Evaluation of General-Purpose Construction Simulation and Visualization tools for Modeling and Animating AirSide Airport Operations

Hiam M. Khoury
Vineet R. Kamat
Photios G. Ioannou
Department of Civil and Environmental Engineering
University of Michigan
2340 GG Brown
2350 Hayward Street
Ann Arbor, Michigan
48109-2125 USA
vkamat@umich.edu

This paper illustrates how simulation modeling and visualization can be of substantial help in studying airside airport operations, and can greatly contribute in planning and designing construction operations at airports in a way that has the least impact on airside operations. The characteristic that distinguishes the current work is the capability to model and animate airside airport operations with high fidelity using general purpose discrete event simulation and visualization tools typically used to model and animate construction operations. The focus of the presented work is on evaluating the capabilities of state-of-the-art construction simulation and visualization tools in being able to accurately model and animate airside airport operations. The paper presents the simulation model and 3D animation of the airside operations at Detroit Metropolitan Wayne County Airport (DTW) in Romulus, Michigan. It also presents simultaneous modeling and visualization of operations in two different domains (i.e. airside operations and construction). The solution to the problem is described in detail using a simulation model developed in STROBOSCOPE and a 3D animation created using VITASCOPE. The obtained results highlight and prove that general-purpose tools, even if originally designed for specific domains, can be effective in studying operations involving the interaction of entities in multiple domains such as construction and airport operations.

Keywords: Air transportation systems, accreditation, animation, construction, discrete-event simulation, validation, verification, visualization.

1. Introduction

Simulation modeling and visualization can be of significant help in planning and designing actual field operations, leading to the most beneficial decisions and providing a pictorial representation of how planned activities relate to one another [1–3].

Construction activities within the operations areas of an airport can considerably affect normal operational safety of aircraft and other airport traffic. The Federal Aviation Administration (FAA) asserts that cautious planning and implementation of alleviating actions are required to diminish the effect construction activities may have on normal airport operations [4]. For this reason, studying airside operations and analyzing how they may interact with planned construction operations are vital in planning airport construction.
However, simulation and visualization tools, even if based on the ‘general-purpose’ paradigm, are typically adept at modeling and animating operations in one specific domain. For instance, most airport modeling tools are special-purpose in nature. They cannot model the interaction of operations in different domains, such as construction and airside operations. They are designed to exclusively model landside and airside aircraft performance and behavior.

The objective of this study is to evaluate the extent to which airside airport operations can be accurately modeled, simulated and animated using general-purpose simulation modeling and visualization tools that have been successfully used for construction operations planning and design [3, 5–9]. As a first step, this research investigates airport operations and adopts Detroit Metropolitan Airport (DTW) as a case study. DTW is an airport in Romulus, Michigan, located 20 miles southwest of downtown Detroit. The example illustrates different airport operation scenarios depending on the meteorological weather conditions. The solution to the problem is described in detail using a simulation model developed in STROBOSCOPE [10] and a 3D animation created using VITASCOPE [11]. As a second step, the presented work illustrates the interaction of both airport and construction operations within the realm of DTW airport.

2. Related Work

Previous research efforts have focused on studying aircraft runway and taxiway operations at airports. Recent work by Hooey [12] described the concept of coordinated runway crossings that provides taxi clearances containing a time or speed component in order to improve runway-crossing efficiency. The goal of this study was to enable pilots to arrive at, and cross, active runways without a delay. The results of interviews, involving eight commercial captains, were used to generate preliminary information requirements, system requirements and procedural requirements for a future coordinated runway crossing system.

Macroscopic models such as the Airport Capacity Model (ACM) and Runway Delay Simulation (RDSIM) have also been used to make policy decisions regarding the best runway operational practices [13]. Microscopic models such as the Total Airport and Airspace Model (TAAM) and the FAA airport and airspace simulation model (SIMMOD) can handle detailed runway and taxiway operations but at an added detailed user cost [13].

Other research executed airport simulations using High Level Architecture [14]. The main purpose was to design an airport modeling and simulation infrastructure aiming at experimenting and validating some solutions to maintain an average level of aircraft movements independent of the existing weather conditions. The main features of the airport modeling and simulation infrastructure were discussed and the ground sensor modeling approach was proposed to simulate aircraft localization.

Simulation models were also developed to analyze the daily taxi and takeoff operation of aircraft at the United Parcel Service Louisville Park. The model assists planners in developing aircraft departure schedules that minimize taxi and ramp delay times [15]. The taxi simulation model was developed and validated using Arena.

