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HEURISTIC OPTIMIZATION OF GROUND TRAFFIC AT AN AIRPORT

A thesis submitted to the

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ABSTRACT

Congestion of aircraft on the tarmac at major airports throughout the country is caused, at least in part, by constraints on airside capacity that lead to costly departure and arrival delays. A simulation model is developed to cope with increasing air traffic demand and to minimize delays caused by inefficient decisions, such as runway assignments, routing, sequencing and scheduling of aircraft ground movements. The simulation is used to study aircraft ground movements, particularly different management strategies for controlling ground traffic. The aircraft ground movements at a major US hub airport are analyzed using a simulation model. The proposed approach quantifies the characteristics of aircraft ground movements for analysis and detailed studies. The simulation model is used to evaluate proposed runway assignment algorithms.

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CHAPTER 1

INTRODUCTION

In the past decade there has been a steady increase in air travel all around the world. The Federal Aviation Administration (FAA) predicts that this demand for air travel will continue well into the 21st century [4]. With the increase in demand, the aircraft manufacturers have rolled out new models of aircraft; both large and small. Airlines all over the world are upgrading their fleets, adding new aircraft and destinations to be more competitive and to improve their safety standards. Also, there is significant growth among low fare carriers. Airports are becoming a major bottleneck in air traffic control operations [10].

The delays in aircraft arrivals and departures are a result of a mismatch between the demand for air transportation and airport capacity. The demand for air transportation is growing at a significant rate, the capacity of most airports in the transportation system is growing at a slower rate, and many airports have not increased capacity [2]. Many constraints on capacity enhancement stem from environmental considerations, specifically noise and emissions due to the construction of additional runways and taxiways. Airports are getting more and more congested with aircraft on the tarmac with the set of available runways as one of the most constraining factors. If the capacity of airports is to be increased to reduce delays, then operations at these airports must become more efficient. One way to alleviate congestion is to assist controllers in the aircraft ground movement planning process. Despite rising traffic levels, a large percentage of air traffic controllers use equipment and decision strategies introduced in the late 1970's [4].

Within the context of aircraft ground movement operations, simulation is proposed as a decision support tool, that controllers can utilize to test new decision strategies. The advantage of simulation is that current operations do not need to be disrupted to do testing.

1.1 Ground Operations

Airport ground operations management includes several control tasks, that is, pushback, engine start time, taxiway entry, runway assignment, and landing and departure clearance. Air traffic controllers typically make time critical decisions under high workload conditions. With simulation as a decision support tool, it will be possible to explore and validate a very large number of possible sequencing and scheduling strategies.

The process described below is based on the operations at a major US airport. The operations at other airports may vary slightly from the one mentioned below due to the uniqueness of airport designs. The following step-by-step operations follow an aircraft the time it pushes back from the gate to the time it receives its departure clearance.

1. Departure aircraft, controlled by the ramp controller push back from the gate and taxi to a designated spot on the ramp.
2. The aircraft waits at the designated spot until contacted by the ground controller. In some cases, the aircraft may contact the tower and request permission to taxi. In all cases the tower is told the flight number.
3. The ground controller issues taxi orders to the aircraft. Typical orders include instructions to obtain the most current weather report, a prescribed taxiway routing, the departure runway, the runway intersection where the aircraft will wait and ground movement rules such as ground traffic right-of-way rules. It may become necessary for the ground controller to issue additional commands to the aircraft while it is taxiing. For example, the controller may wish

for the aircraft to yield to other traffic to either let it into the ramp area, or to allow another aircraft to enter into the taxiway. While there are several taxi routes available a "standard-taxi" exists in order to expedite the issuance of taxi clearances. The standard taxi route varies upon the spot from which the aircraft exited the ramp area and the airport configuration. The ground controller also tends to split aircraft by route when assigning them a runway intersection [4].

4. Once the aircraft reaches the assigned runway intersection, the departure sequence is essentially set. Control of the aircraft at this time is passed to the local controller. The local controller can re-sequence at his/her discretion to decrease delays or if there is a special circumstance.

The sequencing process the ground controller uses is rather straightforward. As the aircraft sits at its spot on the tarmac waiting to taxi, the ground controller has to make two decisions. The first is to assign the aircraft to an intersection for a runway. The second decision is the aircraft's position in the "local" sequence of aircraft on the taxiway. By controlling the flow of ground traffic the ground controller is able to build a sequence locally optimized to maximize runway throughput. The ground controller may stop individual aircraft at taxiway intersections in order to insert a new aircraft ahead of it in the sequence. Likewise, the controller will hold the departure aircraft at its spot in order to put it behind one or more aircraft.

1.2 Contribution of this research

A new approach for modeling aircraft ground movements at major US airports is proposed. This approach is illustrated through a specific example. Heuristic algorithms for runway assignments are proposed to reduce the waiting time and the time taken to travel from the gates to the runway. The contributions made can be summarized as follows:

1. Data analysis on airside operations, at the airport reveals “departure rushes” and “arrival rushes”.
2. Design a full size AutoCAD model for the airport, detailing the intersections, taxiways, runways and ramps.
3. Develop a simulation model, used prescribed schedules as input to the model and validated the model by comparing output statistics from the simulation to actual data.
4. Propose algorithms for runway assignment to reduce the waiting time and the time to travel from the gates to the runway.
5. Validate the algorithms by implementing them in the simulation model and comparing the outputs to the normal operational procedure.

1.3 Organization of the thesis

Chapter 2 discusses the research problem studied in detail. It reviews the current literature on aircraft ground movement operations and justifies the use of simulation over analytical models in this case. In Chapter 3, the simulation model is presented along with a proposed algorithm to assign aircrafts to runways during departure rushes. Chapter 4 presents example data sets and reviews the validation of the model and the algorithm. Chapter 5 discusses conclusions and recommendations for future research.

CHAPTER 2

PROBLEM STATEMENT AND LITERATURE REVIEW

As the volume of air traffic continues to steadily increase, the entire airport system, including the airport surface, is becoming more congested. This congestion results in large delays that affect both arrivals and departures. For arrivals, it means long taxi times from the runway to the terminal. For departures, it means long departure queues, and subsequently long delays. Aviation researchers have recognized the need for enhanced airport surface traffic control systems [2].

