First International Conference on Construction in the 21st Century (CITC2002)
"Challenges and Opportunities in Management and Technology"
25-26 April, 2002, Miami, Florida, USA

SIMULATE ROAD CONSTRUCTION OPERATIONS USING SIMPLIFIED DISCRETE-EVENT SIMULATION APPROACH (SDESA)

Ming Lu
Assistant Professor, The Hong Kong Polytechnic University, Hong Kong SAR, China

ABSTRACT

Operations simulation models for typical construction systems have been developed as electronic realistic prototypes for engineers to plan productive, efficient and economical field operations ever since the inception of CYCLONE technology. Nonetheless, operations simulation has lagged spreadsheets, databases, scheduling packages, and other types of software in acceptance and implementation in the construction industry because of the complexities and time requirements involved in constructing a model.

The Simplified Discrete-Event Simulation Approach (SDESA) has been proposed as a new attempt to make simulation methods easier for users in construction. Compared with the existing event-based and activity-based approaches, SDESA has significantly streamlined the queuing structures and resources management in simulation. SDESA has been coded into a prototype computer system using Microsoft Access, which is a relational database system with supporting VB macro programs. This paper reports two case studies of applying SDESA on real road construction projects in Hong Kong, namely, a granular base-course construction system featuring both cyclic and linear processes and an asphalt paving construction system with complicated technological/logical constraints. Comparing SDESA against the well-known CYCLONE simulation methodology in two case studies has revealed the simplicity and effectiveness of SDESA in modeling complex construction systems and achieving the preset objectives of such modeling.

KEYWORDS

Operations Simulation, Road Construction, Process Modeling, CYCLONE

1. INTRODUCTION

Construction planning is the most crucial, knowledge-intensive, ill-structured, and challenging phase in the project development cycle due to the complicated, interactive, and dynamic nature of construction processes. The methodology of discrete-event simulation, which concerns "the modeling of a system as it evolves over time by a representation in which the state variables change only at a countable number of points in time" (Law and Kelton, 1982), provides a promising alternative solution to construction planning by predicting the future state of a real construction system following creation of a computer model of the real system based on real life statistics and operations. Ever since the inception of CYCLONE technology (Halpin, 1977), simulation models for typical construction systems have been delivered as electronic realistic prototypes for engineers to experiment on, eventually leading to productive, efficient and economical field operations. Nonetheless, operations simulation has lagged spreadsheets, databases, scheduling packages, and other types of software in acceptance and implementation in the construction industry because of the complexities and time requirements involved in constructing a model (Paulson, 1995; Shi and AbouRizk, 1997). For example, the engineer must be familiar with both the software-specific terminology and modeling schematics (such as CYCLONE) and the construction technology in order to simulate with any degree of accuracy and confidence.

The latest research endeavor on construction simulation has been driven to make simulation methods easier to users. Shi (1999) adapted the activity-based simulation approach to a construction simulation model with one single "activity" element. Hajjar and AbouRizk (2000) developed application frameworks that encapsulate reusable codes as well as common design patterns for a specific class of applications in order to expedite and simplify the development of special-purpose construction simulation tools. AbouRizk and Mather (2000) utilized the modular and hierarchical simulation concepts to simplify the process of building earthmoving construction simulation models through integrating with 3D CAD. As a new attempt Lu (2001) proposed a simplified discrete-event simulation approach (SDESA). Compared with the existing event-based and activity-based approaches, SDESA has significantly streamlined the queuing structures and resources management in simulation by (1) reducing the queuing structures at individual activities into one single dynamic queue of flow entities for the whole simulation model; and (2) distinguishing disposable resource entities from reusable ones and managing all types of resources utilized in the simulation model with a dynamic queue of resource entities (Lu, 2001). A prototype of SDESA has been coded into a computer system using Microsoft Access, which is a relational database system with supporting VB macro programs. This paper reports two case studies of applying SDESA to real road construction projects in Hong Kong. In addition, the SDESA-based models are compared with the CYCLONE-based models for cross-validation and demonstrating the simplicity and usefulness of SDESA in complex construction planning.

