading time per cycle (sec/cycle).

(4) Traffic light setup: The traffic light sets rules for vehicles on the general road. The traffic rules for car agents are set when a vehicle approaches the general road from the construction site road and vice versa. In the traffic signal setup, the position of traffic light (m) and cycle of signal change (sec) can be set.

(5) SIM Control: By SIM control, the default setup can be established and the system can be switched on and off. The system can be switched off in the middle of a simulation. If all the work is completed, the simulation is automatically terminated. Moreover, the goal of the system can be set after setting the total amount of work. If the work done by an agent is equal to the total amount of work set in the system, the simulation is automatically terminated. “Param Setup”' sets the input parameters of the moving model for car agents on the road.

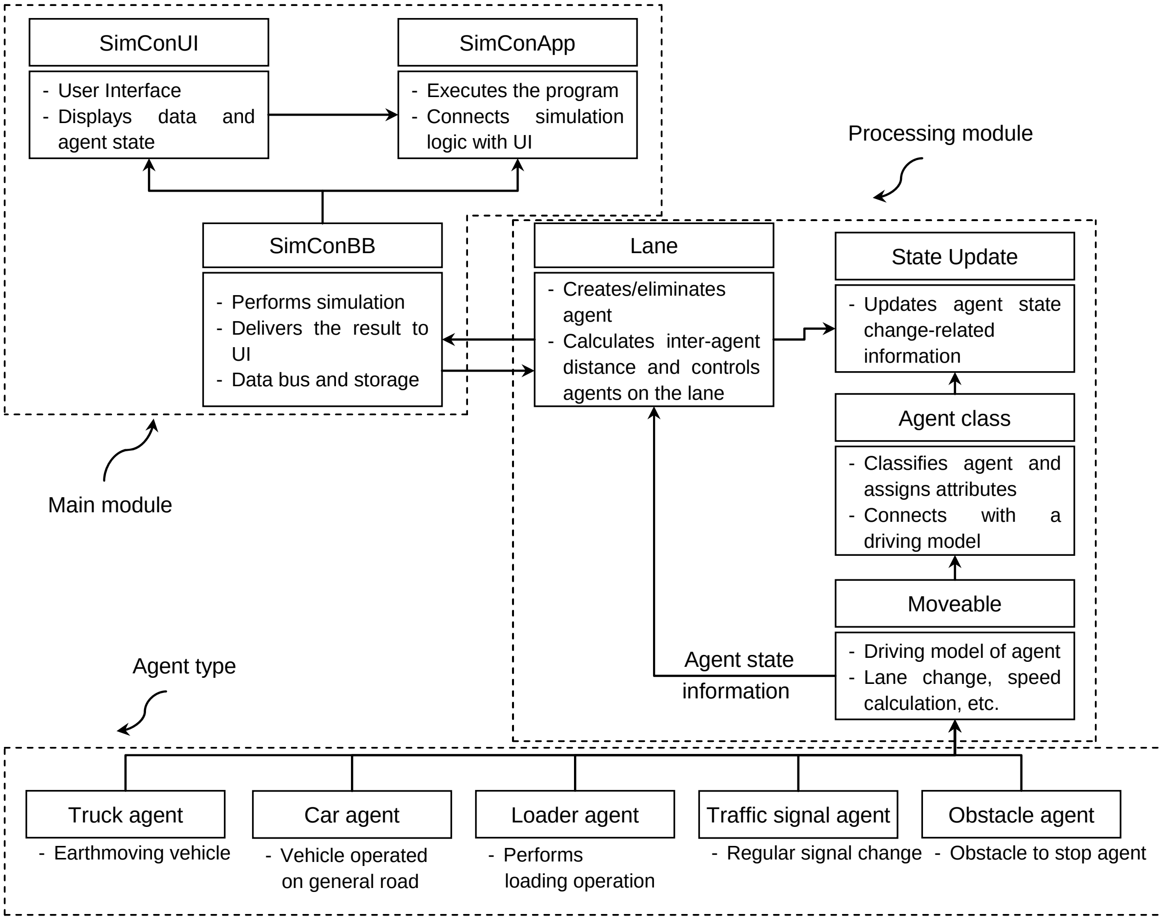

Fig. 1. Configuration of Simulation system

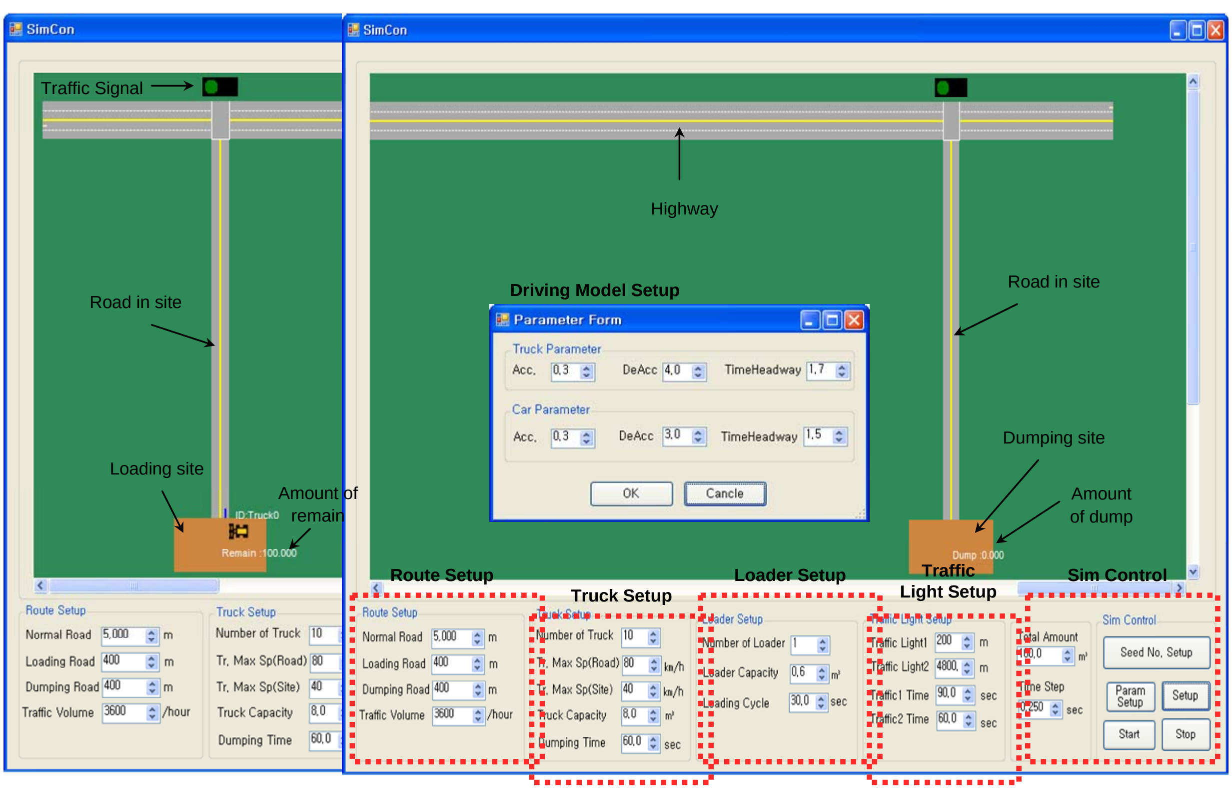

Fig. 2. Simulation system screenshot

5. CONCLUSION

The major objective of this research has been to establish a new simulation modeling approach and develop a simulation system for construction operations in consideration of the impact of congestion in-between equipment and existing traffic flow around the site. The congestion in-between equipment and The traffic flow affect work productivity. However, it is limited in simulating the impact based on the conventional discrete event simulation modeling approach. Therefore, in this paper, a multi-agent based simulation model that can realize characteristics of truck behavior more accurately to consider the impact of congestion was proposed. After preparing a work scenario on construction process and a detailed system design, the multi-agent based simulation system was developed.

To fully satisfy various project scenarios and to provide more flexibility in modeling, the system module and modeling UI should be expanded. In addition, further research should be conducted on the development of algorithm that can be connected with micro process and macro schedule to set up an efficient construction plan in consideration of efficient use of resources.

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