A SCHEDULE RECOVERY PLAN APPROACH:
USING SPARE AIRCAFT

Capstone Final Report
Presented to
The Academic Faculty

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Acronyms and Definitions

ACFTs: Abbreviation for aircraft.

AIMS: Program used for operational control.

Aircraft Rotation: Sequence of flights assigned to each airplane.

Block Time: Total flight time, from the time the airplane pushes back from the gate at the origin airport, until it opens a door in the final destination.

CSC: Customer Service Coordinator. Person responsible for guarantying that all services sold to passengers are completed.

Dispatcher: Person, usually ground based, who exercises with the pilot-in-command the operational control of a flight. The duties of a flight dispatcher include providing meteorological information for the flight, flight planning, arranging the loading and unloading of aircraft, etc.

Disruptions: Events that cause interruptions to the schedule, not allowing it to be completed as planned.

Event: Unplanned situation affecting a flight to be completed in its scheduled time.

Flight Cancelation: A flight is considered canceled when SOCC decides not to operate the flight.

Flight delay: A flight is considered delayed when it does not depart at the scheduled time.

Flight Diversions: A flight is considered to be diverted when it does not reach its planned final destination.

Ground Time: Scheduled time the airplane needs to stay on ground to prepare for its next flight.

Intracam flights: Flights in Central America that do not have PTY as either origin or destination.

KPI: Key performance indicator. Measure in minutes of departure delay (more than 5 minutes) and minutes of arrival delay (more than 14 minutes). This is an airline service metric.

Maintenance Planning: Group who plans all preventive maintenance (aircraft, time and location), and provides plan to router.

Notams: Advices to airmen. Notes that are published by each state notifying airmen of operation restrictions at specific airports, airspace, etc.

Out of Service (OOS): An airplane is considered out of service when it has damage (mechanical or non-mechanical) and the airplane cannot fly in any condition.

Preventive Maintenance: Maintenance that airplanes require to continue operating in satisfactory conditions. There are three different types of preventive maintenance.

- C-Checks and A-Checks: Long maintenance, which requires the airplane to stop flying for more than 16 continuous hours. These are planned from a strategic level.
- Service Visits: Preventive Maintenance that needs to be performed every 6 or 7 days, at night time in specific cities. These are planned at the operational level.

PTY: International Airline Transport Association (IATA) code or abbreviation for Panama City, specifically for Tocumen International Airport.

PTY no Spare: A group of events occurring in Panama City that cannot be solved by using spare airplanes.

PTY Spare: A group of events occurring in Panama City that can be solved by using a spare airplane at given a time frame.

Repair: Work done to airplanes when there is a failure.

Router: Person responsible for aircraft routing and maintenance assignment to airplanes

SOCC: System Operational Control Center. It controls all the operations of the airline.

Spare Airplane: Spare aircraft are additional airplanes left out of schedule on standby in the hub, and are only used if an airplane is not on time to operate its next flight.

Turnaround Time: Time customer service agents take to unload and load the airplane for the next assigned flight.

Introduction

Schedule execution has always been a challenge for all types of companies, especially when unplanned events occur. Unplanned events cause disruptions in the schedule, operations do not flow as planned, and services offered to customers are affected.

Airlines' services are affected by different types of disruptions. Among the most common are: aircraft structural damage, aircraft mechanical repairs, and flight diversions. Airlines use several corrective actions (flight delays, cancelations, deviations, aircraft rerouting, and passenger re-accommodations) enabling them to return to their planned schedule within minutes or few hours.

These disruptions and corrective actions have great economic impact on every airline business. Therefore, recovering from disruptions and bringing operations back to schedule is one of the most complex and challenging tasks airlines have. Airlines have developed unique strategies for schedule recovery based on their business model, such as buffers in schedules and spare aircraft allocation on hub airports.

This project studies the case of Copa Airlines, a leading airline in Latin America. Copa has two hub airports, one in Panama City, Panama and the other in Bogota, Colombia. Both are managed by separated operational control centers. Operational control centers are the brain of every airline and their staff are responsible for the decision making of all operations in the airline.

The general objective of this study is to help Copa Airlines Panama determine the amount of spare aircraft necessary to recover from disruptions, in order to maintain the operation key performance indicators. This study gives the airline a structured, mathematical approach to this problem, and considers main operational aspects.

Copa airlines assigns 2 airplanes to be standby with no assigned flights to recover in case a disruption occurs. The purpose of leaving spare airplanes is to guarantee passenger service and maintain key performance indicators (KPI's).

Today at Copa, spares are assigned at a strategic level by using a subjective input from operational duty managers, who decide when and how to use spares. This study will provide a tool that determines the number of spares required to recover from disruptions, reach KPI goals and be cost effective.

Literature Review

Spare problem can be defined as a recovery plan type problem, fleet size problem, or even as a spare optimization problem similar to those of spare parts. Though, many papers have been written on all of these categories, very little work has been done on integrated airline recovery. Those few papers on integrated airline recovery refer to difficult optimization models that include all operational areas of the airlines including passenger service rules and crew frameworks.

Seyed Hessameddin Zegordi and Niloofar Jafari used the ant colony optimization approach to create a recovery plan model in 2010. Petersen, Clarke, Johnson, and Shebalov (2012) provided and integrated recovery algorithm considering schedule recovery problem (delays, cancellations, and diversions); aircraft recovery problems, considering basically maintenance issues; crew and passenger recovery plans; and constraints imposed by air traffic controls.

Slavica Dožiü*, Milica Kaliü, Obrad Babiü (2012), gave an heuristic approach to the airline disturbance problems that can be used in real time to solve for small disruptions considering only one fleet type. Belfiore and Yoshizaki (2012), also used heuristic methods to determine proper fleet size problems considering time windows. David Osorio (2010) created a model to determine the appropriate size of trucks required to move cargo. However, this document is not based on airlines, and its logic is not applicable to this project.

Papers of spares are rare. Faraci Jr. (2008) developed a spare algorithm using airlines as an example, and based all calculations on probabilities. We will use a similar approach using disruption probabilities. Most of the other papers written on spare parts are very complex models, and are related to spare parts in stock on a given location. All of these approaches provide a complete optimization solution for spare aircraft problem; but seemed to be too complex for this study and its timeline requirements.

Copa Airlines Network

Copa Airlines was founded in 1947 and since then it has grown continuously for 65 years. Today, Copa Airlines is one of the leading airlines in Latin America. It operates with a hub to spoke system having as home base the Republic of Panama, which has an advantageous geographic location in Central America. Copa Airlines has the largest network in the region and reaches more international destinations than any other carrier in Latin America.

Since 2006, Copa Airlines has faced a very rapid growth, going from 2 flight banks to 4 flight banks in 2007, followed by 4 flight banks to 6 flight banks in 2011. Flight banks are peak hours of operation in the hub airport where passengers are connected from one point to another. Every flight bank is composed by a group of landing flights followed by a group of departures. The first 3 flight banks are scheduled between 6:20 am to 12:12 midday; the last 3 banks start at 1:54 pm to 9:40 pm. Panama Time.

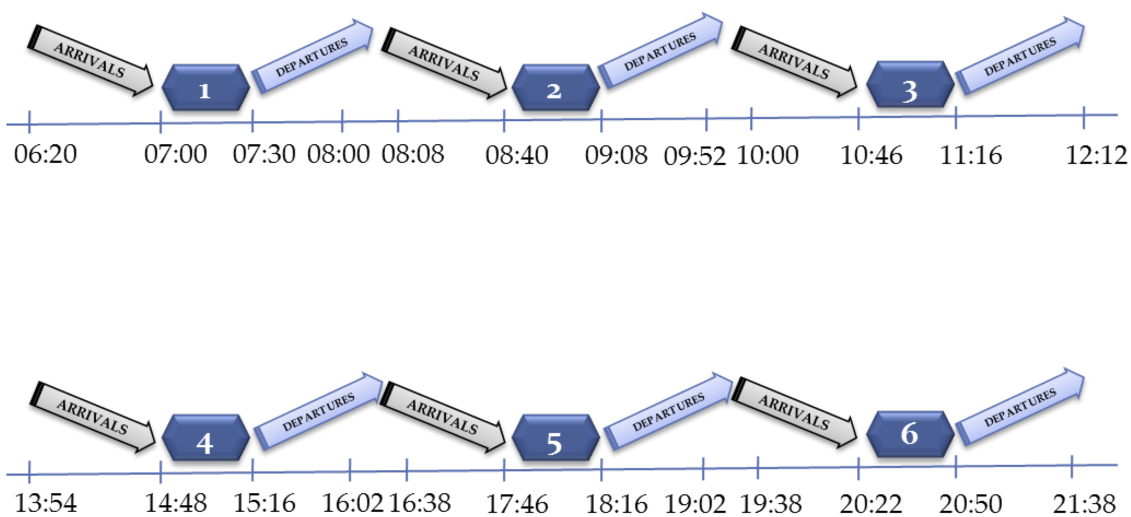


Figure 1: Copa Airlines Flight Banks

Today, Copa Airlines Panama operates approximately 225 daily flights, with one of the youngest fleet worldwide connecting the Americas from South, North and Caribbean using Tocumen International Airport, Panama City as their hub airport. The airline connects passengers in 30 minutes.

Figure 2: Copa Airlines Network

This study will only consider flights with origins or destination in Panama City. Nevertheless, there are flights called Intracam, which do not have Panama City as a destination nor origin (for example, flights from Managua, Nicaragua to Guatemala City, Guatemala). Therefore, though Copa network has on average 225 daily flights per day, this study will focus on 215 average daily flights.

