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Applying discrete event simulation to the design of a service delivery system in the aerospace industry: a case study

Filippo Visintin, Isabella Porcelli,
Andrea Ghini

*IBIS Lab, Department of Energy Management "Sergio Stecco", University of Florence,
Italy (Tel: 0039-055-4796736; e-mail: {filippo.visintin; isabella.porcelli}@unifi.it; andreaghini@alice.it)*

Abstract: this paper presents the results of a simulation study concerned with the design of a service delivery system. In particular the paper shows how discrete event simulation has been used to assess if the service delivery system of a leading supplier in the aerospace industry, will be able to comply, over the time, with the stringent requirements of a contract recently signed with one of its key customers.

1. INTRODUCTION AND LITERATURE REVIEW

The use of simulation as tool to support supply chain management decisions has been widely discussed in the literature (see Terzi and Cavalieri, 2004 for a detailed review). Simulation, in fact, is proved to be an excellent tool to assess the supply chain resilience and to study its dynamics (Carvalho et al., 2011). The literature proposes also approaches to supply chain simulation modeling and analysis (Pundoor and Herrmann, 2006). Nonetheless, the literature is still surprisingly lacking of contributions discussing the utilization of simulation as a tool to support the design of service supply chains and service delivery system (Anderson and Morrice, 1999, Bazargan-Lari et al., 2003, Franzese et al., 2006, Tang et al. 2008). In this paper we aim to address this literature gap by illustrating the preliminary results of a study where discrete event simulation is used to support the design of a service delivery system of a company operating in the aerospace industry, which is asked to supply components and the relevant after sales services. This paper is organized as follows: In the next section we present the unit of analysis (which, for confidentiality reasons, will be referred to as company ALFA); In section 3 we present the simulation model and briefly discuss its validation; In section 4 we present the preliminary results of the simulation study. Finally in section 5 we draw the conclusions and illustrate future research steps.

2. CASE DESCRIPTION

2.1 The company

ALFA is a company leader in the provision of Human to Machine Electronic Controls for commercial and military aircrafts. In 2010, ALFA employed 230 people, had a turnover of 45 M€, new orders for 60 M€, backlog orders for 110 M€ and invested 5 M€ in R&D projects. The customers of ALFA are leading companies producing aircrafts and helicopters. In addition to providing state of the art components for application on top-level rotary and fixed wing aircrafts, ALFA is required to provide customer

services in strict compliance with the laws and stringent regulations in force in the aerospace industry. The service activities of ALFA are coordinated by an independent function named Customer Service. Such a function has the duty to plan, coordinate and execute the service activities. Recently ALFA has signed a contract with BETA for the provision of 26 different types of components. These components will be part of a new type of aircraft for which BETA has already received more than 600 orders. The terms of supply for these components impose: i) stringent requirements in terms of components reliability; ii) precise conditions in terms of supply lead-times; iii) precise infrastructural requirements for the service delivery system; iv) precise conditions in terms of service performances. Consequently, ALFA needs to ascertain if its service delivery system will be able to ensure the agreed condition over the time. These contractual conditions are described in the following paragraph.

2.2 Contractual requirements

The contract clearly defines stringent requisites, in terms of both infrastructural requirements and service performances.

2.2.1 Infrastructure requisites

According to the contract, ALFA must set up a centralized warehouse open 24/7 from which spare parts can be rented or bought by customers all year round. In addition it must set up at least three other service stations located, respectively, in US, Middle East and Far East open 24/7 and certified according to the European Aviation Safety Agency (EASA). In these service stations ALFA must stock at least two types of spare parts: i) maintenance kits to be used for the ordinary maintenance and repair activities; ii) at least one item of each component, to be used in case of Air On Ground (AOG) emergency. AOG occurs when an aircraft is unable to take-off because of the unavailability of a component provided by ALFA. Moreover the service stations are also supposed to provide repair services and to fix the failed components coming from the field. Finally, the contract prescribes the creation of a dedicated hotline available all year round 27/4 for technical enquiries.

