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International Student Team Project in Modeling and Simulating Airport Transportation Operation

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Abstract

The Internet makes international student collaboration in education possible. Thus, modeling and simulation in different areas of concentration can be offered. Transportation is a major area of interest for which models have been developed to monitor and control the essential impacts of constraints in transportation scenario analysis. Therefore, transportation scenario analysis becomes part of international student team project work through the Internet allowing students to access, run, and evaluate transportation scenarios as a cornerstone project. The participating international students develop plans and procedures for common case studies as part of their project work. This approach allows collaborative student work at an international level, independently on time and location.

Keywords: Aviation modeling and simulation, International student team project.

Introduction

The transportation systems sector is a vast, open and interdependent networked system that moves millions tons of freight, and millions of passengers. The transportation systems sector is the most important infrastructure for any economy of the globalized world satisfying these enormous transportation demands. Advanced transportation systems are essential to provide innovative services relating to the presence of multiple modes of transportation which interact and affect each other in a complex manner and cannot be captured by a single existing model of transportation systems traffic and mobility management. This facilitates that transportation systems sector managers are better informed to run their daily business safe and secure and more effective through coordinated actions, which finally approve a smarter use of transportation networks providing optimal conditions in transportation. But transportation in today’s open interdependent networked urban and metropolitan areas necessitates keeping the conditions for people, economy and the environment eligible. This can be achieved successfully if the interactions between the multi modal transportation modes, economy, land use and the impact on the natural environmental resources are included in the transportation system planning strategies of the considered areas. Thus, transportation analysis concentrates on planning, safe operation, performance of transportation systems and the required infrastructure to run this business, including the respective economic and public policy and environmental aspects. A relevant public and environmental aspect in transportation in the next century is the awareness to be much more ecological, effective and flexible to handle the volume of people and cargo projected worldwide. To achieve this goal the existing transportation chains must be improved cost effective and ecological sustainable connecting existing modalities in an innovative way making each of which more efficient. Therefore, it is strongly argued that long-term economic objectives of transportation policy have to be compatible with ecological and social objectives. Besides costs and efficiency the dependency on fossil fuels in transportation remains a crucial objective from the environmental perspective and has become a common denominator for intermodal transportation. But the appearing difficulties resulting from the intrinsic complexity made up by many elements influencing each other, directly and indirectly, often nonlinear and with many feedback cycles, which require specific analytical approaches. Computational modeling and simulation allow identifying an optimal solution for scenarios used for the public and private sectors professional work.

Moreover the increase in global competitiveness requires that the next generation workforce receives innovative training and practice that prepare them to participate and compete in the global transportation economy. Thus, academic institutions adequately have to prepare students for tomorrow’s global transportation job market taking into account the significant changes in educational offers like web-based educational support through e-, b-, m-, and u-learning, simulation environments.

In order to adapt education to global transportation needs modeling and simulation in international student team projects enhance international education collaboration of students without the necessity of international relocation, comparing and fine-tuning learning outcomes and competencies to enhance comparability and transparency of educational structures and programs. A special effort was made to combine international student team projects and coursework to benchmark international education programs. This was realized in an international course program in computational modeling and simulation at a Master level in transportation analysis. In this context the power of simulation lies in the three R´s namely: reductionism, repeatability, and refutation. Reductionism recognizes that any system can be decomposed into a set of components that follows fundamental physical laws. Thus, the diversity of the real world can be reduced into laboratory experiments, which can be validated by their repeatability, and therefore the user is able to make intellectual progress by the refutation of the hypothesis. Therefore, modeling and simulation allowing the analysis of transportation systems accurately under varying operation conditions and/or scenarios to predict the system behavior before the system is actually built.

The international student team project in transportation is based on models which have been developed and implemented by the students. Suitability and efficiency of simulations of the international student team project depends on the criteria discussed in (Balamuralithara and Woods, 2008; Erugrul, 1998). The most important are:

- Modularity: allow to test developed modules easily and to adopt developed modules to specific applications quickly.
- Executability: avoid alteration, to hide the code or to create standalone applications.
- Performance: ensure the modules that meet the required performance.
- Intuitive Graphical User Interface (GUI): enable transatlantic student team members to look at it and see what needs to be done.