Terminal area ground traffic management handles both arriving and departing traffic. The research work on terminal area operations has focused primarily on the arrival flow. However, arrivals and departures are highly coupled processes, especially in the terminal airspace, with complex interactions and sharing of airport resources between arrivals and departures taking place in practically every important terminal area. Therefore, the overall efficiency of the airport can be enhanced by the addition of departure automation aids in cooperation with existing arrival flow automation.

2.1 Problem Statement

To illustrate the problem at the simplest conceptual level, one can imagine an airport with a single runway dedicated for departures and landings, a set of aircrafts waiting to depart and land, and a single air traffic controller. This air traffic controller has a few basic decision problems to solve:

- Which aircraft should depart next?
- Which exit point (from ramp to taxiway) should an aircraft be assigned to?

- Which runway should an aircraft be assigned to?

These decisions must be made repeatedly over the course of a working day. Figure 1 shows a schematic diagram of a major US airport, which is considered for our research.

Constraints

The main constraint of the problem is that the time between successive takeoffs must be greater than a specified minimum that is dependent upon the aircraft involved.

Different components of the airport were identified as flow constraints that introduce delays and inefficiencies and contribute to the low prediction capability associated with departures. The flow constraints identified are associated with the main airport system elements: the gate complex, the ramp area, the taxiway system, and the runway system. The runway system is by far the major source of delays at airports. The delay waiting for other aircraft landing or departing at the runway may be caused by a number of reasons. Hard Constraints are constraints which are absolutely necessary from a safety point of view. These are constraints on separation of takeoff times, and are absolute requirements for safety reasons.

Wake Vortex Constraints are FAA mandates forcing all departing aircraft to have a minimum inter-departure separation. This separation is due to wake vortices that form when an aircraft generates lift, and are necessary, because the vortices may impose a rolling moment strong enough to exceed the trailing aircraft's roll-control authority. The required separations for wake turbulence are given below and are given as a function of weight class.

Table 1: Wake vortex separation between the leading and trailing aircraft

Trailing Aircraft

		Heavy	Large / Small
Leading Aircraft	Heavy	90 sec	120 sec
	Large / Small	60 sec	60 sec

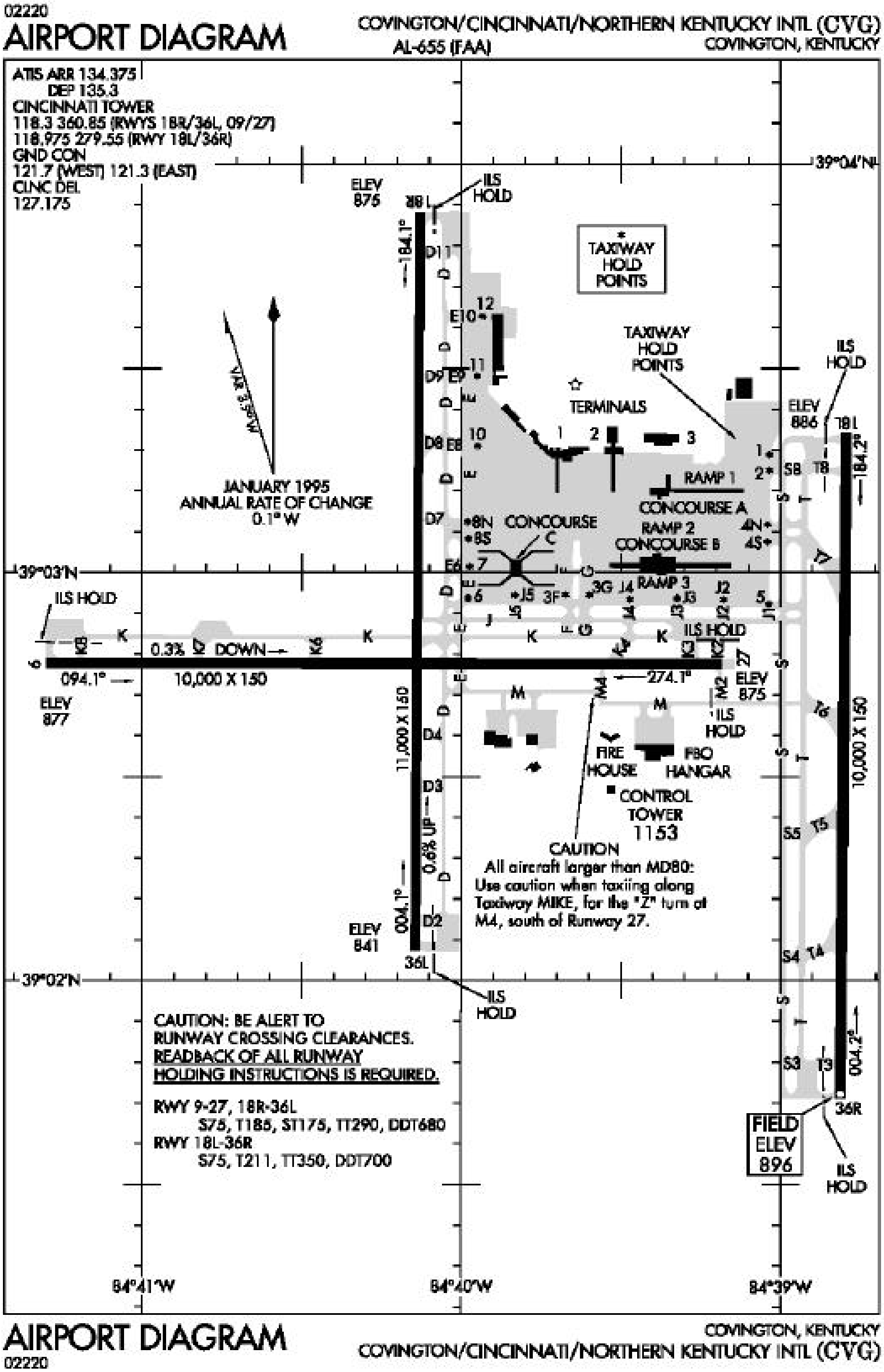

Figure 1: Airport diagram of a major US airport

Miles in Trail Separation depends on the field aircraft routing. Air traffic controllers can use a smaller take-off separation if two aircraft have diverging flight paths. For example, the required separation is 3 nautical miles (nm) or 1 minute (min) if the flight paths diverge to different departure fixes. The separation is increased to 5nm or 2min if the flight paths have the same departure fix.