Prior work on airport simulations also involved an object-oriented approach to model airport ground network traffic operations [16]. The proposed airport modeling framework consisted of a set of components that are fundamental for modeling the basic activities of air traffic operations. Unlike traditional sequential simulation models, activities were organized within this framework into four major groups: flight schedule, aircraft movement, time and animation.

Previous research also included the validation of an airport simulation model referred to as DELCAP (DELay CAPacity) [17]. DELCAP is an airport simulation model developed to assist the FAA in estimating airport capacity. Later, the model was validated for use in assessing air traffic controller performance at the major busy airports. The work describes both the model and the validation effort performed in response to the FAA’s request. The simulation model outputs were compared to those of other models for simple cases to which both apply and to actual throughput data for several airports, with differences usually less than 6–8%.

However, existing airport models have some limitations. Although they are very valuable and effective in airport operations modeling, they are special-purpose tools. They are designed to exclusively model landside and airside aircraft performance and behavior. They cannot model the interaction of operations in different domains, for example construction and air transportation simultaneously. In such situations, general purpose simulation and visualization tools such as STROBOSCOPE and VITASCOPE can be of significant help in modeling and studying how, for example, planned construction operations can interact with airside airport traffic.

3. Technical Approach: Detroit Metropolitan Airport

3.1 Airport Layout

The DTW airport currently has six runways: four main parallel runways (4R–22L, 4L–22R, 3L–21R, 3R–21L) oriented on a northeast–southwest heading and two crosswind runways (9L–27R and 9R–27L) oriented on an east–west heading. In 2001, the new parallel runway 4L–22R added to Metro’s three primary parallel runways and two crosswind runways. The two crosswind runways are rarely used, and therefore were not taken into consideration in the model. In 2002, the nation’s 10th busiest airport completed a $1.2 billion expansion project, which includes
21L. However, in the case of runway 22L, priority is accorded to arrivals over departures and simultaneous arrivals on runways 22L–22R can occur.

The following sections discuss two different scenarios picturing the possible modes of operations at DTW under the aforementioned meteorological conditions (IFR and VFR) and depending on the type of aircraft. In this study, aircraft are classified according to the wake vortex criteria: light, medium and heavy. This classification is based on aircraft maximum gross mass. Light aircraft have a maximum takeoff mass of less than 18 635 kg. Medium size aircraft weigh up to 116 000 kg and heavy aircraft are those with a maximum takeoff mass above 116 000 kg [20]; see Table 2. Runways assigned for departures are the same under both flight conditions.

3.3 Airport Operations Scenario I: IFR Conditions

The first modeled scenario operates under IFR conditions where two runways (21L and 22R) process arrivals. Heavy, medium and light airplanes can land on any of these two runways. For departures, runway 21R processes medium and light aircraft whereas 22L processes heavy ones.

3.4 Airport Operations Scenario II: VFR Conditions

In this case, three runways (21L, 22L and 22R) are used for arrivals for any aircraft type. Departures procedures meet the same requirements for IFR conditions (Scenario I).

4. Simulating Runway Operations at DTW Using Stroboscope

The parameters and assumptions used to create the desired model for the DTW airport are the same as those described in [21]. The common approach path was assumed to be 15 km in length. The minimum separation distances between successive aircraft, which air traffic controllers comply with to account for wake turbulence, depend on the types of the aircraft. They also include a ‘buffer’ distance of 2100 m that acts as a safety factor. Since it is
subject to measurement errors on the part of the air traffic controller, the actual buffer is assumed to be normally distributed with a mean of 2100 m and a standard deviation of 1260 m. When the trailing airplane is slower than the leading airplane, the minimum separation occurs when the airplane that follows enters the common approach path. When the trailing airplane is faster than the leading airplane, the minimum separation occurs when the leading airplane crosses the runway threshold. Table 3 shows the necessary separation between aircraft when the trailing airplane enters the common approach path [21].

