AGING AIRCRAFT COST ANALYSIS USING SYSTEM DYNAMICS MODELING

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Abstract

Ways to reduce an airline`s cost has been studied for years. In fact, in order to achieve this goal, ones need to know different types of airline`s costs including; fuel and oil, maintenance, Ticketing, passenger services, etc. and their impact on the total cost of an airline. According to announcement of ICAO [1], "maintenance cost (about 11% of total cost) is the second major cost after fuel and oil". Therefore, this may attract airline owners` attention to find ways to control maintenance cost and eventually the total cost of an airline. Though, there are many systematic approaches to analyze cost reduction and making policies, in this article, SD modeling is applied to develop a practical policy for maintenance cost reduction.

SD is a modeling methodology with unique capabilities [2] suitable for management and policy analysis. This method is widely used for cost estimation and the behavior of an organization`s cost growth over time. SD models which consist of causal relationships can support fleet management decisions as they age. Therefore, a mature dynamic model can alleviate degradation of aging aircraft and their growing costs.

This paper concentrates on the solutions for reducing airline's costs by bringing the maintenance costs down. Along with the same lines, economizing on this sort of costs, an airline can save considerable money during its fleet`s operation.

So, in this study will use an SD model to estimating Total Life Cycle Costing of a fleet with regard to the "As Is" situation of airlines fleet and statistical data for maintenance of such fleet. Eventually we can use the LCC vs. Desired Average Age of Fleet (DAAF) to determine in witch average age the long term cost of airline will minimize. As System Dynamics Society states "System Dynamics is a computer-aided approach to policy analysis and design". This approach is used for complex system design and simulate in any field such as economics and management, social or ecological systems and it is a methodology for application of Systems Thinking and Holistic View [3]. This approach was developed by Jay W. Forrester at MIT in the 1960th and involves defining a Dynamical Complex System and provides Feedback Loop diagram between causes, effects and influences in the system.

Therefor the outcome of SD model of "Aging Aircraft Life Cycle Costing" will be in the form of policies. Policies that airline managers can imply the in their decision making process, and the resulting decisions will be oriented toward a more cost efficient business model.

1 Introduction

To compete and survive, cost reduction is essential for all airlines. In this way we will need some review of terminology in this industry. Aircraft operating costs includes direct and indirect costs that add up to total cost of ownership (TCO). TCO with regard to Life Cycle Cost (LCC), can be broke up to acquisition cost, operation and maintenance costs, retirement and disposal [4]. According to the nominal cost distribution, operation and support cost are major costs of LCC [5]. As Khan stated, “The operating cost consists of ownership, fuel, crew, insurance, maintenance cost”. The maintenance cost is normally between 14% and 22% of the operating cost.

Aging is the accumulation of unwilling changes in Aircraft structure as it ages. Aging Aircrafts does not necessarily have obvious damages or need of overhaul. However, regarding to the fact that some parts of these aircrafts have borne rising stress, the aircraft needs to be monitored and have some preventive maintenance.

In fact, in aging aircrafts we use Damage Tolerance philosophy, as Scott states “The damage tolerance philosophy to design and maintain an aircraft structure revolves around safe operation with the existence of damage” [6]. Indeed the damage tolerance is about the ability of the manufacturer to predict the fundamental physics of crack growth and reliably of finding the cracks in operation.

The analysis methods like Monte Carlo algorithm are used for setting when and how to apply maintenance program for aging aircrafts [7]. Paying the high costs of Maintenance, repair, and overhaul of aging aircrafts, airlines seeking to find a way to reduce operational and support costs of these aircrafts.

Since SD modeling can expose Systemic Delays and unintended consequences and provide a distinct picture of future view, it is widely used in Cost Estimation, Risk Managements and Decision Making Policy. Therefore, a mature dynamic model can alleviate degradation of aging aircraft and their growing costs. This paper concentrates on maintenance cost and the solutions for reducing airline’s costs, because cost efficiency is a vital ability for an airline.

