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QUANTITATIVE EVALUATION CRITERIA FOR MODERN AVIONIC SYSTEM ARCHITECTURES

K. Neumann, Airbus CIMPA GmbH, Hamburg, Germany
E. Kleemann, Airbus Deutschland GmbH, Hamburg, Germany
R. Reichel, ILS-Institut für Luftfahrtsysteme, Universität Stuttgart, Germany
M. Lehmann, ILS-Institut für Luftfahrtsysteme, Universität Stuttgart, Germany

Abstract

Modern avionic architectures consist of strongly interconnected computing modules. Looking for a new appropriate avionic system architecture, several feasible architectures can be found in many cases. This is especially true for avionic systems, which are based on Integrated Modular Avionics (IMA). Basically, IMA consists of standardized and cross-linked avionic modules. Control tasks of several systems can be hosted as applications on the same avionic module. Consequently, IMA provides a high variety of possible architectures. In order to find the most appropriate one, it is essential to evaluate the different possible architectures at aircraft level by means of quantitative criteria.

In cooperation with ILS, Airbus has developed an approach to analyze system architectures quantitatively applying parametric formulae. The criteria describe technical and economic characteristics of the architecture. the criteria do not depend on architecture or on aircraft type and should be applied on aircraft level.

In this paper, firstly basic principles for the design of avionic architectures are given. By the use of conventional evaluation procedures for general technical systems with uncertain parameters and their corresponding economic models, evaluation criteria are derived.

Relevant evaluation criteria for avionics systems are defined and for some criteria exemplary mathematic models are demonstrated. This is done for ship-set cost, architecture mass and volume. Three operating cost criteria, namely initial provisioning, maintenance and operational interruption, are shortly explained without précising the parameter model.

Finally, the evaluation methodology is analyzed. In particular the influence of uncertain inputs on the outputs of the evaluation model is studied. The method is validated by the application to different academic but representative architecture scenarios.

Keywords:
avionic system architecture, Integrated Modular Avionics (IMA), quantitative evaluation, uncertain parameters, product life cycle

1. MOTIVATION

The parametric architecture evaluation approach is driven by the recent development of modern avionic systems. A rising system complexity and the demand for shorter development cycles require new system design methods.

The system definition strongly influences cost caused by the avionic system during the product life cycle.

The parametric architecture evaluation is a method to help the system designer to choose the best solution among feasible architectures according to certain criteria. Designers resp. management involved in program decisions can use the evaluation criteria for architecture trade-offs. They can use evaluation metrics as pre-assessment to identify avionics architectures favorites, which shall be studied in more detail by specialists. In this process, parametric evaluation criteria shall ensure objectivity of evaluation and transparency of decisions.

Beside general objectives such as system improvement, cost reduction, development cycle acceleration and risk mitigation, parametric evaluation criteria can also be used as basis for automatic architecture optimization.

2. AVIONIC SYSTEM ARCHITECTURES

Avionic system architectures are the subject under evaluation. The following section describes how the system architecture is restrained from the surrounding aircraft structure.

DEF: Avionic System Architecture
Interconnected computing modules of aircraft systems including wiring between modules and wiring between modules and peripheral devices.
EOD

An avionic architecture is not necessarily equal to the common ATA[*]-breakdown. The avionic architecture has different interfaces to the system environment which transfer information, energy, heat mechanical forces etc.
Figure 1 depicts the evaluation scope: Installation and protection elements, such as racks or shielding, are designed to fulfil architecture installation and environmental requirements. The computing modules are connected to different peripheral devices via physical cables. They communicate with each other, receive information by data and signals from sources (sensors, external modules) and transfer information by data and signals to sinks (actuators, external modules). In addition, electrical energy is linked to the modules to provide power but it is also used sometimes to switch external aggregates in a safe manner.

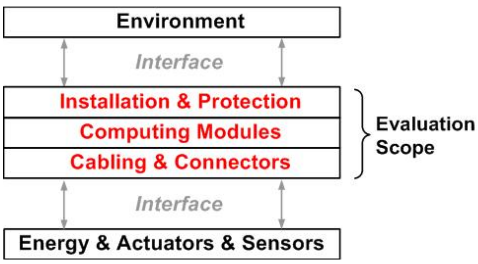

Figure 1 Architecture Scope

For an IMA architecture the system periphery is considered to be given resp. to be fixed.
The aircraft structure and the peripheral devices are out of scope of evaluation.