The arrival/departure distance is assumed to be 3200 m so that a departing airplane terminates its runway occupation before the arriving aircraft touches the runway. Since departing aircraft create wake turbulence that affects other aircraft departing on the same runway, minimum times between successive departures have to be set to account for differences in takeoff speed (i.e. to prevent a fast plane overtaking a slow plane) and for wake turbulence effects. These times are shown in Table 4 [21].
Table 3. Minimum distance between aircraft entering the final approach corridor

<table>
<thead>
<tr>
<th>Following airplane type</th>
<th>Leading airplane type</th>
<th>Minimum distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>Heavy</td>
<td>6000</td>
</tr>
<tr>
<td>Heavy</td>
<td>Medium</td>
<td>6840</td>
</tr>
<tr>
<td>Heavy</td>
<td>Light</td>
<td>8760</td>
</tr>
<tr>
<td>Medium</td>
<td>Heavy</td>
<td>9000</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>6000</td>
</tr>
<tr>
<td>Medium</td>
<td>Light</td>
<td>8120</td>
</tr>
<tr>
<td>Light</td>
<td>Heavy</td>
<td>12000</td>
</tr>
<tr>
<td>Light</td>
<td>Medium</td>
<td>9000</td>
</tr>
<tr>
<td>Light</td>
<td>Light</td>
<td>6000</td>
</tr>
</tbody>
</table>

Table 4. Minimum time between successive departures

<table>
<thead>
<tr>
<th>Trailing plane type</th>
<th>Leading plane type</th>
<th>Minimum time between successive departures (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>Heavy</td>
<td>60</td>
</tr>
<tr>
<td>Heavy</td>
<td>Medium</td>
<td>90</td>
</tr>
<tr>
<td>Heavy</td>
<td>Light</td>
<td>120</td>
</tr>
<tr>
<td>Medium</td>
<td>Heavy</td>
<td>60</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>60</td>
</tr>
<tr>
<td>Medium</td>
<td>Light</td>
<td>90</td>
</tr>
<tr>
<td>Light</td>
<td>Heavy</td>
<td>60</td>
</tr>
<tr>
<td>Light</td>
<td>Medium</td>
<td>60</td>
</tr>
<tr>
<td>Light</td>
<td>Light</td>
<td>60</td>
</tr>
</tbody>
</table>

The speed of landing aircraft while in the common approach path depends on the type of aircraft. The time of runway occupation is normally distributed and depends on the type of aircraft and on whether the aircraft is landing or taking off. Table 5 shows the various approach speeds and runway occupation times (ROT) [21].

The aircraft mix for this simulation model is 33% heavy, 33% medium size and 33% light, but can be easily modified in the model to reflect any other aircraft mix. The DTW arrival and departure schedule shown in Table 6 was obtained from the Bureau of Transportation Statistics (BTS) database by looking up the Detailed Statistics [22] for arrivals and departures according to each airline and then computing the daily averages for the busy month of December 2004.

The purpose of this simulation is to determine the expected average and maximum daily waiting times for arriving and departing airplanes for any runway configuration. This information is used to determine if the airport is capable of supporting the demands shown in Table 6 with acceptable delays.

Other assumptions are taken into consideration. The model does not include holding delays at the gate in calculating the total outbound delay. All aircraft are assumed to leave from and arrive at L.C Smith Terminal, in particular concourse C with several different gates. Figure 4 shows the Smith terminal and highlights the concourse considered.

The model thus assumes oversimplified taxi and gate operations, i.e. all arriving planes taxi to the same concourse C before they exit the simulation. Similarly, departing planes all start from the same concourse C and taxi to the appropriate designated departure runway. The taxi times assumed for all the operations are calculated based on a speed of 10 m s⁻¹ [23].

If waiting times are excessive, minimizing airport traffic or improving runway utilization is a necessary action to be taken. One way to improve the use of the runway is with the employment of better surveillance technology that helps reduce the safety buffer added to the minimum prescribed separation between aircraft by air traffic controllers [21].

4.1 Airport Operations Scenario I

4.1.1 Modeling Arrivals, Approach and Landing

Two runways process arrivals: 21L and 22R. Heavy, medium and light airplanes can land on any of these two runways. The model network that reflects the activities in this case is shown in Figure 5. This network illustrates three major portions. The first introduces airplanes to the system through arrival scheduler resource, the second models approach and landing of airplanes through
resource Plane and the third models the minimum separations between airplanes in the common approach path through Sequencer resource.

