INTELLIGENT PREEMPTION IN CONSTRUCTION OF A MANMADE ISLAND FOR AN AIRPORT

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ABSTRACT

This paper presents the simulation model and 3D animation for a project involving large-scale undersea land reclamation for the construction of a manmade island for an airport. The model illustrates how intelligent preemption can be dynamically used at simulation runtime to enforce the operational policies of a tug boat that guides barges loaded with earth into the island for unloading and then out into the sea after unloading is complete. The example also investigates the repeated stalling of the otherwise continuous unloading operations due to the need to share the narrow island entrance channel with watercraft supporting other construction activities. The solution to this problem is out-lined conceptually using the activity-scanning modeling paradigm. The solution is described in detail using a simulation model developed in STROBOSCOPE and a 3D animation created using VITASCOPE.

1 INTRODUCTION

Preemption is an action taken to check another action beforehand. In simulation, preemption is needed to model the interruption of an activity because of an event that occurs during its execution, or the cancellation of a scheduled activity because of another event that takes place beforehand. In construction, preemption can be useful, for instance, to model disruptions caused by machine breakdowns or to allow higher priority activities to claim active resources.

This paper presents the simulation model and 3D animation for a project involving large-scale undersea land reclamation for the construction of a manmade island for an airport. The model illustrates how intelligent preemption can be dynamically used at simulation runtime to enforce the operational policies of a tug boat that guides barges loaded with earth into the island for unloading and then out into the sea after unloading is complete. The solution is outlined using the activity-scanning paradigm and described using a model developed in STROBOSCOPE and a 3D animation created using VITASCOPE.

2 MANMADE ISLAND PROJECT

A contractor constructing an off-shore airport in Japan is using three types of cargo barges to transport earth from a borrow site on the shore to the manmade island being reclaimed to construct the airport. The contractor has facilities for unloading as many as three barges simultaneously at the jobsite. These three unloading spaces are called *berths*. The berths are located near the southwest corner of the island from where an intricate system of conveyors transports the unloaded earth to the non-stationary workface where the material is being placed to gradually construct the island. Figure 1 presents the project site layout.
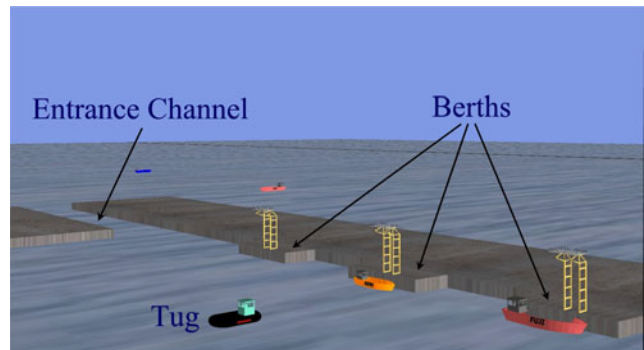

Figure 1: Manmade Island Project Site Layout

Prior to the commencing the reclamation activities, the contractor constructed a concrete seawall around the island perimeter to retain the fill and to act as a buffer during any tidal activity. The entrance for marine vessels into the perimeter of the island is through a narrow inlet channel also located at the southwest corner of the island. Due to turbulent sea conditions, no two marine vessels can simultaneously occupy the narrow inlet channel. The only exception are the barges transporting earth which, because of their relatively large size and limited maneuverability, require the services of a tug to move from the open sea into a berth and (after unloading) out of a berth back into the sea.

A powerful Morimoto class tractor tug with twin-screw omni-directional propulsion is available at the job-site. The tug and the unloading processes operate 24 hours per day, 7 days per week. The arriving barges have different cargo capacities and belong to one of three different classes: Akeno, Fuji, and Haneda. The time between successive barge arrivals to the island entrance is uniform between 4 and 18 hours: U[4,18]. Table 1 lists the three types of arriving barges with their relative frequencies and unloading-time requirements.

Table 1: Barge Relative Frequency and Loading Times

Barge Class	Relative Frequency	Unloading Time, Hours
Akeno	0.25	U[16,20]
Fuji	0.25	U[20,28]
Haneda	0.50	U[32,40]

When the tug is available, any berthing or deberthing activity for a barge takes about 1 hour. It takes the tug 0.25 hour to travel from the channel entrance to the berths, or vice versa, when not pulling a barge. When the tug finishes a berthing activity, it deberths the first barge in the deberthing queue if this queue is not empty. If the deberthing queue is empty but the channel queue is not and a berth is available, the tug travels to the channel entrance and begins berthing the first barge in the channel queue. If both queues are empty, the tug remains idle near the berths.

When the tug finishes a deberthing activity, it berths the first barge in the channel queue if this queue is not empty and a berth is available. Otherwise, the tug travels to the berths, and if the deberthing queue is not empty, begins deberthing the first barge in the queue. If the deberthing queue is empty, the tug stays idle near the berths.

The situation is further complicated due to the fact that the narrow inlet channel must be shared with other watercraft entering and leaving the island perimeter. Such watercraft that support other ongoing construction activities on the island have priority for travel in the inlet channel.

The extraneous watercraft arrive at or depart the island several times during a week and require, due to turbulent sea conditions, anywhere from 2 to 6 hours to traverse the inlet channel: U[2,6]. The time between the arrival of one extraneous marine vessel to the inlet channel (for entering or leaving the island) and the arrival of the next is an exponential random variable with mean 48 hours.

