DEVELOPMENT AND SIMULATION OF A NEW SCHEME FOR THE AIRCRAFT CLEANING SERVICE

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ABSTRACT

During the last decade with the increase of competition, airlines have set up schemes to lower costs. Their present profit margin has narrowed to the point of not being able to compete with companies whose business model is similar to the low-cost ones forcing them to explore novel ways of managing the available resources in order to keep competitive.
One of the costs is the cleaning service generated by contracting this service and the delays that this operation can cause. The aim of this paper is to propose a new management system for scheduling the on board cleaning service, that lowers current costs, using tools such as modelling with coloured petri nets and simulation.

Keywords: Simulation, coloured Petri nets, cleaning services, aeronautics

1. INTRODUCTION

Years ago, airlines had enough capital to be able to have their planes cleaned on each leg of a journey. Moreover, plane tickets were much more expensive in those days, with flying being luxury and longer stopover times.

During the last decade, with the appearance on the scene of low-cost airlines, airlines have set up schemes to lower costs, as their present profit margin has narrowed to the point of not being able to compete with such low prices as these airlines offer for short and medium-haul flights.

One of the costs is the cleaning service and everything involved with cleaning a plane, such as the cost of hiring this service and the delays that this can cause.
The proposed system is based on modelling stopover times, by simulating an airline's flight schedule during a working day.

2. ECONOMIC STRUCTURE OF AIRLINES.

An airline is an organization or company, devoted to the transport of passengers, freight, mail and, in some cases, life animals, using airplanes for a profit.

The economic structure of the airlines in existence at the present time can be segmented as follows:
- Flag-carrying airlines: these are government-operated airlines. They have a wide variety of planes for short- and medium-and long-haul flights and tend to have a monopoly on domestic flights.
- Traditional airlines: these are private companies for passenger, freight or mail transport. They have a varied fleet of planes and their routes can be short- and medium-and long-haul. These are like the flag-carrying airlines but with the difference that, in this case, governments are not involved.
- Charter airlines: these are companies that transport passengers but on an occasion basis, their method of operation is to study the travel needs of a specific sector of customers. They organize a group of passengers and fit them up with a vacation package with the flight, hotel and excursions included. They usually have a small fleet of planes with capacity for approximately 180 passengers, per plane.
- Low-cost airlines: they supply the low-budget market in exchange for eliminating passenger services. Their strategy is to reduce operational and wage costs in order to be able to give their customers very low and affordable prices per route, thus achieving a broad customer base that goes from people with high net worth to people with a low level of purchasing power who would never been in a position to buy a plane ticket.

3. STOP OVER TIMES AND MAINTENANCE.

The stopover of a plane is the temporary space between consecutive flights when the plane is in the airport. Depending on the type of company, the time and space available, the plane's stopover will be more or less long (Basargan, 2004).
It is worth mentioning that every stopover takes a different length of time, as all the flight schedules are different. Moreover, it is impossible to homogenize the times of all the ground handling processes when the plane has already arrived at the airport.
The steps followed by a typical stopover of an aircraft are:

- Prior preparation for boarding: the lines of passengers are organized then all their hand luggage and documentation is checked.
- The plane arrives at the parking stand.
- Block-In is performed.
- The passengers and bags disembark.
- The plane is fuelled.
-Whether there is a scheduled cleaning, the cleaning team will proceed to clean the plane.
- When the last passenger leaves and the cleaning services have finished, the passengers for the next flight shall be boarded. Simultaneously the bags shall start to be loaded on the new flight.
- During the boarding of passengers, the coordinator shall deliver the necessary documentation to the captain.
- As soon as the plane is loaded with fuel, bags and passengers, the doors are closed.
- The chocks are removed.
- The plane performs the taxiing towards the corresponding runway for the take-off.

3.1. Maintenance of the Airplanes

There are three types of maintenance:

a) Daily check.

Inspect for obvious damage and check the general conditions and security.

b) Minor maintenance.

A-check: performed every 500-800 flight hours, consists in a general inspection of the systems, components and structure of the aircraft and it can take 20-100 man-hours.

B-check: is done every 4-6 months, this is a slightly more detailed check of components and systems and it can take 1-3 days.

C-check: is carried out every 15-21 months or after specific flight-hours determined by the manufacturer, this is a thorough inspection of the structures, the systems and the inside and outside areas of the plane and it can take 1-2 weeks.

c) Major maintenance.