2.2.2 Service performance requisites

The main performances that ALFA is asked to control are the following:

Spare parts procurement lead time: is the time required to produce a spare part. Such a lead time must be: less than 7 days for the critical item, i.e. those items classified as “no go/go if” or shelf stock according to the World Airlines and Suppliers Guide (WASG); 45 days for non-critical items.

Spare parts delivery time: is the time required to deliver the parts. In case of Air On Ground (AOG), the service station located in the zone where the AOG takes place, must be able to deliver a functioning back-up component to the nearest airport in 4 hours. The component will be subsequently shipped from this airport to the airport where the aircraft is blocked.

Response time: is the maximum time available to create a service ticket (and the associated documentation). The contract prescribes that the response time to technical enquiries (no matter if AOG, remote assistance or on field assistance) must be 4 hours if the enquiry arrives by telephone or fax, 10 days for enquiries arriving via letter.

Shop Process Time: is the time required to repair a component. The shop process time is 10 days for avionic components, 15 days for non-avionic components (lighting systems) and 3 days for No Fault Found components, i.e. those components that upon inspection do not present any defect.

In addition, the contract carefully defines the (huge amount of) documentation (test reports, certificates of conformity, Component Maintenance Manuals, Ground Equipment Manuals, etc...) relevant to the supplied components that ALFA has to produce. Moreover, it defines precise policies to manage the components buy-back, retrofit, as well as the policies to manage the spare parts obsolescence. Finally it regulates the amount of training activities that ALFA has to impart to its customers to let them perform autonomously certain maintenance tasks.

2.3 Organisational structure and processes.

To comply with the terms of supply, ALFA has organized each service station in six departments.

Technical Service (TS) department: it has the duty to handle critical service requests (i.e. those arising in case of Air On Ground) and to perform on-field technical interventions. In addition, it provides technical remote support.

After sales service (ASS) department: it has the duty to handle regular service requests, to inspect the failed components coming from the field, and to write the documentation which certifies the correct functioning of the repaired components.

Spare parts management (SPM) department: it performs the actual material handling activities, keeps the spare parts inventory under control, reordering parts when needed.

Administration (ADM) department: it produces the

documentation that must accompany new or repaired components when they are shipped to customers.

Shipment (SH) department: it actually packs the components and ships them to customers.

Repair (REP) department: it actually performs the repair activities.

Each service station is involved in four main processes.

Air On Ground process. It takes place when a failed component needs to be replaced as soon as possible because it prevents the aircraft from taking off.

Repair process. It takes place when the customer asks the service station to repair failed component.

Remote technical assistance process. It takes place when the customer needs to be remotely supported.

On-field technical assistance process. It takes place when a technician needs to be dispatched to customer site to fix a problem.

A simplified map of these processes is proposed from Fig. 1 to Fig. 4.