2.1. Topological optimization

Basic architecture concept design is strongly driven by topology and architectural configuration. Focusing on topology first and assuming that the locations of peripheral system devices are fixed, the placement of computing modules within the aircraft plays an important role with respect to the evaluation criteria.
Basically, it can be distinguished between centralized and distributed architecture philosophies. Centralized architectures concentrate the avionics modules in one area – the avionic bay. There, installation and cooling infrastructure can be shared and maintenance can be supported by easy access.
Distributed architectures provide the opportunity to reduce wiring effort significantly but require standalone avionics features such as passive cooling capability.

2.2. Variation of part numbers and module quantities

Part numbers cause cost for the aircraft manufacturer and for the aircraft operator. IMA provides the basis for the reduction of part numbers. On the other hand, the reduction of part numbers resp. the use of just a few different types of modules (standardization) will produce some overhead. This is due to the fact that the module has to fulfil different system requirements and module resources may remain unused.
The variation of module quantities decreases production cost of a single unit but can increase the ship-set cost.

2.3. Integrated Modular Avionics (IMA)

In several civil and military domains of aeronautics the principle of IMA has been introduced.

DEF: Integrated Modular Avionics (IMA)
A shared set of configurable, reusable and interoperable hardware and software resources forming a platform that provides services, designed and verified to a defined set of safety and performance requirement, to host multiple applications performing aircraft functions.
EOD

Consequently, IMA architectures are the general case of common avionics system architectures in which several aircraft functions are mapped on the same module.
IMA can optimize resource usage by the integration of several systems on the same computing module.
An absolute necessary feature for the integration of different avionic applications even of different safety is partitioning. Partitioning in terms of IMA means: segregation in time and space.

[*] ATA chapter are a functional grouping of aircraft functions defined by the Air Transport Association.

3. EVALUATION METHODOLOGY

Evaluation is a discipline, which has been performed since many years for decision support in different technical, economical and other domains [Breiing].

DEF: Evaluation
Evaluation is a procedure, which identifies among different solutions the solution with the highest benefit according to certain criteria [Breiing].
EOD

Solutions in the framework of evaluation can be variants of a technical implementation principle or alternatives, which are quite different in terms of functionality.
The easiest way for the derivation of evaluation criteria is the analysis of requirements. Those are composed of customer requests, economic, technical and legal constraints [Breiing]. In addition, stakeholder interests such as low production cost can be taken into account.
For evaluation the criteria are split into shall and should criteria. Shall criteria have to be fulfilled to qualify the system solution (example: Safety). Should criteria are satisfied if they are fulfilled to a certain degree (example: Mass).
Another classification is the distinction between qualitative and quantitative criteria. The determining factor is the scale level [Backhaus] of the criterion.

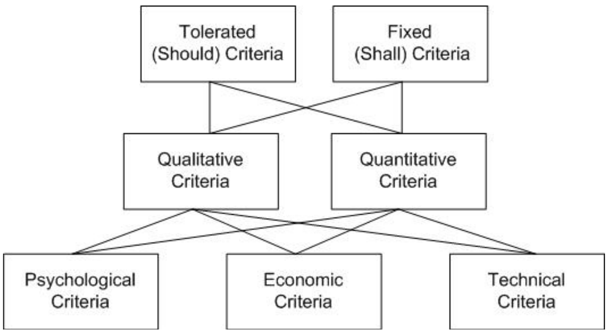

Figure 2 Criteria classification (Source: [Breiing])

Finally, evaluation criteria are divided up into psychological, economic and technical criteria.
Psychological criteria describe subjective, personal or strategic motifs of the decision maker (example: supplier selection).
Economic criteria are related to production and operating cost (example: maintenance cost).
Technical criteria describe functional or non-functional aspects (example: volume).

In this work only ratio scaled, quantitative should criteria are treated, which describe economic and technical characteristics of the avionic system architecture.

3.1. Evaluation functions

To visualize the quantitative evaluation values of analytical evaluation criteria an evaluation function can be formulated for a defined interval [Breiing]. The interval is limited by an upper bound (UB) and a lower bound (LB).
In general, the scalar evaluation value (w) depends on the parameter vector (x).

(1) $w = f(x)$

If a minimization of w is associated to a bigger benefit for the decision maker, the evaluation function of the criterion i is called S_i. Other evaluation functions can be found in [Breiing].
The evaluation function (S) is one-dimensional and describes on the ordinate the evaluation function value S(w) and on the abscissa the evaluation value w with a specific physical unit.

(2) $S = f(w)$

An expert team decided for the problem setting a simple hyperbolic evaluation function.