Soft Constraints are constraints that are based on administrative requirements rather than safety requirements. The calculated takeoff times are an administrative requirement rather than a safety requirement. In fact, at busy times it may not be possible to meet all the calculated takeoff time slots. If an aircraft misses the calculated takeoff time slot, the pilot must wait for the FAA ATC tower to issue a new slot.

Scheduled demand for departures is often higher than the effective capacity of the runway. Generally, the average demand for runway operations is lower than the effective capacity of the runway, but the demand exceeds the capacity during peak hours in the day. Even though high demand occurs only during rush hours, the large queues and delays that form take a long time to deplete.

Capacity limitations due to landing aircrafts are evident when the runway is used for both landings and take-offs the effective capacity for departures are reduced whenever the capacity for arrivals is increased.

Workload constraints occur under heavy traffic conditions, the controllers are forced to adopt strategies that ease their workload, while being unable to use alternative strategies that may reduce runway waiting time.

Runway crossing constraints form when there is coupling between multiple runways. Departures at a runway may experience delays due to operations on other runways when there is coupling between multiple runways. One such case is through the taxiway system where aircraft landing on one runway have to cross another active runway in order to get to the terminal area

2.2 Methodology

Analytical methods may be used to quickly and cheaply approximate solutions aviation problems. When model details influence solutions, simulation provides a mechanism for handling system complexity.

Introduction to Simulation

- A simulation model is a virtual representation of a system.
- A simulation model can be manipulated in ways that are expensive, or impractical, to evaluate using the real system.
- Simulation analysis can quantify the impacts of system modifications.

Simulation is one of the most powerful tools available for decision making. This is particularly true for complex systems. Simulation modeling is a process of designing a model of the real world system that incorporates all relevant features of the real world system. Once a sufficient simulation model is built, it can be used to test various operational system strategies. Simulation can be a cost effective decision making tool. Simulation is a very practical tool because we can perform experiments on the model designed to replicate the real world system without the risk of damaging the real world system. Simulation helps us minimize the risk by letting us play with the system and see the results of our decisions. Simulation is both an art and a science. The programming and statistical components are science. But efficient analysis and sufficient modeling are an art.

Advantages of Simulation

Simulation has a number of advantages over analytical or mathematical models for analyzing systems. First of all, the basic concept of simulation is easy to comprehend and hence often easier to justify to management or customers than some analytical models. In addition, a simulation model may be more credible because its behavior can be compared to that of the real system or because it requires fewer simplifying assumptions and hence captures more of the true characteristics of the system under study. Additional advantages include:

- We can test new designs, layouts, etc. without committing resources to their implementation.
- It can be used to explore new staffing policies, operating procedures, decision rules, organizational structures, information flows, etc. without disrupting ongoing operations.
- Simulation allows us to identify bottlenecks in information, material and product flows and test options for increasing flow rates.
- It allows us to test hypotheses about how or why certain phenomena occur in the system.
- Simulation allows us to control time. Thus we can operate the system for several months or years of experience in a matter of seconds allowing us to quickly look at long time horizons or we can slow down phenomena for study.
- It allows us to gain insights into how a modeled system actually works and understand which variables are most important to performance.
- Simulation’s greatest strength is its ability to let us experiment with new and unfamiliar situations and to answer “what if “questions.

Disadvantages of Simulation:

- Simulation modeling is an art that requires specialized training and therefore skill levels of practitioners vary widely.
- The utility of the study depends upon the quality of the model and the skill of the modeler.

- Gathering highly reliable input data can be time consuming and the resulting data may still be questionable. Simulation cannot compensate for inadequate or poor management decision making.
- Simulation models are input-output models, i.e. they yield the probable output of a system for a given input. They are therefore “run” rather than solved. They do not yield an optimal solution; rather they serve as a tool for analysis of the behavior of a system under conditions specified by the experimenter.

2.3 Airport System and Simulation

An airport system is one that lends itself well to simulation. The system is complex, and using a computer model to analyze the system is more feasible, cheaper, and safer than experimenting with the system itself. Simulating aircraft movements on airport taxiways and runways provides a realistic environment for testing the planning processes related to the management of departing traffic and the interactions among aircraft landing and departing at an airport. Simulation helps in the investigation of a number of crucial issues:

- What are good strategies for managing congestion at key areas of the airport runway/ taxiway system, such as runway crossing points, busy taxiway intersections, blocking due to large departure queues etc.
- How are tactical taxi paths generated for departing and arriving traffic.
- What are the implications of departure insertion on the sequencing and scheduling strategy for runway operations.
- What are good strategies for managing of gate departure times based on a tentative schedule of operations.

CHAPTER 3

THE MODEL

There are two main objectives of the model. The first objective of the simulation model is to be able to determine the taxi times and waiting times (delays) associated with various aircraft types. The second objective of the model is to reduce the delays and the travel time from the gate to the runways by incorporating proposed algorithms and quantifying algorithm performance. There is no randomness modeled in the simulation.

3.1 Model Scope

The simulation model is implemented in ARENA 5.0 from Systems Modeling Corporation. Figure 2 gives a top level overview of the simulation logic. The model begins with