The following table shows the airports to which Copa Airlines operates and are considered in this study.

City	Country	IATA	Airport
Asunción	Paraguay	ASU	Silvio Pettirossi International Airport
Belo Horizonte	Brazil	CNF	Tancredo Neves International Airport
Bogota	Colombia	BOG	El Dorado International Airport
Boston	United States	BOS	Logan International Airport
Brasilia	Brazil	BSB	Brasília International Airport
Buenos Aires	Argentina	EZE	Ministro Pistarini International Airport
Cancún	Mexico	CUN	Cancún International Airport
Caracas	Venezuela	CCS	Simon Bolivar International Airport
Chicago	United States	ORD	O'Hare International Airport
Córdoba	Argentina	COR	Ambrosio L.V. Taravella International Airport
Guadalajara	Mexico	GDL	Miguel Hidalgo y Costilla International Airport
Guatemala City	Guatemala	GUA	La Aurora International Airport
Guayaquil	Ecuador	GYE	José Joaquín de Olmedo International Airport
Havana	Cuba	HAV	José Martí International Airport
Iquitos	Peru	IQT	Francisco Secada Vignetta International Airport
Kingston	Jamaica	KIN	Norman Manley International Airport
Las Vegas	United States	LAS	McCarran International Airport
Liberia	Costa Rica	LIR	Daniel Oduber Quirós International Airport
Lima	Peru	LIM	Jorge Chávez International Airport
Los Angeles	United States	LAX	Los Angeles International Airport
Managua	Nicaragua	MGA	Augusto C. Sandino International Airport
Manaus	Brazil	MAO	Eduardo Gomes International Airport
Maracaibo	Venezuela	MAR	La Chinita International Airport
Mexico City	Mexico	MEX	Mexico City International Airport
Miami	United States	MIA	Miami International Airport
Montego Bay	Jamaica	MBJ	Sangster International Airport
Monterrey	Mexico	MTY	General Mariano Escobedo International Airport
Montevideo	Uruguay	MVD	Cesareo Berisso Airport
Nassau	Bahamas	NAS	Lynden Pindling International Airport
New York City	United States	JFK	John F. Kennedy International Airport
Oranjestad	Aruba	AUA	Queen Beatrix International Airport
Orlando	United States	MCO	Orlando International Airport
Panama City	Panama	PTY	Tocumen International Airport
Pereira	Colombia	PEI	Matecaña International Airport
Philipsburg	Sint Maarten	SXM	Princess Juliana International Airport
Port of Spain	Trinidad and Tobago	POS	Piarco International Airport
Port-au-Prince	Haiti	PAP	Toussaint Louverture International Airport
Porto Alegre	Brazil	POA	Salgado Filho International Airport
Punta Cana	Dominican Republic	PUJ	Punta Cana International Airport
Quito	Ecuador	UIO	Mariscal Sucre International Airport
Recife	Brazil	REC	Recife Airport
Rio de Janeiro	Brazil	GIG	Rio de Janeiro-Galeão International Airport
San José de Costa Rica	Costa Rica	SJO	Juan Santamaría International Airport
San Juan	Puerto Rico	SJU	Luis Muñoz Marín International Airport
San Pedro Sula	Honduras	SAP	Ramón Villeda Morales International Airport
San Salvador	El Salvador	SAL	El Salvador International Airport
Santa Cruz de la Sierra	Bolivia	VVI	Viru Viru International Airport
Santiago	Chile	SCL	Arturo Merino Benítez International Airport
Santiago de los Caballeros	Dominican Republic	STI	Cibao International Airport
Santo Domingo	Dominican Republic	SDQ	Las Américas International Airport
São Paulo	Brazil	GRU	São Paulo-Guarulhos International Airport
Tegucigalpa	Honduras	TGU	Toncontín International Airport
Toronto	Canada	YYZ	Toronto Pearson International Airport
Valencia	Venezuela	VLN	Arturo Michelena International Airport
Washington D.C	United States	IAD	Washington Dulles International Airport
Willemstad	Curaçao	CUR	Hato International Airport

Table 1: Cities were Copa Airlines Operates

It is important to mention, that Copa operates many long haul flights. Flights longer than 5 hours are considered to be long haul flights. The initial idea for assigning an airplane to be spare was to protect these flights in case events occurred because given their distance and their low weekly frequencies, these were very difficult to recover.

Today, the airlines operate many long haul flights, with several daily frequencies to far away cities. Therefore, the usage of spare varies and the decision of its usage relies on specific events, crew availability, and passenger services. Therefore, nearby flights may have priority for assigning spares.

Copa Airlines has one of the youngest fleet in the airline industry. It flies to most cities of America using Boeing 737-700, 737-800 (with two different configurations, one of 160 seats and the other one with 154 seats), and Embraer 190. Today, the airline operates using a total of 68 airplanes and it continues to receive new 737-800 airplanes every year.

Figure 3: Copa Airlines Fleet Characteristics

Fleet Type	Fleet Size
Boeing 737-700	14
Boeing 737-800	42
Embraer 90	12

Table 2: Fleet Size and Type

The number of new airplanes been added into the total fleet size varies every year and depends on the forecasted growth of the airline. According to the airlines' strategic department, the table below shows growth projections of the airline in the following 5 years.

Year	2013	2014	2015	2016	2017	2018
Copa Flights	369	400	424	444	495	**514**
		8.27%	*6.24%*	*4.62%*	*11.41%*	*3.99%*

Table 3: Copa Airlines Growth Projections

The airline has ambitious growth goals, and we can emphasize on the importance of knowing the number of spares by using mathematical approach.

Methodology

This project is focused on the Operational Control Center (SOCC) of Copa Airlines Panama and the decision making process on spare usage to diminish schedule disruptions which affect airline performance and passenger service. The study was divided into three sections.

The first section focused on understanding and documenting the airline's operational environment. Several hours of on the job training were required at SOCC and the Tocumen International Airport to understand the operation. This introduction to the company helped to determine the methodology used in this study.

With the introduction to the airline operation, we were able to define the problem, the objectives of the study and its deliverables within the given time frame. The project officially began with the kickoff meeting on May 15, 2013 and ended on July 31, 2013 (75 calendar days)

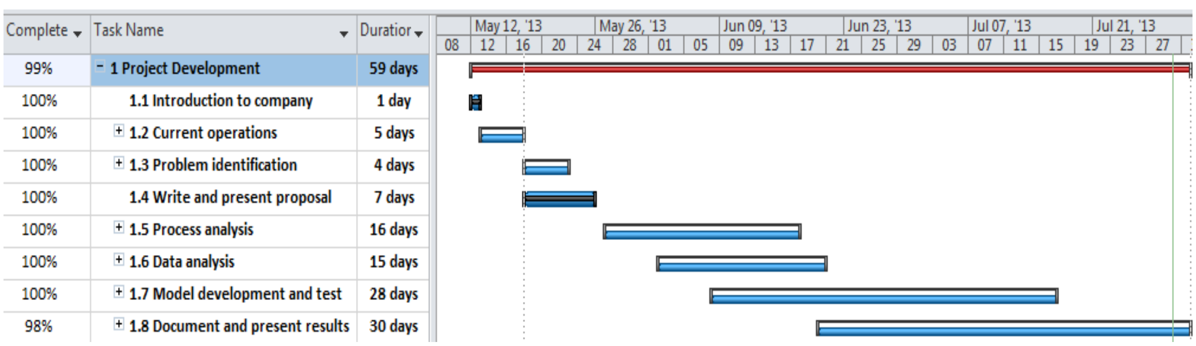


Figure 4: Project Timeline

The second section began with surveys and interviews to Duty Managers to identify data requirements for the study. Data analysis and surveys provided main reasons for which spares are used and allowed generating a model for calculating number of spares. Spare problem can be defined as a recovery plan type problem, fleet size problem, or even as a spare optimization problem similar to those of spare parts.

The third section was to create a tool using information gathered in section 1 and 2. The tool was developed using an Excel spreadsheet that simulates the airline operation. The tool uses as inputs the airline schedule and data on historical disruptions.

Surveys

Decisions and control of operations are very wide and complex. SOCC Duty Managers are in charge of making all operation-related decision (disrupted or not) based on inputs given by other areas in the SOCC. Each Duty Manager makes decisions based on their knowledge of the operations, their experience and inputs from other areas. On the other hand, routers give support to duty managers. They assist managers with flight and maintenance assignment to every airplane.

Both, duty managers and routers (7 from a total of 9), were surveyed to identify the main events spare aircraft are used (based on their experience). The 7 of them agreed that OOS was the main event for which spares are used.