2 Literature Review

Cost analysis is the crucial part of evaluating a specific project. Over time there have been some researches on Cost Analysis using System Dynamics approach. In 1999, Prasad Iyer at Virginia Polytechnic Institute and State University worked on the effects of system maintenance policy on system maintenance and system life-cycle cost. This research aims to examine the impact of technological upgrades, learning and using preventive maintenance on annual operation costs using system dynamics modeling. The general idea in this research was to find the best preventive maintenance using previous data and records, therefore, reducing the number of breakdowns in a fleet. According to this article, by using preventive maintenance and technological upgrade, the total cost of maintenance will be reduced over time [8].

Also, D. Purvis provided a justification for cost estimation with system dynamics [5]. He performed C-17 Operation and Support cost estimation using SD model. The primary goal of this thesis article is to introduce SD modeling as a tool for cost estimation. This article seeks to provide reliable cost estimation and identification of the necessary resources (personnel, Training, data and tools...) to satisfy customers.

Another useful research was an article written by Eesa Sandani in 2013 at Concordia University which was a system dynamics simulation for investigating RFID potential in aircraft disassembly operations. It`s whole idea was to analyzing the cost of RFID in disassembly of an aircraft and to reduce the disassembly time. This study shows that by using RFID technology, the total disassembly time could have been reduced by over 30% on average and lead to decrease the total cost of reassembly and inventory management [9].

Though, system dynamics modeling is one of the useful approaches for cost analyzing, aging aircraft cost analysis has been studied by many other approaches, as well. One of these works is an article written by Nagaraja Iyyer, in which management of aging aircrafts using Deterministic and probabilistic Metrics is studied. Through this article, risk management, maintenance cost and damage tolerance has been analyzed via Design Metrics [10]. Another study in this field is the work of Defense Technical Information Center about Life Cycle

Cost Modeling and Simulation to determine the economic service life of aging aircraft. Dr. K.R. Sperry from The Boeing Company presents a cost estimating methodology to forecast costs associated with maintaining an aging aircraft fleet, by combining traditional Operation and Support (O&S) cost elements from a USAF AFI 65-503 CORE model, with expert analysis to quantify maintenance cost growth due to aging. In order to estimate the cost of maintenance, he analyzed Data and adds uncertainty in the cost forecasting [11]. Furthermore, in another work, Jones Lang LaSalle in his paper, Determining The Economic Value of Preventive Maintenance, provides three different preventive maintenance scenarios and compare the overall cost estimation of each of them. "The result of the analysis comparing scenario 1 to scenario 3 (no PM to industry benchmark PM) were overwhelmingly positive for performing preventive maintenance. The analysis shows that an investment in PM not only pays for itself but also produces a huge return on the investment [12]."

3 The Framework Model

As mentioned earlier, the cost analysis model helps management by introducing a decision making framework. This model is useful for operational managers to set some policies.
In general, the idea is to make a cost-decision for aging aircraft program. Cost forecasting of aging aircraft is a difficult business and needs high quality equipment offered for aging activities; although, it definitely helps managers to lessen total cost during time and boost net profit. As a result, being able to set a reliable way to estimate costs, airlines may provide tools and technology to reach the lowest cost and highest profit.

3.1 Assumptions

1. Aging aircraft maintenance needs test, research, spares, capable personnel, and… so cost of aging aircraft will raise as it ages.
2. The fleet has one type of aircraft which needs the same maintenance program.
3. Total cost is assumed to be sum of Operating, Investment, Maintenance and Disposal costs.

3.2 Parameters and Variables

Mean Time Between Maintenance (MTBM): Time between two Aging Aircraft activities which must be changed due to aircraft`s age in order to satisfy safety requirements

Maintenance Total Cost Rate (M T C Rate): The rate of cost used for Aging Activities which is supposed to be related to MTBAA and Cost factor, it may shows the exact effect of aging activities in the fleet

Fleet Age Change by Purchasing (FACP): The parameter to evaluate the impact of purchased aircraft age into the entire fleet age.

Fleet Age Change by Disposal (FACD): The parameter to evaluate the impact of Disposal into the entire fleet age.