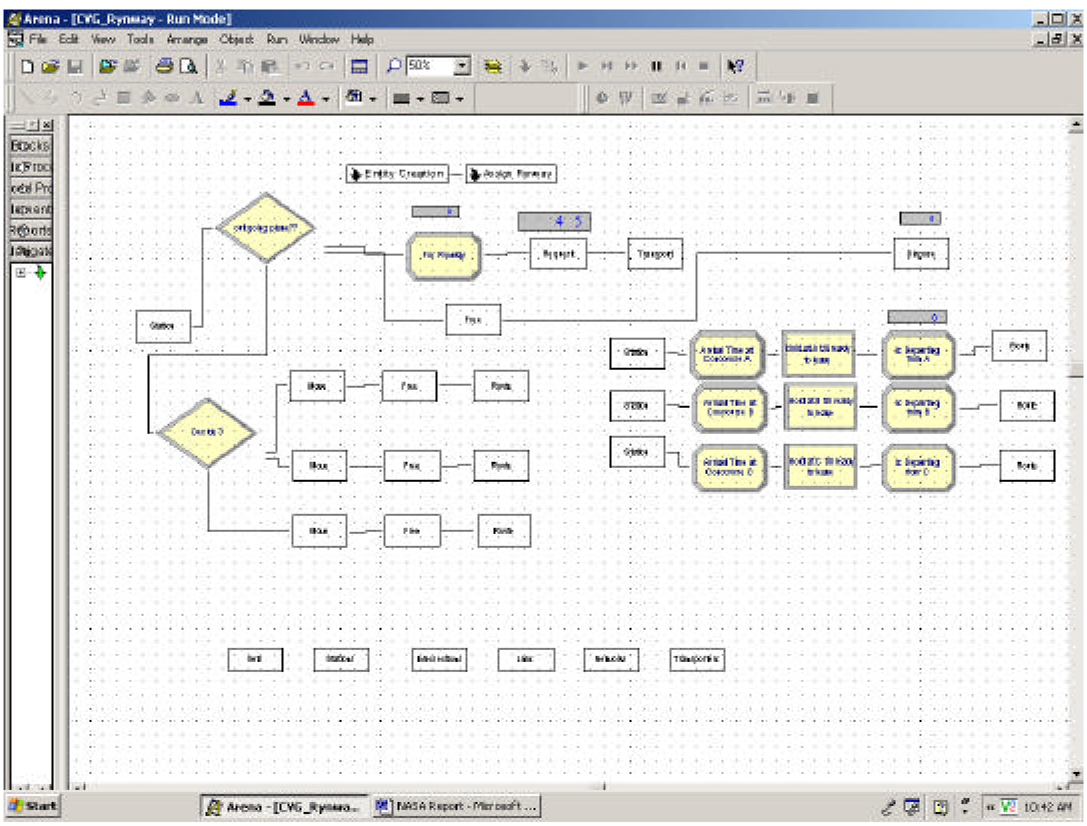

Figure 2: Top level view of the simulation logic

aircraft ready for departure from ramp parking position. Aircraft begin taxi procedures with the removal of the chocks and pylons. The marshalling crew directs the plane to move into the middle of the ramp. The aircraft then proceed down the ramp to the throat of the ramp where it accesses a taxiway. The plane travels down the taxiway to the runway where it is ready for takeoff. The plane takes-off and exits the system. Similarly, landing aircraft travel on the taxiways and ramps after touch down before halting at the gate. The model is designed to serve as a decision support tool to assist air traffic controllers, by providing them a control plan ahead of time. The control plan is determined by evaluating new sequencing and scheduling rules and other algorithms.

3.2 Model Description

The model is designed to be as flexible as possible so the user can change system parameters in external data files without having to alter the actual model. The simulation model is driven by external data files:

- *Departure file* contains statistics on each outbound aircraft including departure time, destination, flight number, aircraft type, and parking position.
- *Arrival file* contains flight arrival times on the runways.

Model logic

The model is broken into processes, which list the events to be carried out in the simulation model, including: model initialization, travel on the ramp, travel on the taxiways, and aircraft takeoff / landings.

Model Initialization

Aircraft push back, which is the reverse movement of the aircraft from the gates with the help of tractors, is the first step in the model and occurs at the time read from the data file.

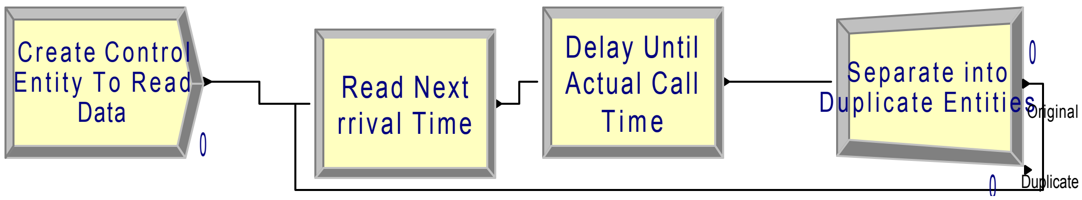

Figure 3: Reading input data from external files.

We need to use the arrival and departure time data stored in an external file to run our simulation model. We use a control entity that mimics the current arriving/ departure and next arrival/departure entity logic directly in our model as shown in the Figure 3. The *create* module generates just a single entity. The created entity enters the *ReadWrite* module where it reads the next value from the data file and assigns this value to the *Call In* entity attribute. The *ReadWrite* module reads one or more values from a source external to ARENA and assigns these values to the model variables. After the entity reads the value from the data file, it moves to the *Delay* module to wait until *Call In*, so that the actual entity representing the call will arrive at the model logic at the appropriate time. Because the values in the data file represent the absolute number of minutes from the beginning of the run for each call rather than the inter-arrival times, the *Delay Time* is specified as *Call In – TNOW* so that the entity will delay until the time stored in the *Call In* attribute. When the control entity completes the delay, it is time to create the actual call entity and dispatch it to the system logic. The *Separate* module sends the control entity back to the *ReadWrite* module to obtain the next call time from the data file and creates one duplicate of itself that is sent into the model logic via the exit point labeled *Duplicate.*

Travel on the Ramps

The ramps are divided into sectors and a simulation resource is used to ensure only one aircraft per sector is allowed to block out at the same time. Travel on the ramps is modeled as an aircraft moving from sector to sector. A simulation resource must be seized before an aircraft is allowed to move into a sector. After traveling through the sector, the resource is released. Ramp taxi speed is an input variable and is applied to all aircraft moving on the ramps.

Travel on the Taxiways

Once the aircraft reaches the end of the ramp, it must enter the FAA-controlled taxiway. The taxiways are modeled using the guided transporter constructs of the ARENA simulation language. A network of links and intersections was constructed to represents the travel paths. The aircraft entity boards a transporter and moves to its assigned runway. The aircraft transporter's destination is the beginning of the runway.

Intersections

The *INTERSECTIONS* element in ARENA is used to define the characteristics of all intersections in our airport air-side system. The intersection name is used in transporter blocks (*REQUEST*, *TRANSPORT*, etc.) and in the *LINKS* element. The distance that an aircraft must travel through the intersection is defined by the *Travel Length* operand. *Travel Length* is specified as an integer in the same units as all other system map descriptions (*links, vehicle size, velocity,* etc.). An aircraft arriving at an intersection that is not the destination of travel moves through the intersection just as it moves through links, using the velocity and the travel length through the intersection. When the aircraft arrives at the end of a link that enters an intersection, it waits to gain access to the intersection. After the vehicle seizes the intersection, it is delayed by the travel time through the intersection (determined by *Travel Length).* When it reaches the end of the intersection, it seizes the first zone of the outgoing link that will take it to its final destination. When it gets the required zone, it continues its travel toward its destination. The timing of seizing and releasing back-most zones (including the intersection) is determined by the zone control characteristic of the transporter. When aircraft are waiting on multiple links to enter the same intersection, the *Link Selection Rule* is used to determine which vehicle is given control of the intersection when it is next vacated. The default rule in our simulation is *FCFS* (first-come, first-served), in which case the aircraft that arrived first at the end of its incoming link is given control of the intersection first.