Also called the “Heavy Maintenance Visit”. It covers the full structural inspection program for the airplane. This usually takes about two months and it should be done every 5 years or 30,000 flying hours.

On the other hand, it sometimes happens that a plane goes into AOG (Aircraft On Ground) which means that the plane has a problem that is sufficiently serious to stop it from making the next flight. In this case, the maintenance team needs to go to the plane to solve the fault.

4. OPERATION OF THE CLEANING SERVICE IN AIRLINES

There are two ways of delivering the service:

a) Subcontracting a company. Every week, they receive the stopovers schedule of each airplane and the pair of origin and destination of the flights. With this information, the cleaning service is scheduled, without any modification throughout the week.

b) Performed by flight attendants. They are in charge of cleaning the planes. The flight attendants have signed an agreement in which they agree to do these types of procedures and accept the conditions imposed by the airline. The aim of this method is to reduce the stopovers between one flight and another. This way the plane spends more time in the air during the day.

5. CASE STUDY OF A SPANISH AIRLINE

A new scheme for the cleaning operations during stopovers has been developed. The proposed scheme uses information that has been provided by a Spanish airline through a confidentiality agreement. We shall refer to this airline, when applicable, as “the airline”. The information of the schedule of one day has been used for the model. The proposed schema is a particular one for the case of the airline, but it can be extrapolated for the case of other airlines in a very straightforward way.

5.1. Current cleaning activities

The following are the cleaning operations currently under use by the airline.

Stopover cleaning.

This is the quickest way of cleaning and applies to stopovers that last for more than 40 minutes, as well as being the most common because, as the name says, it is done during stopovers and it takes 8-14 minutes.

Extra cleaning.

This type of cleaning is unscheduled. The crew or maintenance asks for some of the stopover cleaning jobs to be done. There can be an unexpected use of the temporary space of the stopover time. This type of cleaning does not share all the characteristics of the stopover cleaning. It only makes a required part of it. However the service is charged as a stopover cleaning.

There were 137 extra cleanings during the month of study.

Overnight cleaning.

This type of cleaning is done 4 or 5 times a week, when the plane spends the night in an airport. As this cleaning takes a long amount of time, it is done at night. It aims to improving the plane’s level of disinfection and cleanses places that cannot be reached during the stopover due to the lack of time.

Deep cleaning.

This is a type of cleaning designed to totally disinfect and clean the interior of the airplane. For this purpose, all the seats and luggage compartments are dismantled. As it takes too long, it is performed at night and once in a month.

5.2. Impact of Cleaning Operations

The delays in the aviation industry are one of the most important problems that the sector faces nowadays. Due to the complexity and precedence relationships of the aviation network one delay or primary delay caused in an airport will propagate easily to the rest of the network. Furthermore if more primary delays occur during the day, at the end of the day the accumulated delay would be sometimes huge (Jetzky 2009, Guest 2007). Every minute's delay in the departure of a flight signifies an increase in the different rates that the airport imposes on the airline.

The delays that directly affect the airline and a flight are mainly because of:

- Handling
- Airport authority
- Auxiliary Services
- Safety
- Meteorology

Cleaning service is a portion of the auxiliary services, in which it generates 65% of the delays in scheduled flight times for the airline.

The main characteristics of the current operation can be defined as:

- It is an inflexible system that does not adapt to the stopover times that airlines need under a fierce competitive market.

- The number of cleanings can and must be reduced.

- It does not make much sense to charge for an extra cleaning as if it were a stopover cleaning since the cleaning performed is more superficial.

- The delays caused by the cleaning operation can and must be reduced.

- More variables should be taken into account when a cleaning is assigned, such as, the number of passengers transported, number of previous cleaning among others.

- The current cleaning schedule is fixed and does not admit the variability produced by a plane breaking down or a request for an extra cleaning.

5.3. A novel operative schema for managing the stopover times

There is a very high cost in having the plane standing due mainly to the high tariffs demanded by the airports. Moreover, if the stopover times during the day are shortened, a plane can fly more hours, in other words the useful life of the plane would be maximized. The more hours a plane fly, the more flights it can do, the more passengers it can transport and the less expenditure on airport tariffs is incurred.

For these reasons, airlines seek to reduce the time their planes spend in airports and to increase the number of flights per plane.