Aircraft Stress: This parameter illustrates the effect of flight hours and it is used as a factor that can be lessen or increase the MTBM by comparing the flight hour and TO&L cycles with the desired ones in the fleet

Desired TO/L (Desired Take off /Landing): It is the preferred number of take-off and landing cycle in a specific fleet which is assumed to be a fixed size.

Life Cycle Cost (LCC): The cost of an aircraft from the beginning of its operation till the end of life and disposal.

Repair & Maintenance Activities: It is the rate of becoming inactive aircraft due to the Aging Activities.

3.3 Model

In the main Model we have some features among causal loops, called Stocks and Flows which can be seen in our model.

As Sterman Mentioned “Stocks and flows, along with feedback, are the two central concepts of dynamic systems theory. Stocks are accumulations. They characterize the state of the system and generate the information upon which decisions and actions are based. Stocks give systems inertia and provide them with memory. Stocks create delays by accumulating the difference between the inflow to a process and its outflow. By decoupling rates of flow, stocks are the source of disequilibrium dynamics in systems [13].”

Fig.1 shows the whole model in considerable detail which is built in Vensim PLE software Copyright ©Ventana Systems, Inc. (Academic Use Only).

Multiple interrelated loops gave the diagram a complicated look, but knowing concept and main Causal Loops make it understandable.