The *Velocity Change Factor* operand controls the speed with which an aircraft moves through a given intersection. When an aircraft begins to travel through the intersection, its velocity is multiplied by *Velocity Change Factor*. The vehicle's velocity is specified in the *TRANSPORTERS* element.

Links

The *LINKS* element in Arena is used to define the characteristics of the sections between the beginning and ending intersection pairs. Each link is composed of *beginning intersection ID, ending intersection ID, number of zones, and the length of each zone, link type,* the *velocity change factor*, *beginning direction* and *ending direction*. The fields *Beginning Direction* and *Ending Direction* are used to define the direction of the link (in degrees) as it leaves the beginning intersection and as it enters the ending intersection. The value entered varies between 0 and 360 representing direction of travel in degrees (0 and 360 represent right or east). These directions are used in conjunction with the *turning velocity* of the aircraft to slow it down as it turns a corner. If the link direction is different from the beginning intersection to the ending intersection, the *turning velocity factor* is multiplied to the aircraft's current velocity for movement through the middle zone of a link. Also, if an aircraft moves from one link to another link that has a different direction, the turning velocity factor is applied for movement through the connecting intersection.

The *Number of Zones* is used to determine how to move aircraft through the links. If the number of zones is one, then aircraft move through the link as a single event. If the number of zones is greater than one, then aircraft move through the link zone by zone. The aircraft seizes the first zone in the link before commencing movement. When the aircraft arrives at the end of the zone, it waits to seize the next zone on the link. When it gets this next zone, it commences movement through the new zone. This process repeats until the aircraft arrives at the end of the link. The *Length of Each Zone* is the same for all zones in a link. The product of *Number of Zones* and *Length of Each Zones* is the total length of the link.

Networks

The *NETWORKS* element lists all links to be included when defining a system map that the aircrafts follow. The software generates a shortest-distance table between all intersections in the network using the information supplied in the *INTERSECTIONS*, *LINKS*, and *NETWORKS* elements. All aircraft movements in the model follow these shortest-distance paths defined by the system map. Any network can consist of individual links, groups of links, or combinations of individual and groups of links.

Transporters

The *TRANSPORTERS* element establishes the movement of aircraft. Guided transporters are restricted to run on pre specified fixed paths. Guided transporters require the *INTERSECTIONS, LINKS,* and *NETWORKS* elements to specify the system map. The operand *Number of Units* defines the number of individual transporter available. No more than this number of individual units are used during the simulation run; however, some or all of the transporters may be initially inactive.

The *System Map Type* and the *Map ID* operands define the system map that the transporters are to follow. If the *System Map Type* is set to *Distance,* then the transporter will follow the specified distance set defined by the *Map ID* operand and will be treated as a free-path transporter moving between stations. Setting the *System Map Type* to *Network* indicates a guided transporter whose system map is defined by the network Map ID.

The *Control* operand defines the type of zone control to use for a guided transporter set. Zone control determines when an aircraft controlling a zone releases it, allowing another aircraft access to that zone. We use the *Start* control, wherein the aircraft releases its backward-most zone as soon as it is given the next required zone.

Acceleration and *Deceleration* define the acceleration and deceleration properties of an aircraft. They are entered as constants in distance units per base time units squared. The software applies the specified acceleration and deceleration to aircrafts as they move through the system. In general, when an aircraft arrives at the end of a zone, the software checks the zones ahead to estimate whether or not the vehicle will have to stop. If a stop is anticipated, then "braking" is applied according to the specified deceleration. Likewise, if a transporter has either stopped or slowed down, then the software will apply the specified acceleration to return the vehicle to normal operating velocity.

The *Turning Velocity* field defines the factor to be applied to the aircraft's velocity when it negotiates a turn. In order for slow-downs through turns to be performed automatically, directions must be defined for all links in the network, and a *turning velocity factor* must be defined.

Special Features

An Auto CAD drawing of the airport property is imported as a background for the animation. Figure 4 is a screen shot during the preliminary simulation run.

Model Outputs

Runway and aircraft performance parameters are collected and reported in output files. Overall statistics by aircraft type are directed to the output report file. Among the statistics reported, the waiting time and the time taken to travel from the gate to the runways are of extreme importance. The collection of these statistics was facilitated through the use of the ARENA *Time Persistent Statistics* and *Tallies* features for discrete systems.