The tug will not start a new berthing or deberthing activity when a extraneous watercraft is traversing the inlet channel but will always finish an activity already in progress before yielding the channel right-of-way. In addition, if the tug is traveling from the berths to the channel entrance without a tanker when a extraneous watercraft arrives at the channel, it will turn around and head for the berths. The berths continue to operate during the times when the tug remains idle for the channel traffic to clear.

Due to the high cost of maintaining and operating the tractor tug and the berths, the contractor is keen on maximizing the productivity of the unloading processes. In order to achieve this objective, the contractor is considering several alternatives that might potentially improve the current mode of operation (Base Alternative or Alternative I).

2.1 Alternative II – Supply of Additional Material

As a first step of improvement, the contractor is considering recruiting an additional local material supplier to transport fill to the island. The supplier being considered would commit 5 Nagoya class barges to transport earth from a borrow site located on an offshore natural island to the manmade island under construction. The time in hours for these barges to unload earth at the berths follows a uniform distribution: U[18,24]. After unloading and deberthing, the barges would travel to the offshore natural island, load material, return to the berths for unloading etc. The round-trip travel time in hours, including loading at the remote borrow site, is uniformly distributed: U[216,264].

2.2 Alternative III – Two-Way Radio (Policy I)

As a further improvement step, the contractor is considering retrofitting the tractor tug with a two-way radio that would give the tug operator the position and status of each barge around the island. Given this new information, the tug would change its operating policy as follows. If the tug is traveling from the channel entrance to the berths without a barge and is less than halfway there when a new barge arrives and a berth is free, it would turn around and go pick up the new barge. In addition, if the tug is traveling from the berths to the channel entrance without a barge and is less than halfway there when a barge completes unloading, it would turn around and go deberth the unloaded barge.

2.3 Alternative IV – Two-Way Radio (Policy II)

The contractor is also considering an additional operating policy for the tug compared to the one contemplated in Alternative III. Under this policy, if the tug is traveling from the channel entrance to the berths without a barge when a new barge arrives and a berth is free and the deberthing queue is empty, it would turn around and go pick up the new barge, regardless of the tug's own position.

3   SIMULATION MODEL

The activity-based network for the simulation model for alternative I is shown in Figure 2. This is the base case where the tug services the 3 types of arriving barges. The activity *BargeArrives* represents the inter-arrival time between successive barge arrivals. At any point in time, there can be only one instance of this activity in progress.
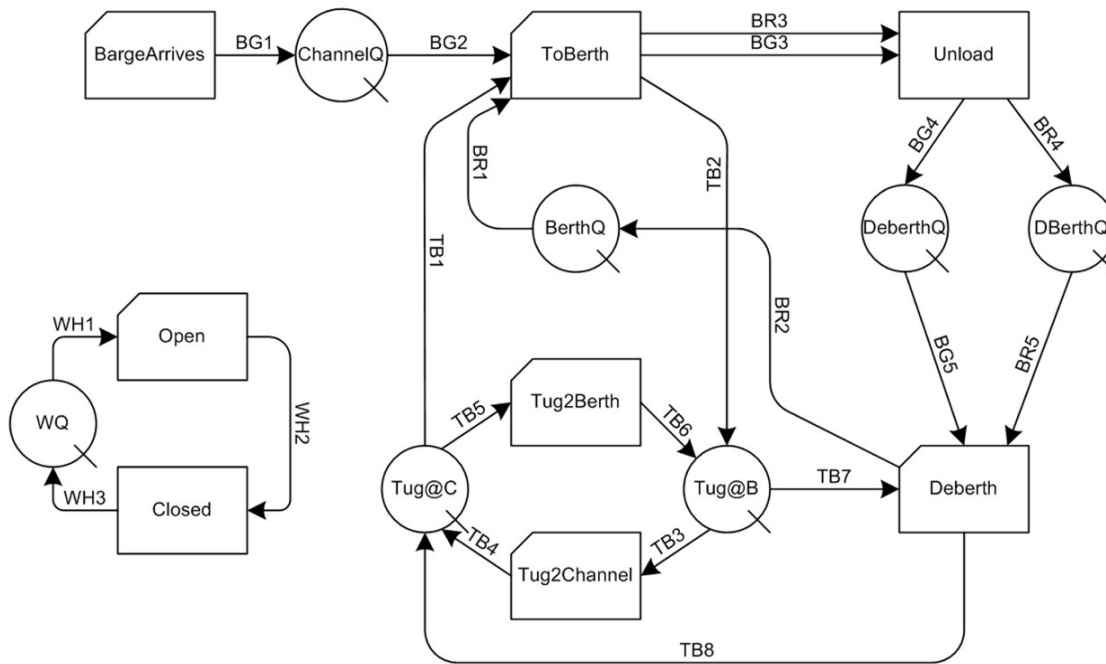
Figure 2: STROBOSCOPE Simulation Model Network for Alternative I

The completion of *BargeArrives* adds a loaded barge to the queue *ChannelQ.* At the start of the simulation, the *BerthQ* queue contains the 3 berths that are available to service arriving barges. The tug is idle at the berths at the beginning of the simulation and is contained in the queue *Tug@B.* The arrival of a loaded barge into *ChannelQ* triggers the activity *Tug2Channel* whereby the tug travels to the channel entrance represented by the queue *Tug@C.* This activity only takes place if there is at least one berth available in *BerthQ* to service the arriving barge and there is no extraneous watercraft activity ongoing in the channel.