The first portion of the network comprises of the Parrival Combi activity; the ArvlSchdls Queue; and the AS1, AS2 and API links model the airplanes arrival within the system. Each of the 24 resources of type ArvSchd, which are initially in ArvlSchdls queue, represent the information in the first two columns of the corresponding row in Table 6, and enable the creation of a separate instance of Parrival. The duration of Parrival is set such that each instance ends at the time at which an airplane of the corresponding time period arrives. This duration is defined in the STROBOSCOPE model using the following expression:

```
DURATION Parrival
  'Parrival.ArvlSchd.I=0?Parrival.
  ArvlSchd.I.SampledIAT:
  Parrival.ArvlSchd.NextAv';
```

SampledIAT is the interarrival time between airplanes and is based on the rates from Table 6. StartHr and EndHr define one hour range timing for each arrival scheduler resource as shown in Table 6. The variable CurHour and the property NextAv, referenced in the above expression, are calculated as follows:

```
VARIABLE CurHour
Mod(SimTime/3600+SimBeginHour,24);
VARPROP ArvlSchd.NextAv
  'SampledIAT+CurHour*3600<EndHr*3600 ?
  SampledIAT:
  SampledIAT+ (24-(EndHr-StartHr))*3600';
```

When Parrival terminates, the arrival scheduler is released to ArvlSchdls, creating another instance of Parrival. Arrival schedulers are thus constantly circulating in this part of the network and constantly introducing arriving airplanes to the system. Each time an instance of Parrival terminates, an airplane of the appropriate type (light, medium or heavy) is generated and placed in the PlanesWaitL queue. The type of the airplane is determined such that there is an equal probability of the plane being light, medium, or heavy.

The second portion of the network represents the system logic that controls airplanes approaching the runway and landing on either 21L or 22R. This is achieved in the model by first defining the property LandRun for the characterized resource Plane and assigning it to any of the runways based on a probabilistic selection. The next step is to use the fork Run22Ror21L and set conditions on links AP4 and AP21. AppRwys is a zero-duration dummy activity that marks the entry of airplanes into the common approach path either for runway 21L or 22R.

From this point, all tasks performed on each runway are almost identical. In other words, the system logic be-

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Table 5. Approach speed and runway occupation times (ROT) [20]

<table>
<thead>
<tr>
<th>Plane type</th>
<th>Approach speed (m s⁻¹)</th>
<th>Land ROT mean (s)</th>
<th>Land ROT std dev (s)</th>
<th>Take off ROT mean (s)</th>
<th>Take off ROT std dev (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy</td>
<td>75</td>
<td>55</td>
<td>6</td>
<td>38</td>
<td>4</td>
</tr>
<tr>
<td>Medium</td>
<td>68</td>
<td>50</td>
<td>10</td>
<td>43</td>
<td>6</td>
</tr>
<tr>
<td>Light</td>
<td>52</td>
<td>45</td>
<td>10</td>
<td>50</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 6. Arrival and departures rates as function of time of day (source: http://www.bts.gov/programs/airline_information/airline_ontime_statistics/DetailedStatistics/)

<table>
<thead>
<tr>
<th>Time</th>
<th>Arrivals per hour</th>
<th>Departures per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VFR</td>
<td>IFR</td>
</tr>
<tr>
<td>00:00-01:00</td>
<td>3.94</td>
<td>3.28</td>
</tr>
<tr>
<td>01:00-02:00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>02:00-03:00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>03:00-04:00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>04:00-05:00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>05:00-06:00</td>
<td>6.55</td>
<td>5.46</td>
</tr>
<tr>
<td>06:00-07:00</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>07:00-08:00</td>
<td>10.51</td>
<td>8.76</td>
</tr>
<tr>
<td>08:00-09:00</td>
<td>18.26</td>
<td>15.22</td>
</tr>
<tr>
<td>09:00-10:00</td>
<td>24.6</td>
<td>20.50</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>22.4</td>
<td>18.67</td>
</tr>
<tr>
<td>11:00-12:00</td>
<td>32.84</td>
<td>27.37</td>
</tr>
<tr>
<td>12:00-13:00</td>
<td>30.54</td>
<td>25.45</td>
</tr>
<tr>
<td>13:00-14:00</td>
<td>6.51</td>
<td>5.43</td>
</tr>
<tr>
<td>14:00-15:00</td>
<td>36.19</td>
<td>30.16</td>
</tr>
<tr>
<td>15:00-16:00</td>
<td>26.29</td>
<td>21.91</td>
</tr>
<tr>
<td>16:00-17:00</td>
<td>30.35</td>
<td>25.29</td>
</tr>
<tr>
<td>17:00-18:00</td>
<td>21</td>
<td>17.50</td>
</tr>
<tr>
<td>18:00-19:00</td>
<td>29.22</td>
<td>24.35</td>
</tr>
<tr>
<td>19:00-20:00</td>
<td>23</td>
<td>19.17</td>
</tr>
<tr>
<td>20:00-21:00</td>
<td>32.32</td>
<td>26.93</td>
</tr>
<tr>
<td>21:00-22:00</td>
<td>17.16</td>
<td>14.30</td>
</tr>
<tr>
<td>22:00-23:00</td>
<td>8.5</td>
<td>7.08</td>
</tr>
<tr>
<td>23:00-24:00</td>
<td>6.06</td>
<td>5.05</td>
</tr>
</tbody>
</table>
Figure 5. Stroboscope network for arrivals, Scenario I
hind the operations on both runways is the same, and only operations carried out on runway 21L are therefore described in this paper. Before proceeding with this portion of the network, it is important to first introduce the third.