2. CASE STUDY: GRANULAR BASECOURSE CONSTRUCTION

A road granular base-course construction system features both cyclic and linear processes. Dump trucks haul the granular materials from a quarry to the site, the capacity of each being 12 m^3. The base course to be constructed is 1 km long in total and is divided into 25 sections, each being 40 meters long, 12 meters wide, and 0.25 meters deep. The basic building block of a SDESA model is the *Activity*. The construction activities along with the time estimates, resource requirements and the technological/logical relationships between activities are listed in Table 1. The SDESA model for the construction system described is illustrated in Fig. 1. Note that the beta distributions for describing the activity duration were fitted based on the three-point time estimates in minutes (minimum, mode, and maximum) in Table 1 using VIBES (AbouRizk et al. 1991). The objective of the case study is to predict the production rate of each activity in the next working day and decide on how many trucks to rent to match the resources owned by the contractor (the first column in Table 2). The total simulation time is set to be 480 minutes (8 hrs). The simulation starts at time zero.

Table 1: Resource Requirements and Duration Estimates for Each Activity

Act. ID	Activity	Flow Entity	Resource Requirements	Duration (Minutes) Estimates (Min. Mode, Max.)	Remarks
1	Load	Truck	A loader	4,5,6	10 Trucks initialized at Load activity at the start of simulation
2	Travel	Truck	None	15, 20, 25	Requiring no resource entities
3	Dump	Truck	A flagman	0.8, 1, 1.2	1 truckload of granular (disposable resource entity) is generated at the end of "Dump"
4	Return	Truck	None	15, 20, 25	Requiring no resource entities
5	Grade	Road section	A grader, ten truckloads of granular	18, 25, 28	25 road sections initialized at start; requires 10 truckloads accumulated on one road section
6	Moist	Road section	A water truck, & a flagman	3.5, 4, 4.5	The flagman is water truck driver
7	Compact	Road section	A roller	20, 25, 30	Base completed on one road section

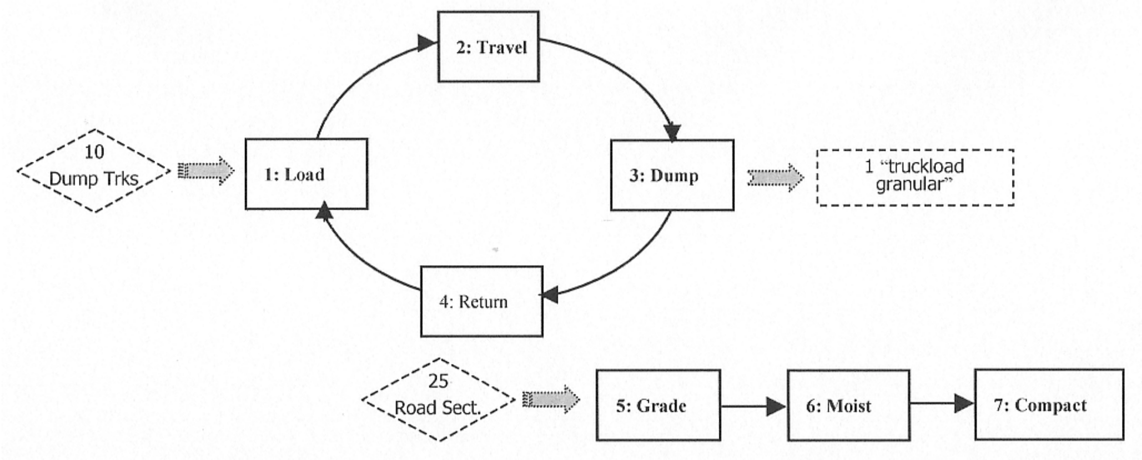


Figure 1: Granular Base Course Construction SDESA Model

Two scenarios are experimented with for comparison using the SDESA model, i.e. Scenario 1 for renting 10 trucks, and Scenario 2 for renting 20 trucks. The simulation results of Scenario 1 reveal that a total of 101 truckloads of granular materials are dumped on site and 9 road sections (i.e. 360 m) of road base-course completed by the end of the day; while under Scenario 2, a total of 180 truckloads have been delivered to site and 16 road sections (i.e. 640 m) are completed in one day. The average waiting time of trucks at the "load" activity has increased from 1.92 minutes in scenario 1 to 6.28 minutes in scenario 2 due to the increased number of trucks. By comparing the utilization rates of the contractor's resources (Table 2), renting 10 more trucks not only dramatically increases the production output, but also nearly doubles the utilization of the contractor's resources. Hence, through simulation experiments, the contractor can decide on an ideal scenario to guide the next-day's operations by weighing the cost of rental trucks against the gain of production output and resource utilization.