However, shorter stopover times make the ground handling of the plane all the harder.

To better manage the stopover time, a cleaning system that fits with current needs must be designed.

New stopover times have been proposed and they are organized into 4 groups that are presented in Table1

Table1: Length of Stopover Time

Groups	Length of Stopover Time	Description
Group 1	Less than 41 minutes	A very short stopover is contemplated
Group 2	Between 41 and 50 minutes.	A short stopover is contemplated
Group 3	Between 51 and 60 minutes.	A medium/long stopover is contemplated
Group 4	Over 60 minutes.	A long stopover is contemplated.

Using the proposed segmentation, a cleaning management system has being designed for these new stop over times.

The proposed model has 5 cleaning types:

- Cleaning 1. This type of cleaning has been designed to give a basic and fast service, it takes 5-8 minutes. It shall be assigned in a very short stopover or when the last cleaning is type 4 or 5.

- Cleaning 2. This type of cleaning gives the same service as the stopover cleaning in the actual model. It shall be assigned in a short and medium stopover or when the last cleaning is type 4 or 5.

- Cleaning 3. This type has been designed to give a good level of cleaning in medium and long stopovers, and also to set back the cleaning number 4 and 5.

- Cleaning 4. This type of cleaning is just done once a week during long stopovers, to give a better level of disinfection and also set back the cleaning number 5.

- Cleaning 5. This type of cleaning is the same as the deep cleaning in the actual model, yet it can be done every month and a half.

6. DESCRIPTION OF THE CAUSAL MODEL

A causal model is proposed for evaluating the cleaning operations, in which stopover times are grouped according to the above division. The objective of the causal model is to assess the validity of the proposed schema while at the same time evaluate the magnitude of savings that can be achieved.

The model was developed in the coloured petri net formalism and tested using the CPNTools program.

6.1. Coloured Petri Nets

Coloured Petri Nets (CPN) is a simple yet powerful modelling formalism which allows to properly modelling discrete-event dynamic systems which present a concurrent, asynchronous and parallel behaviour (Moore et al. 1996, Jensen 1997, Christensen et al. 2001). CPN can be graphically represented as a bipartite graph which is composed of two types of nodes: the place nodes and the transition nodes. The entities that flow in the model are known as tokens and they have attributes known as colours.

The formal definition is as follows (Jensen1997):

$$CPN = (\sum, P, T, A, N, C, G, E, I)$$

Where

- $\sum = \{ C1, C2, \dots , Cnc\}$ represent the finite and not-empty set of colours. They allow the attribute specification of each modelled entity.

- P = { P1, P2, … , Pnp} represent the finite set of place nodes.
- T = { T1, T2, … , Tnt} represent the set of transition nodes such that $P \cap T = \varnothing$ which normally are associated to activities in the real system.
- A = { A1, A2, … , Ana} represent the directed arc set, which relate transition and place nodes such as $A \subseteq P \times T \cup T \times P$
- N = It is the node function N(Ai), which is associated to the input and output arcs. If one is a place node then the other must be a transition node and vice versa.
- C = is the colour set functions, C(Pi), which specify for the combination of colours for each place node such as C: $P \rightarrow \sum$.

$$C(P_i) = C_j \qquad\qquad P_i \in P, C_j \in \sum$$

- G = Guard function, it is associated to transition nodes, G(Ti), G: $T \rightarrow$ EXPR. It is normally used to inhibit the event associated with the transition upon the attribute values of the processed entities.
- E = these are the arc expressions E(Ai) such as E: $A \rightarrow$ EXPR. For the input arcs they specify the quantity and type of entities that can be selected among the ones present in the place node in order to enable the transition. When it is dealing with an output place, they specify the values of the output tokens for the state generated when transition fires.
- I = Initialization function I(Pi), it allows the value specification for the initial entities in the place nodes at the beginning of the simulation. It is the initial state of a particular scenario.
- EXPR denotes logic expressions provided by any inscription language (logic, functional, etc.)
- The state of every CPN model is also called the marking which is composed by the expressions associated to each place p and they must be closed expressions i.e. they cannot have any free variables.

6.2. Model Definition

The model is divided into two main modules:

1) Decision-making: the necessary information is collected to decide what the model is going to do. The results of this decision are:
The plane does not have to be cleaned.
The plane has to be cleaned.
The plane has suffered a problem.
An extra cleaning has been requested.