The third portion of the network comprises AppSignals, PAppSep and the SE1, SE2 and SE3 links control the separation distances between airplanes in the common approach path. PAppSep takes place immediately after PAppRun concludes and its duration is set to the minimum lead-time of the corresponding plane. MinLeadTime is a property of Plane, which specifies the minimum separation time between the arriving plane and the next plane to arrive. This value is determined from Table 4 (which is represented by a matrix in STROBOSCOPE), adding a stochastic buffer and dividing by the approach speed. This is defined in the model from the expression:

```plaintext
ONRELEASE AP1 ASSIGN MinLeadTime
`Min [ComAppL, (MatrixIJ[NextArvType==
Heavy ?0:NextArvType==Medium?1:2, Type] +Max[MinBufferd,Min[mNormal[BufferDist,
BuffDistsd,2],MaxBufferd]])]/AppSpeed;
```

It is after this time has passed that a resource is released to AppSignals, thus preventing other airplanes that may be in AppR21L to begin approaching during that time. PAppRun, a zero-duration dummy that marks the entry of an airplane into the common approach path toward runway 21L, can then start whenever both AppSignals and AppR21L queues contain at least one resource each (first available resource in each is removed, FIFO). The common approach path is broken into two parts, FirstSCAP and LastSCAP. FirstSCAP, which takes place immediately after PAppRun concludes, represents an airplane traversing the first 11 800 m of the common approach path. LastSCAP starts immediately after FirstSCAP and represents an airplane traversing the last 3200 m of the common approach path. The arriving airplane then lands on the runway and starts to roll on the landing run. Each airplane has properties determined from its type that correspond to those specified in Table 5. However, depending on the type of the plane and the sampled duration of the ROT, the arriving plane can either use the nearest possible exit and clear the runway or roll beyond the first possible exit and takes the next exit. The first case applies to light and medium airplanes, whereas the second case applies to heavy airplanes. This is achieved in the model by defining the fork TaxiOrRoll and setting the conditions on links AP10 (heavy) and AP11 (medium or light) as follows:

```plaintext
STRENGTH AP10 `(PLand1.Plane.Type==0)?1:0'; / type 0 refer to heavy
STRENGTH AP11 `((PLand1.Plane.Type!=0))?1:0'; / in this case its either type 1 or 2 (medium or light)
```

Upon exiting the runway, the aircraft uses the best feasible taxiway to travel from the exit to the designated parking gate. Heavy airplanes travel on a different taxiway (WT5PPF2Run21R) from medium and light airplanes (PPF2Run21R). A taxiing airplane is always aware of the operations that take place on the airport. For example, an airplane will obviously not cross a runway when there are arrivals or departures being processed on that runway. In our case, airplanes taxiing from R21L to concourse C in Smith Terminal cannot cross runway 21R while departures are being conducted on it. This is achieved in the model by using a semaphore for the activity R21RF2Gate as in the expression below. After crossing runway 21R, airplanes travel to gate in concourse C, which is represented by R21RF2Gate in the model.

```plaintext
SEMAPHORE R21RF2Gatec
```

### 4.1.2 Modeling Departures

The model network that describes the logic of airplanes departing is defined in Figure 6.

This network illustrates two major portions: the first introduces departing airplanes to the system through arrival scheduler resource and the second models departures of airplanes through resource Plane. Airplanes departing are generated independently of arrivals according to the rates specified in Table 6 and are placed in the PlanesWaitD queue.