(3) $S = w_{IMAG1} \cdot \frac{1}{w} = \frac{a}{w}$

The function depends on an evaluation value w_{EVAL} and on a reference value w_{REF}, which will always be derived from the reference architecture scenario and kept constant.

(4) $w_{REF} = w_{IMAG1}$

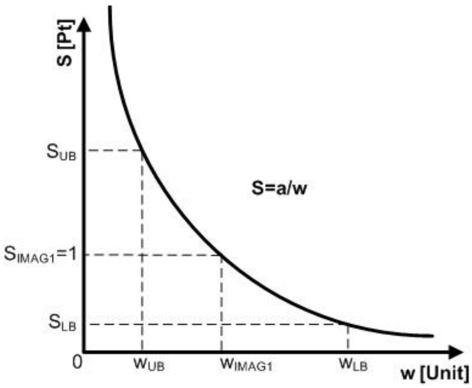

Figure 3 Rising evaluation function

Weighting factors and analytic procedures to determine the best system solution from a set of several evaluation criteria are not treated in this paper.

3.2. Evaluation method

Expert estimations are a widespread mean to determine quantitative evaluation values (see [Breiing], [Leung]). Practice shows that

"engineering judgement" is an appropriate mean for evaluation. But inconsistent decisions are possible.
Analytic evaluation methods can simplify linguistic, intuitive expert decisions by parametric formulae. Due to a lack of information, inputs for the evaluation model have to be estimated as well. But the evaluation is broken down into many smaller and easier parameter estimations (example: determination of the time for a maintenance task of a module instead of an estimation of the overall maintenance cost).
Parametric evaluation models can be overtaken from existing models in the company or from general literature.
The formulation of new metrics requires analytic human design and in more complicated cases heuristic or statistical approaches [Backhaus].

3.3. Economic model

The economic model, which is used for evaluation is based on financial models from literature [Wöhe] and on the terminology used by Airbus.
Total cost (CFC) can be split up into non recurring cost (NRC) and into recurring cost (RC). The cost are referred to one year.
(5) CFC=NRC+RC

3.3.1. Aircraft life cycle cost

DEF: Life cycle cost (LCC)
LCC contain cost for procurement, production and usage of the product. The product life cycle contains the development, industrial production, use, maintenance and the dismantling.
EOD

One particular part of the LCC of an aircraft are the direct operating cost (DOC) of the airline. The aircraft manufacturer strongly influences some parts of the direct operation cost by system definition.
Specific DOC break downs can be different according to the author. However, the same cost terms can be found in most models.
Typical cost are financial cost for purchase, interest and specific tools and operating cost for fuel, crew, maintenance and cancellations.

3.4. Investment model

An investment is the usage of financial means [Müller]. The change of monetary value in time is one the most important effects to be considered.
A fictive interest rate (i) is proposed, which is composed of the average inflation rate ($i_{Inflation}$) and of the credit rate (i_{Credit})

(6) $$i = i_{Credit} - i_{Inflation}$$

The capital for an investment is paid with a constant rate (c_a) over a given amortization period (t).

(7) $$c_a = \frac{Capital}{t}$$

The interest rate i is combined with the annuity credit model. The annuity method considers the averaged annual financial flows [Wöhe]. One part of the money is used to pay the credit and another part is used to pay the interest (see Figure 4).

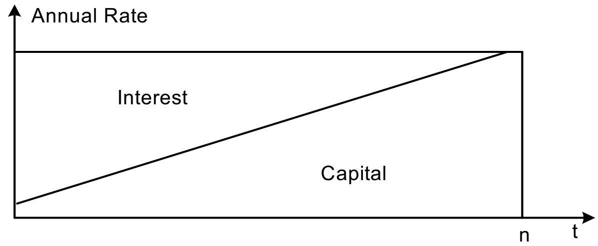

Figure 4 Cash flow for annuity credit

The regaining factor (r) is calculated with the above introduced variables by

(8) $$r = \frac{i \cdot (1+i)^t}{(1+i)^t - 1}$$

The annuity (a) reads

(9) $$a = Capital \cdot r$$

The interest rate (c_i) can be calculated by the interest (Interest)

(10) $$Interest = t \cdot a - Capital$$

through

(11) $$c_i = \frac{Interest}{t}$$

Finally the ship-set cost (SSC) are defined by constant annual rates (see Figure 5).