For the international student team project ProModel was selected as a simulation package allowing inclusion of comparative studies, scenario planning and analysis, modeling and simulating case studies.

Beside hard skills, soft skills are an impart knowledge too, which involve cultural, social, and educational interactions and networking with students and instructors. The goals are:

- Establishing an international program for students in interdisciplinary student team projects that fosters cross-cultural interaction and networking,
- Exposing students through this network to cultural, social, and communication issues in intercultural student based modeling and simulation use case based study program,

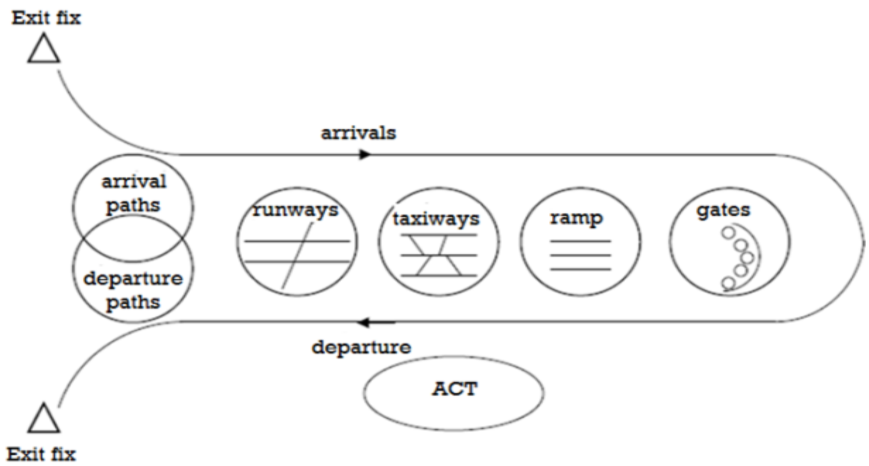
- Reinforcing fundamental scientific concepts, providing opportunities to put fundamental scientific concepts into practice through computational modeling and simulation,

Providing students with experience in international student ream projects through the web.

Principles of Operation on the Airport Surface

This student team project in transportation focus on modeling and simulating the operation on the airport surface which include those at gate areas, ramp, and taxiway and runway systems, strongly influenced by terminal-area operations. The different components of the airport system illustrated in Figure 1 have aircraft queues associated with them and interact with each other. The cost per unit time spent by an aircraft in one of these queues depends on the queue itself; for example, an aircraft waiting in the gate area for pushback clearance predominantly incurs flight crew costs, while an aircraft taxiing to the runway or waiting for departure clearance in a runway queue with its running engines incurs additional fuel costs, and increasing surface emissions (http://bit.ly/2c5nZxk). Arrivals and departures of airport operation occur at scheduled times.

Figure 1. *Schematic of the Airport System Including the Terminal Area after [12]*



Beside real scheduled times of arrivals and departures random times are defined for a random analysis integrating an approach on how to handle the procedure with scheduled times and with delays which result in different scenarios:

- Scenario 1: considers random arrivals, characterized by a probability distribution. Poisson distribution is a good approach; because it describes events independently with the average rate (waiting times between k occurrences of event are Erlang distributed).

- Scenario 2: scheduled arrivals of flights and introduced resources, like ground handling workers, etc.

The international student team project is based on data of Raffaello Sanzio Airport of Falconara, Ancona (Italy) for the following reasons:

- No big airport: easy to start with a simple use case compared with a big hub airport. Simulation can be used as starting point to simulate bigger airports and hubs.
- International airport: more flights to simulate use cases, even if not an intercontinental one.
- Used by two low-cost carriers (Ryanair, Volotea) and two Star Alliance carriers (Lufthansa, Alitalia).

Raffaello Sanzio Airport of Falconara, Ancona (Italy) has only one runway. In the terminal building two arrivals and two departure gates are available. After arrival the ramp hold position the plane turns off the engines and passengers can de-board. They reach the arrival gate by foot or by bus. The luggage is delivered at the conveyer belt. In between the plane will be cleaned and refueled. After that procedure new passengers can board and thereafter the airplane can leave if the taxi- and runway is cleared.

The scenario based simulation of the airport operation workflow is based on two different simulation tools:

- GPSS for the first scenario
- ProModel for the second scenario.

