

## OPTIMIZING EARTHMOVING OPERATIONS USING OBJECT-ORIENTED SIMULATION

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### ABSTRACT

This paper presents an automated system for optimizing earthmoving operations. The proposed system can assist earthmoving contractors, during bid preparation stage, in estimating the time and cost required in order to accomplish the task at hand. It also provides a methodology for recommending the most suitable equipment fleet that satisfies the job requirements and the stated objectives of contractors. The system consists of four components: 1) simulation module; 2) equipment cost application (ECA); 3) equipment database application (EDA); 4) reporting module. The paper provides a brief description of the system and focuses primarily on the design of the simulation module utilizing object-oriented simulation (OOS). A numerical example is presented to demonstrate the use of the developed system and illustrate its capabilities.

### 1 INTRODUCTION

Simulation has been utilized to capture the dynamic behavior and the characteristics of the process being modeled. Under different configurations, the performance of the simulated process can be measured in order to identify the bottlenecks and accordingly recognize the optimum resource utilization. Coupling simulation with object orientation increases the capabilities of the system to model the problem at hand and provides an efficient computational environment.

Construction operations are frequently impacted by uncertainties and characterized by dynamically shared resources. Accordingly, simulation is considered a potent modeling technique to capture their essential characteristics. Considerable efforts have been made to develop general simulation languages to model these operations. These include CYCLONE (Halpin 1977) and STROBOSCOPE (Martinez 1996). Special purpose simulation (SPS) was also introduced (AbouRizk and

Hajjar 1998) to model a specific operation in an easy to use simulation environment.

AbouRizk and Shi (1994) developed an optimization model that considers only the quantities of resources being used along with their respective user-specified boundaries. The system recommends a resource combination, within the specified boundaries, closer to the optimum resource allocation. MaCabe (1998) introduced belief networks as a diagnostic tool in order to obtain a near optimum solution, accounting for both the quantity and capacity of each utilized resource.

In most situations, earthmoving contractors are limited with a specific set of fleets, whether owned or rented. This paper presents an automated system for optimizing earthmoving operations using object-oriented simulation. The system recommends the most suitable fleet scenario chosen from a predefined feasible list of fleets to meet the objective(s) set by the contractor.

### 2 SYSTEM COMPONENTS

The proposed system consists of two main modules, equipment cost application (ECA), and equipment database application (EDA). The modules are: 1) simulation that captures the dynamic behavior of the utilized resources in earthmoving operations, and 2) reporting which provides the contractor with a facility to generate a number of reports pertaining to project cost, project schedule, characteristics of the selected equipment, and the owning and operating cost of any given piece of equipment. It also recommends the most suitable scenario according to the contractor's stated objective. The equipment database feeds the system with the information associated with each piece of equipment including its characteristics, attachments, range of dimensions, and hourly owning and operating cost. The ECA is an application dedicated for estimating equipment's owning and operating costs, which are project dependent. Figure 1 depicts the system components and their connectivity.