(12) $$SSC = c_a + c_i$$

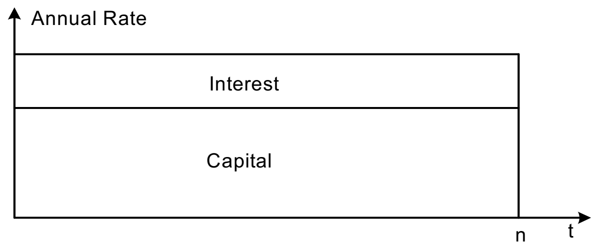

Figure 5 Financial model for evaluation

3.5. Uncertainty

Any evaluation, which is conducted before the realization of a technical solution requires assumptions. The assumptions can be expert estimations or extrapolations from previous programmes.

One possible method to treat uncertainty is the use of the Fuzzy theory, which was already introduced by Zadeh in 1965.

3.5.1. Definition of the fuzzy number

The following definitions are overtaken from [Breiing]. To each uncertain parameter a minimum value (w_{min}) a maximum value (w_{max}) and a value, which is the most probable value (w) are associated. w is always in the interval $W=[w_{min}...w_{max}]$

The membership function (μ) consist of two branches: the left branch (L) and the right branch (R). L and R are described by the two modal parameters a and b.

(13) $a = w - w_{min}$

(14) $b = w_{max} - w$

Figure 7 shows, that w becomes zero for any point outside the considered interval W. It is assumed, that the estimated value w_x is sure in W. μ is a value describing the “degree of affiliation”.

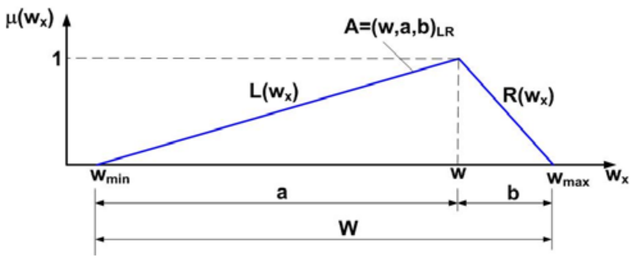

Figure 6 Visualization of the fuzzy number

The uncertain number A is called LR-Fuzzy number and has got a triangular distribution function.

A is only true for the exception w_x=w. Inside W the evaluation value w is only true to a certain degree and outside w doesn’t exist.

The linear equations of L and R read:

(15) $$\mu(w_x) = \begin{cases} L\left(\frac{w - w_x}{a}\right) \forall w_x \in [a,w], w_x \le w, a > 0 \\ R\left(\frac{w_x - w}{b}\right) \forall w_x \in [w,b], w_x > w, b > 0 \end{cases}$$

A can be written in an abbreviated form as

(16) $A = (w,a,b)_{LR}$

With this model for uncertain figures basic operations, such as multiplication and addition, can be conducted.

3.5.2. Resolution of fuzzy numbers

The resolution of fuzzy numbers is always required, if during an evaluation a decision has to be made. Among the different methods from literature, one approach is the centroid method [Bothe], which is also valid for non triangular affiliation function. A general fuzzy number, as described in the previous section, is resolved to a strict number p by

(17) $$p = \frac{\int_A x_S \cdot \mu(w_x) dw_x}{\int_A \mu(w_x) dw_x}$$

If the affiliation function is linear, equation (18) becomes

(18) $$p = \frac{\sum_A A_i \cdot x_{Si}}{\sum_A A_i}$$

The geometric interpretation of p is the abscissa sector of the centre of gravity of the surface between the w_x-axis and the fuzzy affiliation function μ.

If the affiliation function is triangular, the value of p can be directly calculated from the surfaces A_i and the coordinates x_i of the triangles.

(19) $$p = \frac{A_1 \cdot x_{S1} + A_2 \cdot x_{S2}}{A_1 + A_2} + w_{min}$$

with

(20) $$x_{S1} = \frac{2}{3} \cdot a$$

and

(21) $$x_{S2} = a + \frac{1}{3} \cdot b$$

4. AVIONIC SYSTEM EVALUATION CRITERIA

The basic assumption for evaluation is, that the more complete the evaluation is, the higher objectivity becomes.
A set of relevant evaluation criteria for avionics system architectures is proposed. The evaluation criteria describe typical characteristics of avionics systems, which are only determined qualitatively in many practical cases.