Table 2: Utilization Rates of Contractor's Resources

Resource Entity	Utilization (10 rental trucks)	Utilization (20 rental trucks)
(1)	(2)	(3)
Loader 1	54.6%	100%
Loader 2	53.4%	99.9%
Flagman	29.1%	51%
Grader	49.4%	89.8%
Water truck	7.6%	13.5%
Roller	47.4%	84.5%

The counterpart CYCLONE model is also constructed as shown in Fig. 2 and the CYCLONE template of SIMPHOY simulation package (SIMPHONY, 2000) is used to run the two scenarios under identical circumstances. The CYCLONE model has arrived at similar simulation outputs as the SDESA model, both reflecting the actual situation. Based on Case 1, the SDESA model is easier and more straightforward to construct than the CYCLONE one in three respects:

(1) Simplifying queuing structures. The SDESA reduce the queuing nodes for individual activities (as in CYCLONE) into one single dynamic queue of flow entities for the entire simulation model, which is hidden from the user.
(2) Connecting interdependent construction processes. For example, the CYCLONE model requires a CONSOLIDATE function node ("CON 10") after the "Dump" activity to link up the cyclic truck-moving process and the linear road section building process, representing the generation of a truckload of granular materials and the accumulation of 10 truckloads for building one road section. Using SDESA, the user simply specifies that one "truckload granular" is produced as one disposable resource entity at the end of the "Dump" activity, and the "Grade" activity requires 10 such resource entities.
(3) Modeling multitasking resources that are shared by multiple activities. For instance, the spotter who directs trucks to the unloading position at the "Dump" activity also works on the "Moisten" activity as a water truck driver. CYCLONE requires linking one Queue node with two COMBI activities; while SDESA only requires the modeler to specify the spotter as the resource required in both activities when defining the model.