2) As soon as the decision has been taken, the plane shall be sent to the corresponding section of the model to execute the next task. The variability is integrated in the model through the use of two variables that simulate the situations that the plane undergoes a breakdown or an extra cleaning is requested.

The developed model in CPN is composed by 11 place nodes and 5 transition nodes. Table 1 describes the place nodes of the model.

Table 1: Place Nodes

Place	Colour	Description
Airplanes	airplane=product(ac*sa*p*h*te1*te2*te3*te4*nt*a*q*n*s)	The initial state of this place has 27 tokens with the information of the first flight of each airplane. This place will keep track of the status of the airplanes.
Next stopover	new=product(ac*sa*sa2*p1*h1*ne1*ne2*ne3)	This place has the flight schedule information for each airplane, except the first flight.
AOG	aog	This place has 170 tokens to generate the airplane-break-down probability
Extra Cleaning	le	This place has 252 tokens to generate the request –extra-cleaning probability.
Control	y	This place controls the activation of transition 1 or 2.
Decision	airplanes1=product(p*h*te1*te2*te3*te4*nt*s*a*q*n*b*x*y*ne1*ne2*ne3*ne4*up)	This place receives and sends the information of the next step of the airplane process.
New stopover without cleaning	airplane=product(ac*sa*p*h*te1*te2*te3*te4*nt*a*q*n*s)	This place receives a token whether the airplane does not have to be cleaned, which means the airplane will do the next flight without the need of cleaning.
Aircraft in AOG	airplane=product(ac*sa*p*h*te1*te2*te3*te4*nt*a*q*n*s)	This place receives the token whether the airplane breaks down and needs major reparation.
Counter	ne=product (u*d*tr*cu*ci*ex)	This place keeps track of the number of times the aircraft has been cleaned.
Solution	airplanes1=product(p*h*te1*te2*te3*te4*nt*s*a*q*n*b*x*y*ne1*ne2*ne3*ne4*up)	This place records the final state of the aircraft.
Cleaning	airplane=product(ac*sa*p*h*te1*te2*te3*te4*nt*a*q*n*s)	This place records the information necessary to decide if airplane has to be cleaned.

Table 2 presents the colour definition used in the CPN model of the new cleaning system.

Table 2: Colours and Definitions

Colour	Definition
Ac	Aircraft identification.
Sa	Flight identification.
H	Amount of minutes that the aircraft has flown since the last cleaning service.
P	The total of passengers that has been transported since the last cleaning service.
te1	Whether the stopover is in the first group of the table 1.
te2	Whether the stopover is in the second group of the table 1.
te3	Whether the stopover is in the third group of the table 1.
te4	Whether the stopover is in the fourth group of the table 1.
Nt	The type of cleaning that was done last time.
A	The amount of minutes that the aircraft has flown since the last cleaning number 5.
Q	Whether the plane can carry out all types of cleaning.

Table 2 (cont.)

Colour	Definition
N	The amount of minutes that the airplane has flown since the last cleaning number 4.
S	The number of flights has flown the aircraft, since the last cleaning service.
Up	The operational status of the aircraft.
E	Whether an extra cleaning has been requested.
sa2	Next flight identification.
h1	The duration of the next flight.
p1	The number of passengers will be transported on the next flight.
ne1	Whether the next stopover is in the first group of table 1.
ne2	Whether the stopover is in the second group of table 1.
ne3	Whether the stopover is in the third group of table 1.
ne4	Whether the stopover is in the fourth group of table 1.
U	Cleaning counter of type 1
D	Cleaning counter of type 2
Tr	Cleaning counter of type 3
Cu	Cleaning counter of type 4
Ci	Cleaning counter of type 5

The model has been run using the information of a particular day in which the airline had 27 operative aircrafts.

Figure 1 presents transition T1, which would receive the information related to the actual and future flights, the operational status of the incoming aircraft and whether an extra cleaning has been requested.

The outcome information of the transition will be used to decide the next step of the airplane.