Tab. 1 Classification of evaluation criteria

Criterion	technical	economic	shall	should
Reusability	x			x
Maturity	x		x	
Development Cost		x		x
Industrialization Potential	x			x
Manufacturing Cost		x		x
Flight Cost		x		x
Safety	x		x	
Reliability	x		x	
Availability	x		x	
Growth Potential	x			x
Modifiability		x		x
Volume	x			x
Weight	x			x
Ship-Set Cost		x		x
Initial Provisioning		x		x
Maintenance		x		x
Operational Interruption		x		x

4.1. Linguistic criteria definition

To clarify the notions from Tab. 1 all criteria are précised linguistically because the name often leads to misunderstandings.
A common understanding among all stake holders is needed to get a consistent balancing of the criteria and to avoid different views on the problem and inconsistent evaluations.

DEF: Reusability
The Reusability is the percentage of the used H/W, S/W and processes, which can be used several times within an A/C programme or between different A/C programmes by the A/C manufacturer and by the module supplier.
EOD

DEF: Maturity
The maturity is defined by the arithmetic mean of an Airbus adapted technical readiness level (TRL), which is determined for each module of the avionics architecture under evaluation.
EOD

DEF: Development Cost
The development cost are the cost which the aircraft manufacturer has to spend once per aircraft programme, to develop all H/W and S/W of the avionics architecture.
EOD

DEF: Industrialization potential
The industrialization Potential describes the capability of an avionics system to support industrial work share scenarios as well as third party S/W development and interfaces.
EOD

DEF: Manufacturing cost
The manufacturing cost are the direct cost, which the aircraft manufacturer has to spend to install the avionics architecture in the fuselage to load application S/W on the computing modules and to drive the obligatory ground tests.
EOD

DEF: Flight cost
The flight cost are the direct cost spent by the aircraft operator for fuel, landing and navigation fees and crew due to the mass of the avionics architecture.
EOD

DEF: Safety
Characteristic of an avionics system to fulfil it's mission (functionality and performance) at defined environmental conditions without endangering human health, equipment (aircraft, infrastructure) and the environment [Gajewski].
EOD

DEF: Reliability
Characteristic of an avionics system to fulfil it's mission (functionality and performance) at defined environmental conditions during a given time span (mission duration) [Gajewski].
EOD

DEF: Availability
Characteristic of an avionics system to fulfil it's mission (functionality and performance) at defined environmental conditions at a given instant (mission time) [Gajewski].
EOD

DEF: Growth potential
The growth potential of an avionics system is defined by the effort for recertification regarding software timing, additional software functionality, additional I/O, additional CPU performance and additional memory evaluated for each module specifically and resumed by an arithmetic mean.
EOD

DEF: Modifiability
Direct cost which have to be expended by the aircraft manufacturer and the airline if the hardware and/or the software of one computation module has to be changed during development or during aircraft service period. The cost are determined for each computing module of the system under evaluation and averaged by an arithmetic mean.
EOD

4.2. Analytic criteria definition

The intention of the presented approach is the analytic, quantitative evaluation of avionic systems. In the following section some metrics for parametric evaluation are added to the linguistic definitions.

4.2.1. Volume

The volume of the avionic system plays an important role for the technical feasibility of the architecture.

DEF: Volume (V)
The volume of the avionics system architecture is the space, which is necessary to install all computing modules within the aircraft structure.
EOD

The volume of one computing module (V_n) is defined by the depth (d_n), the width (w_n) and the hight (h_n) of the cuboid defined in Figure 7.

(22) $$V_n = d_n \cdot h_n \cdot w_n$$

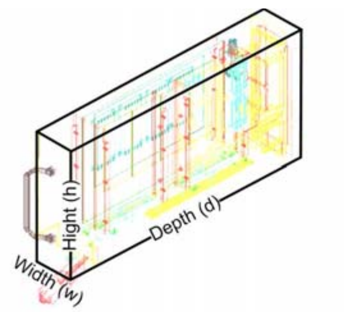

Figure 7 Computing module geometry

For an avionic system architecture the total volume ($V_{EvalSys}$) is calculated by the sum over all modules.

(23) $$V_{EvalSys} = \sum_{n=1}^{N} V_n$$

For M part numbers, $V_{EvalSys}$ can be alternatively calculated using the quantity per aircraft (QPA_m) by the sum over all part numbers M.

(24) $$V_{EvalSys} = \sum_{m=1}^{M} \left(QPA_m \cdot V_m \right)$$

The criterion S_V for the relative evaluation of the volume reads

(25) $$S_V = \frac{V_{Ref}}{V_{Eval\,Sys}}$$

The volume criterion can be completed by the volume of wiring and installation structure. In addition, it can be transferred to cost of freight.

4.2.2. Mass

System mass has got a strong impact on fuel consumption of the aircraft.