Departures are modeled by the portion of the network comprised of the PDeparture Combi activity, the DptSchdls Queue and the DS1, DS2 and DP1 links in much the same way that the arrivals to the system are modeled. A generated departing plane is assigned a particular runway for departure at the time of its creation. In this case, two runways process departures: 22L and 21R. The assigned runway depends on the current runways designated for processing departures and the type of the departing airplane. Heavy airplanes depart on 22L and light and medium on 21R. This is achieved in the model by creating the fork WestOrEast and setting the probabilistic conditions on links DP4 and DP5 as follows:

```plaintext
STRENGTH DP4
`((TaxiOut2Run.Plane.Type==0)?1:0'; / type 0 refer to heavy
STRENGTH DP5
`((TaxiOut2Run.Plane.Type!=0)) ?1: 0'; / in this case its either type 1 or 2 (medium or light)
```

An airplane ready to depart uses the optimum taxiway path to travel from the parking gate to the assigned runway. Thus, heavy planes travel heading west and medium
and light heading east. An airplane departing from any of the runways is cleared for departure when there is no other traffic on the assigned departure runway. As shown below, this is achieved in the model by setting semaphores for both activities ONRun22L and ONRun21R as well as RollingR22L and RollingR21R.

Rolling activities, in both cases, are given priority over runway crossings (R22LV2Gatec and R21RF2Gatec). In addition, they can not start if there is a plane taking off. For rolling activity RollingR21R, additional conditions are set because under IFR conditions, runways 21R and 21L can not process simultaneous arrivals/departures since the centerline distance is approximately 610 m which is less than the required distance of 762 m. A plane ready to depart from runway 21R must therefore be cleared for rolling when there are no arrivals to be conducted on runway 21L. (arrivals are first allowed to be conducted). A departing plane, after being cleared for departure, then occupies the runway for the sampled ROT duration before taking off. Since departing aircraft create wake turbulence that affect other aircraft departing on the same runway, minimum times between successive departures (shown in Table 4) have to be set to account for differences in takeoff speed, thus preventing a fast plane overtaking a slow plane and avoiding wake turbulence effects. The duration for takeoff is therefore equivalent to the difference between minimum times between successive departures and ROT before taking off.

4.2 Airport Operations Scenario II

4.2.1 Modeling Arrivals, Approach and Landing

Three runways process arrivals: 21L, 22R and 22L. The simulation network (Figure 7) that corresponds to this scenario is the same as in Figure 5 but with an additional portion (middle branch) accounting for runway 22L.

Heavy airplanes land on runway 22L and medium and light airplanes land on either of the runways 21L or 22R, defined in STROBOSCOPE as:

```
ONDRAW AP2 ASSIGN LandRun 'Type==0?R22L:Rnd [1] <=0.5?R22R:R21L' ;
```

The property LandRun for the characterized resource Plane is assigned a third new variable representing runway 22L based on a probabilistic selection. Moreover, a new condition on link AP46 is set.

```
STRENGTH AP46 'AppRwys.Plane.LandRun==R22L' ;
```

The main change to this model compared to the Scenario I model is that for each runway no forks are needed to model the path of resource Plane based on a probabilistic selection procedure. This is because each runway processes only planes of the same type, whether heavy or medium and light. By consequence, all forks are removed and all activities and queues which are not related to the plane type allowed to land on this specific runway are also excluded.

drawFigure{6}{Stroboscope network for departures, Scenario I}{0.6}
Figure 7. Stroboscope network for arrivals, Scenario II
4.2.2 Modeling Departures

The simulation network that models departures under this scenario is the same as in Figure 6. But in this case, new conditions are added to the semaphores related to departure activities performed on runway 22L since this runway is processing arrivals and departures. This is defined in the STROBOSCOPE code as follows:

```
SEMAPHORE ONRrun22L 'ONRun22L.CurInst & 
!RollingR22L.CurInst& 
!Rdy2RollR22L.CurCount 
&!R22LV2Gatec.CurInst&!LastSCAPI.CurInst 
&!PLandI.CurInst& 
!PLandII.CurInst 
&!TakeOffR22L.CurInst' ;
```

Other differences include removal of conditions from semaphores for departure activities performed on runway 21R since operations are conducted under VFR conditions. In this case, there are no constraints concerning the arrival activities performed on the parallel runway 21L as opposed to the other scenario.

