DOC-Assessment Method

TU Berlin – DOC Method
- A simplified DOC Model
- JAVA DOC Applet

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(with remarks in red by D. Scholz)
Two elements are required for the most simple DOC model:
- C1: Route independent (fixed) Cost
- C2: Route dependent (variable) Cost

\[
\text{DOC} = C_1 + C_2
\]

- Depreciation
- Interest
- Insurance
- Flight & Cabin Crews (part of C2?)
- Fuel
- Lubricants
- Fees
- Maintenance

COC = DOC without capital cost (depreciation, interest, insurance)

How does a typical cost scenario look like?
Which parameters do we need to know in order to use that formula?
Which parameters have to be assessed from statistical data?
Simplifications:

- All route independent cost are primarily based on the aircraft size and its respective operational empty weight (OEW).
- The major element is the capital cost which can be assumed to be a linear function of the OEW (if the aircraft market influence is considered negligible) and thus

\[
C_{\text{CAP}} = \left[ P_{\text{OEW}} \cdot (\text{OEW} - W_{\text{Eng}} \cdot N_{\text{Eng}}) + W_{\text{Eng}} \cdot N_{\text{Eng}} \cdot P_{\text{Eng}} \right] \cdot (a + f_{\text{Ins}})
\]

with

\[
a = \text{IR} \cdot \frac{1 - f_{\text{RV}} \cdot \frac{1}{1 + \text{IR}}^{\text{DP}}}{1 - \left( \frac{1}{1 + \text{IR}} \right)^{\text{DP}}}
\]

with:
- \(a\): Annuity factor
- \(P_{\text{OEW}}\): Price per kg OEW (Structure/Systems/Equipment, 1150 €/kg)
- \(P_{\text{Eng}}\): Price per Engine Weight (2500 €/kg)
- \(\text{IR}\): Interest rate (5%)
- \(\text{DP}\): Depreciation period (14 years), also mortgage payback period
- \(f_{\text{RV}}\): Residual value factor (Residual value / aircraft price, 10%)
- \(f_{\text{Ins}}\): Insurance rate (0,5%)
- \(N_{\text{Eng}}\): Number of Engines
- \(W_{\text{Eng}}\): Weight per Engine
That annuity formula, which is based on a modified mortgage equation, addresses both yearly depreciation and interest.

The reason for the a.m. modification is to include the residual aircraft value at the end of the depreciation period into the capital cost, which is occasionally meaningful.

That does assume that an operator is buying an aircraft at a constant price per kg and spends the corresponding capital cost constantly per year all over the depreciation period.

Insurance cost are also proportional to the aircraft price.
Personnel cost are assumed to be route independent because an airline has to provide a sufficient number of crews to ensure flight operations over the entire service time and therefore are proportional to the payload.

- 50 passengers per Flight attendant (certification requirement) and 100 kg per passenger are assumed.
- Flight crew cost are considered constant per year and result from the sum of the average of a commander and a first officer salary and thus:

\[
C_{Crew} = CC \cdot \left( S_{FA} \cdot \frac{MPL}{5000} + S_{FC} \right)
\]

or:

\[
C_{Crew} = CC \cdot (S_{FA} \cdot n_{FA} + S_{FC})
\]

where:
- \(n_{PAX}\): Maximum number of passengers; MPL: max. payload
- \(S_{FA}\): Average yearly salary of a flight attendant (60,000 €/year)
- \(S_{FC}\): Average yearly salary of a cockpit crew (300,000 €/year for 2 pilots)
- CC: Crew Complement (Number of crews per Aircraft, 5) (independent of utilization?)

The route independent cost per year therefore sum up to

\[
C_1 = C_{CAP} + C_{Crew}
\]
Within the route dependent cost lubrication cost can be assumed to be of minor order of magnitude compared to the fuel cost and can be addressed by a minor correction of the fuel price.

The fees are comprising payload dependent handling fees and maximum take-off weight (MTOW) dependent ATC fees and landing fees.