The sub-network consisting of the queue *WQ*, the combi activity *Open* and the normal activity *Closed* model the extraneous channel traffic and thus the availability or non-availability of the channel for the tug. The activity *Tug2Channel* will thus be instantiated only if an instance of *Open* is in progress and there are no ongoing instances of *Closed*. The initialization of *WQ* with one counter resource at the start of the simulation ensures that only one instance of either *Open* or *Close* is in progress at any time.

If there is a barge in *ChannelQ*, a berth in *BerthQ*, and the tug is in *Tug@C*, an instance of the activity *ToBerth* can start if there is no ongoing instance of the activity *Closed* in progress. The completion of *ToBerth* initiates the unloading of the barge that has just arrived at a berth via the activity *Unload.* The barge and the berth being released by the activity *ToBerth* arrive to *Unload* via links *BG3* and *BR3* respectively. At the same time, the tug is released to queue *Tug@B* to represent its arrival back at the berths. Upon completion of *Unload,* the barge and the berth in

context are released to queues *DeberthQ* and *DBerthQ* respectively. The *DBerthQ* in particular represents the fact that an empty barge occupies a berth until the time it is serviced by the tug with the start of activity *Deberth.*

The activity *Deberth* can start if there is an empty barge in *DeberthQ*, the corresponding occupied berth in *DBerthQ*, and the tug is at the berths in *Tug@B*. Similar to *ToBerth*, the activity *Deberth* can only start if there is no ongoing instance of the activity *Closed* in progress. Completion of an instance of *Deberth* releases the occupied berth to *BerthQ* making it available to arriving barges in *ChannelQ.* The tug similarly is released to *Tug@C* to indicate that it has arrived at the channel entrance.

3.1 Alternative II

In alternative II, another local material supplier will transport fill from an offshore borrow site to the manmade island using 5 additional Nagoya class barges. The model network that reflects the activities of this additional material supplier is presented in Figure 3. In particular, the 5 loaded Nagoya class barges are assumed to be in *ChannelQ* at the beginning of the simulation. In addition, if the barge involved in any instant of activity *Deberth* happens to be Nagoya class, then it is released to queue *ToIsland* via link *BG6* at the end of a activity instance instead of implicitly destroying it to represent its departure from the jobsite. Any empty barge waiting in queue *ToIsland* initiates an instance of the activity *IslandTrip* that represents a barge's roundtrip to the offshore borrow site.
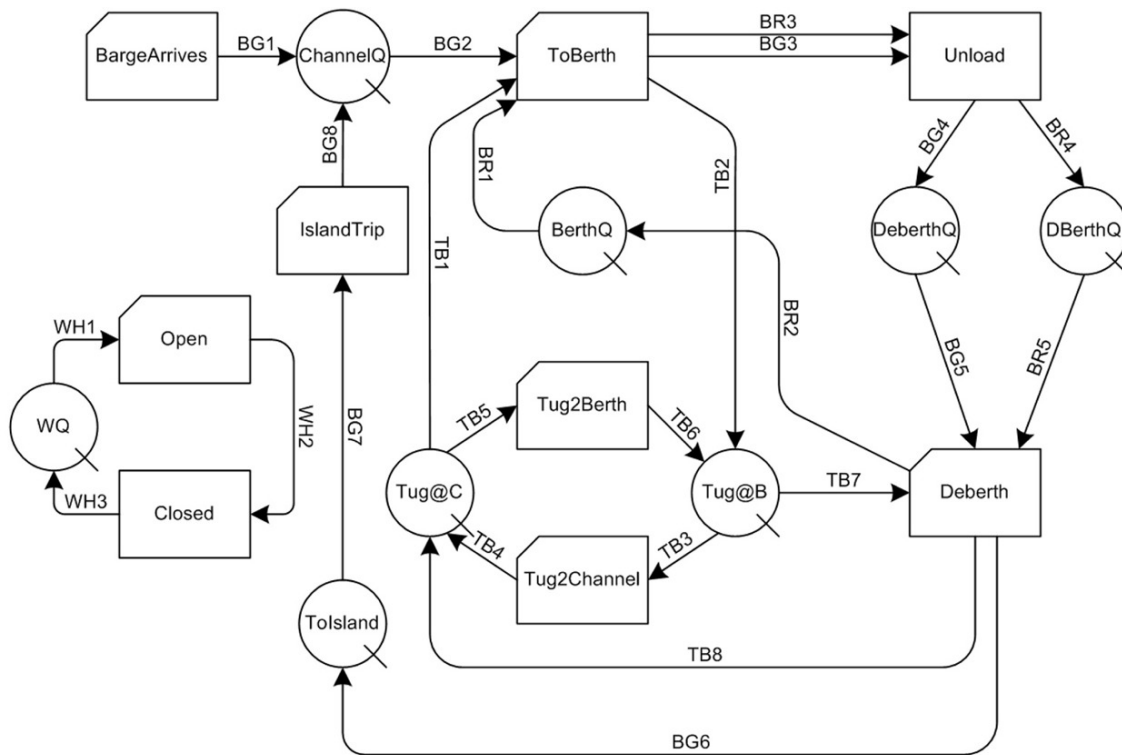
Figure 3: STROBOSCOPE Simulation Model Network for Alternative II

Upon completion of *IslandTrip,* the loaded barge is back in *ChannelQ* waiting to enter the island to unload.