5. STROBOSCOPE Simulation Results

5.1 Variables and Collectors

Variables and collectors were used to store all the necessary results. Collectors are action targets that keep statistics about the number they receive. This was achieved in the model by first defining the variables and collectors and then collecting the results as follows:

```
/Arrivals
COLLECT ArvPerHr ArvsPerHr;
COLLECT ArvMxWt ArvMaxWt;
COLLECT ArvAvWt ArvAveWt;

/Departures
COLLECT DptPerHr DptsPerHr;
COLLECT DptMxWt DptMaxWt;
COLLECT DptAvWt DptAveWt;
```

5.2 Runway Performance

5.2.1 Scenario I

A run of the model with ten batch means replications, each 1 day in length (86 400 s), yielded the results in Table 7 which are taken directly from the output. The runway configuration assumed for this simulation run is the one performing under IFR conditions: arrivals on Runway 21L and 22R and departures on Runways 21R and 22L.

These results indicate that the average daily waiting time for arriving and departing airplanes over the 10 days simulated in December 2004 was about 2.28 min and about 0.71 min, respectively (Figure 8).

5.2.2 Scenario II

Another run of the model considering VFR conditions yielded the results in Table 8.

Under Scenario II, Figure 9 indicates that the average daily waiting time for arriving and departing airplanes over the 10 days simulated in December 2004 was about 1 min and about 0.24 min, respectively. These results show clearly that under better weather conditions, waiting times diminish.
Table 7. Scenario I results

<table>
<thead>
<tr>
<th>Daily arrival values</th>
<th>Daily departure values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average arrivals (hr⁻¹)</td>
<td>Maximum wait</td>
</tr>
<tr>
<td>9.79</td>
<td>11.19</td>
</tr>
<tr>
<td>10.58</td>
<td>15.68</td>
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<tr>
<td>10.42</td>
<td>20.24</td>
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<td>10.29</td>
<td>14.16</td>
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<tr>
<td>9.96</td>
<td>14.04</td>
</tr>
<tr>
<td>9.38</td>
<td>14.49</td>
</tr>
<tr>
<td>10.21</td>
<td>10.09</td>
</tr>
<tr>
<td>9.88</td>
<td>7.53</td>
</tr>
<tr>
<td>9.71</td>
<td>10.52</td>
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<tr>
<td>9.33</td>
<td>12.11</td>
</tr>
<tr>
<td>Mean</td>
<td>9.95</td>
</tr>
<tr>
<td>SD</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Table 8. Scenario II Results

<table>
<thead>
<tr>
<th>Daily arrival values</th>
<th>Daily departure values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average arrivals (hr⁻¹)</td>
<td>Maximum wait</td>
</tr>
<tr>
<td>10.42</td>
<td>8.18</td>
</tr>
<tr>
<td>10.75</td>
<td>16.55</td>
</tr>
<tr>
<td>9.13</td>
<td>11.59</td>
</tr>
<tr>
<td>8.92</td>
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<td>9.54</td>
<td>7.69</td>
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<td>10.25</td>
<td>8.19</td>
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<td>10.13</td>
<td>7.17</td>
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<td>10.08</td>
<td>9.73</td>
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</tr>
<tr>
<td>Mean</td>
<td>9.86</td>
</tr>
<tr>
<td>SD</td>
<td>0.63</td>
</tr>
</tbody>
</table>

6. Validating DTW Airport Simulation Models Using 3D Vitalsec Animation

6.1 3D Animation Objectives

One of the primary disadvantages in the use of discrete-event simulation models is that there are often no means to check the credibility of the models and the authenticity of the results [7]. Visualization and animation of simulated operations can be very helpful in the verification, validation and accreditation (VV&A) of models [24]. As such, the objectives of 3D animations are: (1) to verify that code is free of errors; (2) to validate simulation models; and (3) to ensure the credibility of models once verified and validated [25]. The STROBOSCOPE models presented earlier are validated in this study using VITASCOPE [11].

6.2 VITASCOPE Characteristics

VITASCOPE is a general-purpose, user-extensible 3D animation system designed for visualizing simulated processes in smooth, continuous, 3D virtual worlds. VITASCOPE is capable of visualizing modeled operations in 3D by connecting ASCII animation trace and 3D CAD models of the involved resources [7]. VITASCOPE characteristics are: (1) maintaining an independent simulation clock; (2) allowing the user to navigate in 3D space; (3) allowing the user to jump to any desired time; and (4) permitting the viewer to start and pause the animation at any simulation time to check the trace files [9].
VITASCOPE trace file consists of sequential animation command statements such as TIME, CLASS, CREATE, MOVE and DESTROY. The trace file also contains statements such as PATH and NONDIRECPATH that define resource movement trajectories for the animated simulation entities.