The route dependent yearly cost thus be calculated by

$$C_2 = FC \cdot \left( P_F \cdot TF + P_{PL} \cdot PL + P_L \cdot MTOW + f(R) \cdot R \cdot \sqrt{\frac{MTOW[to]}{50}} + MC \right)$$

with
- $P_F$: Fuel price [0,5 €/kg] (see p. 13)
- $P_{PL}$: Handling fees [0,1 €/kg]
- TF: Trip fuel [kg]
- $P_L$: Landing fees [0,01 €/kg]
- PL: Payload [kg]
- FC: Yearly flight cycles
- FH: Yearly flight time
- R: Range [km]
- MC: Maintenance cost per flight cycle
- f(R): Range dependent ATC price factor (1,0 for domestic Europe, 0,7 for transatlantic flights, 0,6 for far east flights (only half of landings at European airports))
Fuel cost are based on the trip fuel (e.g. from payload range diagram)

The fourth term represents the EUROCONTROL formula for ATC-fees. The price factor considers the fact that the price scenarios are varying strongly for each continent (or even region)

Landing fees are charged on basis of aircraft MTOW and Handling fees on Payload whereas ATC fees are based on both the secured flight distance (Range) and the discounted (square root!) MTOW

Maintenance cost split into

- flight cycle dependent cost, reflecting primarily structural fatigue and overhaul burden,
- flight hour dependent cost, which take into account primarily wear and the associated line maintenance work and
- calendar time dependent cost, which is a constant share reflecting for example the rectification of corrosion during overhaul, the latter being route independent and thus considered as constant
The following method is an approximation for maintenance cost per flight cycle is given by the sum of three parts:

- \( MC_{AF,MAT} \): Airframe material maintenance cost (repair and replacement)
- \( MC_{AF,PER} \): Airframe personnel maintenance cost (inspection and repair)
- \( MC_{ENG} \): Engine total maintenance cost

\[
MC_{AF,MAT} = OEW[to] \cdot (0.21 \cdot FT + 13.7) + 57.5
\]
\[
MC_{AF,PER} = LR \cdot (1 + \text{Burden}) \cdot \left\{ (0.655 + 0.01 \cdot OEW[to]) \cdot FT + 0.254 + 0.01 \cdot OEW[to] \right\}
\]
\[
MC_{ENG} = N_{ENG} \left( 1.5 \cdot SLST[to] + 30.5 \cdot FT + 10.6 \right)
\]
\[
MC = MC_{AF,MAT} + MC_{AF,PER} + MC_{ENG}
\]

- **Burden**: Cost burden (2)
- **FT**: Flight time
- **LR**: Labor rate (50 €/h)
- **N_{ENG}**: Number of engines
- **SLST**: Sea level static thrust of one engine [to]
- **OEW**: Operating empty weight

These empirical formulae include time dependent constant shares as well as burden reflecting fixed maintenance cost and administrative overhead.
A basic structure of a generic utilization formula is

\[
FC = \frac{OT_{\text{p.a.}}}{(FT + BT)} = \frac{OT_{\text{p.a.}}}{\left(\frac{R}{v} + BT\right)} \quad \text{with} \quad OT_{\text{p.a.}} = POT_{\text{p.a.}} - DT_{\text{p.a.}}
\]

with \( OT_{\text{p.a.}} \): Yearly operation Time

\( POT_{\text{p.a.}} \): Potential yearly operation time (\(365 \cdot 24h = 8760\) h)

\( DT_{\text{p.a.}} \): Yearly forced downtime (2748.8 hours) consisting of

- C-Checks (3.2 days p.a., 4 days per 15 month)
- D-Checks (5.6 days p.a., 4 weeks per 5 years)
- Repairs (2.6 days p.a., statistical average)
- Night Curfew (7 days p.a., from 11:00 p.m. until 6:00 a.m. at operation days)

\( FT \): Flight time

\( BT \): Block time supplement per flight

(1.83 hours \(\text{too high ?}\), statist. average)

\( R \): Average stage length

\( v \): Cruise speed

Note: It is hereby assumed, that the flight is performed with constant speed, which is not the actual case (ref. climb/descent/approach segments)
A simplified DOC Model

- Statistical values for large airlines operating in the European scenario are
  - Average operation time: 6011.2 hours (Maintenance, night curfews)
  - Average block time increment: 1.83 hours

- With that the Utilization formula can be written

\[
FC = \frac{6011.2}{R + \frac{1.83}{v}}
\]

- The yearly flight time yields

\[
FH_{p.a.} = FC \cdot FT
\]

\[
= \frac{6011.2}{1 + \frac{v \cdot 1.83}{R}}
\]
Only a limited number of parameters are necessary to calculate DOC

- **Financial parameters** (Interest rates, depreciation period, residual value)
- **Operational parameters** (Yearly flight cycles & downtime, block time supplement, crew salaries, crew complement, specific maintenance cost)
- **Aircraft design weights** (MTOW, OEW, PL)

Whereas financial and operational parameters can be obtained from statistical investigations, the aircraft weights have a flight physical origin.