3.2 Alternative III

In alternative III, the installation of the two-way radio system on the tug would allow its operator to determine the position and status of each barge at the berths and at the channel entrance in real-time. Having access to this information, the contractor is considering changing the tug's operating policy as follows: The tug will make a U-turn back to the berths/channel if it travels alone to the channel/berths and is not more than half way there when it is needed at the place it just left. The model network that reflects this operating policy is presented in Figure 4.

The tug's U-turns are modeled by links *TB9* and *TB10* in the network. If the tug makes a U-turn while *Tug2Berth* is in progress, then it returns to *Tug@C* via link *TB9* instead of arriving at the berths in *Tug@B* via link *TB6.* Similarly, if the tug makes a U-turn while *Tug2Channel* is in progress, then it returns to the berths in *Tug@B* via link *TB10* instead of arriving at *Tug@C* via *TB4.* From the modeling perspective, the challenge is to determine when the tug makes U-turns and then release it through the appropriate queue via the correct link. In STROBOSCOPE, an activity in progress cannot be directly interrupted to allow other tasks to reclaim active resources.

As such, any ongoing instance of *Tug2Berth* or *Tug2Channel* cannot be abruptly ended to model the tug's U-turn. The operational policy of the tug must thus be modeled with intelligent preemption. In other words, each instance of *Tug2Berth* or *Tug2Channel* must know beforehand (i.e. before it starts) whether that particular instance of the activity will be interrupted (i.e. whether the tug will have to make a U-turn before that activity instance would otherwise have normally ended).

This is achieved in the model by determining and keeping track of a) when the next barge will arrive at the channel entrance, and b) when the next barge at the berths will be ready to deberth. Knowing this information, instantiated instances of *Tug2Berth* or *Tug2Channel* can determine beforehand whether a particular activity instance will be interrupted due to a required U-turn, and if so, at what simulation time the U-turn will be made.

The implementation of this policy can be explained using the corresponding STROBOSCOPE simulation code. The duration of the activity *Tug2Berth* is set to be the variable *Tug2BerthDur*. This variable is defined in the model with the following expression:

```
VARIABLE Tug2BerthDur
'Closed.CurInst | !BerthQ.CurCount ?
0.25 : (TimeToNextArrival < 0.125) ?
(2 * TimeToNextArrival) : 0.25';
```
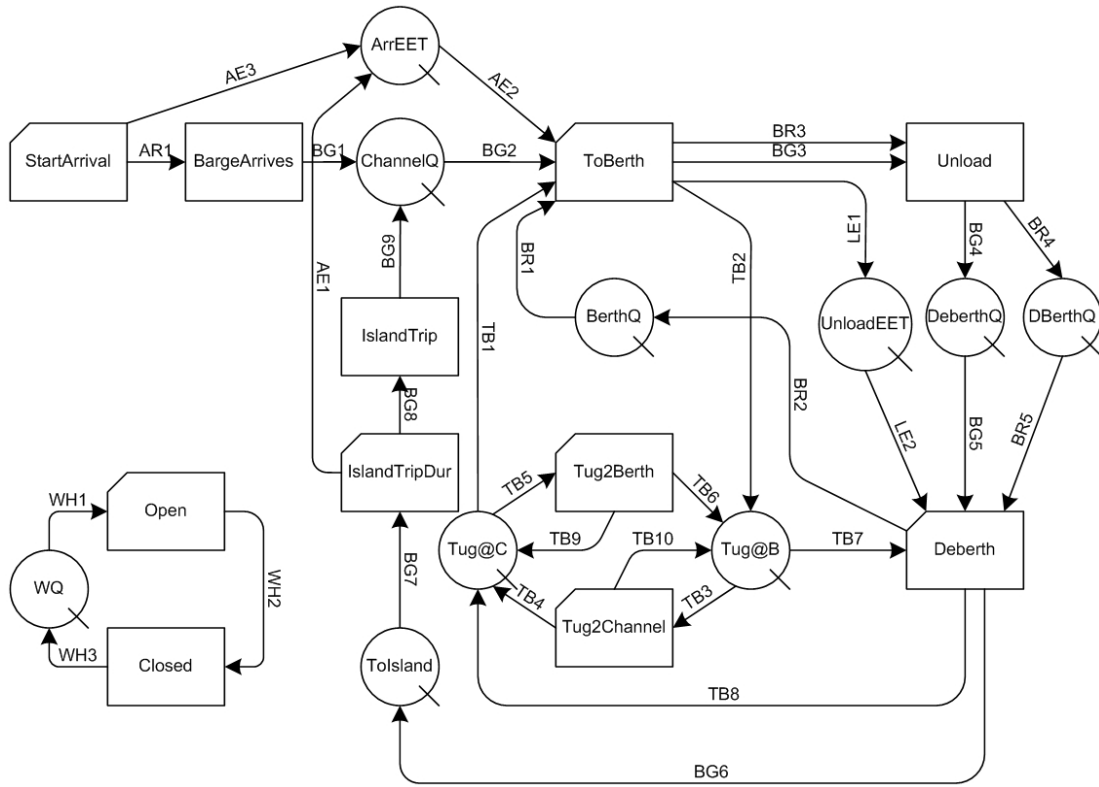
Figure 4: STROBOSCOPE Simulation Model Network for Alternatives III and IV