Simulation models need to be instrumented to generate VITASCOPE animation commands during a simulation run. Three-dimensional CAD models need to be imported to visualize the simulated operations.

6.3 Animation Snapshots of Visualized Operations at DTW

Once all the models are instrumented, trace files are generated during each simulation run. After the statements are processed, the result is a pictorial representation of the actual operations being conducted in a 3D virtual environment. All VITASCOPE characteristics can be of great use here. The animation can be replayed at varying speeds but in our case the animation is set to a speed of 40 (VIEWRATIO 40). The user can jump to any desired time and inspect the state of the system and can also navigate easily in the 3D virtual space. Figure 10 presents VITASCOPE animation snapshots of the operations on the airport.

7. Simulating and Validating Simultaneous Airport and Construction Operations at DTW

Previous sections modeled and visualized only airport operations at DTW. This section, however, presents the interaction between airport and construction operations. With the new McNamara Terminal and more than $2 billion worth of recent airport improvements complete, the Wayne County Airport Authority is moving forward with the next round of improvements at DTW Airport, including the North Terminal Redevelopment (NTR) Project, a planned 26-gate terminal complex [26]. When complete, the new North Terminal complex will be used to accommodate DTW’s airlines that are currently operating out of the aging L.C. Smith and Berry Terminals. The new facility is located on the site of the existing Davey Terminal, Airport Hotel and between the L.C. Smith Terminal and the Berry International Terminal (Figure 11). Figure 12 depicts the STROBOSCOPE simulation model representing the construction operations at DTW. Figure 13 shows VITASCOPE animation snapshots of the interaction between construction and airport operations.

8. Conclusions and Future Work

We modeled airside airport operations using a general purpose simulation tool typically used in construction in order to determine the simulation tool’s ability to simultaneously model operations in the construction and airport operation domains. Previous work on airport simulation and animation was examined, followed by a description
of how airport operations at Detroit Metropolitan Airport were modeled and animated using general purpose tools typically used in construction simulation and visualization.

Two scenarios based on different meteorological conditions were examined and respective STROBOSCOPE models with all required parameters were presented. VITASCOPE was used as a 3D animation tool to ensure the credibility and validation of the models. Finally, results were generated from STROBOSCOPE models. The obtained results prove that general-purpose tools, even if originally designed for specific domains, can be effective in studying operations involving the interaction of entities in multiple domains such as construction and airport
Figure 11. Construction operations at DTW between Smith and Berry terminals

Figure 12. STROBOSCOPE simulation model representing construction operations at DTW
Figure 13. VITASCOPE Animation of Construction Operations at DTW between Smith and Berry Terminals

operations. Only airport operations were modeled in this study using general-purpose tools. Future work will include mixed construction-airport operations.

9. References


Hiam M. Khoury is a Ph.D. Candidate at the Department of Civil and Environmental Engineering at the University of Michigan. She received an M.S.E. in Construction Engineering and Management in 2005 and a B.E. in Civil Engineering from the Lebanese American University (Byblos, Lebanon) in 2004. As part of her doctoral research, she is investigating feasible techniques of user position and orientation tracking to enable visualization of construction graphics in augmented reality in indoor construction environments.

Vineet R. Kamat is an Assistant Professor in the Department of Civil and Environmental Engineering at the University of Michigan. He received a Ph.D. in Civil Engineering at Virginia Tech in 2003, a M.S. in Civil Engineering at Virginia Tech in 2000 and a B.E. degree in Civil Engineering from Goa University (India) in 1998. He designed and implemented the VITASCOPE visualization system with J. Martinez as part of his doctoral research. In addition to visualization, his research interests include discrete event simulation, information technology and decision support systems for construction engineering.

Photos G. Ioannou is a Professor in the Department of Civil and Environmental Engineering at the University of Michigan. He received a Civil Engineer’s degree from the National Technical University, Athens, Greece, in 1979, and a SMCE and Ph.D. in Civil Engineering from MIT in 1981 and 1984, respectively. From 1989–1995 he served as Chair of the Computing in Construction Technical Committee of the ASCE. He co-developed the UM-CYCLONE construction process simulation system with R.I. Carr, supervised the design and development of COOPS by L.Y. Liu and chaired J.C. Martinez’s Ph.D. dissertation on STROBOSCOPE. His research interests are primarily focused on the areas of decision support systems and construction process modeling.