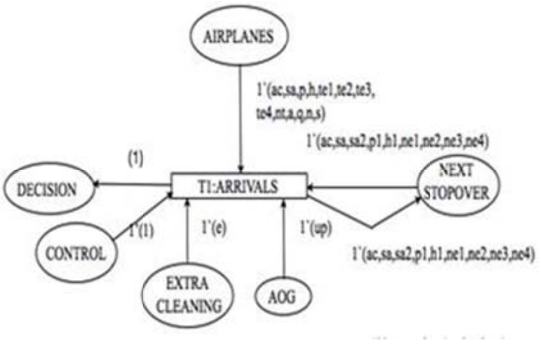

Figure1: Transition T1

Arc (1): This arc has the restrictions to decide the next step of the airplane. It evaluates the operational status of the aircraft, whether is necessary a cleaning service or it has being requested an extra cleaning. The outcome information will assign what the next step of the aircraft is. This information is evaluated by the second transition.

Figure 2 illustrates transition T2; it receives the information about what the next step of the aircraft will be and based on that information it will send the aircraft to the corresponding place.

Figure 2: Transition T2

Arc (2): this arc evaluates the restrictions related to what type of cleaning will be performed in the airplane and it will increase the value of the correspondent cleaning counter. The place node contains the information about which flight must be cleaned.

Arc (3): this arc send the current status of the data information to the correspondent place node (SOLUTION). The income data contains the information of the flight that must be cleaned and the next flight. The SOLUTION place node keeps track of the current status of the system.

Arc (4): this arc evaluates the information of the tokens concerning what type of cleaning operation shall be performed. The decision takes into account the stopover time, the information of the airplane and the information of the flights. The outcome information will assign the type of cleaning to be performed. The information is used by the fourth transition.

The Figure 3 presents transition T3. This transition represents the outcome when the airplane does not need a cleaning service. The data will be updated with the information of the next flight and passed through with the token colours to the AIRPLANES place node.

Figure3: Stopover without cleaning

Figure 4 presents transition T4, it evaluates the variables to assign a cleaning in the next stopover. The data will be updated using the token created in the AIRPLANES place node.

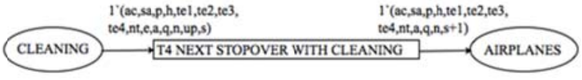

Figure 4: Stopover with cleaning

Finally Figure 5 presents transition T5. This transition evaluates the correspondent variables and simulates an AOG to the correspondent Aircraft. Once the AOG has been performed, the variables' data is updated through the correspondent token created in the AIRPLANES place node.

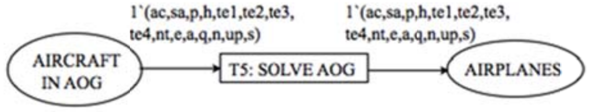

Figure 5: Solve AOG

6.3. Analysis of the causal model.

To evaluate the proposed system, the model was simulated 15 times. Table 3 presents the results obtained with the simulation.

Table 3: Simulated Results from the causal model

Results	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average value
Cleaning 1	**17**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**19**	**18**	**17**	**17**	**18**	17,93
Cleaning 2	**15**	**14**	**14**	**14**	**15**	**14**	**15**	**15**	**15**	**15**	**16**	**15**	**15**	**15**	**15**	14,80
Cleaning 3	**11**	**11**	**10**	**11**	**11**	**12**	**11**	**9**	**11**	**11**	**11**	**11**	**11**	**11**	**11**	10,87
Cleaning 4	**3**	**3**	**4**	**3**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	3
Cleaning 5	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	1
Extra Cleaning	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	1

On the other hand, it is possible to evaluate the cost impact of implementing the new schema. The cost analysis can be appreciated in Table 4.

Table 4: Economic analysis

Economic Variables	Actual System	Proposed System	Difference between Systems
Number of cleaning flights	1978	1310	668
Number os extra cleanings	133	18	115
Percentage of cleaned flights	43,84%	29,03%	14,81%
Cost of the cleaning service *	€ 49.421	€ 24.675,8	€ 24.745,20
Airport Rates	€ 37.895,99	€ 34.102,69	€ 3.793,30
Percentage of delayed flights	19,32%	9,64%	9,68%
Number of delay flights	493	50	443
The cost of delay flights	€ 4.317,66	€ 340,87	€ 3.976,79
RESULTS	€ 91.634,65	€ 59.119,36	€ 32.515,29

Through the results, it can be concluded that the proposed model is less expensive than the actual model due to:

- Creating more types of cleaning with different durations makes the cleaning service more flexible which means the cleaning service has been adapted to the stopovers time. The number of cleaning operations has been reduced due to the flexibility achieved. With the proposed model only the 29,03% of flights were cleaned rather than 43,84% of the current schema.
- The amount of delay flights has been reduced. With the proposed model only the 9,64% of the flights were delayed by the cleaning service rather than the 19,32% of the current schema.
- The proposed schema decreases the number of extra cleanings. With the proposed model it is needed 18 extra cleaning rather than 133 extra cleaning in the current system.
- The total amount of cost in the proposed model for November's month is € 59.119,36 rather the € 91.634,65 of the current schema.