DEF: Mass (m)
The mass of the avionics system is the sum of all H/W components of the architecture including the wiring for data and energy transfer.
EOD

The wiring mass (m_{Cable}) is calculated by a generic, simplified aircraft geometry with given wiring routes. The aircraft geometry is defined in a global system of coordinates. The model is symmetric to the ZX-plane.

- The fuselage is a horizontal cylinder along the x-axis beginning at $X=x_0$.
- The wings are two horizontal trapezoidal planes parallel to the XY-plane.
- Ceiling, passenger deck and cargo deck are horizontal planes within the fuselage cylinder and parallel to the XY-plane.
- The main cable routes are horizontal lines trough the whole cylinder parallel to the X-axis.

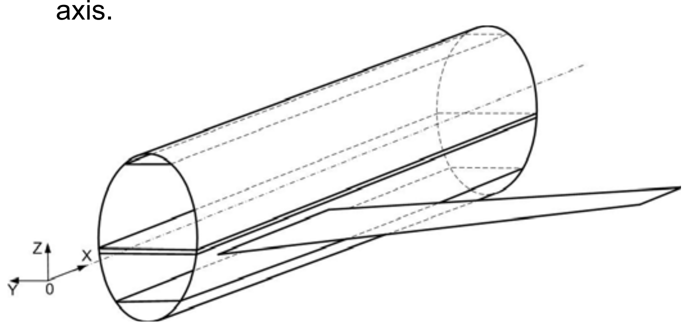

Figure 8 Simplified aircraft geometry - ISO view

The wiring algorithm is based on a defined number of cable sections s_n. The wiring length l_{12} between two points 1 and 2 is the sum over all sections N.

(26) $$l_{12} = \sum_{i=n}^{N} s_n$$

The routing mode "direct flow" is the absolute value of the position vectors of G_{Mod} and G_{Eqt} in the global system of coordinates. The route doesn't consider any cable routes, it consists of one section and is calculated via

(27)
$$l_{12} = \sqrt{\left(x_{Mod} - x_{Eqt}\right)^2 + \left(y_{Mod} - y_{Eqt}\right)^2 + \left(z_{Mod} - z_{Eqt}\right)^2}$$

The general case of cable connections within the fuselage is covered by an algorithm based on a cable consisting of seven sections s_i summed up according to equation (26).

- s_1: Go vertical to the nearest point of cylinder hull.
- s_2: Go along cylinder hull in YZ-plane until minimal distance to specified route.
- s_3: Go vertical from cylinder hull to wiring route.
- s_4: Follow parallel to X-axis the specified route.
- s_5: Go vertical from wiring route to cylinder hull.
- s_6: Go along cylinder hull in YZ-plane until minimal distance to peripheral device.
- s_7: Go vertical from cylinder hull to peripheral device.

A more complex wiring case results from the connection of one point within the fuselage with another one in the wing. The respective wiring route consists of eight sections s_i summed up according to equation (26).

- s_1: Go vertical to the nearest point of cylinder hull.
- s_2: Go along cylinder hull in YZ-plane until minimal distance to specified route.
- s_3: Go vertical to cylinder hull to wiring route.
- s_4: Follow parallel to X-axis the specified route to specified wing route.
- s_5: Go vertical from wiring route to cylinder hull.
- s_6: Go along cylinder hull in YZ-plane until minimal distance to wing root.
- s_7: Follow wing edge.
- s_8: Go parallel to specified peripheral device.

Calculation of total system mass:
Each cable length l_n is multiplied with the specific cable mass per meter (r_{Cable_n}).
The mass of all modules ($m_{TotalModule}$) is the sum of the installation mass ($m_{Installation}$), of the cooling mass ($m_{Cooling}$) and of the controller mass ($m_{Controller}$) summed up over all modules N.

(28)
$$m_{TotalModule} = \sum_{n=1}^{N} \left(m_{Installation\_n} + m_{Cooling\_n} + m_{Controller\_n} \right)$$

The total system mass ($m_{EvalSys}$) becomes

(29) $$m_{EvalSys} = m_{Cable} + m_{TotalModule}$$

The criterion S_m for the relative evaluation of the evaluation mass $m_{EvalSys}$ and the reference mass m_{Ref} reads

(30) $$S_m = \frac{m_{Ref}}{m_{Eval\,Sys}}$$

4.2.3. *Ship set cost*

The ship set cost (SSC) for computing module procurement are calculated according to the investment model from section 3.6.