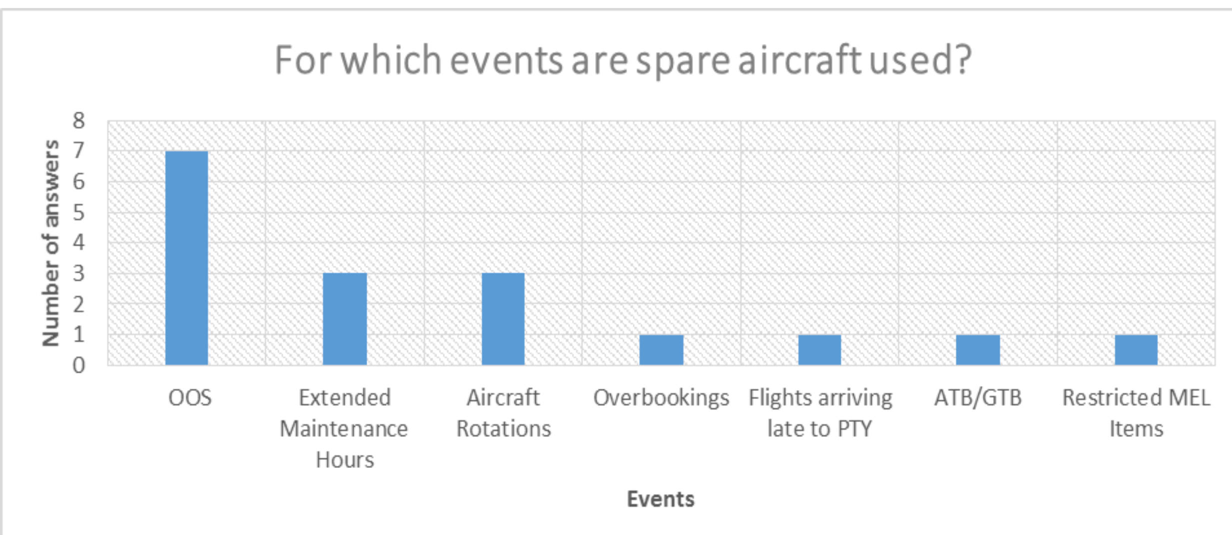


Figure 5: Events that require spares

Data Collection

One of our main limitations for this project was data availability. In order to collect data, we were required to understand the operations system, read the AIMS tool graphical display and interpret it to properly relate it to the itinerary, mainly due to the lack of a reporting system that shows when spares where required.

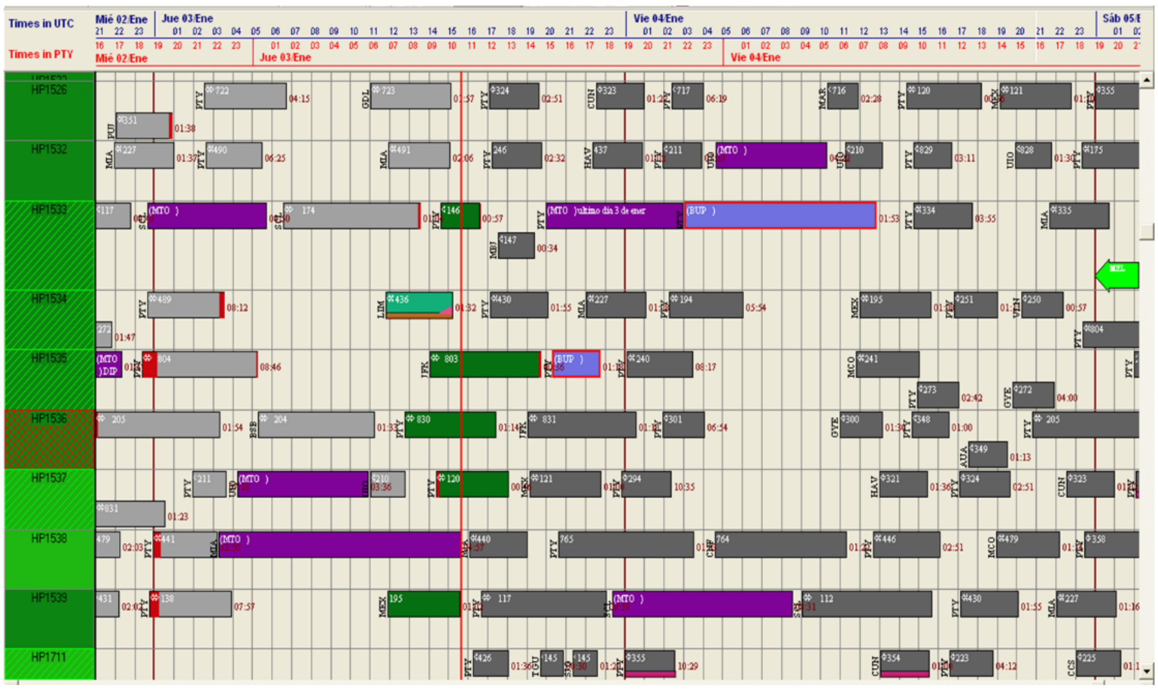


Figure 6: AIMS System

The data sets collected for the period between January to May 2013 where the following:

- Flight Delays report: This report has information on all flights that had any type of delay. From this report we calculated most of the events occurrence and duration probabilities.
- Delay code table: This table was used to understand the flight delay report. This table explains all reasons that Copa Airlines has identified as causes of schedule disruptions.

- OOS report: This report contains information on damaged aircraft. It was used for calculating probabilities of occurrence and duration of this event per aircraft taking place only in Panama City. The OOS occurring outstation where aggregated grouped into another group that will be presented later in this paper.
- Data on preventive maintenance but not scheduled at a strategic level was also requested but we were informed historical data was not available.

Identification of Main Reasons that Require Spare Usage

By studying irregularities in AIMS, analyzing the collected data sets, and the information gathered by surveys it was possible to identify and validate the main situations in which spares where used. Later, Copa's delay code was analyzed to identify which disruptions could be solved by using spares, and to classify these delays into categories.

Copa delay code table has a total of 212 different codes. These codes were grouped into categories to simplify the analysis. Only 17 were identified as delays that could be solved by having spares. For events occurring in Panama City, these situations were mainly damages to airplanes and repairs. These 17 codes where grouped into a category called PTY Spare.

Some codes from the list were excluded: codes 36 and 39, because these are related to making swaps between equipment, which is a limitation in this project. Codes related to reactionary or domino effect were also excluded, because these probabilities were not required for this analysis. Domino effect is created when multiple flight are affected by a disruption.

For example: A flight departed late because the airplane was under repair. Besides the original flight that had the event, other flights that the airplane had assigned will sometimes be delayed because of the original event. The remaining codes other codes where grouped into a category called PTY no Spare.

Flights classified as 98(x) in the Flight Delay Data Set are related to aircraft damage. These flights were compared against the OOS data set to ensure that flights reported in both tables were not duplicated. Flight information on the OOS table related to Panama City (events occurring in PTY) where grouped into a category called OOS. The code table is available in Appendix B.

The last group identified was named outstation. This group includes all flights with events that occurred outside of Panama. For this category we consider all codes in the table. The reason for this is that airplanes arriving to Panama are schedule to complete another flight 50 or 60 minutes later depending of the aircraft type. Therefore, if any airplane arrives late to PTY, a flight departing from PTY is automatically going to be late. This event can also be solved with spare airplane. Which can cover the schedule until the late arriving airplane gets to Panama.

Another identified group was preventive maintenance events that are not scheduled at a strategic level, but at an operational level one month prior to day of operation. Examples of this type of preventive maintenance are: airplane painting events, repairs that can be done later with authorization of the manufacturer, and some engineering orders that are due before the airplane has a programmed heavy maintenance. This data was not available at the time of the analysis and therefore was excluded from the project.

Figure 7: Airplane requiring new painting

All the identified events were validated against the surveys. In summary, the categories used in this study were:

- Outstation: Flights arriving late into Panama City.
- PTY Spare: Flights departing late from Panama City mainly due to repairs.
- OOS: Airplanes out of service in Panama.
- PTY No Spare: Events in Panama City that cannot be solved by having a spare airplane.