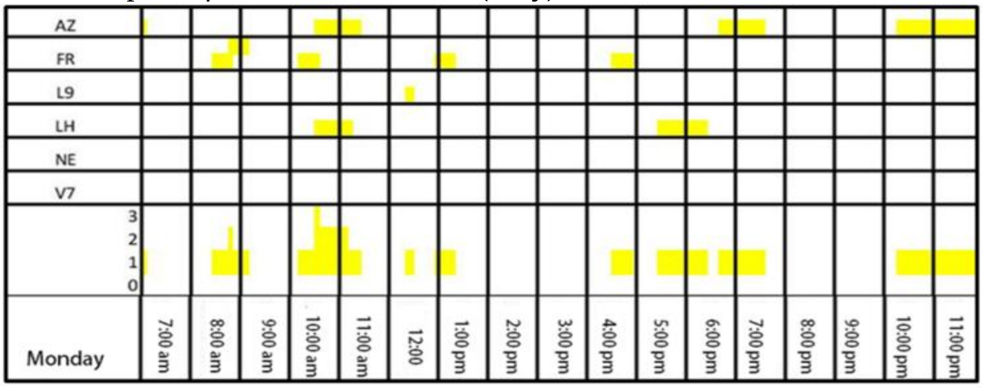
Data Analysis TYP

The student team project work optimizes the occupancy rate of arrival and departure gates in a cost efficient way. This requires workflow information of the airport operation available from the airport information office, provided by the website http://www.ancona-airport.com, which shows airport flight plans. Plans used for data analysis were downloaded. Every week new flight plans are published, but significant values like frequency of flights and workload of airport operation remain the same for weeks. Therefore, the data set can be used as a basis for the models developed and used in the student team project. For this reason the arrivals are sorted for a weekly schedule and for any further analysis. As a first result it could be seen that Alitalia flight departing from Roma Fiumicino and arriving at Ancona Airport stays overnight at the airport. Thus, an empty line was introduced to show airplanes which remain in the airport and leaves on the following day.

A first result obtained is given in Figure 2 showing:

- Hours of operation for each flight (in other words, how long they remain at the airport);
- Number of flights at the airport at the same time;for Monday, June 3rd 2013. Times in the chart are restricted from 07:00am to 11:00 pm because first arrival is at 08:25 am and last one at 10:15 pm, and a departure at 07:05 am.

Figure 2. *Chart of Arrivals and Departures of Airline Flights at Raffaello Sanzio Airport of Falconara, Ancona (Italy)*



According to Figure 2 flights have a higher frequency during the morning, lower rows of Figure 2, in which each block denotes 5 minutes, indicate total numbers of planes. Furthermore, it can be deduced that between 10:00 am and 11:00 pm three planes are at the airport, but only two gates available, a fact which happens every day due to resource shortages.

Numbers of flights per day extracted from the airport information office website are in total 72 flights per week.

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
11	7	14	8	11	12	9

Based on data obtained from the airport information office, the average turnaround time for each company can be determined as follows:

Agenzia Viaggio	**Alitalia**	**Belleair**	**Lufthansa**	**Ryanair**	**Volotea**
50 min	55 min	22.86 min	52.69 min	25.42 min	Remains at airport for the night

Separating airlines with regard to the turnaround times two groups are identified:

- Group 1: Aircrafts stay approx. 20-25 min at the airport (Ryanair, Belleair, Volotea);

- Group 2: Aircrafts stay approx. 50-55 min at the airport (Lufthansa, Alitalia, Agenzia viaggio).

Description of the Model for the First Scenario

Overview

Airport ground handling and terminal positions are illustrated with regard to the airport operation workflow, as indicated in Figure 3. The airport operation model shows that airplanes arrive at the Airplane_Arrival location, then move to the final parking position and turn off the engines. If turnaround procedures completed, aircraft is ready to move to Airplane_Departure and thereafter to leave the airport, the end of the simulation analysis in ProModel [ProModel%202011%20Tutorial/PM2011Tutorial.html].