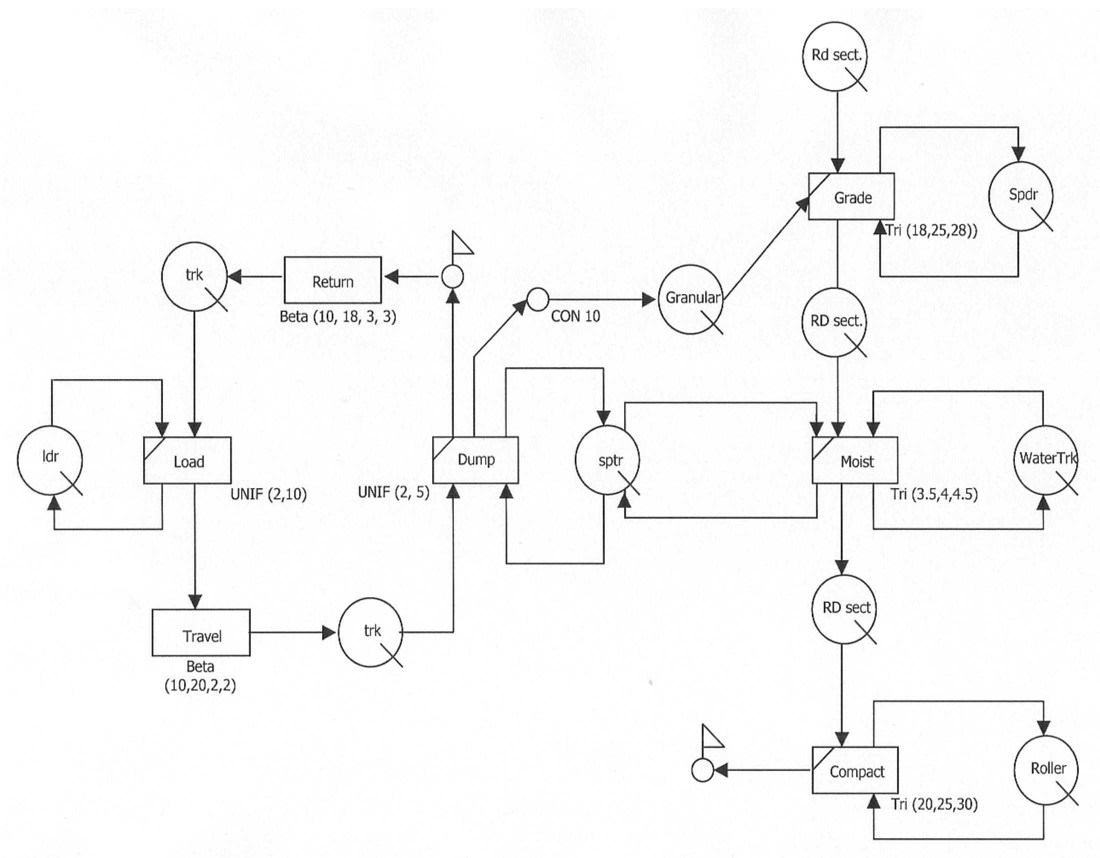


Figure 2: Granular Basecourse Construction CYCLONE Model

Next, a more complicated asphalt paving construction system is examined and modeled with SDESA

3. CASE STUDY: ASPHALT PAVEMENT CONSTRUCTION

The road to be rehabilitated is 250 m long and 5 m wide and is paved in two parallel passes using a 2.5 m wide paver. On this project, trucks, being 15 m^3 each of volume capacity, transport hot asphalt mix from a remote asphalt plant to the site. The hopper capacity of the paver is 3 m^3. Thus, one truckload of asphalt is dumped to the paver in five cycles before departing from the site. A full hopper of asphalt can be used for 4 spreads, each being a 5 m long 2.5 m wide section. Once the paver finishes two spreads a steel wheel roller starts its work, followed by the rubber roller to perform the finish compaction. Additionally, the paver should be repositioned and cleaned once 10 spreads (i.e. every 50 m) have been completed. The process is illustrated using photos in Table 3. Asphalt truck arrival times are sensitive in paving operations. Early truck arrivals will lead to trucks waiting on the site, possibly causing the asphalt temperature to drop below the minimum requirement for paving (normally around 135 degrees Celsius). On the other hand, site-paving operations may be interrupted due to late asphalt truck delivery. Hence, the objective of the simulation modeling is to predict the arrival times of asphalt trucks.