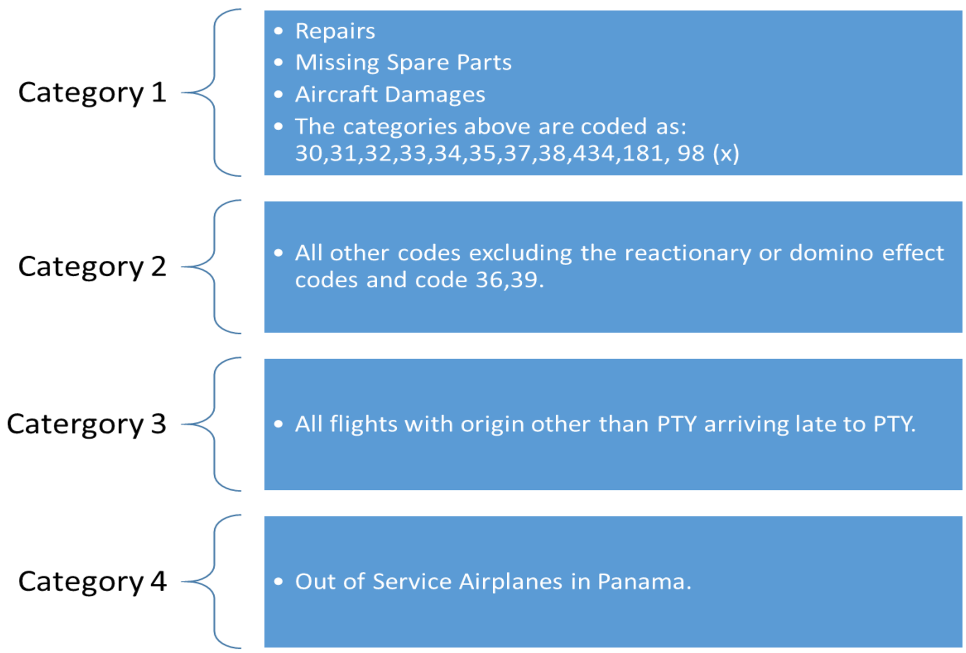
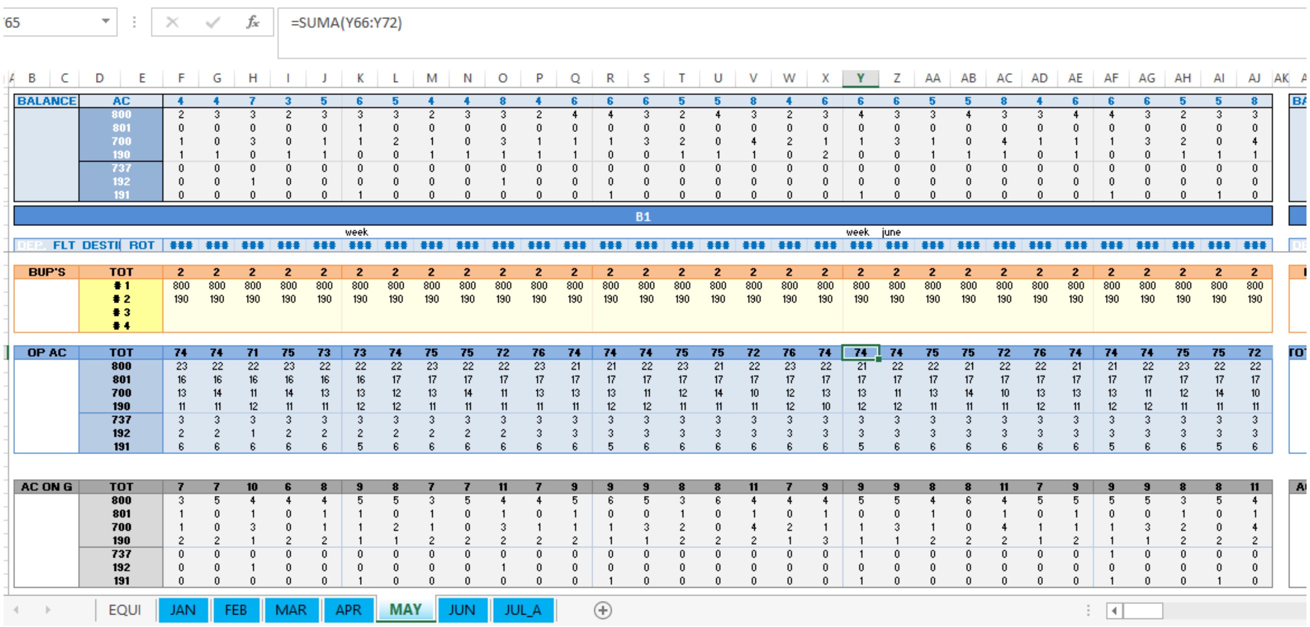


Figure 8: Events Lists and Code

Development of Spare Assignment and Usage Process

Before understanding how spares were used, it was important to know how spares are created in the schedule and how these are assigned to specific aircrafts. Interviews with the department of schedule planning and routers allowed understanding helped to understand the general process on how spares are identified and assigned. Spares, at a strategic level are any 2 additional airplanes that have no schedule assigned to it.

Copa uses an excel spreadsheet to determine airplane requirements. In this sheet they also have information on the number of spares. The orange box in figure 7 represents the number of spares and type of airplane defined at a strategic level.


'65 =SUMA(Y66:Y72)

B–C	D–E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
BALANCE	AC	4	4	7	3	5	6	5	4	4	8	4	6	6	6
	800	2	3	3	2	3	3	3	2	3	3	2	4	4	3
	801	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	700	1	0	3	0	1	1	2	1	0	3	1	1	1	3
	190	1	1	0	1	1	0	0	1	1	1	1	1	0	0
	737	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	192	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	191	0	0	0	0	0	1	0	0	0	0	0	0	1	0
															B1
							week								
DEP. FLT DESTI	ROT	###	###	###	###	###	###	###	###	###	###	###	###	###	###
BUP'S	TOT	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	# 1	800	800	800	800	800	800	800	800	800	800	800	800	800	800
	# 2	190	190	190	190	190	190	190	190	190	190	190	190	190	190
	# 3														
	# 4														
OP AC	TOT	74	74	71	75	73	73	74	75	75	72	76	74	74	74
	800	23	22	22	23	22	22	22	23	22	22	23	21	21	22
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	700	13	14	11	14	13	13	12	13	14	11	13	13	13	11
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	191	6	6	6	6	6	5	6	6	6	6	6	6	5	6
AC ON G	TOT	7	7	10	6	8	9	8	7	7	11	7	9	9	9
	800	3	5	4	4	4	5	5	3	5	4	4	5	6	5
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	737	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	192	0	0	1	0	0	0	0	0	0	1	0	0	0	0
	191	0	0	0	0	0	1	0	0	0	0	0	0	1	0

B–C	D–E	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ
BALANCE	AC	5	5	8	4	6	6	6	5	5	8	4	6	6	6	5	5	8
	800	2	4	3	2	3	4	3	3	4	3	3	4	4	3	2	3	3
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	191	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0
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DEP. FLT DESTI	ROT	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###
BUP'S	TOT	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	# 1	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
	# 2	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190	190
	# 3																	
	# 4																	
OP AC	TOT	75	75	72	76	74	74	74	75	75	72	76	74	74	74	75	75	72
	800	23	21	22	23	22	21	22	22	21	22	22	21	21	22	23	22	22
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AC ON G	TOT	8	8	11	7	9	9	9	8	8	11	7	9	9	9	8	8	11
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	192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	191	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0

EQUI JAN FEB MAR APR MAY JUN JUL_A

Figure 9: Aircraft Planning at Strategy Level

Spares are airplanes not considered in the schedule at strategic level. It is at an operational level, where specific airplanes are assigned to be spares. Several airplanes can be assigned to be spare on a given day depending on the operational schedule.

The next step was to understand how the assigned spares where used. Duty managers are the ones who decide the situations and the time in which these are used. This process occurs on the day of operation and decisions will vary depending on several factors mainly because of the high variability in the operation.

Standardize when to use spare.

At Copa Airlines, decision making process of the duty manager is not documented nor has been specified meaning it has yet to be standardized. Every duty manager had a different approach and used different criteria to solve the same type of disruptions, so a standardized process was developed and mapped. The creation of this standardized process was necessary in order to be able develop a model.

The standardized process is based on the main categories of events that were identified. The process and spare usage time frames where validated with the airline managers, and are based on the managers' experience of the operation.

Type Of Decision	Events
Use Buffer	Airplanes arriving late to Panama.
Use Spares	Airplanes arriving late to Panama.
	Airplanes under repair or damaged in Panama
Delay Flights	All Flights having other types of problems not related to the airplane. Such as waiting for passengers in a connecting flight.
Flight Cancelations	Last option Duty Manager take. Requires extensive analysis.

Figure 10: Decisions taken by Duty Managers

Probability Analysis of identified events

After documenting the standardized process for duty managers' decision making, a probability analysis was developed. Probabilities of occurrences and duration were calculated for the four categories mentioned in the previous section. This probability analysis was completed using an excel spreadsheet and it is used as input for the random generation of events similar to the ones that had occurred in the past. This sheet helps to simulate events that occur in Copa Airlines Network. A complete manual on the use of this spreadsheet was added to this document as Appendix G.

The probability analysis is based on historical events obtained from the delay and OOS data sets. The data was cleaned to match the codes that were analyzed in this study. From the OOS table, only data for Panama City was used. All OOS events occurring in outstation are used from the delay table and grouped as Category Outstation.

Step 1	•Use historical data to determine probabilities of amounts of events occurring per day. Example: Probabilities of 0, 1, 2,3 … events occurring per day.
Step 2	•Divide events occurring by each of the 4 types and calculate probabilities of occurrence for each of them.
Step 3	•Calculate probabilities of an event occurring in a city for the outstation type of events.
Step 4	•Calculate probabilities of event of each type occurring for each type of airplane.
Step 5	•Calculate probabilities of durations in ranges of 30 minutes.

Figure 11: Probability Calculation Steps

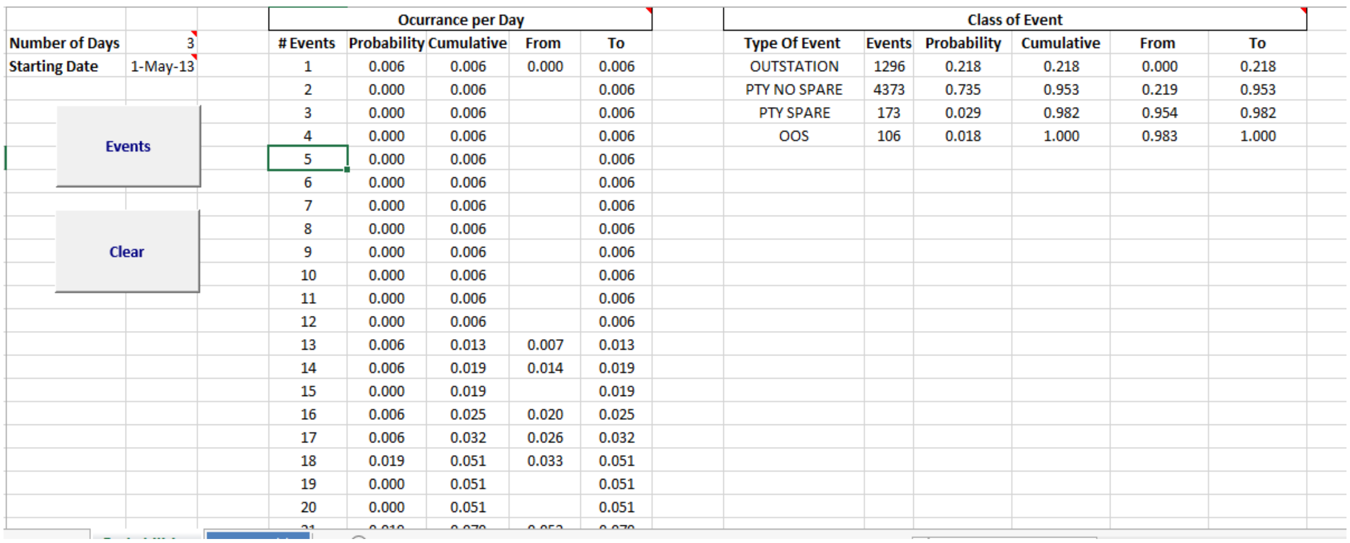
From the probability analysis we were able to validate that the probability of occurrence of events group as PTY no Spare has the highest probability of occurrence (Approximately 73%) for the period of historical data used, followed by events occurring in outstation.