The above expression references another variable *TimeToNextArrival* which contains the value of the simulation time at which the next loaded barge is scheduled to arrive. The variable *TimeToNextArrival* is computed by having a dummy resource named *Event* travel through the network in parallel to the arriving barges.

This is accomplished via combi *StartArrival,* links *AE1* and *AE3,* queue *ArrEET,* link *AE2,* link *LE1,* and queue *UnloadEET.* The completion of activities *StartArrival* and *IslandTripDuration* each create an *Event* that is released to queue *ArrEET.* The resource *Event* is a compound characterized resource with a property named *EET* that is set to be the simulation time at which the next barge will arrive at the island entrance for unloading.

An *Event* resource arriving to *ArrEET* from *AE1* will have its *EET* property set to be the simulation time at which the next Nagoya class barge will arrive at the island. Similarly, the *EET* property of an *Event* arriving to *ArrEET* from *AE3* will contain the simulation time at which the next barge of any of the other 3 classes will arrive to the island. All resources of type *Event* are then arranged in *ArrEET* in ascending order of their *EET* values. Thus, the *Event* corresponding to the barge that is scheduled to arrive first will always be at the front of the *ArrEET* queue. With this information, the variable *TimeToNextArrival* is calculated by the following expression:

```
VARIABLE  TimeToNextArrival  ArrEET.CurCount  ?
(ArrEET.EET.MinVal – SimTime) : 1;
```

When the above expression is interpreted in the model (just before an instance of *Tug2Berth* starts and before the expression for *Tug2BerthDur* is interpreted), if there is a scheduled arrival *Event* in *ArrEET,* then the value of *TimeToNextArrival* (which represents time remaining until next barge arrives) is set to the minimum of the *Event* resources' *EET* property (which corresponds to the barge scheduled to arrive first) minus the current simulation time. The variable *Tug2BerthDur* is then evaluated as follows based on the expression presented earlier.

If the channel is closed to tug traffic (i.e. an instance of *Closed* is in progress) or there are no berths available inside the island, then there is no point making a U-turn if a barge arrives. In this circumstance, *Tug2BerthDur* is set to 0.25 hours indicating that the tug will travel straight to the berths without making a U-turn. If both the above conditions are not true, and the next barge is scheduled to arrive before the tug reaches halfway back to the berths (i.e. *TimeToNextArrival* is less than 0.125), then the tug will make a U-turn and its duration is set to be twice the *TimeToNextArrival.* This is because the tug will travel for *TimeToNextArrival* hour before turning back and traveling for an equal duration to be back at the channel entrance.

If no barge is scheduled to arrive in the next 0.125 hours, then the tug will not turn back and the duration of the activity is set to be usual 0.25 hour. In order to make sure that the tug in *Tug2Berth* is released to the correct queue (*Tug@B* or *Tug@C*) based on whether or not it has made a U-turn in an activity instance, the *ReleaseWhere* property of the links *TB6* and *TB9* is used as follows:

```
RELEASEWHERE TB6 Tug2Berth.Duration==0.25;
RELEASEWHERE TB9 Tug2Berth.Duration!=0.25;
```

The first statement in the above code specifies that the tug being released by *Tug2Berth* after completion of an instance should be released via link *TB6* (to queue *Tug@B*) if the duration of the just completed activity instance is 0.25 (which indicates that the tug has not made a U-turn). The next statement similarly routes the tug via *TB9* back to *Tug@C* when the duration of the finishing activity instance is anything other than 0.25 (which indicates that the tug did make a U-turn during this activity instance).

The duration of the activity *Tug2Channel* is similarly set to be a variable named *Tug2ChannelDur* which is defined in the model with the following expression:

```
VARIABLE Tug2ChannelDur
TimeToNextDeberth >= 0.125?
0.25 : (2 * TimeToNextDeberth);
```

The variable *TimeToNextDeberth* which is referenced in the above expression is itself calculated as follows:

```
VARIABLE TimeToNextDeberth UnloadEET.CurCount?
(UnloadEET.EET.MinVal – SimTime) : 1;
```

The variable *TimeToNextDeberth* thus computes and saves the time remaining until the next barge will be done unloading and will be ready to depart. Based on this information, the variable *Tug2ChannelDur* is then set to 0.25 or 2 times *TimeToNextDeberth* depending on whether or not the tug will have traveled more than halfway to the channel when it is required back at the berths, which in turn determines whether or not the tug will make the U-turn. The routing of the tug released by *Tug2Channel* to the correct queue is then similarly modeled using the *ReleaseWhere* property of the outgoing links'.