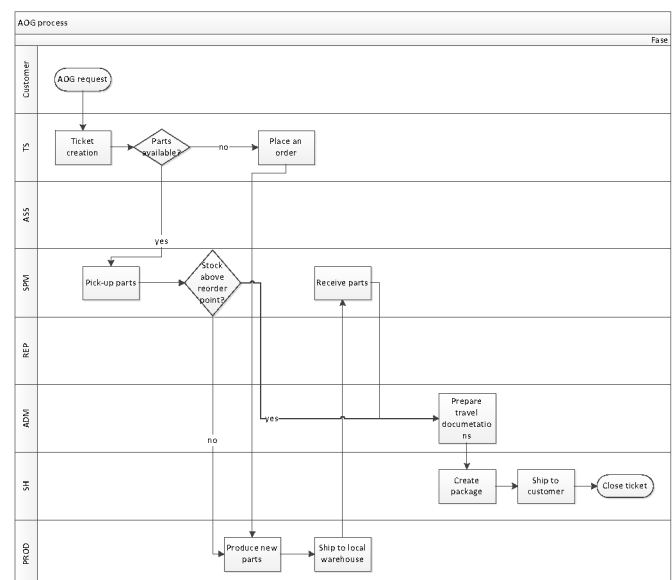


Fig. 1 “Air On Ground” process

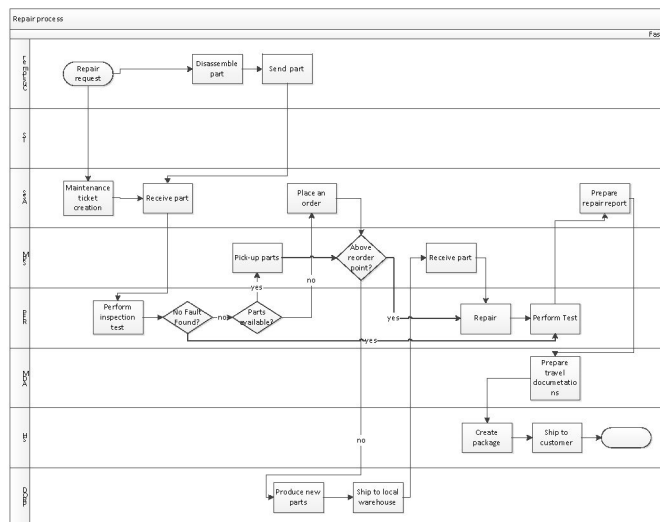


Fig. 2 Repair process

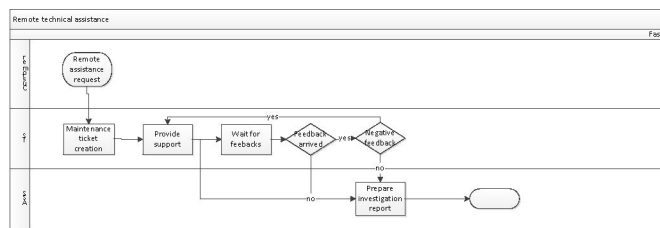


Fig. 3 Remote technical assistance process

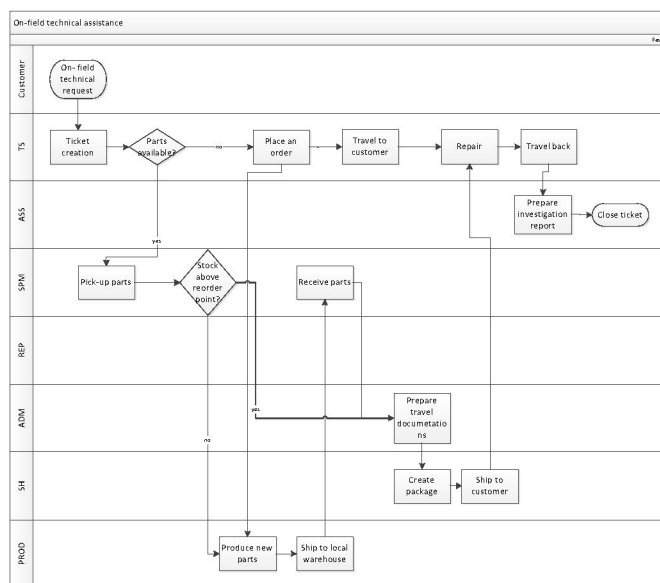


Fig. 4 On field technical assistance process

These processes, as well as the resources involved in their executions, have been modeled to verify if the ALFA will be able to meet its contractual requirements. A description of the model is provided in the next section.

3. THE MODEL

3.1 Data

The data utilized in the simulation have been provided by the ALFA's Customer Service Manager. They can be subdivided in: i) reliability-related data; ii) demand-related data; iii)

resource consumption related data. These data are described in the next sub-sections.

3.2.1 Reliability –related data

For each supplied component it is known the failure rate λ , which is assumed to be constant, and the Mean Time Between Failure (MTBF). This data has been estimated by ALFA. In particular for each component, the failure rate has been calculated by adding up the failure rates of its components, thereby assuming a series system. These assumptions are justified by the fact that the components are made of electronic parts and the failure of any single component determines a malfunctioning of the component as a whole.