D	E	F	G	H	I
Delay Outstation	All delays of flight with destination PTY.				
Delay Code Pty that require spare use.		30, 31, 32, 33, 34, 35, 37, 38, 98A, 98B, 98C, 98D, 98E, 98F, 9		181, 434	
Codes not considered in the analisis		36 y 39			
Class Of Event	Events	Probability	Cumulative	FROM	TO
Outstation	1296	0.218	0.218	0.000	0.218
PTY - No Spare	4373	0.735	0.953	0.219	0.953
PTY - Requiere Spare	173	0.029	0.982	0.954	0.982
OOS	106	0.0178	1.0000	0.983	1.000
Total	5948	1			

Figure 12: Probability Calculation Sheet

Random Generation of Events.

Probabilities calculated in the previous step are used to generate random events. These events are used to create disruptions in the schedule. They are three main inputs for the generator sheet: amount of days for which events must be generated, starting date for event generations, and import of probabilities previously calculated.



Number of Days	3
Starting Date	1-May-13

Events

Clear

Ocurrance per Day				
# Events	Probability	Cumulative	From	To
1	0.006	0.006	0.000	0.006
2	0.000	0.006		0.006
3	0.000	0.006		0.006
4	0.000	0.006		0.006
5	0.000	0.006		0.006
6	0.000	0.006		0.006
7	0.000	0.006		0.006
8	0.000	0.006		0.006
9	0.000	0.006		0.006
10	0.000	0.006		0.006
11	0.000	0.006		0.006
12	0.000	0.006		0.006
13	0.006	0.013	0.007	0.013
14	0.006	0.019	0.014	0.019
15	0.000	0.019		0.019
16	0.006	0.025	0.020	0.025
17	0.006	0.032	0.026	0.032
18	0.019	0.051	0.033	0.051
19	0.000	0.051		0.051
20	0.000	0.051		0.051

Class of Event					
Type Of Event	Events	Probability	Cumulative	From	To
OUTSTATION	1296	0.218	0.218	0.000	0.218
PTY NO SPARE	4373	0.735	0.953	0.219	0.953
PTY SPARE	173	0.029	0.982	0.954	0.982
OOS	106	0.018	1.000	0.983	1.000

Figure 13: Random Generator Sheet

The events generator sheet, generates events one by one until it completes the count of total events. For example, depending on the probability of event occurring at a given day, it will randomly generate a number of events for a specific day. Then, it will process each event individually assigning it to a type of events, type of equipment and duration.

Creation of tool for computing spares

The tool simulates events and disruptions that historically occurred in the airlines network for any time frame desired. It takes as inputs the probability analysis, the creation of random events and a schedule without disruptions. The tool was validated by adding historical disruption data and an old schedule to see if it created similar scenarios to those that happened. Results varied by 1 to 5%. Details are shown in the result section.

The tool allows the airline to import new schedules with historical probability data and determine an approximate number of required spares. The tool uses the standardized decision process documented for this study. Parameters of the standardized process can be changed to observe how KPIs and number of spares changes. The tool was created following 4 basic steps.

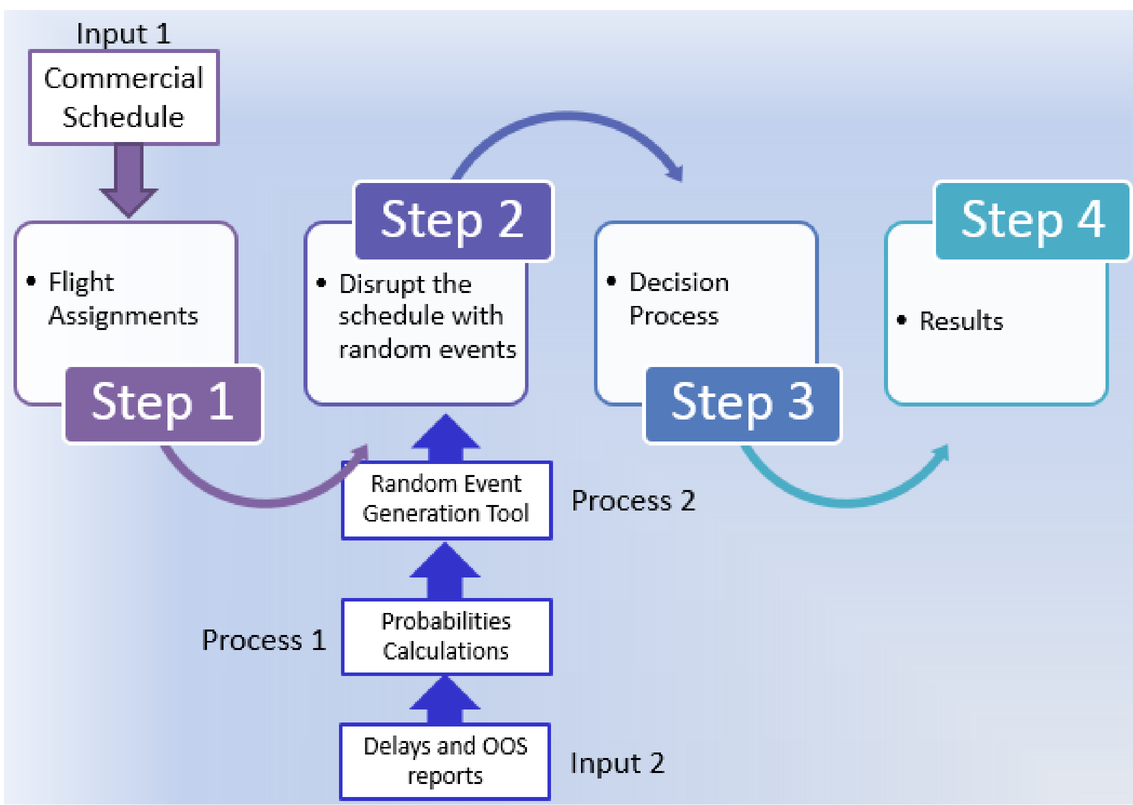


Figure 14: Tool Main Steps

Step 1, creates the sequence of flights for each airplane. This sequence of flights is assigned under ideal conditions, no disruptions. This section determines the number of airplanes that are required to operate the planned schedule. The flight assignment is also used to determine buffer availability in the schedule which is used in step 3 in the decision making process. Flight sequencing was created using 3 rules:

- Use the same type of airplane.
- For Panama, use first in-first out rule. Keeping minimum ground time for each type of airplane.
- For Outstation, inbound and outbound flights are fixed.

Step 2 and 3 of the tool simulates disruptions on a schedule. It takes each generated event, and solves the disruption (based on the duty manager's decision process) and makes the schedule feasible again. Once the decision has been made, it lists the flights with the decisions in a table so all decision can be seen and be evaluated. Once the decision is made and printed in the table, it returns to the events table and analyses the next event. It makes a decision by evaluating the event (delay type), and modifies decision of previous events if required.

For all delay decisions, the toll will delay the flight that had the event and will continue to delay other flights in the airplane sequence until it finds ground times that are more than the minimum required to prepare the airplane for the next flight.

For example: Flight 354 Cancun to operating in an 800 had a delay of 1 hour. Its ground time in PTY is 60 minutes. The next flight assigned to that airplane is Panama to Sao Pablo (CM701). Because the airplane has minimum ground time in PTY, the flight 701 will be delayed for 1 hour also. This applies to both PTY and Outstations delays.

For spare decision, the tool assigns a new airplane for the duration of the event only if it cannot delay the flight or if it did not find a buffer in a given time frame, and prints in the decision table that a spare was assigned to cover the disruption. The tools logic for decision making is in Appendix F.

For example: A flight CM764 with a route Belo Horizonte, Brazil to Panama City, Panama departs 1 hour late. It is programmed to arrive at PTY in bank1. The tool will first search for a buffer in the same bank that is equal or greater to 1 hour. If it finds a buffer, it will change the airplane sequence and no delay or spares will be generated. Buffers can only be used once. If it has been assigned for a specific day it cannot be used again.

Limitations and assumptions used to create the tool are below.

Area	Limitation
Flights	Intracam flight were not analyzed.
	Cancelations are not included in the study.
	Copa Airlines flights operated by Copa Colombia are not included.
	Flights are always assigned to its scheduled airplane model. Flights cannot be changed to other airplanes model.
Passengers	Number of passenger per flights where not analyzed.
	Passenger Service was not taking into account.
Crew	Crew availability and regulations were not consider.
Rules	Service Visits are not programmed in the flights sequence.
	Fast turnaround time were not evaluated.
	A flight with a delay in its departure, will have the same delay in its arrival.