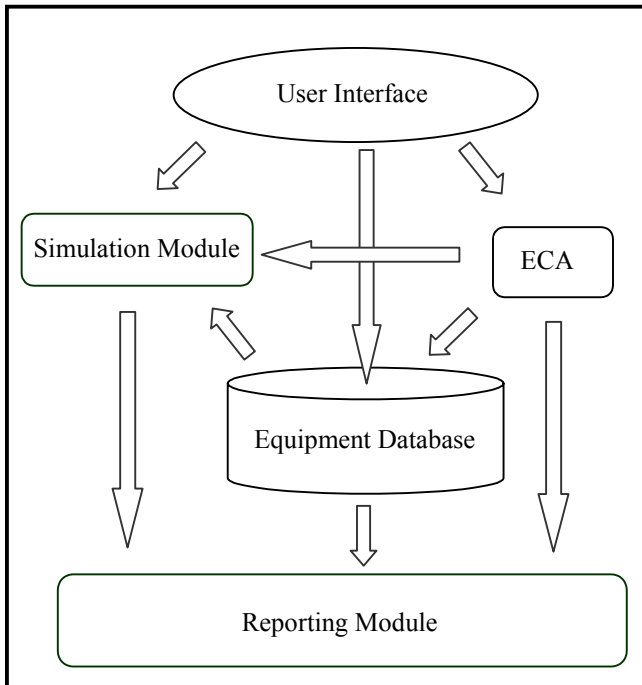


Figure 1: System's Components

### 3 SIMULATION MODULE

This module represents the main component of the system. It has been designed utilizing discrete event simulation (DEVS) technique, employing object-oriented concepts. The three-phase simulation (Pidd 1995) was employed rather than process interaction to control the system dynamics by tracking the activities of the simulated process (i.e., pile, load, haul, dump, spread, and compact). The three-phase simulation approach is considered the most appropriate for object oriented simulation (OOS) specially when there are too many entities involved in the process being modeling (Pidd 1995). Object oriented simulation has been utilized by defining the simulated process components into objects that interact and communicate together. Different features of object orientation have been utilized including classes, encapsulation, dynamic data structure, and polymorphism. Classes have been utilized to capture the properties of objects. For example *Moved\_Earth* class is used in order to define the progress of moving earth during the simulation process (see Figure 2). The attributes of that class are AOETM and *Moved\_Earth*, which define the scope of work and the amount of earth that has been moved at a specific time. These attributes are stored in the private sector of the class to encapsulate and limit their use inside the class definition.

```
class Moved_Earth
{
public:
//constructor
Moved_Earth() {MovedEarth=0, AOETM=0;}

Void Set_MovedEarth(double SMovedEarth)
    {MovedEarth=SMovedEarth;}

void Set_RequiredMovedEarth(double SAOETM)
    {AOETM=SAOETM;}

double get_MovedEarth(){return MovedEarth;}

void Increase_MovedEarth(double CT, double
IncEarth)
    {MovedEarth +=IncEarth;}

int IsEarthMoved ()
    {
    if (MovedEarth < AOETM)
        return 0;
    else
        return 1;
    }

private:
double MovedEarth;
double AOETM;
};
```

Figure 2: Moved\_Earth Class

Dynamic data structure has been utilized in terms of queues and lists in order to gather information from the objects under consideration without knowing their number in advance. Polymorphism has been utilized to define one class that can be used with different data types by using class *templates* terminology. For example, class *Queue* has been defined to be used by different objects (e.g. haulers, loaders, ....., etc.) as shown in Figure 3.

```
template <class ELETYPE>
class Queue {
public:
    Queue();           // constructor
    ~Queue();         // destructor
    .
    .
};
```

Figure 3: Queue Template Class

#### 3.1 Classification of Activities

Earthmoving operations generally are common in heavy civil engineering projects including mining, dams, and highways. The activities involved in any operation are project dependent. For instance, in highway construction, backfilling using material from borrowed pits must be

compacted after dumping while, in other projects, this may not be a necessity. Another example of project dependent activities is soil required to be cut by excavators or piled by tractors in order to be loaded.

Accordingly, all activities involved in earthmoving operations could further be classified as primary and secondary activities. Primary activities are those which must exist in any earthmoving operation such as load, haul, dump and return. Whereas secondary activities might or might not exist such as pile, compact, and spread.

Figure 4 shows the CYCLONE network diagram for the primary and secondary activities, considered during the design stage of the system. The shaded blocks are used to identify secondary activities and their respective resource queues.

### 3.2 Specifying the Physical Entities

The user of the system is required to specify the type of secondary activities involved in the project, along with their associated fleet scenario. The user then specifies the type of equipment that may exist on the project to perform each secondary activity and its corresponding model (see Figure 5).

After specifying the equipment, for both primary and secondary activities, the user is further required to specify the characteristics of the haulers' road segments and the soil material to be hauled. As such, all the physical entities of the system are specified and can readily be mapped by

their representative classes. For example, the class that represents the hauler objects has the characteristics of hauler unit including unit type, model, payload, and hourly owning and operating costs. These characteristics are referred to later as the data member variables of that particular class.

### 3.3 Data Modeling

One of the powerful capabilities of the object-orientation concept is the dynamic data structure. This ability enables the system to store, track, and gather information from the objects under consideration without knowing the number of the objects in advance. Queues and lists have been utilized in the development of the proposed system as an application of the dynamic data structure. Queues are used to store the resources associated with the various activities during their idle time and gather their status accordingly. Lists, on the other hand, are used to track all activities, primary and secondary, that are in progress. These activities are organized in a chronological order according to their finish time in the current activity list (CAL). In the DEVS, the simulation clock is advanced at specific time events. These events are the finish time of CAL activities, which are tracked according to the three-phase simulation approach. Figure 6 shows the system dynamic flowchart that illustrates how the simulation clock is reset and how activities are added and removed from the system.