Locations

To run, airport operations essential locations have to be set keeping the model as realistic as possible, which is introduced by:

- Airplane_Arrival: place reached by the airplane once it is landed. There is only one runway in Ancona Airport; therefore, the capacity of this location is set to 1.
- Parking_Positions: position where aircraft after landing has to wait in case both gates of Ancona-Falconara Airport are busy; for this location capacity is set 6. According to the airport situation and to the fact that the airplane switched off its engines, the following three locations coincide with the Parking_Positions;
    - Gate_Arrival: passengers and luggage leave plane; thus, capacity of this position is set to 2, because only two conveyer belts are available in the airport.
    - Cleaning_and_Refueling_Positions: cleaning and refueling are done before passengers enter;
    - Gate_Departure: place where passengers and their luggage enter the plane;
- Airplane_Departure: beginning of runway, where plane take off if runway is set clear. Airport has only one runway; therefore, capacity of this location is set1.

Figure 3. *Falconara Airport based on Open Street Map with Marked Airport Ground Handling and Terminal Positions*

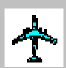
Entities

Airlines using Raffaello Sanzio Airport classified as:

- Low-cost carriers: turnaround time at airport in between 20-25 minutes;
- Regular carriers: turnaround time at airport in between 50-55 minutes.

Entities introduced did not distinguish international flights from national:

- Airplane1: represent aircrafts of regular carriers;
- Airplane2: represents aircrafts of low-cost carriers.

Icon	Name	Speed (fpm)
	Airplane1	10
	Airplane2	10

Path Networks

To let planes move to different positions a path network was created:

- **Net1:** Path that link Airplane_Arrival with locations Parking_Positions, Gate_Arrival, Cleaning_and_ Refueling_Positions and Gate_Departure;

- **Net2:** Path that link Parking_Positions, Gate_Arrival, Cleaning_ and_Refueling_Positions and Gate_Departure with Aircraft_Departure

Shift Assignments

Ancona-Falconara Airport is closed during the night. Airplane_Arrival is activated from 7:00 am to 10:00 pm every day, and location Gate_ Departure is activated every day from 7:00 am to 11:00 pm.

Arrival

Setting arrivals of planes requires:

- Use airplane arrival rates in a way which allow to consider the two different kinds of airplane which arrive in Ancona-Falconara Airport;
- Increase arrival rate in order to optimize the utilization of the airport.

Since numbers of arrivals of two categories of planes can be described by a Poisson process, inter arrival frequencies are described through exponential distribution, whose parameters show the mean time (in hours) between two adjacent arrivals. Parameters for inter arrival frequencies are listed in the following table. To analyze a more realistic model of airport operation for scheduling the arrivals, the schedule of the first arrival is weekly repeated with adding a variation of 0.5 for Airplane2. In the following table, column occurrences is always of value INF to show there is no upper limit in the number of incoming airplanes (otherwise, if the input was a number, for example x, no other plane would arrive after the x-th plane is landed)

Entity	**Location**	**Qty Each**	**First Time**	**Occurrences**	**Frequency**
Airplane1	Plane_Arrival	1	Week 1 Mon7:00	INF	E(2)
Airplane2	Plane_Arrival	1	Week 1 Mon7:00	INF	E(1)

Processing

To run airport operation simulations some procedures and processes have to be defined like movements from Airplane_Arrival to Airplane_Departure for both types of planes, whereas some other procedures and processes are depending from the type of plane. This distinction is useful to set different mean operation times. After a plane arrives at a location Airplane_Arrival, it moves to a Parking_Position to stop if both Gate_Arrival units are busy.

The Column Move Logic in the next table shows to which of the two nets the plane is moving. Actually there is no logic structure behind this movement implemented. As soon as plane is in Airplane_Arrival, it moves to Parking_Position.

Process			**Routing**		
Entity	Location	Output	Destination	Rule	Move Logic
ALL	Airplane_Arrival	ALL	Parking_Positions	First 1	Move on Net1
ALL	Parking_Positins	ALL	Gate_Arrival	First 1	Move on Net1

Once the aircraft is at Gate_Arrival passengers de-board. Describing de-boarding, a normal distribution was chosen, whose parameters depend from the kind of aircraft in the simulation run. Normal distribution is denoted in ProModel in the notation: N(*a*,*b*), where parameter *a* is the mean value and parameter *b* is the standard deviation with parameters:

- Low-cost carrier: the following parameters are set:
  - Mean: 8 minutes;
  - Standard deviation: 2 minutes
- Regular carrier: the following parameters are set:
  - Mean: 15 minutes;
  - Standard deviation: 3 minutes.