For comparison purposes, the operational scenario described by the above figures can be set relatively arbitrary, however, within reasonable limits.

In order to adopt the method to a known result, the most uncertain parameters can easily be calculated by applying a non-linear optimization algorithm (e.g. EXCEL-SOLVER) to a least squares formulation of the error sum.
Consideration of additional cargo

- Method of freight equivalent passenger seats
  - Cargo revenue from residual cargo payload at MZFW (\(PL_{\text{Max}} - PL\))
  \[
  E_{\text{CARGO}} = FR \cdot \left( G_{N,\text{max}} - G_{\text{PAX}} \right)
  \]
  - Equivalent seat revenue
  \[
  n_{\text{PAX,Cargo}} = \frac{E_{\text{CARGO}}}{E_{\text{PAX}}} \cdot R
  \]
  - \(E_{\text{Pax}}\): Revenue per seat and flight [\(\€\)], 370 \(\€\) (constant ?)
  - FR: Revenue per freight-km [\(\€/\text{to-\text{km}}\)], 0.07 \(\€\)

- DOC correction
  \[
  \left( \frac{\text{DOC}}{\text{SKO}} \right)_{\text{kor}} = \left( \frac{\text{DOC}}{\text{SKO}} \right) \cdot \frac{n_{\text{PAX}}}{n_{\text{PAX}} + n_{\text{PAX,Cargo}}}
  \]
Current kerosene price is about constant since 2011

Current fuel price: 0.80 €/kg

3,7854 l/USgal; 0,8 kg/l; 1,3 US$/€; “Into Plane Differential”: 0,05 US$/kg

The fuel price is higher than the fuel price on page 6
The increase of kerosene price in the future is predicted by Airbus to be linear: 2 US$/bbl/year

Barrel: 1 bbl (US) = 159 l; 1.3 US$/€; 0.8 kg/l

Future fuel price: current fuel price (2013: 0.53 €/kg) plus price increase


0.012 €/kg/year
### JAVA DOC Applet

#### Cost Parameters

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<thead>
<tr>
<th>Aircraft</th>
<th>Engine</th>
<th>Reference</th>
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<th>Aircraft</th>
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<td>CF6-50E2</td>
<td>FCAS/99</td>
<td>2 × 692kN</td>
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</table>

#### Graphs

- **Payload vs. Range**
- **Fuel vs. Range**
- **Spec. Total Cost vs. Range**
- **Break even PL vs. Range**

#### Comparison of Direct Operating Costs (DOC)

- **A 300 84-200**
  - Probability: 45.4
  - Risk: 5.5
  - Break even PL: infinity
  - Spec. Total Cost: infinity
  - Break even PL: 854.0

- **A 300-500**
  - Probability: 42.4 (-6.5%)
  - Risk: 4.7 (-13.4%)
  - Break even PL: infinity
  - Spec. Total Cost: infinity
  - Break even PL: 841.0 (-1.5%)

Comparison of Direct Operating Costs (DOC): Aircraft Design & Aerostructures Group / Technical University Berlin
The applet provides the following functions:

- Selection of two comparison aircraft out of an integrated aircraft data base
- Defining a new aircraft by its design characteristics
- Altering the DOC assumptions
- Comparing the influence of a parameter change for a selected aircraft
- Graphical representation of up to four of the following selectable parameters over the range axis:
  - Absolute DOC of components and resulting total
  - Relative DOC on TKO, Paxkm and km basis of components and resulting total
  - Payload
  - Break even Payload
  - Trip and reserve fuel
  - Flight time
  - Take of weight
  - Average mission weight
  - Productivity (per flight & p.a.)
  - Utilization (flight hours & flight cycles p.a.)
  - Payload factor
For a proper comparative assessment of aircraft it is helpful to calculate and display also the break even payload BEPL.

For a given revenue rate (RR) in terms of €/TK the comparison of cost (DOC) and revenue leads directly to the break even payload (BEPL) because for break even the condition must be

\[ \text{Revenue} = DOC \Rightarrow RR \cdot BEPL = SMC \cdot PL \Rightarrow BEPL = \frac{SMC \cdot PL}{RR} \]

The area between the BEPL and PL line in the payload range diagram indicates the profitable domain of operations.

Below BEPL the operation is prone to financial losses.

The best result is achieved, if the aircraft is operated with maximum payload in the domain close to design range.

For testing of the a.m. formulae, a java applet has been supplied, which can be accessed via the internet under http://www.luftbau.tu-berlin.de/menue/studium_und_lehre/java_applets/