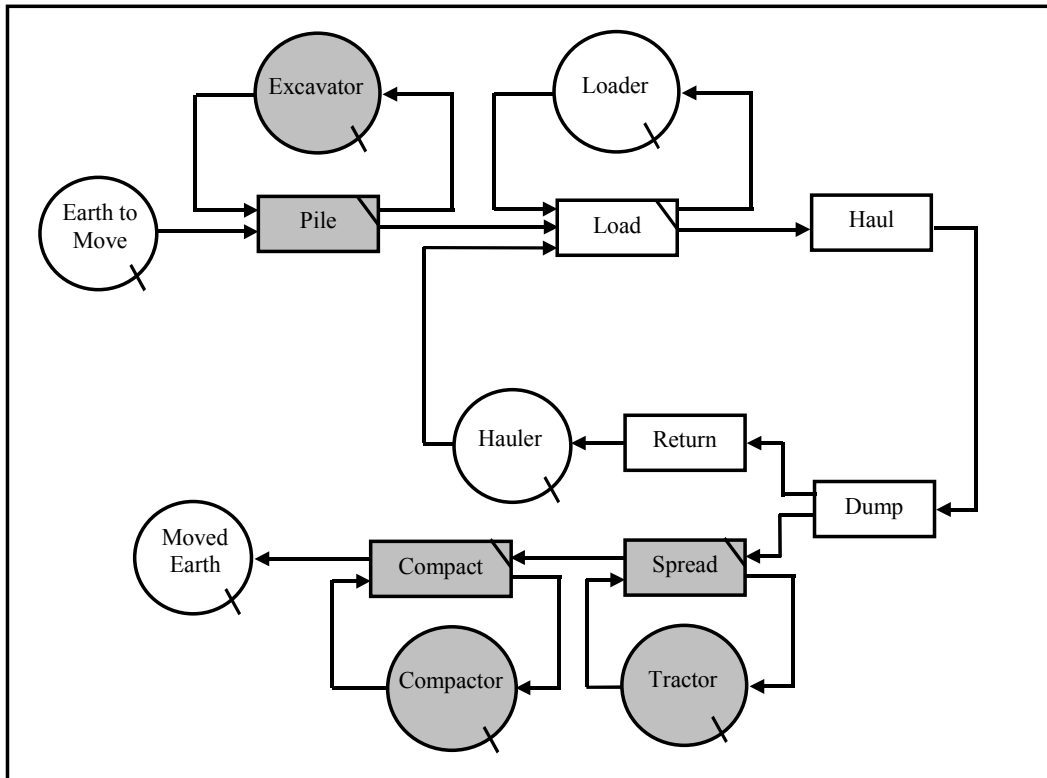


Figure 4: CYCLONE Network Diagram: the Primary and Secondary Activities

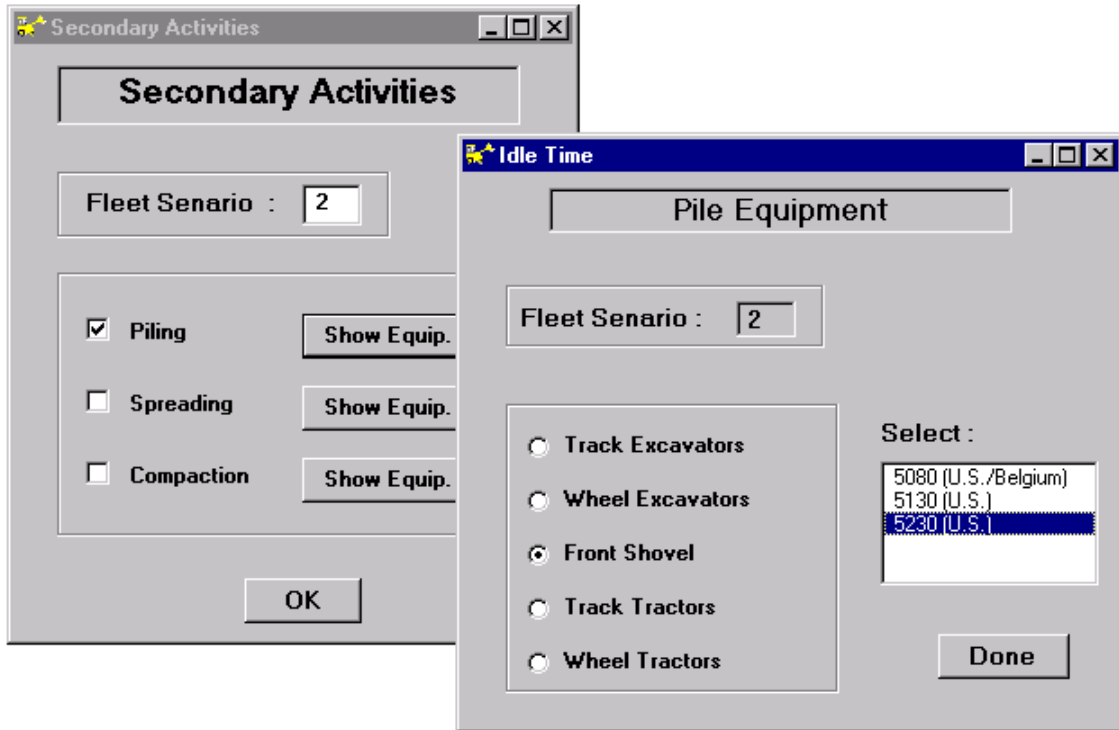


Figure 5: Secondary Activities Dialog Boxes

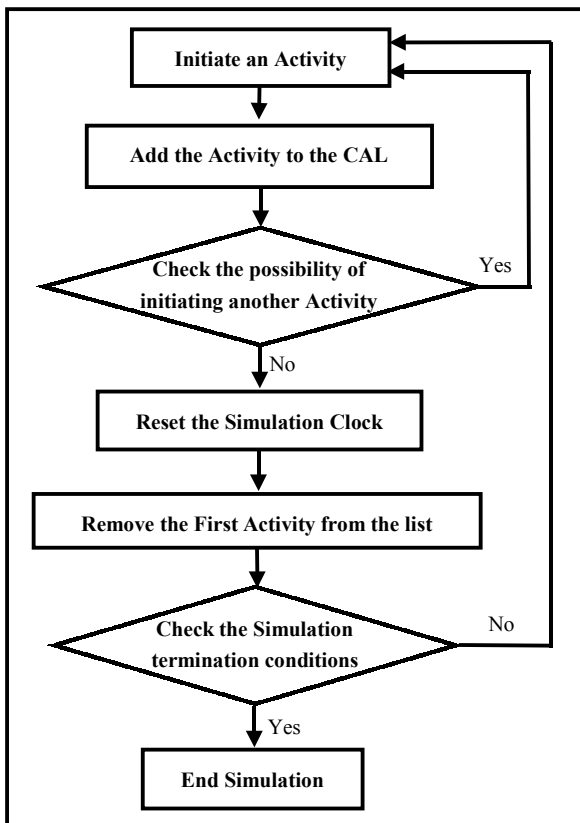


Figure 6: System Dynamic Flowchart

#### 4 REPORTING MODULE

This module tracks all information and processed data from the rest of the system. It also provides the user with the most suitable fleet scenario(s) according to his stated objective(s). As mentioned before, earthmoving contractors are limited with a feasible set of fleets, whether owned or rented. In this respect, the system is designed to provide the user with the flexibility to configure a number of feasible equipment fleets. A change in equipment quantity and/or capacity represents a new fleet scenario.

##### 4.1 Connectivity

The user enters the entire feasible fleet scenarios, which are configured utilizing the system's equipment database. The configured fleet scenarios are then fed to the simulation module, which runs the simulation for each scenario separately. The reporting module receives the statistical results from simulation module and recommends the most suitable fleet scenario.

Figure 7 illustrates the data flow between the simulation and reporting modules.