After de-boarding the plane virtually moves to Cleaning_ and_Refueling within the simulation model shown in Figure 3.

Process			**Routing**			
Entity	Location	Operation	Output	Destination	Rule	Move Logic
Airplane 1	Gate_Arrival	WAIT N(15,3) MIN	Airplane 1	Cleaning_and Refueling_Positions	FIRST 1	Move on Net2
Airplane 2	Gate_Arrival	WAIT N(8,2) MIN	Airplane 2	Cleaning_and_Refueling_ Positions	FIRST 1	Move on net 2

At Cleaning_and_Refueling_Position cleaning and fueling processes take place. Again a normal distribution was used to describe the needed times for the procedures and its parameters depend from the type of plane served:

- Low-cost carrier flights:
  - Mean: 7 minutes;
  - Standard deviation: 2 minutes;
- Regular carrier flights:
  - Mean: 20 minutes;

Standard deviation: 3 minutes

Process			Routing			
Entity	Location	Operatio n	Output	Destination	Rule	Mov e Logi c
Airplane 1	Cleaning_and Refueling_Positio ns	WAIT N(20,3) MIN	Airplane 1	Gate_Departu re	FIRST 1	Mov e on Net2
Airplane 2	Cleaning_and Refueling_Positio ns	WAIT N(7,2) MIN	Airplane 2	Gate_Departu re	FIRST 1	Mov e on net 2

If plane is ready to move to the Gate_Departure, the passengers can board the aircraft. Again a normal deviation is used to describe the needed times and distinguish between the two different kinds of airplanes.

Process			Routing			
Entity	Location	Operatio n	Output	Destination	Rule	Mov e Logi c
Airplane 1	Gate_Departur e	WAIT N(15,3) MIN	Airplane 1	Airplane_Departu re	FIRST 1	Mov e on Net2
Airplane 2	Gate_Departur e	WAIT N(7,2) MIN	Airplane 2	Airplane_Departu re	FIRST 1	Mov e on net 2

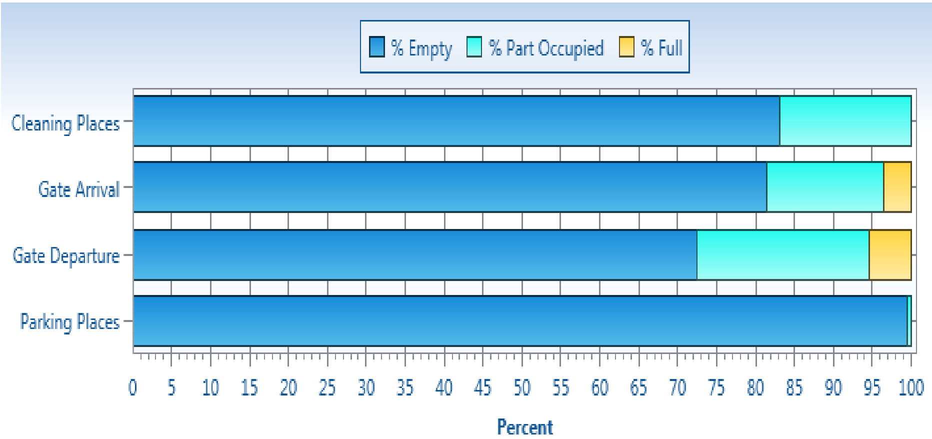
Once passengers and baggage are on board, airplane can move to Airplane_Departure where it can take off. If plane has reached Airplane_Departure, it is ready to run the runway to EXIT the simulation system which means take off.

Simulation Results

After a 4 weeks simulation run we obtained the following data:

Name	Total Exits	Average Time In System (Min)	Average Time In Operation (Min)
Airplane1	202,00	54,52	49,52
Airplane2	429,00	28,19	23,32

As assumed the number of different types of planes is in relation with data showed in the analysis of data of Ancona-Falconara Airport. Time each aircraft spend in the system corresponds with time obtained from data analysis. Regular carrier planes turnaround is approx. 55 minutes and low cost carrier turnaround is 28 minutes, which is compatible with the time planes switched off their engine and starting their engine again (turnaround time) which result to 20 - 25 minutes.