3.3 Alternative IV

In alternative IV, the contractor is contemplating changing the operating policy in alternative III by having the tug turn around and go pick up the new barge regardless of the tug's own position when it is traveling from the channel entrance to the berths without a barge. The tug will only make such U-turns when a new barge arrives and a berth is free and the deberthing queue is empty. The simulation model network that corresponds to this policy is the same

as that presented in Figure 4. The only change to the model that reflects this additional policy is the expression for *Tug2BerthDur* which is modified as follows:

```
VARIABLE Tug2BerthDur
'Closed.CurInst | !BerthQ.CurCount ?
0.25 : (TimeToNextArrival < 0.125) |
(TimeToNextArrival<0.25&!DeberthQ.CurCount) ?
(2 * TimeToNextArrival) : 0.25';
```

In addition to the circumstances that cause the tug to make a U-turn in alternative III, the above expression sets the value of the variable *Tug2BerthDur* to 2 times *TimeToNextArrival* (indicating a U-turn) when the tug travels beyond the halfway mark but there is no barge waiting in the deberthing queue. The method of routing the released tug to the appropriate queue remains unchanged from the one implemented for alternative III. The results shown in Figure 5 were collected by running the simulation models for the four alternatives for a period of 1 year (8760 hours).

4 3D ANIMATION

In operations analysis and design using discrete-event simulation, the ability to see a 3D animation of an operation that has been simulated allows for three very important things: 1) The developer of the simulation model can make sure that there are no errors in the coding (Verification); 2) The domain experts and decision makers can discover differences between the way they understand the operation and the way the model developer understands it (Validation); and 3) The model can be communicated effectively which, coupled with verification and validation, makes it credible and thus used in making decisions. The presented STROBOSCOPE simulation models were designed to produce VITASCOPE animation trace files that could then be played back in 3D in post-processor mode.

VITASCOPE is a general-purpose, user-extensible 3D animation system designed for visualizing simulated processes in smooth, continuous, 3D virtual worlds. Using an ASCII animation trace and 3D CAD models of simulated system entities, VITASCOPE recreates modeled processes with chronological and spatial accuracy in 3D. The trace file driven approach allows its seamless integration with numerous process modeling tools that are capable of generating formatted text output during a simulation run.