3.2.2 Demand-related data

First of all ALFA provided an esteem of the number of aircrafts that will enter in service, each year, from 2011 to 2017. According to such esteem 3 aircrafts will enter in service in 2011, 15 in 2012, 24 in 2013, 46 in 2014, 78 in 2015, 114 in 2016, 134 in 2017 (Fig. 5). All these aircrafts will have 38 components on board since some of the 26 aforementioned components are installed more than one time in the aircraft.

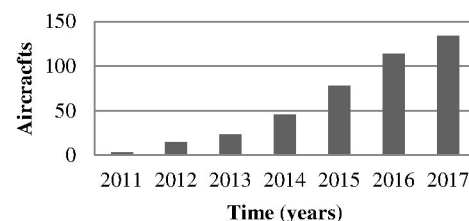


Fig. 5 Number of aircraft commissioning

ALFA provided also an esteem of the number of flight cycle (FC) each aircraft is expected to perform every year, the flight hours (FH) associated to each cycle and the average time between two consecutive flights (TBF). (FC = 940 flights/year; FH = 5 h/flight; TBF = 4,3 h/flight). This information is extremely relevant because failures can occur only when the aircraft is on flight. ALFA identified also the possible routes that aircrafts will likely use. This information is really relevant as well, since they can help identifying where the demand for technical assistance and parts is likely to emerge. However the routes cannot be known in advance since ALFA has no information about the airline companies (BETA's customers) that will operate the aircrafts. A rough esteem has been done by assuming four generic destinations: United States (US), Europe (EU), Middle East (ME), and Far East (FE). Hence, given the characteristics of the aircraft, which are designed to flight on average 5 hours, we have identified the following "macro" routes:

- EU-EU; EU-US; EU-ME for aircrafts departing from the EU;
- US-US; US-EU; US-FE for aircrafts departing from the US;

- ME-EU; ME-FE; for aircrafts departing from the ME;
- FE-US; FE-ME for aircrafts departing from the FE.

Each route is considered equiprobable.

3.2.3 Resource consumption related data

ALFA provided an esteem of the minimum, maximum and modal value of the time required to perform all the activities the aforesaid processes are composed of (Table 1). Moreover ALFA provided an esteem of the time that its carrier requires shipping the spare parts from the central production facility to the service station and from the service station to the customers.

Table 1. Activities

Activities	Dept.
Ticket creation	TS
Inspection test	REP
Defect Isolation	REP
Component disassembling	REP
Component repair	REP
Component re-assembling	REP
Component cleaning and visual inspection	REP
Component test	REP
Investigation Report Creation	ASS
Travel documentation creation	ADM
Spare parts production	PROD
Spare part shipment to local service station	PROD
Field Technician travel time to customers	TS
Response time	TS
Spare parts picking	SPM
Packaging & shipment to customer	SH

3.3 Output variables

The model keeps track of: i) the resources required by each department (TS, ASS, SM, ADM, SH, REP) to fulfill the service demand over the time; ii) the contractually agreed performances (i.e., spare parts procurement lead time, spare parts delivery time, response time, shop process time).

3.4 Model structure

The ALFA service delivery system has been modeled using Rockwell ARENA 13. The model can be subdivided in six sub-models. The first one generates the aircraft entities following the demand pattern illustrated in subsection 3.2.2. In addition, it models the aircraft flight activities, allowing to track the aircraft status (idle – on flight) as well as its route. The second sub-model generates failure entities, according to the component's MTBF. Each failure is randomly associated to an aircraft, and can give rise to different types of service requests (AOG, on field support, remote support). These requests are handled by the repair station located in the region when the aircraft will land. The third, fourth, fifth and sixth sub-models reproduce, respectively, the AOG, repair,

remote technical assistance and on field technical assistance processes. Due to space constraints a full description of the model is not provided upon here.