7. VALIDATION OF THE MODEL

The previous results have been validated using a discrete-event-oriented simulation program (SIMIO) in which the complete elements of the Turnaround of a A320 aircraft have been taken into account. The purpose of the simulation model is twofold, on the one hand to evaluate the results of the CPN causal model and on the other to include all the elements of an actual turnaround that could not be included in the causal model. The final goal is to obtain a better management for the turnaround process that allows mitigating the delays caused by the current management schema.
Figure 6 shows a snap shot of the graphical aspect of the model for the turnaround of the Aircrafts of the company (Airbus-A320).

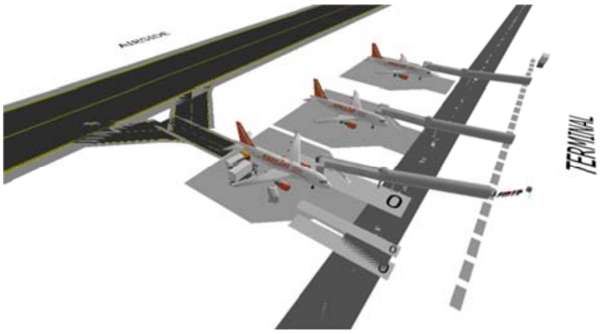

Figure 6: Virtual environment

Several operations occur during the stop over: Catering, Fuelling, Disembarking-Boarding of Passengers, Cleaning. In Figure 6 three trucks can be appreciated, 1 big truck performs the catering operation, the one under the wing is fuelling the aircraft and the one in the rear position of the aircraft is cleaning the system from organic disposals. It can also be appreciated that the passengers are deboarding the plane through the fingers. Is important to note that in the particular case of the fueling operation it does not start until all the passengers have left the aircraft; this is due to security reasons.
In the turnaround process some activities has been identified as being the critical path of the turnaround time. Figure 7 illustrates the total operations that can be performed in such an aircraft and the ones that are part of the critical path of the process (AIRBUS 2012).

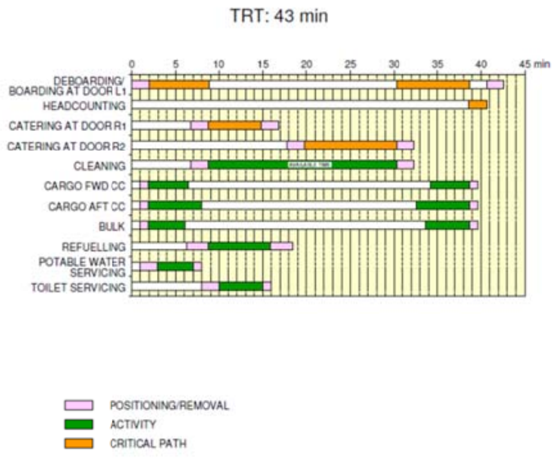

Figure 7: Operations of the turnaround for a A320

The airline of the study does not perform all the operations; in order to reduce the turnaround time the company perform only a few operations, namely boarding, deboarding, catering on door R2 only, cleaning, refuelling, cargo operations and toilet servicing. Under this operative schema the cleaning operation becomes part of the critical path that determines the turnaround time of the aircrafts.

Parameters of the Simulation Model

In order to assess the importance of the cleaning operations, the current process was simulated using information provided by the airline. Table 5 presents the values used for the model.