A VITASCOPE trace file consists of sequential animation command statements such as CREATE, DESTROY, PLACE, and MOVE. The trace file also contains statements such as PATH and NONDIRECPATH that define resource movement trajectories for the animated simulation entities. The statements in a recorded trace file are then processed sequentially to visualize the modeled operations in 3D. This is accomplished using 3D CAD models of the involved system resources (e.g. barges, tug, etc.) and other model entities.

```
*************************************************************************
                 ALTERNATIVE I : 1 TUG and 3 TYPES OF BARGES (BASE CASE)
*************************************************************************

    |Percent Time TUG is||Percent Time BERTHs||Avg #Barges||Avg Tot In-Island Time|
    |Idle  Alone  Pulls|| Free   Idle  Unload|| DBQ  ChanQ||  Akeno   Fuji  Haneda|
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======
     80.51   1.14   18.35    5.78   7.02   87.20   0.03   1.09   32.45   39.56   49.21
     80.96   0.89   18.15    5.38   6.94   87.68   0.03   1.61   36.63   43.95   56.70
     80.77   1.06   18.17    5.18   7.12   87.70   0.03   1.10   31.62   38.53   50.60
     80.68   1.35   17.97    7.41   6.82   85.78   0.02   1.28   35.90   39.57   52.53
     80.27   1.49   18.25    8.03   7.11   84.85   0.03   1.07   30.92   37.56   51.19
     80.65   1.24   18.11    6.92   7.08   86.00   0.03   1.58   38.42   41.44   56.87
     80.58   1.14   18.28    5.76   7.07   87.17   0.03   1.64   36.71   44.90   56.76
     80.57   1.81   17.62   11.21   6.57   82.22   0.02   0.64   27.01   33.71   45.83
     80.60   1.54   17.86    9.04   6.83   84.13   0.03   0.87   30.42   36.80   47.56
     80.59   0.90   18.51    5.25   7.17   87.58   0.03   2.01   43.55   48.04   59.22
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======
AVG  80.62   1.26   18.13    7.00   6.97   86.03   0.03   1.29   34.36   40.41   52.65
STD   0.18   0.29    0.26    1.97   0.18    1.83   0.00   0.41    4.79    4.25    4.53
MIN  80.27   0.89   17.62    5.18   6.57   82.22   0.02   0.64   27.01   33.71   45.83
MAX  80.96   1.81   18.51   11.21   7.17   87.70   0.03   2.01   43.55   48.04   59.22


*************************************************************************
         ALTERNATIVE II : 1 TUG and 4 TYPES OF BARGES (NAGOYA CASE)
*************************************************************************

    |Percent Time TUG is||Percent Time BERTHs||Avg #Barges||   Avg Tot In-Island Time For |  Nagoya
    |Idle  Alone  Pulls|| Free   Idle  Unload|| DBQ  ChanQ|| Akeno    Fuji   Haneda  Nagoya| CycleT
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======  ======  ======
     79.92   0.12   19.96    0.33   7.67   92.00   0.03   20.31  223.25  223.79  235.68  209.27  449.23
     80.25   0.14   19.61    0.41   7.77   91.82   0.04   21.57  229.58  241.80  255.23  207.96  447.12
     80.22   0.19   19.59    0.51   7.65   91.84   0.03   24.01  262.18  270.01  277.56  238.21  477.63
     80.06   0.16   19.78    0.62   7.79   91.59   0.04   19.26  214.49  227.53  228.34  194.32  436.79
     79.53   0.09   20.38    0.25   7.76   91.99   0.03   14.95  165.93  174.45  182.18  159.39  397.97
     79.99   0.11   19.90    0.29   7.86   91.85   0.03   20.83  227.01  237.13  246.90  214.07  455.43
     80.09   0.07   19.84    0.21   7.72   92.07   0.03   20.88  224.33  237.36  241.90  213.54  452.04
     79.47   0.22   20.31    0.79   7.84   91.38   0.03    9.83  120.29  124.28  134.13  112.02  352.29
     79.71   0.10   20.18    0.30   7.86   91.83   0.03   11.01  124.05  137.77  143.44  120.11  359.39
     79.91   0.16   19.93    0.47   7.70   91.83   0.03   21.97  242.81  239.19  250.42  218.07  457.79
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======  ======  ======
AVG  79.92   0.14   19.95    0.42   7.76   91.82   0.03   18.46  203.39  211.33  219.58  188.70  428.57
STD   0.27   0.05    0.27    0.18   0.08    0.20   0.00    4.84   49.23   48.60   49.06   43.26   43.35
MIN  79.47   0.07   19.59    0.21   7.65   91.38   0.03    9.83  120.29  124.28  134.13  112.02  352.29
MAX  80.25   0.22   20.38    0.79   7.86   92.07   0.04   24.01  262.18  270.01  277.56  238.21  477.63


*************************************************************************
        ALTERNATIVE III : 1 TUG and 4 TYPES OF BARGES - TWO WAY RADIO - POLICY I
*************************************************************************

    |Percent Time TUG is||Percent Time BERTHs||Avg #Barges||   Avg Tot In-Island Time For |  Nagoya
    |Idle  Alone  Pulls|| Free   Idle  Unload|| DBQ  ChanQ|| Akeno    Fuji   Haneda  Nagoya| CycleT
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======  ======  ======
     79.92   0.12   19.96    0.33   7.67   92.00   0.03   20.31  223.25  223.79  235.68  209.27  449.23
     80.25   0.14   19.61    0.41   7.77   91.82   0.04   21.57  229.58  241.80  255.23  207.96  447.12
     80.23   0.18   19.59    0.51   7.65   91.85   0.03   24.01  262.23  270.22  277.59  238.21  477.63
     80.06   0.16   19.78    0.62   7.79   91.59   0.04   19.26  214.49  227.53  228.34  194.32  436.79
     79.53   0.09   20.38    0.25   7.76   91.99   0.03   14.95  165.93  174.45  182.18  159.39  397.97
     79.99   0.11   19.90    0.29   7.86   91.85   0.04   20.83  227.01  237.13  246.90  214.07  455.43
     80.09   0.07   19.84    0.21   7.72   92.07   0.03   20.88  224.33  237.36  241.90  213.54  452.04
     79.47   0.22   20.31    0.79   7.84   91.38   0.03    9.83  120.29  124.28  134.13  112.02  352.29
     79.71   0.10   20.18    0.31   7.86   91.83   0.03   11.01  124.08  137.78  143.45  120.11  359.39
     79.91   0.16   19.93    0.48   7.69   91.83   0.03   21.97  242.79  239.16  250.38  218.07  457.79
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======  ======  ======
AVG  79.92   0.14   19.95    0.42   7.76   91.82   0.03   18.46  203.40  211.35  219.58  188.70  428.57
STD   0.27   0.04    0.27    0.18   0.08    0.20   0.00    4.84   49.23   48.62   49.06   43.26   43.35
MIN  79.47   0.07   19.59    0.21   7.65   91.38   0.03    9.83  120.29  124.28  134.13  112.02  352.29
MAX  80.25   0.22   20.38    0.79   7.86   92.07   0.04   24.01  262.23  270.22  277.59  238.21  477.63


*************************************************************************
        ALTERNATIVE IV : 1 TUG and 4 TYPES OF BARGES - TWO WAY RADIO - POLICY II
*************************************************************************

    |Percent Time TUG is||Percent Time BERTHs||Avg #Barges||   Avg Tot In-Island Time For |  Nagoya
    |Idle  Alone  Pulls|| Free   Idle  Unload|| DBQ  ChanQ|| Akeno    Fuji   Haneda  Nagoya| CycleT
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======  ======  ======
     79.92   0.12   19.96    0.33   7.67   92.00   0.03   20.31  223.25  223.79  235.68  209.27  449.23
     80.25   0.14   19.61    0.41   7.77   91.82   0.04   21.57  229.58  241.80  255.23  207.96  447.12
     80.23   0.18   19.59    0.51   7.65   91.85   0.03   24.01  262.23  270.22  277.59  238.21  477.63
     80.06   0.16   19.78    0.62   7.79   91.59   0.04   19.26  214.49  227.53  228.34  194.32  436.79
     79.53   0.09   20.38    0.25   7.76   91.99   0.03   14.95  165.93  174.45  182.18  159.39  397.97
     79.99   0.11   19.90    0.29   7.86   91.85   0.04   20.83  227.01  237.13  246.90  214.07  455.43
     80.09   0.07   19.84    0.21   7.72   92.07   0.03   20.88  224.33  237.36  241.90  213.54  452.04
     79.47   0.22   20.31    0.79   7.84   91.38   0.03    9.83  120.29  124.28  134.13  112.02  352.29
     79.71   0.10   20.18    0.31   7.86   91.83   0.03   11.01  124.08  137.78  143.45  120.11  359.39
     79.91   0.16   19.93    0.48   7.69   91.83   0.03   21.97  242.79  239.16  250.38  218.07  457.79
    ======  ======  ======  ======  ======  ======  =====  =====  ======  ======  ======  ======  ======
AVG  79.92   0.14   19.95    0.42   7.76   91.82   0.03   18.46  203.40  211.35  219.58  188.70  428.57
STD   0.27   0.04    0.27    0.18   0.08    0.20   0.00    4.84   49.23   48.62   49.06   43.26   43.35
MIN  79.47   0.07   19.59    0.21   7.65   91.38   0.03    9.83  120.29  124.28  134.13  112.02  352.29
MAX  80.25   0.22   20.38    0.79   7.86   92.07   0.04   24.01  262.23  270.22  277.59  238.21  477.63
```