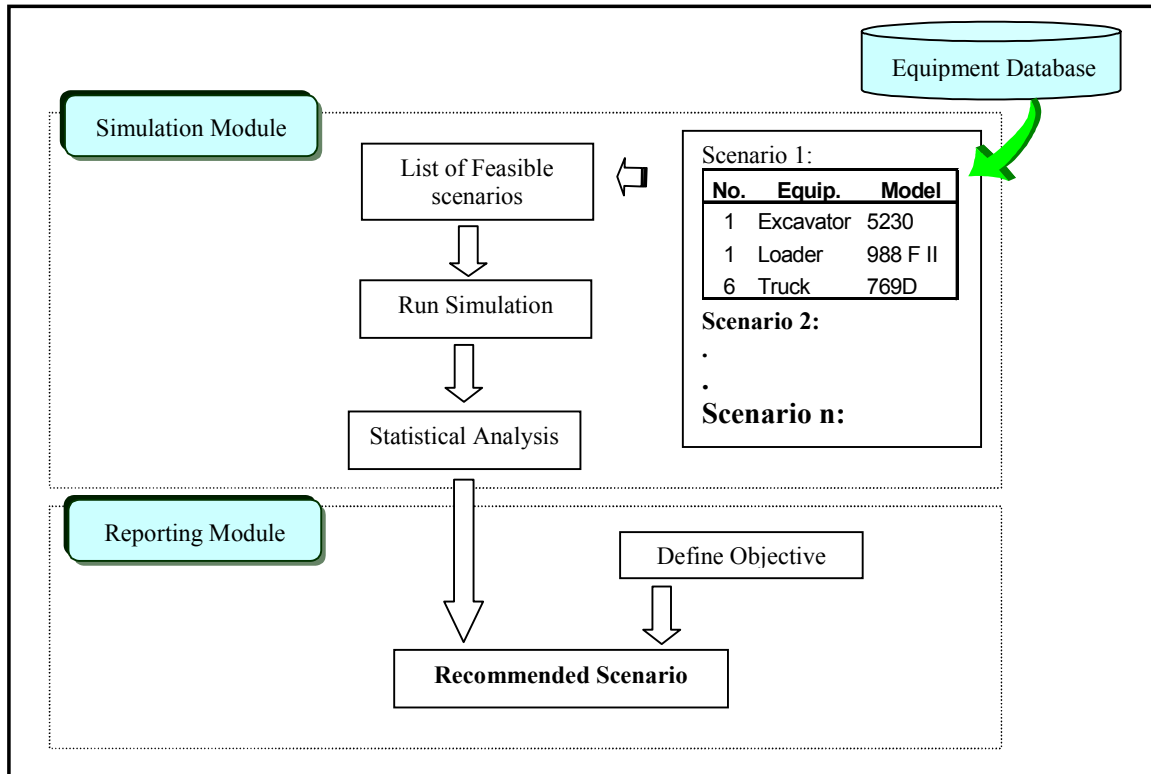


Figure 7: Data Flow between Simulation and Reporting Modules

#### 4.2 Optimization Objectives

The system provides the user with the recommended scenario according to his stated objective. In case of more than one objective, the system provides a recommended scenario that satisfies each individual objective. The user can select one of the following alternatives:

- Minimize the total project cost.
- Minimize the overall project duration.
- Minimize the idle time for specific piece of equipment.

Figure 8 depicts user interactive screens to articulate his/her objective. In case of choosing the minimum idle time for an equipment, the user needs to specify the fleet scenario, equipment type, and its corresponding model.

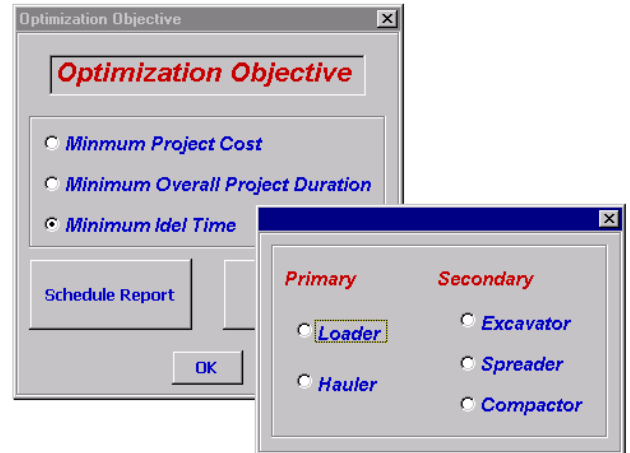


Figure 8: Optimization Objective(s) Dialog Boxes

#### 5 NUMERICAL EXAMPLE

In order to demonstrate the use and capabilities of the developed system, a hypothetical earthmoving example project is considered. The project involves moving 10,000 (m<sup>3</sup>) of blasted basalt from station 1 to station 2, considering the following:

1. The soil has a loose density of 2.0 (ton/ m<sup>3</sup>) and bank density of 3.0 (ton/ m<sup>3</sup>).

2. The contractor has available four trucks (CAT 793) from his owned fleet available for the project.
3. The project consists of the four primary activities: 1) load, 2) haul, 3) dump, and 4) return, and there are no secondary activities.
4. The experienced contractor decided to examine two fleet scenarios with the configurations given in Tables 1 and 2, respectively.
5. The contractor stated objective is to minimize total project cost.

6. The characteristics of the road segments between the two stations lead to a travel time data as per Table 3.

Table 1: First Fleet Scenario Characteristics

Loaders (Wheel Type)	
Type :	CAT 988
Number :	1 (rented)
Bucket Capacity (m <sup>3</sup> ) :	5
Hourly O & OCost (\$/hr) :	65
Haulers (Trucks)	
Type :	CAT 793
Number :	6 (4 owned+ 2 rented)
Payload (kg) :	197,847
Hourly O & OCost (\$/hr) :	50

Table 2: Second Fleet Scenario Characteristics

Loaders (Wheel Type)	
Type :	CAT 988
Number :	1 (rented)
Bucket Capacity (m <sup>3</sup> ) :	5
Hourly O & OCost (\$/hr) :	65
Haulers (Trucks)	
Type :	CAT 793
Number :	4 (owned)
Payload (kg) :	197,847
Hourly O & OCost (\$/hr) :	50
Type :	CAT 785
Number :	3 (rented)
Payload (kg) :	99,671
Hourly O & OCost (\$/hr) :	45

Upon the completion of the data entry, the simulation module is invoked and data processing is performed as described in Section 3. Subsequently, the system activates the optimization module, which analyzes the statistical data obtained from the simulation module. And finally, records the most suitable fleet that satisfies the contractors stated objectives of minimizing the total project cost. In this case, the system recommends the first fleet with a total project cost of \$16,030 associated with an overall project duration of 43.92 hr. A cost breakdown of the selected fleet is included in Appendix A.

Table 3: Travel Time Distribution between the Two Stations

Hauler Type	Activity Type	Distribution	Parameters
CAT 793	Haul	Exponential	Mean = 60 (min)
	Return	Normal	Mean = 30 (min) SD = 2 (min)
CAT 785	Haul	Uniform	LL = 40 (min) UL = 50 (min)
	Return	Uniform	LL = 22 (min) UL = 26 (min)

LL : Lower limit, UL : Upper limit, and SD : Standard deviation

6 CONCLUSIONS

This paper presented an automated system for optimizing earthmoving operations using object-oriented simulation. The system consists of two main modules (simulation and reporting), equipment database, and equipment cost application (ECA). The simulation module was designed employing object-oriented simulation (OOS) approach to benefit from its capabilities. The paper also described earthmoving, focusing on their respective primary and secondary activities. These activities are tracked in the current activity list (CAL) according to the three-phase simulation approach, which is more appropriate to OOS. A numerical example was analyzed in order to demonstrate the use of the developed system and illustrate its capabilities.

APPENDIX A: PROJECT COST REPORT

```

MINIMUM TOTAL COST SCENARIO (1)
=====
*****
*** FLEET ELEMENTS COST DETAILS ***
*****

*****
**** HAULERS COST ****
*****

=====
Model Type  No.  $/Hr.  Operation Hrs  Total Cost ($)
-----
Truck (793)  6    50     43.92         13176
-----
Total Hualer(s) Cost ($)                13176
=====
    
```

```

*****
**** LOADERS COST ****
*****
=====
No.      $/Hr.    Operation Hrs    Total Cost ($)
-----
Loader (988)  65        43.92           2854
=====

```

```

*****
**** SUMMARY COST ****
*****
=====
Equipment                                Cost ($)
-----
Haulers                                  13176
Loaders                                  2854
-----
Total Cost ($)                           16030
=====

```

The Cost per cubic meter to Haul is : 1.603 \$/CM

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