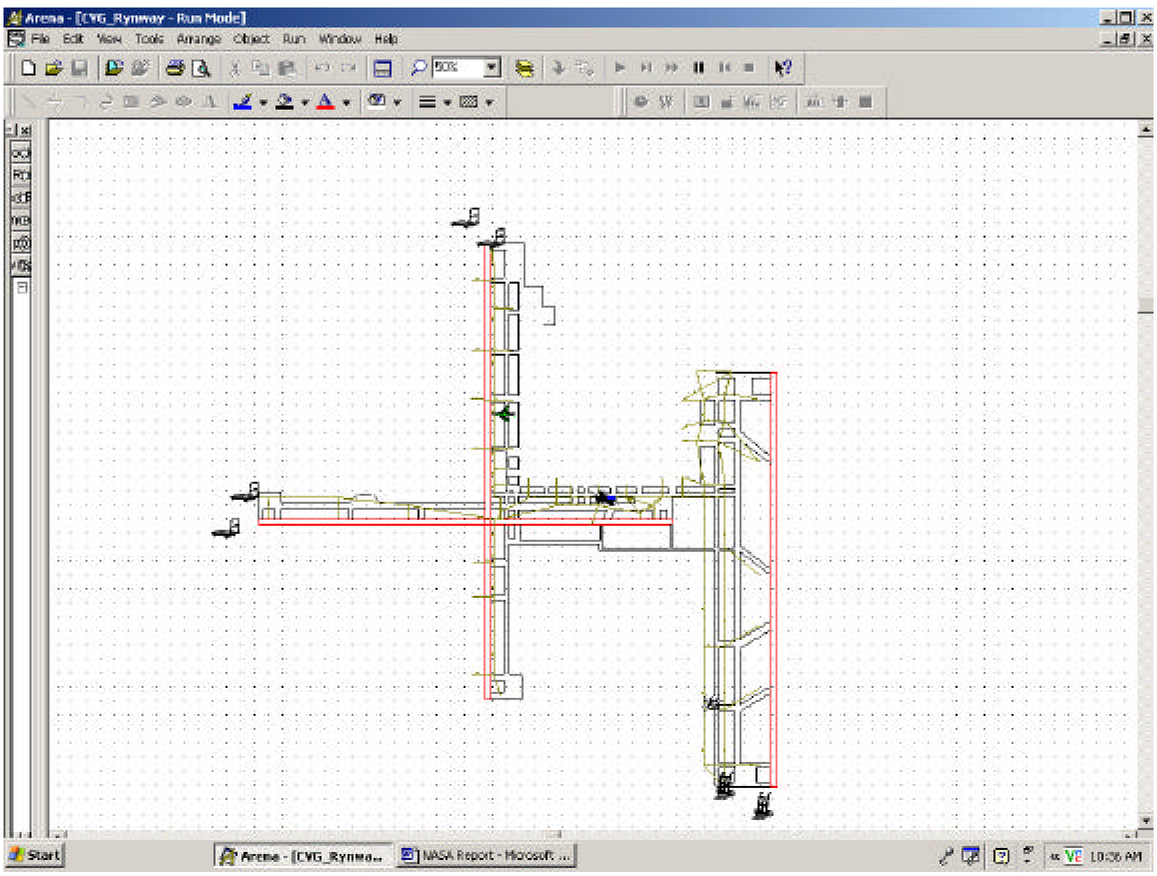

Figure 4: Screen shot for a simulation run

3.3 Algorithms

Four algorithms are proposed to assign a particular runway to an aircraft. At any airport there are periods of peak arrivals and departures. This is what is generally termed as the "Arrival or Departure Rush". These are the periods when there is maximum congestion of aircraft on the tarmac at the airside of an airport. These rushes are characterized by long waiting queues at the runway hold points, taxiways and ramps. The algorithm aims to reduce the congestion and waiting times at airsides by efficiently assigning runways during these peak periods. The algorithm reads the departure or arrival data well ahead of the actual time and creates a time window. During this time window, the data is analyzed for rushes. If there is no rush during the time window under consideration, the normal operational procedure is followed. However, if there is a rush, then a modified assignment of the runways is to be followed, such that all the arrivals are on one runway and the departures are on the remaining two runways.

After this, there is another decision branching out here. To minimize the effect of the separation constraints, the small aircrafts are routed to one runway and the other aircrafts take-off from the third runway.

The following algorithms are proposed for assigning aircraft to runways during departure rushes.

Algorithm 1

1) Read current simulation time T0 = current time of simulation

2) Initialize the time window T1 = T0 + 15

3) Close the time window T2 = T1 +15

4) Read the number of departures N = Number of departures between T1 & T2

5) Set a restriction on the number of departures

    If N > 15,

        1) For T = T0 to (T1 – 5)

Follow normal operational procedure

2) For T = (T1-5) to T2

a) Assign Runway 18L-36R for landings

b) Stop routing aircrafts from the gate to Runway 18L-36R

Else follow normal operational procedures

Algorithm 2

---

1) Read current simulation time T0 = current time of simulation.

2) Initialize the time window T1 = T0 + 15

3) Close the time window T2 = T1 +15

4) Read the number of departures N = Number of departures between T1 & T2

5) Set a restriction on the number of departures

If N > 15,

For T = T0 to (T1 – 5)

Follow normal operational procedure

For T = (T1-5) to T2

Assign Runway 18R-36L for landings

Stop routing aircrafts from the gate to Runway 18R-36L

Else follow normal operational procedures

Algorithm 3

---

1) Read current simulation time T0 = current time of simulation.

2) Initialize the time window T1 = T0 + 15

3) Close the time window T2 = T1 +15

4) Read the number of departures N = Number of departures between T1 & T2

5) Set a restriction on the number of departures

If N > 15,

For T = T0 to (T1 – 5)

Follow normal operational procedure

For T = (T1-5) to T2

Assign Runway 18L-36R for landings

Stop routing aircrafts from the gate to Runway 18L-36R

If Aircraft Type = Small Then Assign Runway 9-27

Else Assign Runway 18R-36L

Else follow normal operational procedures

Algorithm 4:

---

1) Read current simulation time T0 = current time of simulation.
2) Initialize the time window T1 = T0 + 15
3) Close the time window T2 = T1 +15
4) Read the number of departures N = Number of departures between T1 & T2
5) Set a restriction on the number of departures

If N > 15,

1) For T = T0 to (T1 – 5)

Follow normal operational procedure

2) For T = (T1-5) to T2

a) Assign Runway 18R-36L for landings

b) Stop routing aircrafts from the gate to Runway 18R-36L

Check aircraft type

If Aircraft Type = Small

Assign Runway 9-27

Else Assign Runway 18L-36R

Else follow normal operational procedures

CHAPTER 4

VALIDATION OF THE MODEL

The simulation model proposed is tested using data from a major US airport, for which the simulation model is built. The data set contains data on the number of scheduled take-offs and landings for the three types of aircrafts during a typical weekday of operations at the airport during Fall of 2002. This data has been obtained from the official airport schedule. In all, there are 1,344 scheduled departures and arrivals in an 18-hour time horizon from 6 a.m. until midnight. Randomness is not modeled in this simulation. Departure and arrival times are read as static inputs from the airport schedule.

The simulation model is validated by examining the output reports and visual validation through observation of the model's animation. Validation of the model involved validating: input data, aircraft taxi movements, and aircraft takeoff / landings. Input data was thoroughly examined for consistency and accuracy. Also, the input data was confirmed through various sources before feeding into the model.

Validation of the taxi process included examination of: ramp travel, taxiway travel, intersection decisions, and takeoff and landing procedures. Once the processes were confirmed, the output reports were used to validate them. The simulated taxi times, delays and actual take off and departure times of aircrafts from the simulation model were compared to the actual times captured at the airport.