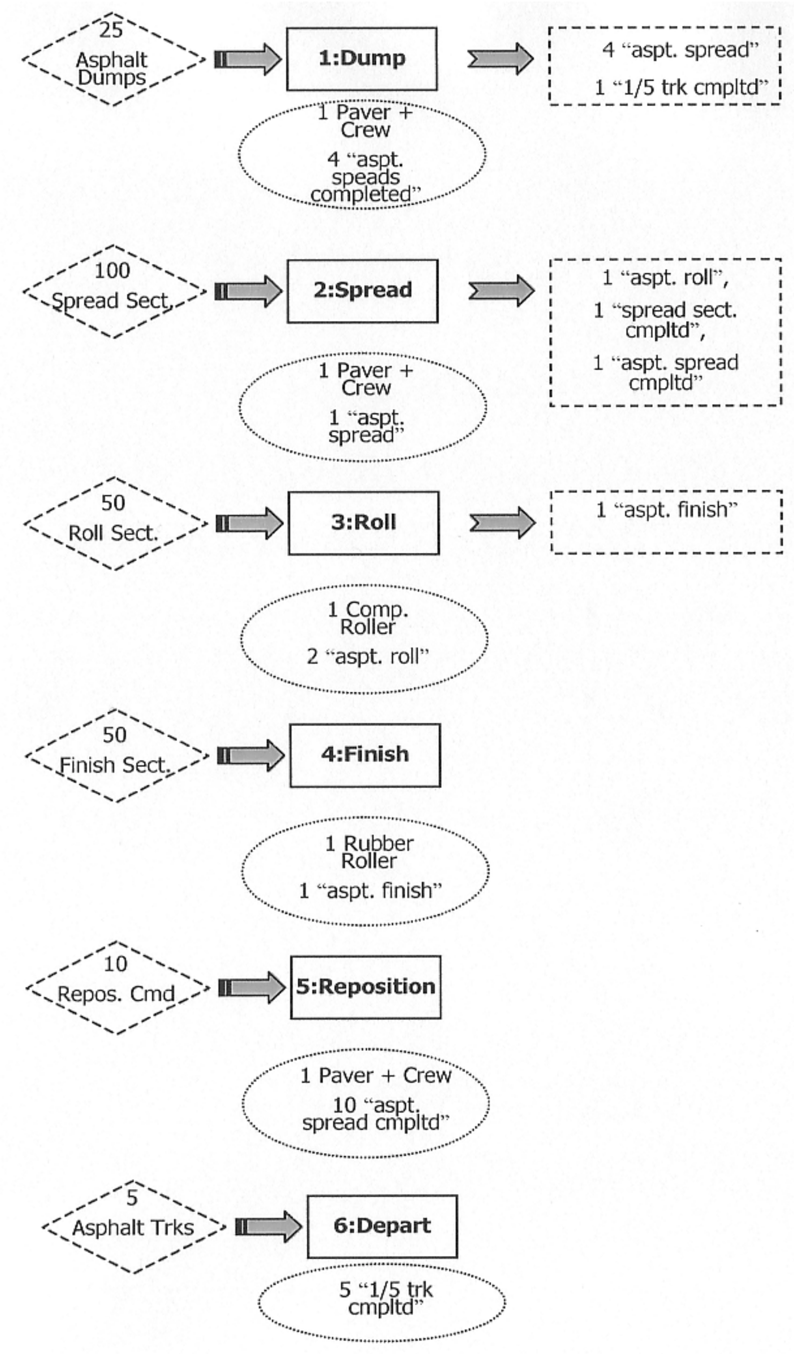
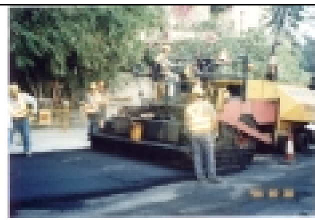
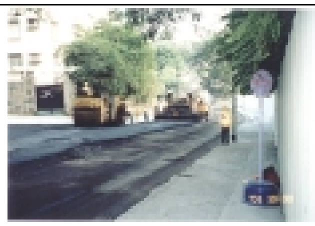


Figure 3: Asphalt Paving Operations SDESA Model

Table 3: Paving Process Description

Sequence	Photo Illustration	*Description*
1		The truck dumps 1/5 of asphalt into the hopper of the paver.
2		Paver moves forward slowly and spreads out the asphalt mix carried.
3		The steel drum roller keeps idle until the spread distance up to about 10m.
4		The steel drum roller compacts the distributed asphalt.
5		The four-wheels rubber roller follows the steel drum roller and compacts the road path.
6		The truck departs the site and the paver is repositioned to a new location for further paving.

The SDESA model for the paving operations has 6 activities as given in Fig. 3 and the activity times as observed from the site are summarized in Table 4. In Fig. 3, the flow entities entering each activity are highlighted in dashed diamonds. The resource requirements and the disposable resource entities generated by each activity are shown in dashed ovals and the dashed rectangles respectively (Fig.3).

Table 4: Activity Times Recorded On Site

Act. ID	Task of work	#1	#2	#3	#4	Section length
1	Dumping 1/5 asphalt from truck to paver	45sec	50sec	45sec	40sec	0m
2	Fully spread the material carried by the paving machine	8min30sec	7min	6min30sec	6min	4-5m
3	Compact the material just spread by compaction of roller	--	2min 5 rounds	--	2min 5 rounds	About 10m
4	Carry out primary compaction by the four-wheel-compactor after the roller	--	18mins 45 rounds		22mins 42 rounds	10-15m
5	Relocation of paving machine	--	--	--	20mins	50m

Running the SDESA paving model takes 30 seconds computer time on a Pentium III 850 MHz IBM PC, resulting in a total of 15 actual working hours to complete the paving job. This fits closely with actual site records. The arrival time of asphalt trucks to ensure continuous site operations are obtained from simulation as shown in Table 5.