DEF: Ship-set cost (SSC)
The ship set cost are the recurrent cost, which the aircraft manufacturer has to incur to buy all computing modules, fixations and harnesses for an aircraft avionics system architecture of a purchase option.
EOD

The ship-set cost ($SSC_{EvalSys}$) for the whole A/C are the sum of the SSC_m over all part numbers M.

(31) $$SSC_{EvalSys} = \sum_{m=1}^{M} SSC_m \qquad 1.32$$

The criterion S_{SSC} for the relative evaluation of the ship-set cost $SSC_{EvalSys}$ of the reference architecture and the reference architecture SSC_{Ref} reads

(33) $$S_{SSC} = \frac{SSC_{Ref}}{SSC_{Eval\,Sys}}$$

4.2.4. *Initial provisioning*

The initial provisioning criterion is based on risk insurance considerations of the airline and on the airline policy.

DEF: Initial provisioning (IP)
The initial provisioning cost (IP) are an investment, which the airline has to incur before EIS of a new fleet to provide necessary spare parts for all unscheduled maintenance actions during A/C operation.
EOD

An amount of required spare parts is determined and the generic investment model (see section 3.6) is applied for each part number.

The initial provisioning cost (IPC) are summed up over all part numbers M

(34) $$IPC = \sum_{m=1}^{M} IPC_m$$

The criterion S_{IP} for the relative evaluation of a system solution (EvalSys) to a reference (Ref) reads

(35) $$S_{IP} = 100 \cdot \frac{IPC_{Ref}}{IPC_{EvalSys}}$$

4.2.5. Direct maintenance cost

Direct maintenance cost can be separated into scheduled and unscheduled maintenance cost, and into ON/AC and of OFF/AC maintenance cost.

DEF: Direct maintenance cost (DMC)
The direct maintenance cost are the direct cost for labour and material spend by the airline for overhaul, test, maintenance, removal and repair of the computing modules of an avionics system.
EOD

The metric is based on the consideration of maintenance intervals and the cost which are associated to specific maintenance tasks.
The total DMC are calculated by the sum of the ON/AC and OFF/AC maintenance cost over all part numbers M.

(36) $$DMC = \sum_{m=1}^{M} \left(DMC_{ONA/C\_m} + DMC_{OFFA/C\_m} \right)$$

The criterion S_{DMC} for the relative evaluation of a system solution (EvalSys) to a reference (Ref) reads

(37) $$S_{DMC} = 100 \cdot \frac{DMC_{Ref}}{DMC_{EvalSys}}$$

4.2.6. Operational interruption cost

The operational interruption cost use the criticality of the computing module.

DEF: Operational interruption cost (OIC)
The operational interruption cost are the direct cost spent by the airline for airport taxes, crew, freight and passengers due to delays and cancellations of scheduled flights.
EOD

The operational interruption cost (OIC) are defined as the sum of the delay cost and the cancellation cost summed up over all modules N

(38) $$OIC = \sum_{n=1}^{N} \left(c_{Delay\_n} + c_{Cancel\_n} \right)$$

The criterion S_{OI} for the relative evaluation of a system solution (EvalSys) to a reference (Ref) reads

(39) $$S_{OI} = \frac{OIC_{Ref}}{OIC_{EvalSys}}$$

5. ANALYSIS OF EVALUATION MODEL

The analysis treats particularities of the evaluation model and takes into account, how parameter uncertainties are translated to the outputs.
In the last part, the evaluation metrics are applied to the exemplary IMA architectures from section 2.2.

5.1. General characteristics

The input parameter can be classified into business parameter, which describe the general technical and economic constraints for evaluation (example: interest rate) and into architecture parameter, which have to be determined for each computing module (example: MTBF).
In addition, a decomposition in numerical and logic parameters is reasonable. Numerical parameters are at least ratio scaled (example: Quantity), whereas logical parameters are ordinal scaled (example: MEL-Code).
Logical parameters cause several branches in the evaluation metrics, which cannot be treated with the proposed fuzzy method (see Figure 9).

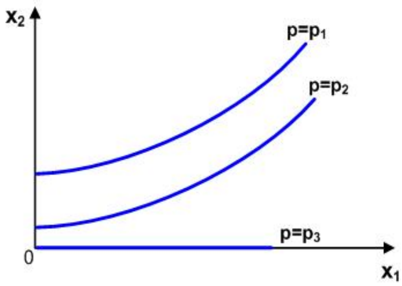

Figure 9 Branches in the evaluation metrics

In addition, the functional behaviour of all treated evaluation metrics is monotone. But non steady points are identified in the IP criterion (see Figure 10).