Table 2 shows the number of aircrafts belonging to each aircraft type. This output from the simulation model is in accordance with the observation at the airport. Figure 5 shows the time it takes for the different aircraft types to travel from the gates to the runway. From Figure 5 we see that the average time taken by the aircraft to travel from the gate to the runway is around 17 minutes. (Large 16.9064 minutes, Medium 16.5671 minutes, Small 16.4459 minutes). Also, the maximum time taken to travel from the gates to the runway is around 30 minutes. (Large 30.2494 minutes, Medium 31.6949 minutes, Small 32.1317 minutes).

Table 2: Number of aircrafts of each type

Aircraft Type	Number
Large	390
Medium	439
Small	515
Total	1,344

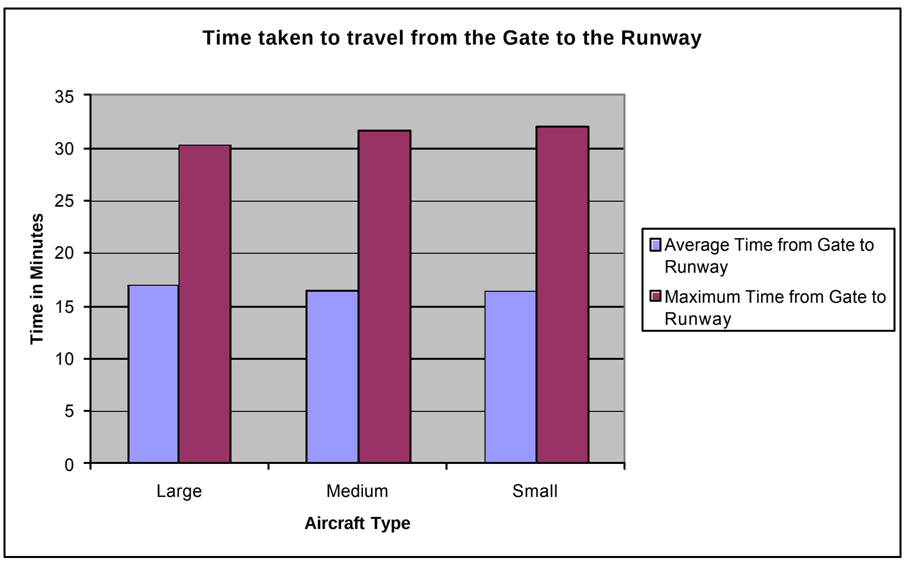

Figure 5: Average and maximum time taken to travel from the gate to the runway

Figure 6 shows the waiting time for the different aircraft types. From Figure 6 we see that the average waiting time for the aircraft is around 2 minutes. (Large 1.385 minutes, Medium 1.9623 minutes, Small 1.9191 minutes). Also, the maximum time taken to travel from the gates to the runway is around 22 minutes. (Large 24.1362 minutes, Medium 26.7268 minutes, Small 17.8938 minutes).

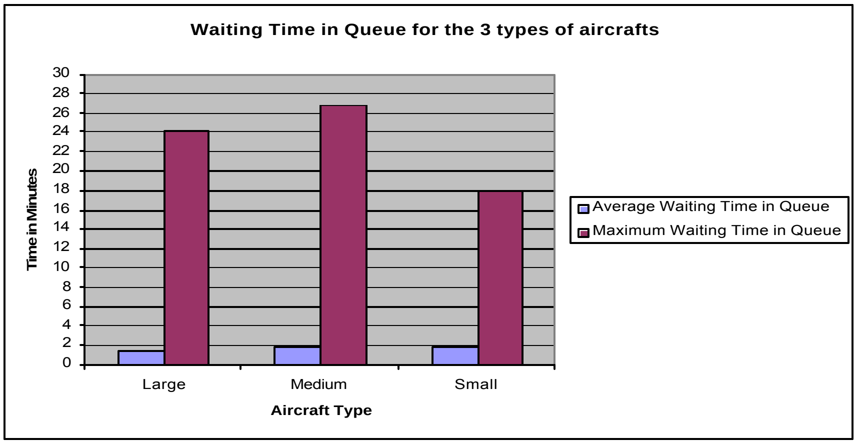

Figure 6: Average and maximum waiting time for the 3 types of aircrafts

The statistics obtained for the time taken to travel from the gates to the runway and the waiting time for the aircraft are in accordance to the observations at the airport. This comparison validates the model and gives us a reassurance that the model is an accurate description of the operations being modeled. The animation in the model is extremely important because in addition to helping us visualize the operations, it helps us raise questions that are extremely helpful during validation.

4.1 Validation of the Algorithm

The simulation model is used to analyze the proposed algorithms for efficient runway assignments. The simulation model is run as per the protocols described in the algorithms. The output statistics from this simulation run are shown in Tables 3 and 4.

Table 3: Comparing the average and maximum time to travel from the gate to the runway

	Average Time in minutes to travel from the gates to the runway					Maximum Time in minutes to travel from the gates to the runway				
Algorithm	Initial	1	2	3	4	Initial	1	2	3	4
Large	16.91	20.21	25.55	16.80	25.10	30.25	40.36	44.67	29.46	43.75
Medium	16.57	20.01	26.99	16.03	25.48	31.69	42.68	46.84	31.35	45.73
Small	16.45	20.11	25.83	15.79	23.47	32.13	42.99	48.68	24.37	39.79

Table 4: Comparing the average and maximum waiting time.

	Average Waiting Time					Maximum Waiting Time				
Algorithm	Initial	1	2	3	4	Initial	1	2	3	4
Large	1.39	1.71	2.78	1.31	2.57	24.14	24.87	35.26	18.26	29.08
Medium	1.96	2.46	3.13	1.74	2.66	26.73	27.99	38.68	20.35	30.85
Small	1.92	2.41	3.27	1.83	2.54	17.89	17.90	33.68	15.73	26.13