Figure 5: STROBOSCOPE Simulation Results for Alternatives I, II, III and IV

The result is a "motion picture" of the actual operations being carried out in a 3D virtual environment. This "motion picture" can be replayed at varying speeds depending on a viewer's preferences. In addition, the system also allows users to jump ahead or back to any point in simulation time which is fairly analogous to being able to instantaneously rewind and fast forward a motion picture tape to a desired location. The user is able to navigate easily in 3D virtual space and hence can be positioned at any vantage position at any time during an animation.

Figure 6 presents snapshots of the VITASCOPE animation for the presented simulation models. Another snapshot was presented in Figure 1. A relatively short playback of the 3D animation can verify that the tug's operational policy has been correctly implemented in all the 4 cases.
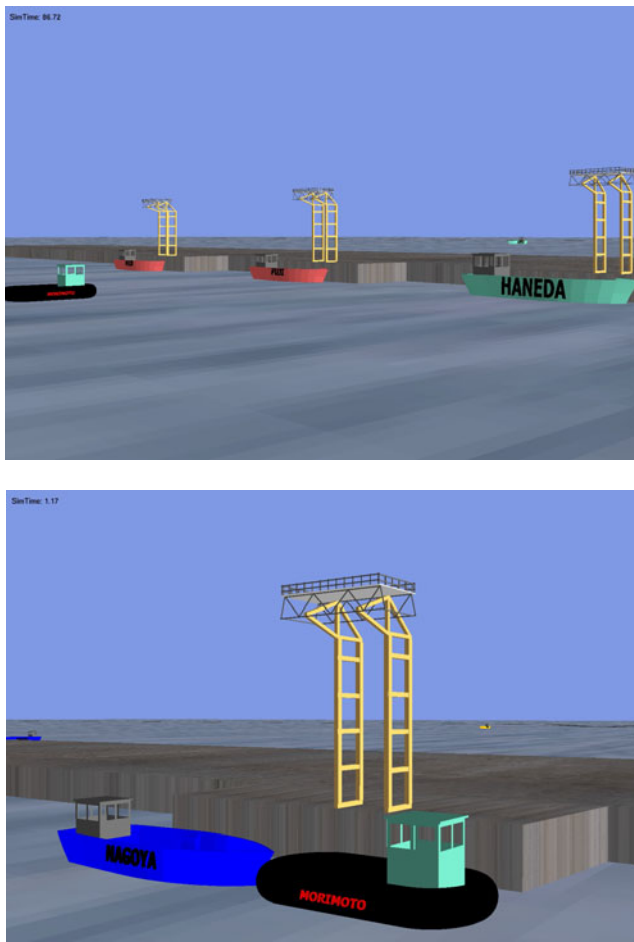
Figure 6: VITASCOPE Animation Snapshots

5   CONCLUSION

This example illustrates the power of STROBOSCOPE, an activity scanning system to model activity preemption. The model illustrated how intelligent preemption can be dynamically used at simulation runtime to enforce the opera-

tional policies of a tug boat that guides barges loaded with earth into the island for unloading and then out into the sea after unloading is complete. The example also investigated the repeated stalling of the otherwise continuous unloading operations due to the need to share the narrow island entrance channel with watercraft supporting other construction activities. The simulation models have been animated using VITASCOPE to verify that they are indeed correct.

The STROBOSCOPE language is described in (Martinez 1996). Example applications can be found in (Ioannou & Martinez 1996a, 1996b, 1996c) and (Martinez & Ioannou 1994, 1999). The VITASCOPE visualization system is described in (Kamat 2003). Example applications and add-ons can be found in (Kamat & Martinez 2001a, 2001b, 2002a, 2002b, 2003a, 2003b, 2003c, 2004a, 2004b, 2004c, 2005). STROBOSCOPE, its documentation, and several solved examples are available at <http://strobos.ce.vt.edu>. VITASCOPE, its documentation, and solved examples are also available from <http://pathfinder.engin.umich.edu>.

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