The chart above shows how often every location is used, apart from the Airplane_Arrival and Airplane_Departure, and to what percentage it is empty, partly occupied or full in use. From a statistical analysis it can be seen that the airport is not used at its maximum capacity. In fact the Gate_Arrival and Gate_Departure are mostly empty, and only for a small percentage fully occupied.

Modeling the Second Scenario

Locations

This Scenario uses different locations in order to represent different steps of the operation flow around the plane.

The second scenario introduces resources used during each phase of work to be done on the plane allowing using locations as geographic spots on the apron where planes park.

Locations Airplane_Arrival and Airplane_Depature are as in the previous scenario. The other locations are:

- Three parking positions for regular carrier flights, Parking_PositionBig.1, Parking_PositionBig.2 Parking_PositionBig.3, which are closer to gates;
- Three parking positions for low cost carrier flights, located on outer positions on apron Parking_ PositionLow.1, Parking_PositionLow. 2, Parking_ PositionLow.3.

As mentioned before, Parking_PositionBigx is considered a unique location that has three different spots: once an airplane from a regular carrier lands, it move to Parking_Position.Bigx. According to which of the three available spots is free, it occupies one of the three spots belonging to the location. When a location has more than one unit, ProModel repeats the name of the location with a number, for each unit of the location.

Entities

To be able to distinguish different demands of resources entities are split into national and international flights and kept the division into regular carrier and low cost flights which result in four kinds of entities:

- Regular carrier flights:
  - Airplane1_national;
  - Airplane1_international;
- Low cost carrier flights:
  - Airplane2_national ;

- Airplane2_International.

Entities

Icon	Name	Speed (mpm)
	Airplane1_national	10
	Airplane2_national	10
	Airplane1_international	10
	Airplane2_international	10

Path Networks

In order to move resources and entities the network has two sets, one for entities and one for resources:

- Net1 used for movements of planes through the airport;
- Net2 path of resources moving from their base to planes in their different parking positions.

Planes arrive at the Airplane_Arrival; from there moving on Net1 and according to the kind of airline, they reach one of the free slots respectively in Parking_PositionBig or Parking_PositionLow.

Interfaces [1]

Node	Location
N1	Airplane_Arrival
N2	Parking_PositionsBIG
N3	Airplane_Departure
N2	Parking_PositionLow

Distinction between the Parking_PositionsBig and Parking_ PositionsLow introduced to show that regular carrier occupy spots closer to gate (Parking_PositionsBig), used by the low cost carriers (Parking_PositionsLow).

ResourceLocation is where resources are stationed if not in use from where they move to different parking positions serving planes. Planes located in different spots, according to the air company to which they belong, ResourceLocation is connected through Net2 to both locations for the plane.

Interfaces [1]

Node	Location
N1	ResourceLocation
N2	Parking_PositionsBIG
N3	Parking_PositionLow

Arrival Cycles

In scenario 1 the planes arrived in a random manner. In scenario 2 plane arrivals are scheduled. Times are from the information derived from the data analysis of flight plans. To achieve this option of arrival cycles a ProModel is used. There is one schedule for each type of entity. As reference for the schedules the flight plan from Wednesday is used.

Arrival Cycles

ID	Qty / %	Cumulative	Table...
BigInt	Quantity	No	Defined
BigNat	Quantity	No	Defined
LowInt	Quantity	No	Defined
LowNat	Quantity	No	Defined

The schedule of regular carrier national planes is as follows:

Table for BigNat [1]

Time (Hours)	Qty / %
10.5	0
10.51	1
18.66	0
18.67	1
22.25	0
22.26	1
24	0

It can be seen that the decimal system is used meaning that one hour is not divided in 60 minutes, but in 10 tenths, 100 hundredths, 1000 thousandths… Furthermore time is cumulative meaning that there are 0 arrivals between 0:00 and 10.50 (i.e. 10:30), and 1 between 10.50 and 10.51. Having 0.01 hours for each arrival to have an exact schedule of arrivals to know when the planes enter in the system.