Table 5: Simulation parameters

Operation	Time
Opening/closing doors	2 min
Deboarding Rate	22 pax/min
Deboarding Rate/pax	Triangular (2.5,2.7,3) sec
Boarding Rate	18 pax/min
Boarding Rate/pax	Triangular (3,3.3,5) sec
Fueling Time	Triangular (7,8,9) mins
Cleaning Operation	Triangular (8,13,16) mins
Full size trolley equivalent (FSTE) to unload/load	7 for R2
Load Time of each Trolley	1.5 min/FSTE
Catering Equipment Position/Removal	2 min
Probability of Cleaning	0.4348
Probability of Extra Cleaning/P.of Cleaning	0.0664

The previous data was used for developing the turnaround model for the current and the proposed schema. The last two rows were obtained from the information provided by the causal model. The first value (P. of Cleaning) is the probability that the aircraft performs a cleaning operation; and the second value corresponds to the conditional probability of an extra cleaning once the cleaning has been performed. The rest of the values will be the same for the current scenario and the proposed one.

7.1. Evaluation of the Proposed Schema

The simulation model was used for analysing the current operations and at the same time obtaining different values that provide insight about the inefficiencies present in the current performance. The second scenario will be implemented assuming new values for the cleaning operations (based on the results provided by the causal model).

Current Operations

The simulation model was run with the aforementioned values and the turnaround times, number of extracleanings and delays were analyzed. Table 6 presents the results obtained with the current operations.

Table 6: Information from the current process

	Cleaning Operation			
	AVG	Min.	Max.	STD. Dev.
Max. No. of Extra Cleanings	6.7	3	12	2.306
Max.No. of Total Delays	37.43	13	81	15.904
Turnaround Times	38.59	37.17	40.9	0.8262
Max. Turnaround Times	54.38	49.14	59.31	1.8539

The previous values were obtained of a total of 240 flights and the simulator was run for 30 replications. As it can be appreciated the first row gives information about the maximal number of extra cleanings, the second row about the maximum number of total delays and the last two rows the average and maximal turnaround times for this scenario.

In the case of the delays it should be pointed out that the upper bound of delays is 81 out of 240 flights which correspond approximately to 33% of the scheduled flights incurred in a delay. On the other hand the maximal turnaround times which are the upper bound for the model mean that some aircrafts could have a turnaround time of 59 minutes which would be translated into a big cost penalty for the airline.

Proposed Schema

The new schema was tested using the same values of the standard operations but in this case the probability of the cleaning operation and the conditional probability of an extra-cleaning once the cleaning operation has been performed are 0.2903 and 0.0137 respectively.

The cleaning times in this new schema also change to a Triangular(5,7,8) since it is assumed that the aircraft in the simulation model are only of group type I. Table 7 presents the results obtained with the proposed schema.

Table 7: Proposed Scenario

	Cleaning Operation			
	AVG	Min.	Max.	STD. Dev.
Max. No. of Extra Cleanings	1.65	1	4	0.8846
Max.No. of Total Delays	12.42	1	56	18.69
Turnaround Times	37.57	36.03	39.47	0.9127
Max. Turnaround Times	40.4	38.57	43.47	1.235

From the previous table it can be appreciated that the mean average turnaround time has been reduced about a minute. As it will be clear with the next figure, the most important achievement is that the dispersion or variability is drastically reduced. As a consequence the probability of delays has been reduced as it can be appreciated in Figure 8.

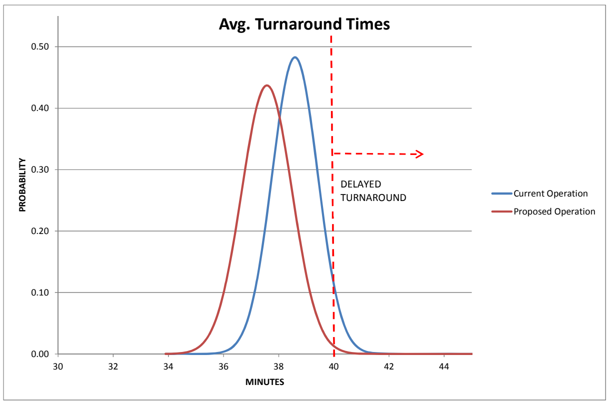

Figure 8: The reduction in the avg. turnaround times

With the new implementations and with the dispersion obtained from the simulation model, it can be appreciated that the curve of the new schema falls within the acceptable region while with the current operations approximately 33% of the flights incur in delays.

On the other hand, if the worst-case scenarios are analysed (i.e. the max. turnaround times) the improvements are more evident. As it can be appreciated from Figure 9, the worst-case values from the current operations fall out of the accepted region while with the new schema only approximately the 50% of the worst-case turnaround times would incur in a delay.