Table 5: Arrival Times Of Asphalt Trucks To Ensure Continuous Site Operations

Truck ID	Truck Arrival Time (Minutes after starting paving)
1	0
2	140.8
3	326.0
4	507.7
5	691.8

The CYCLONE model for the paving operations described above is also constructed (Fig. 4) for comparison. Note that a GENERATE function node (“GEN 4”) after the “Dump” COMBI activity node is used to transform each truck “dump” (i.e. 1/5 of its capacity) into four resource entities representing the asphalt mix to be paved on four spreads. A CONSOLIDATE function node (“CON 5”) after the “Dump” COMBI keeps track of the number of truck dumps; once five dumps are accumulated, unloading one truck is finished, and the truck departs from the site. The three CONSIDATE function nodes following the “Spread” COMBI node are used to trigger the repositioning of the paver, the initiation of the compacting operations, and the occurrence of dumping operations. In this case, the CYCLONE model is far more complicated and entails more efforts to build, interpret and update when compared to the SDESA one.

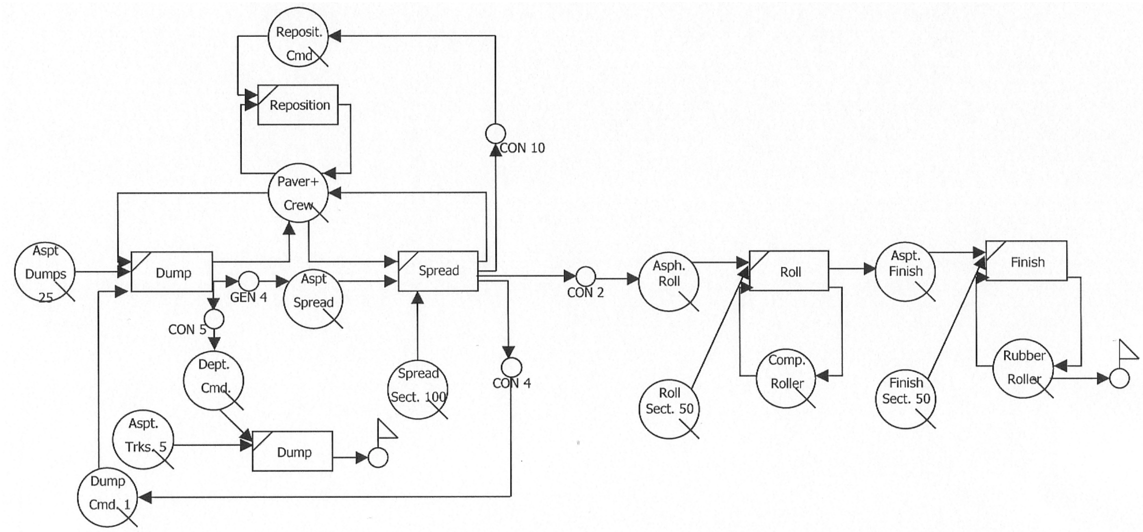


Figure 4: Asphalt paving operations CYCLONE model

4. CONCLUSION

A new Simplified Discrete-Event Simulation Approach or SDESA for planning construction operations has been developed by incorporating the constructive features from existing approaches. In essence, the executive program of SDESA controls the simulation operations by manipulating two dynamic queues -the flow entity queue and the resource entity queue. The SDESA is easy to implement and has been coded into a prototype program using Microsoft Access, which is a relational database system with supporting VB macro programs. Constructing a SDESA model for repetitive and resource-driven construction operations is no different from making a CPM plan, as demonstrated in two case studies based on road construction projects in Hong Kong. Comparing SDESA against the well-known CYCLONE simulation methodology in the case studies has revealed the simplicity and effectiveness of SDESA in modeling complex construction systems and attaining the preset objectives of such modeling.

5. ACKNOWLEDGEMENT

Eric W. H. Chan, a final year civil engineering student at the Hong Kong Polytechnic University, is acknowledged for collecting site data and preparing photo records used for the case studies in the paper.

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