Resources

To represent the different services of the airport four different types of resources are introduced:

- Fueling: represents a fueling truck to refuel arrived planes. This quantity was also set equal 2 to investigate its impact which was less than 1% in use.
- PeopleOut: gangways used by passengers to leave a plane via the two arrival gates.
- PeopleIn: gangways used to let the passengers enter a plane via the two departure gates.
- Workers: represent the staff working with the described resources.

Global Variables

Before describing the procedure a plane has to pass through, variables are needed which can be global or local. One global variable is the Refueling_Machine, with a default value 0. With this variable it can be described whether or not the fueling truck is used by the values 0 or 1 which describe respectively if the truck is free or used.

Processes

Scheduling arrivals, defining resources and nets in which airplanes and resources move the processes each plane is part of during its stay at the airport has to be described. The processes set for Airplane1_National are:

1. First is de-boarding, which is described by a normal distribution with mean of 13 minutes and standard deviation of 3 minutes;
2. Creating a local variable Refueling_Procedure_ Airplane1_National, with default value 0, describes whether or not the refueling procedure has been done or not. If the value is 0, refueling still needs to be done; if the value is 1, refueling has been done;
3. In case the fueling truck is free refueling can start: a set value of global variable Refueling_Machine equal to 1 to indicates that fueling truck is being used; a set work for an interval time with normal distribution with a mean of 11 minutes and a standard variation of 2; if the procedure is complete, the set value of Refueling_ Procedure_Airplane1_National is equal to 1 and set value of global variable Refueling_Machine to 0;
4. If the fueling truck is not free start with cleaning procedure with 2 workers and time with normal distribution with mean 12 and standard deviation 1;
5. If the first operation is done proceed with the second one: in case that refueling was done first, thereafter the clean plane, or opposite;

6. Now, new passenger's board: this requires a time window with normal distribution with mean 13 and standard deviation 3 minutes.

Numbers in expressions like Fueling 150 are priorities required to use resources because regular carriers pay more for services than the airport offers. Thus priority to services is needed for their flights. A distinction among priorities can also be achieved between international and national flights for the same kind of carriers: international flights are more likely to be connected with intercontinental flights, because connected airports, like Munich, are used by passengers as a hub to reach other destinations.

Analysis of the Results

The analysis goal was to identify the scheduled arrivals of planes the required number of ground handling staff to optimize their number and resources used. The second goal has to identify how airplane delays affect airport efficiency; in fact, regular carriers have to receive a good treatment even if there are delays. For this reason different scenarios of delays have been analyzed:

1. The first scenario has only one delayed plane with a few minutes of delay;
2. The next two scenarios assume that planes have a bigger delay and many planes arrive at the same time, or within a short time window.

<u>Scheduled Arrivals</u>

Simulation runs with scheduled arrivals of planes, according to the timetable of arrivals at the Raffaello Sanzio airport at Ancona, have been done for a week. The simulation was set with 10 ground handling workers. Simulation shows that only 5 workers actually are required whereby the refueling machine was one of the most used resources. Since the duty for the fifth worker is small another scenario with scheduled arrivals of planes was simulated using only 4 workers to see how this affects the results shown in Table 1.

Table 1. *Simulation with 4 Workers*

Table 1 shows the percentage of time spent by each entity:

- Time entity is in move logic represented by the light blue colored bar;
- Yellow colored bar represents time entity is waiting;
- Green colored bar is time entity is in operation;
- Time entity is blocked is described by the purple.

Comparing these results with the once for 5 workers it can be deduced that only small variations happen which affect regular carriers: mean time of international flights decreases, according to their high priority, whereas national flight increases.

First Scenario with Delays

Three different scenarios with delays are investigated. International regular carrier plane arrives at 5:39 pm with 14 minutes of delay. National low cost carrier flight arrives 5:45 pm. Both planes need the refueling truck. Simulating turnaround times by each plane with scheduled arrivals for different numbers of resources has been done. Turnaround with 5 workers for planes affected by the delay (Airplane1_international and Airplane2_ national) is not much different with respect to the turnaround time if all planes arrive as scheduled. Same happens with 4 workers. In this case time of third resource decreases according to the priority but time of second resource increase. This shows that the turnaround process is well stabled. According to priority there is no impact for regular carriers. Investigating times obtained for the delay uses 4 and 5 workers. In this case reducing one unit of workers does not result in changes regarding the turnaround time of the planes, confirming what mentioned above. Thus, it is reasonable to maintain the turnaround with only 4 workers.