3.5 Model verification and validation

Model verification was made by the modellers utilizing the debug features of Rockwell ARENA 13. Since the simulation model does not replicate an existing system but a system that needs to be created to accommodate the requirements of the contract signed by ALFA and BETA, we couldn't validate the model by confronting real data with the simulated ones. Nonetheless, the results produced by the model has been thoroughly discussed with ALFA's Customer Service Manager which defined these results "reasonable" and the overall model "credible" (Law and Kelton, 2000). Despite these limitations, we validated the sub-model that generates the components failures. In fact, we assessed if the number of components failures generated by this sub-model over the time, is coherent with the homogeneous Poisson process the sub-model is aimed to reproduce. In order to do so, we considered the number of components that are expected to operate every year (which obviously depends on the number of operating aircrafts, see Fig. 5). Hence, we hypothesized that failed components are replaced with components "as good as new". Finally, we performed a Monte Carlo simulation to estimate how many failures we should have expected every year. The number of failures obtained with the discrete-event simulation, every year, falls within the confidence intervals obtained with the Monte Carlo simulation.

3.6. Simulation duration

To assess the optimal duration of the simulation time, we analyzed the Mean Square Pure Error (MSPE) of the utilization rate of the aforementioned departments. The MSPE has been obtained in three steps. First, we performed $n=10$ simulation runs (i) and kept track of the value of the utilization rate of the departments every month (j) for 30 years, thereby obtaining 360 observations. Second, for each variable we computed the squared relative MSPE.

$$MSPE_j = \frac{\sum_{i=1}^n (x_{ij} - \bar{x}_j)^2}{(n-1)} \quad (1)$$

$$MSPE_{j,rel} = \frac{MSPE_j}{\bar{x}_j} \quad (2)$$

$$\bar{x}_j = \frac{\sum_{i=1}^n x_{ij}}{n} \quad (3)$$

Then we have plotted for each variable the MSPE against the simulation time and we have identified the knee-point, i.e. the value of T for which the MSPE becomes lower than 2%.

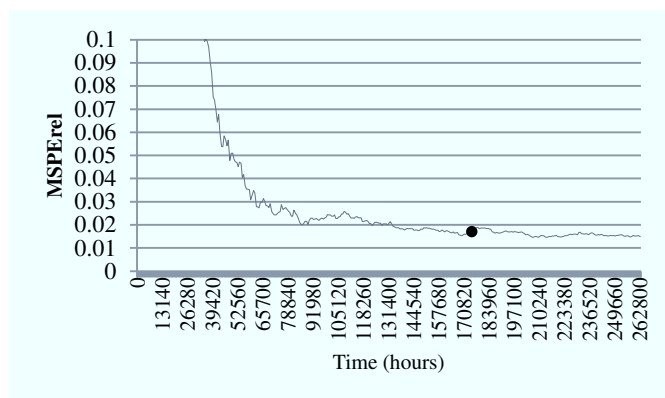


Fig. 6 MSPE analysis

The analysis of the MSPE led us to conclude that the optimal duration of the simulation is 20 years (175200 h). After 20 years the model can be considered stable. As a result we simulated the functioning of the system from 2011 to 2030.

4. PRELIMINARY RESULTS

The first analysis we performed was aimed to verify if the ALFA service delivery system, in its current configuration, is able to fulfill the contractual requirements. We have thus hypothesized that time required to perform each activity is distributed according to a triangular distribution whose parameters (minimum, maximum and modal value) are those provided by ALFA. Moreover we have hypothesized to have 1 piece of each component in stock in each repair station (which is the current policy in ALFA) to be used in case of AOG, plus 1 maintenance kit for each component.

We have thus performed 10 runs of 20 years each, and calculated, for each repair station, the mean value of all the performances included in the contract, that is: i) Utilization rate of each department; ii) Response time for Air On Ground requests; iii) Response time for remote technical assistance requests; iv) Response time for on field technical assistance; v) Spare parts delivery time in case of Air On Ground; vi) Shop Process Time (SPT). Fig. 7, Fig. 8 and Fig. 9 show the results of the simulation referred to the average response times.