Table 4: Tool's Limitations

Assumptions

All flights are operated by Copa Airlines Panama.
Crew is always available for spare usage.
Spare aircraft are only used to recover flights in Panama and not in other stations (countries).
Occasional aircraft lending to Copa Colombia will not affect spare aircraft usage.
Days and times in schedule were all considered in UTC.
Minimum Ground times are always 50 min for 700 and E90, and 60 minutes for 800, and 801.
All flights with decision “spare “ are considered to operate on time.

Table 5: Tool's Assumptions

Schedule Design and Spare Aircraft Assignment Process

Airline operations are generally handled in two phases: strategic and operational. Strategic operations are responsible for schedule planning, while operational focuses on schedule executions. This schedule only includes flight numbers, city pairs of operation, airplane model assigned to every flight, and mayor maintenance inspections (such as C-checks A-checks). C-Checks require around 21 days while A-Checks approximately 16 hours, both scheduled based on the airplane's flight time and number of takeoffs and landings.

Nevertheless, this schedule does not include information on crew, service visit locations (where regular maintenance will be performed), or which specific airplane requires the C or A checks. At Copa Airlines, the schedule is planned on total fleet size minus 2. For example: today, Copa Airlines operates 65 airplanes, but the schedule is based on 63. The 2 remaining airplanes are considered as spares, and used to recover operations from disruptions. These spares are called backups. The schedule only includes the model of the airplanes left as spares, but these are not fixed or specific aircraft.

The schedule is developed 6 months in advance at a strategic level and is updated continuously one month prior to its execution. The operational level will be in charge of assigning and adjusting operation aircraft and spares.

At the operational level, the operation control center (SOCC in Copa Airlines) manages and executes the strategic schedule. One month prior to execution, the schedule is sent to SOCC. At this point, crew is assigned to each flight and determined in conjunction with Maintenance, which airplanes need to be scheduled (when and where) for mayor maintenance inspections. This process can take from 15 to 20 days.

Once all mayor maintenance inspections are assigned to specific airplanes, the aircraft router assigns the remaining flights to airplanes considering service visits, and determines which airplane will be assigned as backup. This process is done on a rolling 7-day period.

Aircraft and Spare Assignment

At the strategic level, Management begins planning the master schedule (six months in advance). This schedule is generated by using a phasing file with inputs such as planned flights, heavy maintenance required per aircraft (A-checks, C-Checks), total fleet size, and number of hours required for operating the future schedule.

At an operational level, 20 to 45 days prior to the day of operation master schedule is exported in SSIM format file and sent via e-mail to the router. Router will import file to AIMS system and reviews master schedule to update AIMS system with the current planned schedule. Planned inbound flights are merged with planned outbound flights creating steadiness in the system operations.

This merged flights report is then exported in SSIM formal file and compared to the original master schedule file. If there are any discrepancies, schedule’s status will appear as “unassigned “ (waiting for maintenance hours required and spare to be assigned) and will need to be adjusted in AIMS.

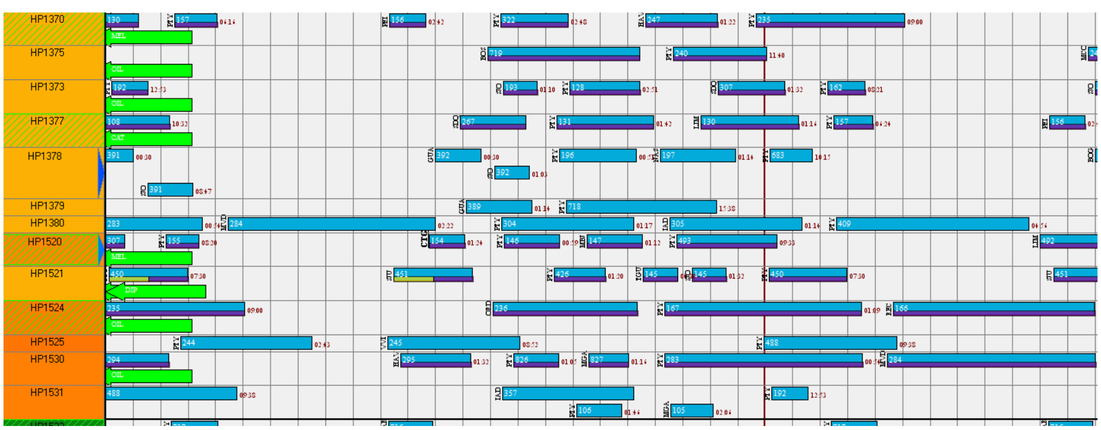


Figure 15: AIMS - Blue bars represent unassigned flights. Airplanes list to the left.

At an operational level, seven days before day of operation, Router receives via e-mail information such as tail numbers, cities, and dates when maintenance ought to be performed. Router assigns required maintenance to specific aircraft. Once all required maintenances are assigned, he proceeds to assign specific aircraft to each flight. At this point, the router will know which aircraft can be assigned as spares (these aircraft will have no planned maintenance or flights assigned).

Once spares are assigned to specific aircraft, if the schedule becomes unfeasible (due to disruptions of programmed maintenance and aircraft assignment), the router is able to correct the schedule with flight overlaps, swap programmed maintenance among aircraft or even exchange equipment for a specific operation. This 7-day schedule will change in a rolling day basis prior to the operation, as the router receives requests from maintenance, crew and stations departments.

The figure below is an image from AIMS. The number and boxed on green at the left side of the picture represent each airplane. Vertical Lines represent 1 hour of time. Boxes in light gray represent completed flights, and for those flight completed with red marks represent time the flight was delayed. Boxed in dark gray represent assigned flight, while the dark purple are maintenance events and the light blue are assigned spare aircraft.

Schedule Execution and Spare Usage

Duty Managers rely greatly on the inputs that other operative areas provide for a given situation. The graph below shows the interaction between the SOCC Duty Manager and the operative areas. The graph includes the main inputs of each area to the Duty Manager. All inputs are analyzed by the manager prior to decision making.

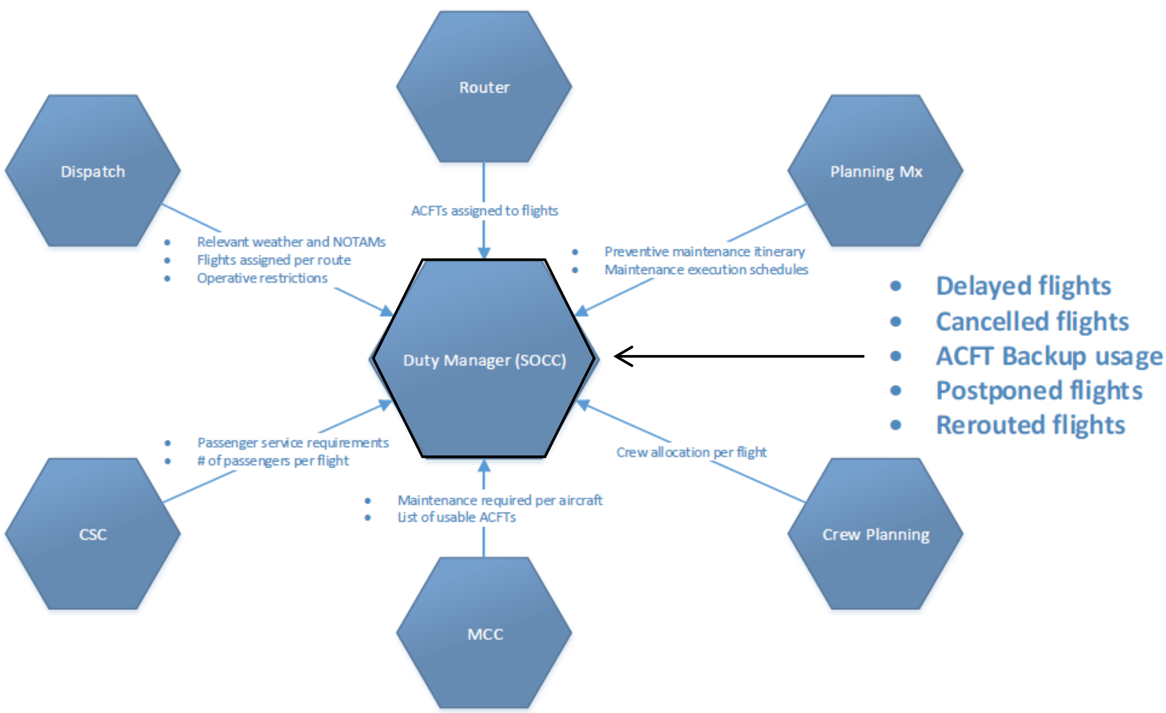


Figure 16: Inputs to Duty Managers

Spare Usage Rules

Daily operations in an airline are disrupted by many factors, such as imminent repairs, severe weather conditions, unavailable crew, airport restrictions, etc. The need of having spares results from the fact that the planned schedule gets disrupted each day by these factors, which will now be considered as “events”.

Not in all cases, a spare will be the solution to cover such disruptions; for example, the airline must reassign a flight to one of its spares, since the one that was programmed diverted to another airport. Then a spare is available but there is no available crew to operate this flight. In this case the available spare couldn't cover the schedule disruption. This leaves operational restrictions and weather disturbances as the only events that can lead directly into requiring an additional aircraft to cover interrupted operations.

Once the flight schedule is created, the Duty Manager is now able to see in AIMS system the specific aircraft that are programmed as spares. Given current characteristics of the network, such as total fleet size and spare fleet available; when the Duty Manager is notified of an event with one aircraft he must first determine where the event has occurred, is it In-station (PTY) or out-station (all other airports) and if such event will generate a delay of its next programmed flight.