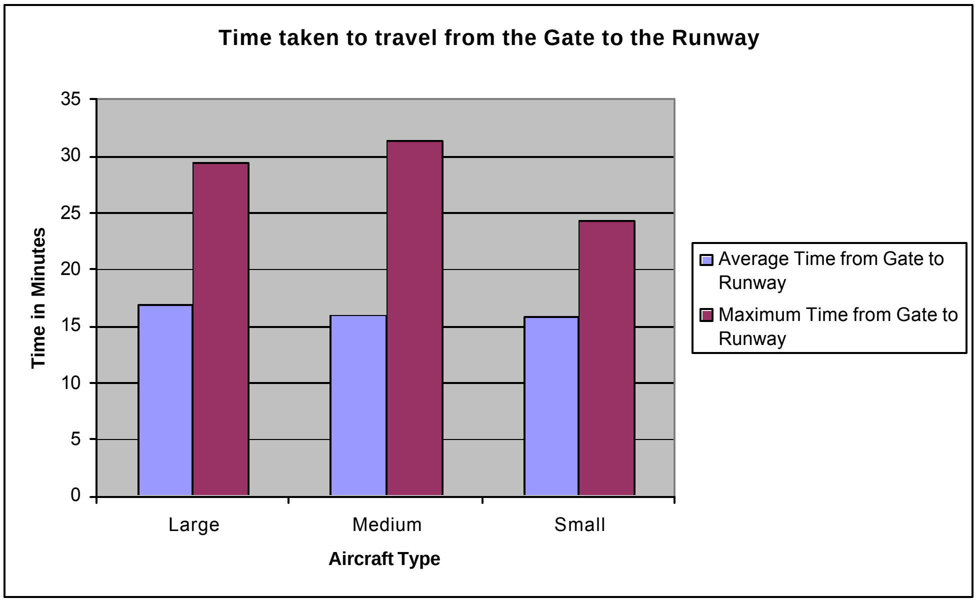

Figure 7: Statistics for time to travel from gate to the runway with algorithm 3

Comparing Figure 7 to Figure 5 we see that there is a reduction in the average time taken as compared to the normal operations. Also, there is a slight reduction in the maximum time taken for large and medium aircrafts. However, there is a substantial reduction in the maximum time taken by the small aircraft to travel from the gates to the runway.

Comparing Figure 8 to Figure 6 we observe that there is a significant reduction in the average waiting time in queue for all the three aircraft types. Also, there is a considerable reduction in the maximum waiting times for all the three aircraft types.

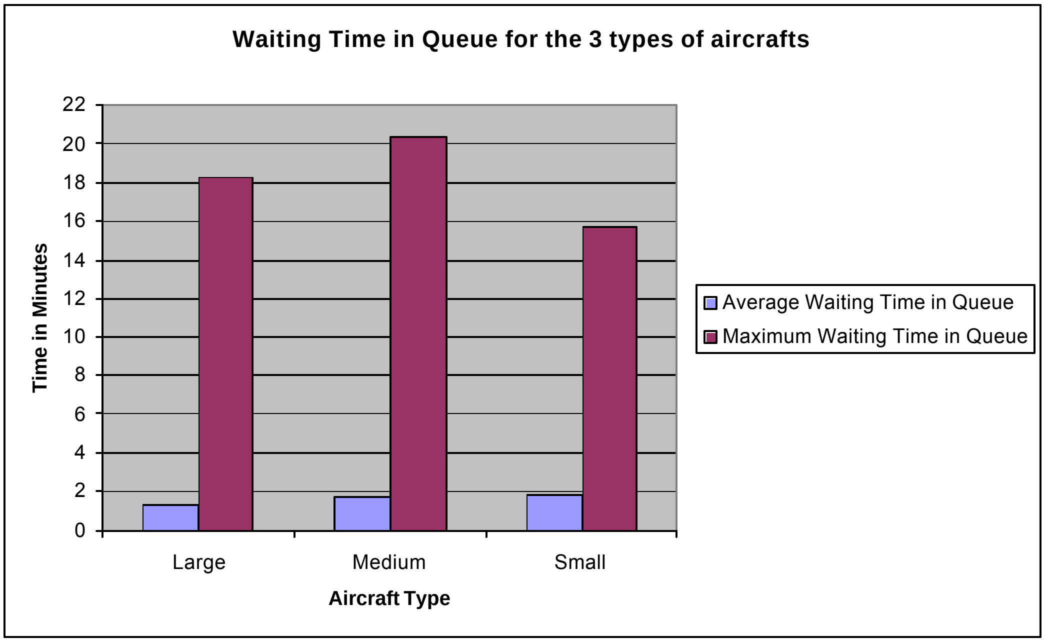

Figure 8: Statistics for waiting time by aircraft types with algorithm 3

By comparing the results obtained by incorporating the algorithm logic in the simulation model with the normal operating procedure, we can see that there is a significant reduction in both the waiting times as well as the time taken by the aircrafts to travel from the gates to the runway when algorithm 3 is implemented. Hence, algorithm 3 can be used to improve ground movement operations at airports.

CHAPTER 5

CONCLUSIONS

Airport operations are widely influenced by runway assignment and aircraft sequencing and scheduling. Ground operations at a major US airport were analyzed in order to provide insights into aircraft ground operations. As a tool for improving the efficiency of airport airside management operations and airport capacity, a new approach using simulation modeling is proposed to minimize the delays caused by inefficient aircraft ground movements and runway assignments. For each aircraft, the air traffic controllers must make a number of decisions related to the runway assignment, taxiway routing, sequencing and scheduling. Thus the proposed algorithms validated using the simulation model will only aid the air traffic controllers and not eliminate their jobs. The simulation model is used to evaluate the air traffic controller strategies. As a summary, the principal conclusions are as follows:

- The proposed simulation model can be used as an effective decision support tool for ground movement operations. The proposed simulation model developed can be used as a flexible, data driven model to investigate the ground movement operations at an airport. Thus the delays can be reduced and the delay costs can be reduced. The results obtained, confirm the efficiency of the model and its ability to operate in a satisfactory way.
- The proposed method has the advantage of reducing the uncertainty of operations by providing the air traffic controller a clear picture of the scenario well ahead of time. By careful sequencing, scheduling, re-routing and runway assignments, the waiting time of the aircrafts can be reduced greatly and the ever increasing air traffic demand can be satisfied.

- By applying a knowledge-based system, new rules can be added to improve efficiency. The simulation model provides an easy way to verify new rules and algorithms. With the increase of knowledge, it can also be expected that the continuous improvement of system functions and "intelligence level" of the system can be achieved.

Because this research considered the operations at a specific airport, the model can be valid only for the considered airport. Each airport in the US has a different layout, runway geometry and taxiway system. Therefore constructing a decision support tool for a specific airport requires consideration of the constraints imposed by the uniqueness of the airport.

Further research is required to extend the model to concern more constraints and factors from the airside and landside. This will lead to automated procedures to assist the airport controllers achieve more effective ground traffic management.

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