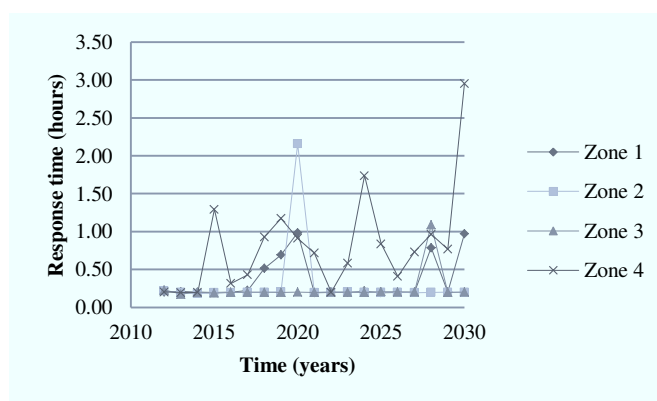


Fig. 7 Response time to Air On Ground requests

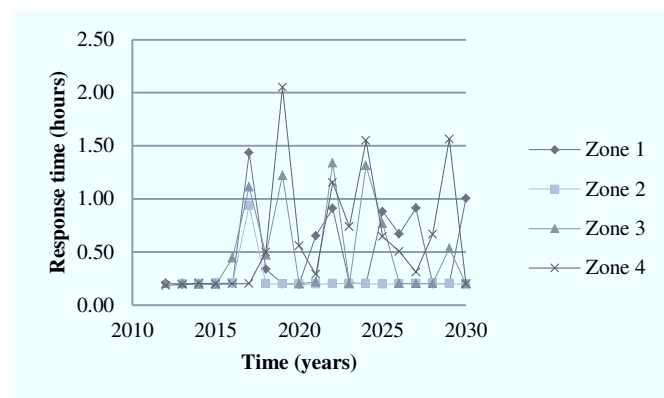


Fig. 8 Response time to remote technical assistance requests

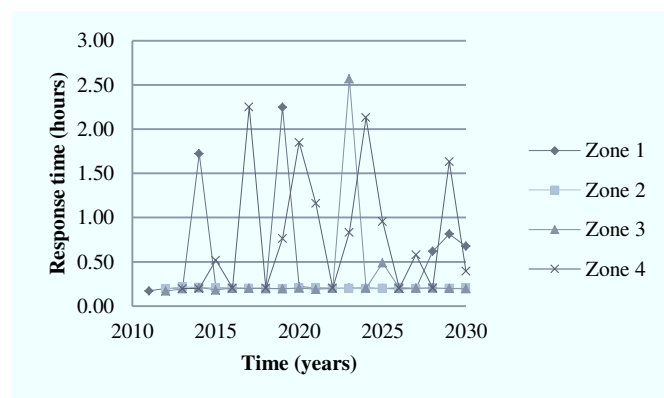


Fig. 9 Response time to on field technical assistance requests

As can be noticed, ALFA is able to comply with the contractual requirements. It is worth noticing that the values reported in the graphs are average values (these times are slightly different depending on the components but are always lower than contractual agreed value of 4 hours). These results are not surprising, given the extremely high value of the MTBF of each component. In the same way, the utilization rate (that is not shown due to space constraints) increases from 2011 to 2017 as a consequence of the increase of the aircrafts, but remains anyway under a critical threshold (one person for each department can handle the additional work coming from the BETA job). Fig. 10 shows the average values of the Shop Process Time.