If the event is In-station, and it can be solved during its required ground time, the next programmed flight for that aircraft will not be affected, else the Duty Manager must evaluate if such affectation will take longer than an acceptable delay time (1 or 2 hours) that the passengers would be willing to wait. If the delay won't take that long, maintenance staff is able to start working on solving the issue and passengers are notified of the delay; else if the event takes more than 2 hours, the Duty Manager has now the task of reassigning that flight.

When there are several delayed flights, the Duty Manager must prioritize among the delayed flights and decide which flight will be covered by the available spare, usually giving priority to those that have most passengers. Then if there is an available spare to cover the delayed flight, he must be aware of the physical location of the aircraft; since moving it from the hangar might take longer than passengers would be willing to wait and it would add additional complications if the airport is at a congestion hour.

In the situation that there are no spares for the moment, but one will be available later, the Duty Manager has the authority to decide to use an aircraft programmed for another flight that will depart in the next bank; this is known as virtual spare or buffer.

Deciding on using the largest buffer usually gives the benefit of leaving the aircraft that will be recovered later as a spare for later departures. If there aren't any spares or buffers available, depending on when the next spare will be available, the Duty Manager will decide to postpone or even cancel the flight.

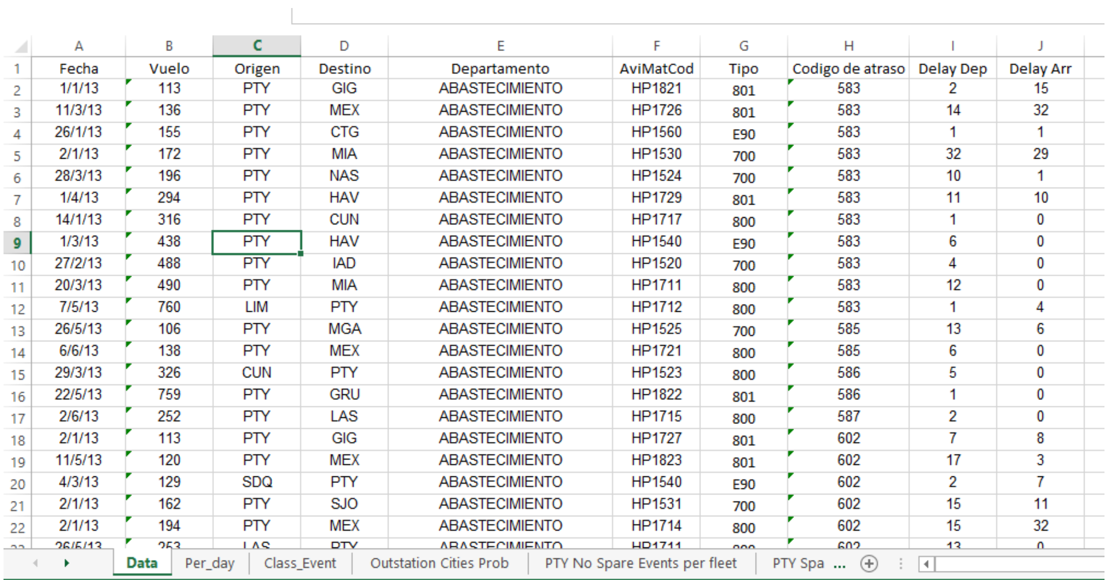
Given the scenario now that the event occurs in Out-station, the Duty Manager must determine if this will affect another departure in PTY. If a buffer is available to cover this flight, and it is large enough to cover the delayed arrival and minimum ground time, the buffer can be assigned; else if there isn't buffer available, the Duty Manager must consider using a spare aircraft. The following table summarizes the group of events and possible decisions for each one of them.

Type Of Event	Decision
OOS	Use Spare
PTY No Spare	Delay Flight
PTY Spare	< = 60 minutes Delay Flight
	> 60 minutes Use Spare
Outstation	< = 90 minutes, use buffer, then Delay Flight
	> 90 minutes Use Spare

Table 6: Decisions

The tool was created to help the airline determine the number of spares that are required for the operation. The tool calculations and decisions are based on airplane availability. It was developed in Excel and it has 4 sections. The first section takes historical data of events and calculates all probabilities for events occurrence and their durations. It takes as inputs delay and OOS reports.

Delay data and OOS data was provided by the airline. The data must be entered in the data tab of the Probability Analysis Book. Using the refresh data button in excel will refresh all pivot tables and generate new probability calculations. More details on the use of the tool are available in Appendix G.



	A	B	C	D	E	F	G	H	I	J
1	Fecha	Vuelo	Origen	Destino	Departamento	AviMatCod	Tipo	Codigo de atraso	Delay Dep	Delay Arr
2	1/1/13	113	PTY	GIG	ABASTECIMIENTO	HP1821	801	583	2	15
3	11/3/13	136	PTY	MEX	ABASTECIMIENTO	HP1726	801	583	14	32
4	26/1/13	155	PTY	CTG	ABASTECIMIENTO	HP1560	E90	583	1	1
5	2/1/13	172	PTY	MIA	ABASTECIMIENTO	HP1530	700	583	32	29
6	28/3/13	196	PTY	NAS	ABASTECIMIENTO	HP1524	700	583	10	1
7	1/4/13	294	PTY	HAV	ABASTECIMIENTO	HP1729	801	583	11	10
8	14/1/13	316	PTY	CUN	ABASTECIMIENTO	HP1717	800	583	1	0
9	1/3/13	438	PTY	HAV	ABASTECIMIENTO	HP1540	E90	583	6	0
10	27/2/13	488	PTY	IAD	ABASTECIMIENTO	HP1520	700	583	4	0
11	20/3/13	490	PTY	MIA	ABASTECIMIENTO	HP1711	800	583	12	0
12	7/5/13	760	LIM	PTY	ABASTECIMIENTO	HP1712	800	583	1	4
13	26/5/13	106	PTY	MGA	ABASTECIMIENTO	HP1525	700	585	13	6
14	6/6/13	138	PTY	MEX	ABASTECIMIENTO	HP1721	800	585	6	0
15	29/3/13	326	CUN	PTY	ABASTECIMIENTO	HP1523	800	586	5	0
16	22/5/13	759	PTY	GRU	ABASTECIMIENTO	HP1822	801	586	1	0
17	2/6/13	252	PTY	LAS	ABASTECIMIENTO	HP1715	800	587	2	0
18	2/1/13	113	PTY	GIG	ABASTECIMIENTO	HP1727	801	602	7	8
19	11/5/13	120	PTY	MEX	ABASTECIMIENTO	HP1823	801	602	17	3
20	4/3/13	129	SDQ	PTY	ABASTECIMIENTO	HP1540	E90	602	2	7
21	2/1/13	162	PTY	SJO	ABASTECIMIENTO	HP1531	700	602	15	11
22	2/1/13	194	PTY	MEX	ABASTECIMIENTO	HP1714	800	602	15	32

Figure 17: Probability Data Tab

The tool only considers 4 types of events, but other types of events can be added once they are identified to disrupt the schedule. These can be added in the class Events tab of this same file. Clicking on Refresh again will update the information.

The second section of the tool is a random event generator Excel book. It takes as input the probabilities computed in section one and randomly creates events and durations accordingly. Once random events are created, these are imported to a third book, which is section 3 of the tool. To import the information we have to do a copy paste from the generator file to the Events table in the Decision Tool. More details are available in tools manual in the appendix section.

	A	B	C	D	E	F	G	H	J
1	Date	Flight	Dep Arp	Event	EventType	Duration	A/C Type	Dep Time	New Available Time
2	1/5/13	872	GIG	1	OUTSTATION	0:11:00	801	4:37	4:48
3	1/5/13	322	PTY	1	PTY NO SPARE	0:29:00	700	14:32	15:01
4	1/5/13	205	PTY	1	PTY NO SPARE	0:10:00	801	20:48	20:58
5	1/5/13	454	PTY	1	PTY NO SPARE	0:17:00	801	2:40	2:57
6	1/5/13	317	CUN	1	OUTSTATION	0:17:00	801	16:44	17:01
7	1/5/13		TGU	0	OUTSTATION	0:30:00	801		
8	1/5/13	870	PTY	1	PTY NO SPARE	0:26:00	E90	1:45	2:11
9	1/5/13	334	PTY	1	PTY NO SPARE	0:25:00	800	14:46	15:11
10	1/5/13	804	PTY	1	PTY NO SPARE	0:21:00	800	23:33	23:54
11	1/5/13	156	PEI	1	OUTSTATION	0:18:00	700	10:18	10:36
12	1/5/13	159	PTY	1	PTY NO SPARE	0:14:00	700	20:30	20:44
13	1/5/13	761	PTY	1	PTY NO SPARE	2:11:00	700	14:18	16:29
14	1/5/13	106	PTY	1	PTY NO SPARE	0:08:00	E90	17:00	17:08
15	1/5/13	759	PTY	1	PTY NO SPARE	0:28:00	801	2:20	2:48
16	1/5/13	111	PTY	1	PTY NO SPARE	0:06:00	801	20:58	21:04
17	2/5/13	144	PTY	1	PTY NO SPARE	0:11:00	800	14:14	14:25
18	2/5/13	231	HAV	1	OUTSTATION	0:09:00	E90		
19	2/5/13	117	PTY	1	PTY NO SPARE	0:07:00	801	16:42	16:49
20	2/5/13		SJO	0	OUTSTATION	0:05:00	800		