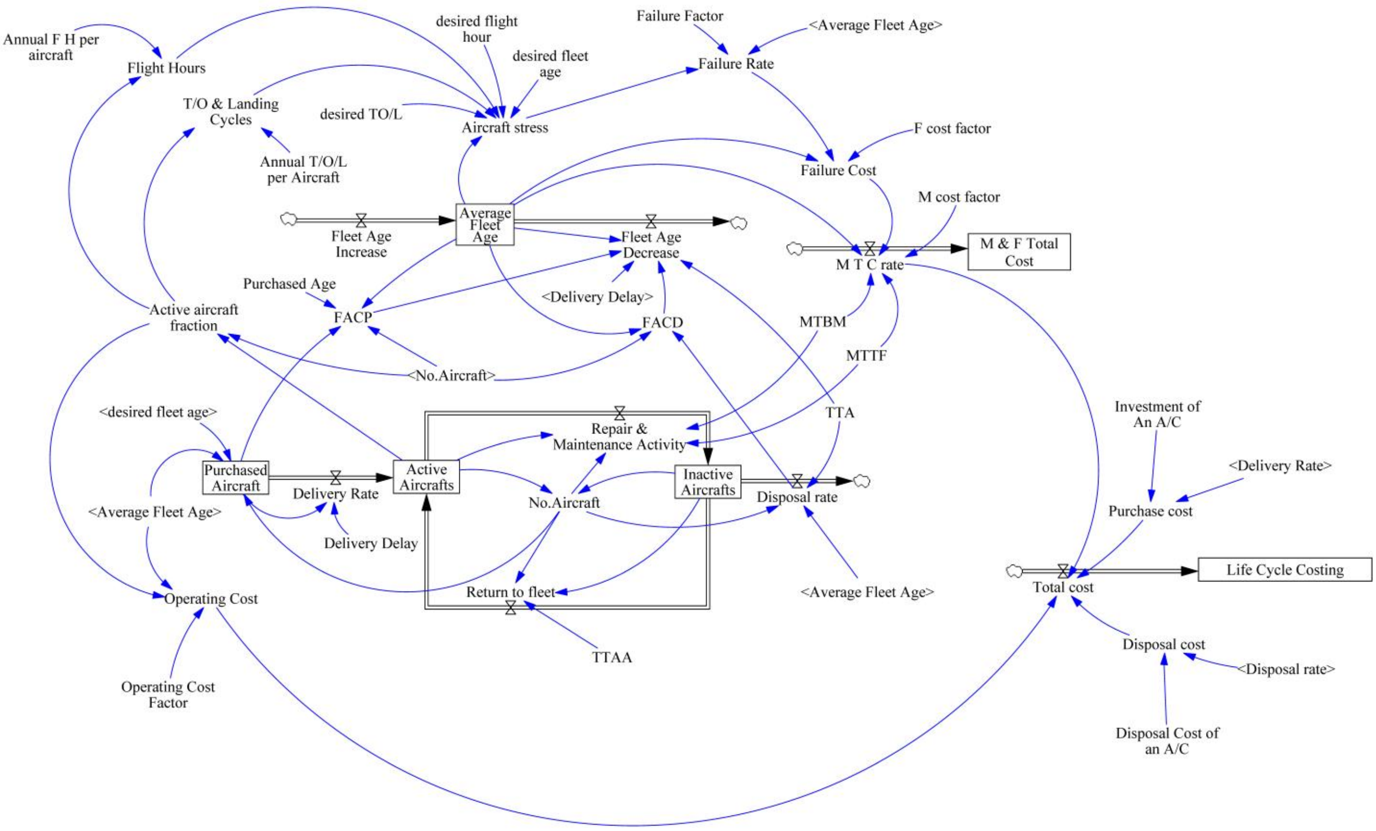

Figure 1

As Sterman stated “Causal loop diagrams (CLDs) are an important tool for representing the feedback structure of systems. Long used in academic work, and increasingly common in business, CLDs are excellent for quickly capturing hypotheses about the causes of dynamics; Eliciting and capturing the mental models of individuals or teams; communicating the important feedbacks you believe are responsible for a problem [13].”

There are some main loops that have been built the entire Model. Bellow, Fig.2 illustrates the core Casual Diagram that consists of three negative (Balancing) loops at the top in which by the nature of such loops the changes alleviate and one positive (Reinforcing) loop that enhances the changes but the outer Balancing loops will overcome and subside its overshoots and system remains steady.

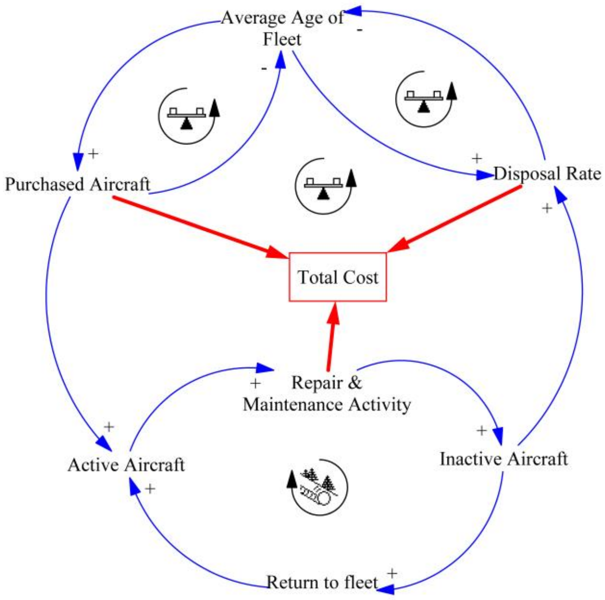

Figure 2

3.4 Equations

In SD modeling, causal relationships and feedback loops are described by mathematical equations. In fact, these equations can modify real world features into quantities variables by simple and linear mathematical relations so as to compute and predict real phenomenon. Meanwhile, this methodology allows us to use previous statistics data by a function called LOOK UP table. In this way, we can give desired statistics data to the model by adding graphs to LOOK UP function. In our model we used both look up functions and linear mathematical relations.