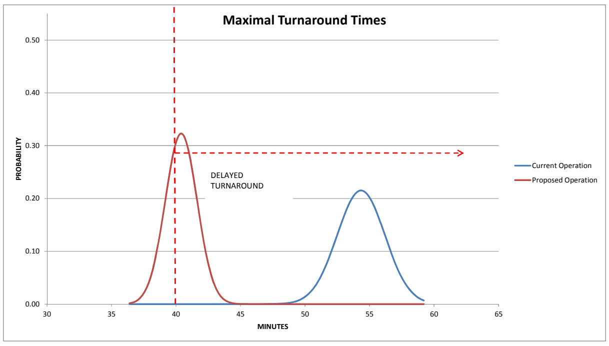

Figure 9: The worst-case scenarios

8. CONCLUSIONS

In this article a new cleaning schema for an airline was devised with the objective of reducing the costs of extra-cleanings and to avoid as much as possible the probability of delays in the turnaround time. The proposed schema has been analysed using a causal model developed using the coloured Petri net formalism and it has been validated with a more detailed simulation model that takes into account all the different operations that are critical for the turnaround time. The results clearly indicate that it is possible not only to reduce the extra-cleanings which is a common practice for a commercial airline but also reducing the possibility of incurring in delays due to the cleaning operations.

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APPENDIX A

Definitions

Chocks: A block or wedge placed under the aircraft wheels, to keep it from moving

Medium haul flights: is a flight between 3 and 6 hours in length.

On board cleaning service: is the main job in cabin service. They include task such as cleaning the passenger cabin, replenishment of on-board consumables or washable items such as soap, pillows, tissues and blankets, and do the sanitation service.

Short haul flights: is flight: is a flight under 3 hours in length.

APPENDIX B

Operational Costs

Airport Rates	Every 15 minutes	Every 30 mins	Per Flight	Monthly
Airport Use			€ 9,88	
Vehicle Parking		€ 0,02		
Workers				€ 33,90
Energy system 400HZ	€ 6,79			
Fingers use	€ 27,18			
rate for cleaning 1, 2 and stopover cleaning	€ 9,90			
rate for cleaning 3 and Overnight cleaning	€ 43,87			
rate for cleaning 4	€ 77,86			
rate for cleaning 5 and 3 and deep cleaning	€ 111,82			
Delays	€ 2,27			

REFERENCES

AENA air tariffs. Available from http://www.aena.es/csee/ccurl/124/479/guiaTarifasNA_2013-EN.pdf. [accesed May 20, 2013]

Airbus, "A320, 2012. Aircraft Characteristics Airport and Maintenance Planning",*Technical Report,* Airbus.

Bazargan, M., 2004. Airline operations and Scheduling. Burlington, USA, *Ashgate publishing company*.

Christensen, S., Jensen, K., Mailund, T., Kristensen, L.M., 2001. State Space Methods for Timed Coloured Petri Nets. *Proc. of 2nd International Colloquium on Petri Net Technologies for Modelling Communication Based Systems*, 33-42, Berlin.

Civil Aviation Department Hong Kong, China, 2012. *CAD 452 Aircraft Maintenance Schedules and Programmes, Information and Guidance*. Available from http://www.cad.gov.hk/english/pdf/CAD452.pdf uk [accessed June 15, 2013].

CPNTools Available from http://www.cpntools.org.

Guest, T. 2007. Air traffic delay in Europe. *Trends in Air Traffic Vol. 2, Brussels*-Belgium, EUROCONTROL.

Jensen, K., 1997. *Coloured Petri Nets: Basic Concepts, Analysis Methods and Practical Use*. Springer-Verlag, Berlin.

Jetsky, M, 2009. *The propagation of air transport delays in Europe*, Thesis, RWTH Aachen University.

Moore, K.E., Gupta, S.M., 1996. Petri Net Models of Flexible and Automated Manufacturing Systems: A Survey. *International Journal of Production Research*, 34(11), 3001-3035.

Rhodes, W., Lounsbury, R., Steele, K., Ladha, N., 2003. *Fatigue Risk Assessment of Aircraft Maintenance Tasks*. Transportation Development Centre Safety and Security Transport Canada.

Yeung, S.S.M, Yu, I. T. S., Hui, K.Y.L., 2005. World at Work:Aircraft cabin cleaning. *Occupational and Environmental Medicine*, 62:58-60.

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