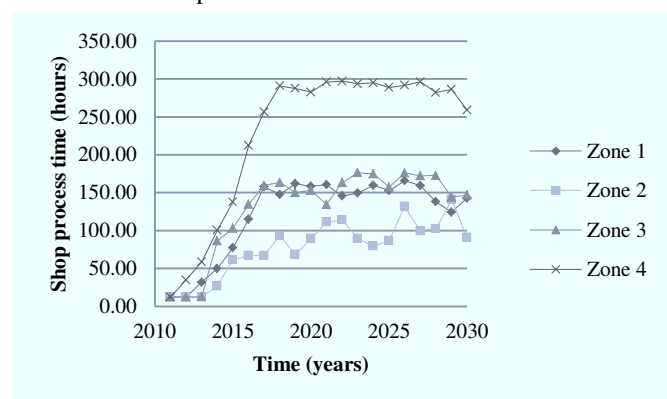


Fig. 10 Average shop process time

As can be noticed these values are surprisingly high. Such a

result is due to the fact that the graph refers to average values. Looking at the simulation output data, segmented for each component, however, it can be noticed that these average values, are highly conditioned by few extremely high values which occur when in the same zone, the same type of component fails more than one time within few days. If that happens, ALFA incurs in a shortage of maintenance kits which prevents repair of the components on time. In these cases in fact, ALFA has to produce a new maintenance kit and send it to the repair station. The shop-process time, in fact, assumes an average value smaller than one hour if the maintenance kits are available and higher than 500 hours if they are not (bimodal distribution). Table 2 shows, for each simulated year, the stock-out frequency.

Table 2 Stock Out (SO) frequency

Year	2011	2012	2013	2014	2015	2016	2017
S.O.%	0,00	0,14	0,31	0,74	1,10	1,70	2,12
Year	2018	2019	2020	2021	2022	2023	2024
S.O.%	2,30	2,29	2,27	2,35	2,35	2,34	2,39
Year	2025	2026	2027	2028	2029	2030	
S.O.%	2,29	2,40	2,37	2,25	2,19	2,09	

Fig. 11 instead shows the AOG delivery time.

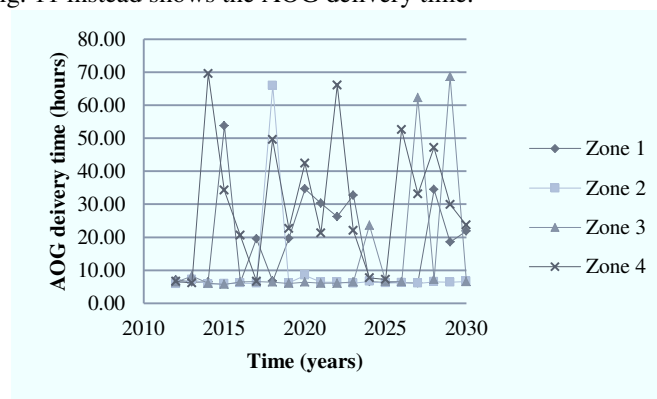


Fig. 11 Average spare parts delivery time in case of Air On Ground

Looking at Fig.11 it can be seen how the average spare parts delivery time in case of Air On Ground is systematically higher than the required 4 hours. It means that ALFA will not be able to comply with the contractual agreement in such a critical situation. Moreover, as for the shop process time, the average values are conditioned by few extremely high values which occur when two AOGs happen in the same zone within a few days. Also in these situations, ALFA incurs in a stock-out and has to produce a new component. The average value of the spare part delivery time, however, is lower than the average value of the SPT since AOG situations are very unlikely to occur.

The implications of this preliminary analysis are twofold. First, by increasing the stock level, ALFA could meet the contractual agreed performance except for the AOG spare parts delivery time. Second, the AOG process, even when the spare parts are available, requires too much time and needs to be improved.

5. CONCLUSIONS

This paper suggests that simulation can be a useful tool to support the design of a service delivery system. This paper presents the preliminary results of an ongoing research, which will be expanded in several ways. First, the model will be used to assess the “optimal” stock level for each type of component. Second, it will be used to assess whether satisfactory service performance could be obtained by transshipping parts between service stations (instead of keeping more parts in stock in each station). Third, it will be used to assess the extent to which the (underutilized) departments of each repair station could be used to provide support also to other existing and future customers.

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