	Scheduled arrival	Scheduled arrival	Delay one	Delay one
	5 Workers	4 Workers	5 Workers	4 Workers
Airplane1_national	60.07	61.05	60.07	61.05
Airplane2_national	29.33	29.33	29.67	29.67
Airplane1_international	66.29	65.97	66.20	65.88
Airplane2_international	32.49	32.49	32.49	32.49

Analysis of the Results

A more critical situation happens supposing that the number of planes arriving at the same time is up to 4. Assuming two low-cost flights scheduled at 8:25 am arrive both at 10:30 am, with 2:05 hour's delay, the same time when two regular carrier flights arrive. In this case the number of workers needed amounts to 7. Resources are not used at their maximum level. Thus, it can be seen what will happen in case the number of workers are reduced. With regard to the used resources there is no big difference for regular carrier planes, between this scenario and the one without delays. The major difference occurs for low cost carriers, especially for national flights which have no priority at all. This is compatible with the fact that priorities are in this order:

1. Airplane1_international;
2. Airplane1_national;
3. Airplane2_international
4. Airplane2_national (no priority at all)

and that airplanes which are delayed are the ones operated by low cost carrier: they have to be rescheduled. Comparing the results, no big changes in the turnaround meantime happen, if the number of workers has been reduced; the results have been achieved only for two kinds of resources which affect the turnaround time but only by less than a minute. Also in this case it can be assumed that it is reasonable to use only 4 workers and to take one or two more only during peak times they are really needed.

	Scheduled arrival	Scheduled arrival	Delay two	Delay two	Delay two
	5 Workers	4 Workers	7 Workers	5 Workers	4 Workers
Airplane1_national	60.07	61.05	59.90	60.33	60.58
Airplane2_national	29.33	29.33	37.90	37.73	37.14
Airplane1_international	66.29	65.97	66.96	66.84	66.84
Airplane2_international	32.49	32.49	38.49	39.30	38.94

<u>Third Scenario: Delays</u>

The last scenario was used to study a case with an increased number of flights. Let two airplanes regular carriers be delayed, one national and one international, both scheduled at 10:30 am, arrive respectively at 12:30 and 12:50. Let this have an impact on three low-cost carrier international flights coming from different places, arriving at 0:20 pm, 0:45pm and 1:05pm. The simulation run was executed for a week. In this case the number of resources needed is 6. Comparing the simulation results for the required quantity of workers, it is deduced that, according to the priorities given to the different planes, the only big impact involves Airplane2_international, whose mean time in system increases more than 2 minutes. The same happens for other entities: Airplane2_international is also affected by changes of the number of workers. Another effect is by the fact that three Airplane2_international are in the scenario at the same time, when the delays take place. Choosing only 4 workers is a restrictive constraint, but with the possibility to use staff doing cleaning work inside the airport building for a short time, this option helps to minimize costs.

	Scheduled arrival	Scheduled arrival	Delay three	Delay three	Delay three
	5 Workers	4 Workers	6 Workers	5 Workers	4 Workers
Airplane1_national	60.07	61.05	59.68	59.86	59.83
Airplane2_national	29.33	29.33	29.11	29.11	29.11
Airplane1_international	66.29	65.97	66.83	66.93	66.51
Airplane2_international	32.49	32.49	35.19	37.16	40.18

Conclusions

The process to analyze and optimize was the turnaround process of planes at the airport with the point minimizing costs choosing a strategy with respect to customers' needs. We have decided to give priority to the regular airlines, as a marketing strategy which is similar to what happens in reality. For a deeper understanding of how many resources are needed we implemented a second scenario. At first we let the simulation run with the scheduled time, in order to see how many resources are needed in reality. We saw that the number of workers used is up to 5; the statistics showed that the fifth worker was used only for a very short percentage of time. Furthermore, scenarios with delays where simulated. From this analysis we can take the following conclusions:

1) The airport works perfectly with respect to the priority given to the different kind of flights;
2) There is no need for the airport to buy a new refueling machine, because negligible problems during the simulations affected only the low cost carriers;

The airport can use 4 workers instead of 5 and use one or two workers who work inside the building in case there is a delay, or in the few times the fifth worker is needed, even if a delay does not occur.

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