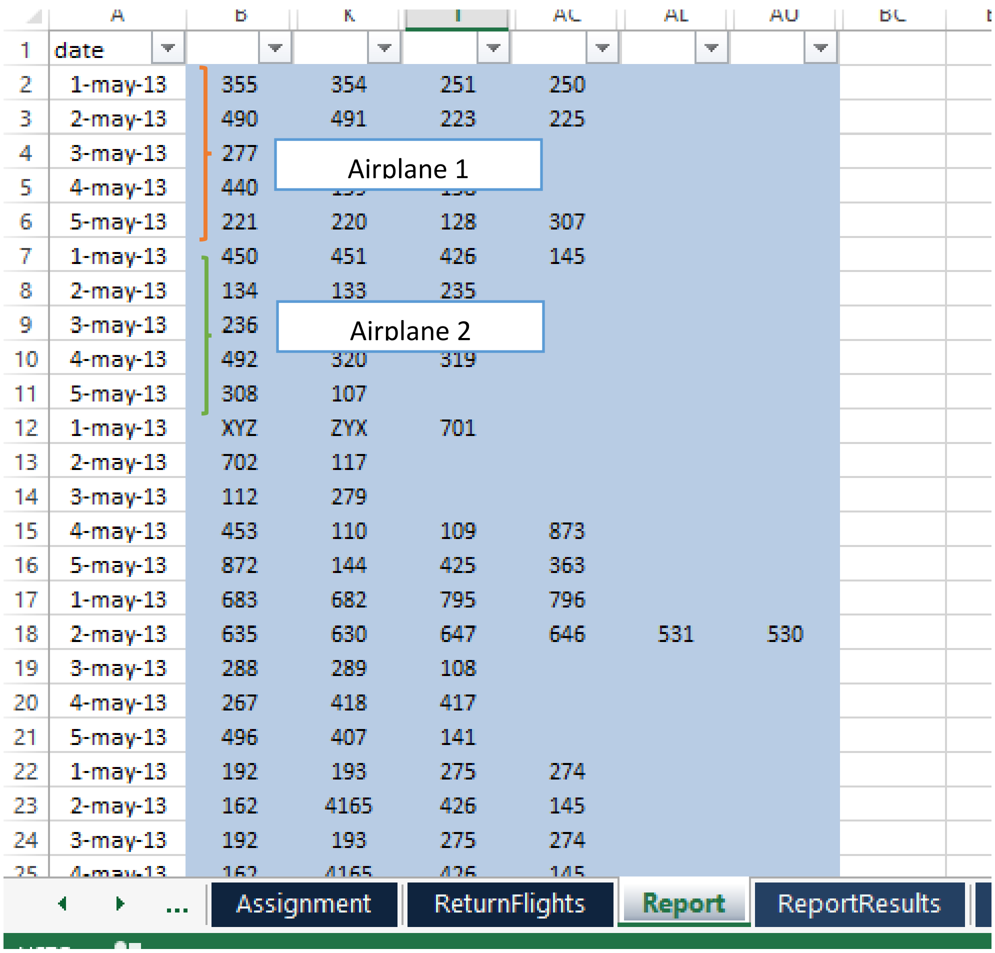
... Assignment | ReturnFlights | Report | ReportResults | EventsTable | DelaysTable | BufferTable | Results | DoNotE ...

Figure 18: Tools event table

Section 3 is the main part of the tool. It is the decision making book. It calculates the amount of spares required using as inputs the strategic schedule and the random event generator file. This part of the decision making tool is also divided into 3 parts. The first step is to insert the planned airline schedule.

After insertion, the first step of the tool is to calculate the sequence in which flights are assigned to airplanes. It will give as result the number of airplanes the airlines need to operate their planned schedule. It does not include maintenances nor spare airplanes. Flight sequence is created in the tab called report.

The first column shows the date, and the following one represent the flight numbers that are assigned to the airplane. The sheet shows all flight assigned to an airplane for all the period of time that is introduced to the tool. For example, we introduced 5 days of schedule. In the figure below, row 2 to 6 represents the first airplane. Airplane number 2 will start from row 7, where the date goes back to the initial date of the schedule. In this example, Airplane 1 has assigned flights: 355, 354, 251, 250, 490, 491, 223, 225, 277 and so on until the end of row 6.



	A	B	K	T	AC	AL	AU	BC
1	date							
2	1-may-13	355	354	251	250			
3	2-may-13	490	491	223	225			
4	3-may-13	277						
5	4-may-13	440						
6	5-may-13	221	220	128	307			
7	1-may-13	450	451	426	145			
8	2-may-13	134	133	235				
9	3-may-13	236						
10	4-may-13	492	320	319				
11	5-may-13	308	107					
12	1-may-13	XYZ	ZYX	701				
13	2-may-13	702	117					
14	3-may-13	112	279					
15	4-may-13	453	110	109	873			
16	5-may-13	872	144	425	363			
17	1-may-13	683	682	795	796			
18	2-may-13	635	630	647	646	531	530	
19	3-may-13	288	289	108				
20	4-may-13	267	418	417				
21	5-may-13	496	407	141				
22	1-may-13	192	193	275	274			
23	2-may-13	162	4165	426	145			
24	3-may-13	192	193	275	274			
25	4-may-13	162	4165	426	145			

Figure 19: Flight Sequence - Report Tab

This flight sequencing is used to determine the number of airplanes required to operate the schedule without any disruption (excel report results tab) and to determine the buffers availability in the schedule (Buffer table tab). Buffers are used only in Panama City where sequences of flights can be changed to adjust the schedule from a disruption. Buffers are time frames an airplane is on ground in Panama City for more than the minimum ground time.

For example: An airplane has a schedule time arrival at 10:00 am, and the next assigned flight has a departing time at 11:30 pm. For this example let's assume the airplane is an 800. The minimum ground time for an 800 is 60 minutes. But in this case the airplane has a total of 90 minutes on ground. Therefore this sequence of flights has a buffer of 30 minutes that can be used to recover from a disruption of 30 minutes or less.

	A	B
1	1-may-13	64
2	2-may-13	64
3	3-may-13	65
4	4-may-13	66
5	5-may-13	65

Figure 20: Aircraft Required for Operation

	Date	Flt Desg	Dept Arp	Dept Time	Arvl Arp	Arrv Time	Flight time	A/C Type	Buffer Time	Bank	Us
2	1-may-13	251	PTY	16:48	VLN	19:04	2:16	800	0:14	B3	
3	1-may-13	110	PTY	12:32	PUJ	15:01	2:29	800	0:10	B1	
4	1-may-13	161	PTY	12:40	CTG	13:45	1:05	800	0:14	B1	
5	1-may-13	446	PTY	12:42	MCO	16:07	3:25	800	0:08	B1	
6	1-may-13	280	PTY	12:44	NAS	15:36	2:52	700	0:10	B1	
7	1-may-13	360	PTY	12:47	LAX	19:37	6:50	801	0:27	B1	
8	1-may-13	830	PTY	12:48	JFK	17:50	5:02	801	0:18	B1	
9	1-may-13	316	PTY	12:52	CUN	15:33	2:41	801	0:13	B1	
10	1-may-13	308	PTY	12:54	SDQ	15:24	2:30	700	0:02	B1	
11	1-may-13	226	PTY	13:00	MIA	16:00	3:00	800	0:24	B1	
12	1-may-13	218	PTY	13:02	HAV	15:37	2:35	801	0:22	B1	
13	1-may-13	208	PTY	13:04	CUN	15:45	2:41	800	0:26	B1	
14	1-may-13	224	PTY	14:12	CCS	16:32	2:20	801	1:22	B2	
15	1-may-13	144	PTY	14:14	SJO	15:31	1:17	700	0:08	B2	
16	1-may-13	761	PTY	14:18	LIM	17:53	3:35	700	0:10	B2	
17	1-may-13	647	PTY	14:20	MDE	15:36	1:16	E90	1:58	B2	
18	1-may-13	120	PTY	14:24	MEX	18:14	3:50	800	1:28	B2	
19	1-may-13	322	PTY	14:32	HAV	17:07	2:35	700	0:06	B2	
20	1-may-13	252	PTY	14:34	LAS	21:10	6:36	800	0:28	B2	
21	1-may-13	262	PTY	14:42	MTY	19:13	4:31	E90	0:14	B2	
22	1-may-13	829	PTY	14:44	UIO	16:44	2:00	800	0:34	B2	
23	1-may-13	334	PTY	14:46	MIA	17:46	3:00	800	0:34	B2	
24	1-may-13	826	PTY	14:50	MGA	16:30	1:40	801	0:36	B2	YES

Figure 21: Buffer Table

The next step is to apply the imported random events to the sequences of flights to create disruptions to the schedule. Then the tool makes a decision for each of the events that were generated and each decision is listed in a separate file, so that we can see which decision was taken for each of the events that occurred.

Finally the tool evaluates all of the decisions made and generates a report with data on Departure (more than 5 minutes delays) and Arrival KPIs (more than 14 minutes delays) and the amount of spares required per day and the time frames in which they were used. These amounts then are averaged and gives the total amount of spares required for the operation.

			Buffers used							
Date	Total Flights	Spares used	B1	B2	B3	B4	B5	B6	Late departures	Late arrivals
1-may-13	211	2	0	1	0	1	0	0	14	9
2-may-13	218	0	0	2	2	0	0	3	12	6
3-may-13	213	0	0	2	0	0	3	0	10	5
4-may-13	217	0	2	2	0	0	2	2	15	10
5-may-13	217	0	0	0	3	0	5	0	13	8

KPIs	
Late departures	Late arrivals
94.0520%	96.4684%

Figure 22: Results Table

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