- Active Aircraft = INTEG (Return to fleet+ Production rate- Repair & Maintenance Activity), initial: 12
- Repair and Maintenance Activity = ((Active Aircrafts/MTBM)+(Active Aircrafts/MTTF)) /No.Aircraft
- Aircraft Stress = (Average Fleet Age/ desired fleet age)*("T/O & Landing Cycles"/"desired TO/L")*(Flight Hours/desired flight hour)
- Annual F H per aircraft = 12*4*7*12 = 4032
- Annual T/O/L per Aircraft = 12*4*7*4 = 1344
- Average Fleet Age = INTEG (Fleet Age Increase-Fleet Age Decrease), initial: 15
- Delivery Delay = 2 years
- Desired flight hours = 12*4*7*16 = 5376
- Desired TO/L = 12*4*7*6 = 2016
- Disposal cost= 500 $
- Disposal rate = No. Aircraft/ (TTA-Average Fleet Age)
- FACD = ((NO. Aircraft*Average Fleet Age)-(Disposal rate*25))/ (NO. Aircraft-Disposal rate)
- FACP = ((Purchased Aircraft*Purchased Age) + (NO. Aircraft*Average Fleet Age))/ (Purchase Aircraft + NO. Aircraft)
- Fleet Age Decrease = ((Average Fleet Age-FACD)/TTA) + ((Average Fleet Age-FACP)/Delivery Delay
- Flight Hours = Annual F H per aircraft/Active aircraft fraction
- Inactive Aircrafts = INTEG (Repair and Maintenance Activity-Return to fleet-Disposal rate); initial: 5
- Investment of an A/C = 1500 $
- Life Cycle Costing = INTEG (Total Cost); initial: 0
- Maintenance Total Cost Rate (M T C rate) = M cost factor (Average Fleet Age)/MTBM
- M & F Total Cost = INTEG (M T C rate), initial: 300
- MTBM = 1/12
- No. Aircraft = Active Aircraft +Inactive Aircraft
- Operating Cost = Operating Cost Factor (Average Fleet Age)*Active aircraft fraction
- Production Rate = Purchase Aircraft / Delivery Delay
- Purchase Age = 0 years
- Purchased Aircraft = INTEG (IF THEN ELSE(Average Fleet Age<desired fleet age, 0-Delivery Rate , (-Delivery Rate)+ "No.Aircraft"*((Average Fleet Age/desired fleet age)-1))), initial: 0
- Return to fleet = (Inactive Aircraft/No. Aircraft)/TTAA
- Total Cost = Operating Cost + M T C rate + Disposal cost + Purchase cost
- TTA = 30
- TTAA = 1/12

4 Results

After running our model, we can see its results that have been shown in the graphs over a period of time.

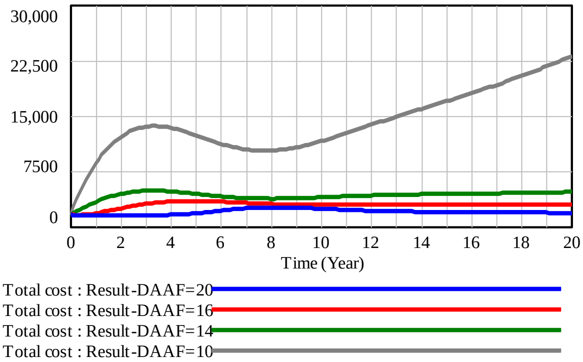

Figure 3

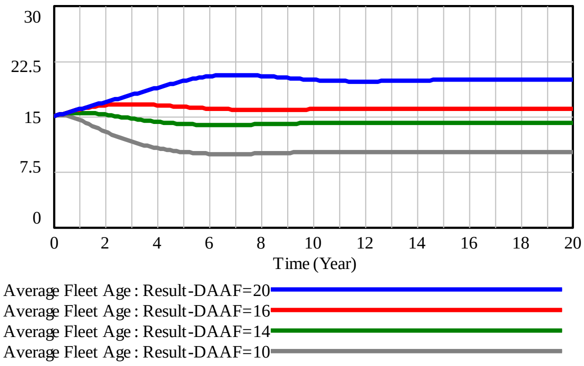

Figure 4

5 Conclusion

Looking at the results and Model behavior, one can conclude that there must be some specific deductions as stated bellow.

1. With hypothetical input data mentioned earlier, first output graph (Fig.3) shows that we can achieve the minimum total cost of fleet if Average Age of Fleet (AAF) is 20.
2. The same figure shows the cost rate airline will opposed to if it tries to reach desirable AAF –probably the optimum AAF value resulted from previous deduction- and maybe other arbitrary AAFs.
3. The amount of time required to reach aimed goals, percentage of costs, desired work pressure on aircrafts,… can be either output or input of model based on managers requirement sets.

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