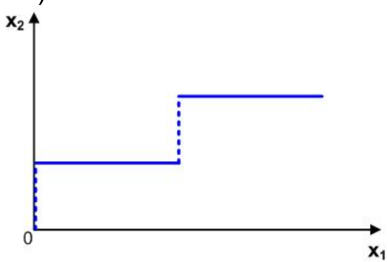

Figure 10 Non steady points in the evaluation metrics

5.2. Influence of model uncertainties

For the exemplary evaluation of the architectures from section 2.2, only uncertain architecture parameters are considered (see Figure 11).

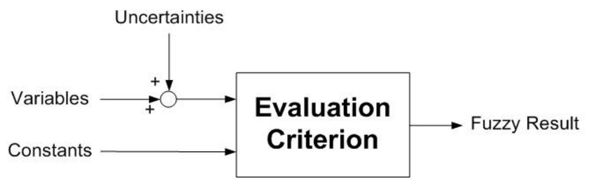

Figure 11 Introduction of uncertainties

Due to the branches of the evaluation metrics the fuzzy method from section 3.6 could only be applied to the outputs (defuzzyfication).
The uncertainties where respected by the calculation of extreme configurations – worst (best) case combinations of parameters.
Another interesting study is the examination of the influence of specific input variations to the model outputs. The analysis was conducted by the variation of all numerical architecture parameters by ±10%.

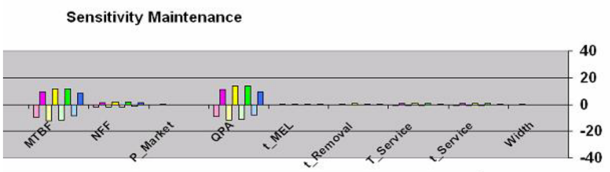

Figure 12 Sensitivity of the DMC criterion

In Figure 12 the sensitivity of the DMC-criterion is shown. The metric is more sensitive to inputs such as the quantity or the repair cost, than to service or removal times. Strong sensitivity indicates design driver of avionics architectures.

5.3. Architecture Evaluation

Finally, the six evaluation metrics where calculated for the three evaluation scenarios IMGA21, IMAG22 and IMAG23 relative to the reference scenario IMAG1. Wiring mass is not included in the trade-off, what makes the mass result very vulnerable.
Figure 13 shows the results for the average parameter configuration in a radar chart. Each point outside the reference line is advantageous.
Many conclusions can be derived from the results. For example, initial provisioning is influenced in a positive way by part number reduction but the frequent use of expensive modules results in an degradation.

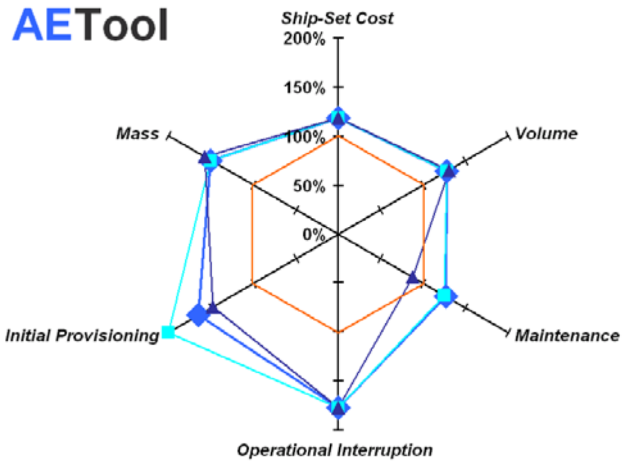

Figure 13 Visualization of the IMA trade-off

This optimistic and not representative example shows that about 20% of ship set cost, 50% of module mass, 30% of volume, 35%-50% of initial provisioning cost, 80% of operational interruption cost and 30% of maintenance cost can be saved with the new IMA technology. The last value is not achieved by the last evaluation scenario .
A summation of all evaluation functions has to be seen critical due to bandwidth effects and input uncertainties. The limitation of the example is explained in the chapter 5.4

5.4. Critical review

The proposed methodology has got several disadvantages.
Methodical weak points are the model simplifications for the complex reality and the non applicability of the fuzzy method. The heuristic method of extreme parameter configurations is not a probabilistic approach and can only be done by human logic.
The business case parameters where not varied and the revenue was considered to be independent from the operating cost.
In addition, input uncertainty for some criteria is quite high. This makes impossible to evaluate small system variations.
Other weak points are based on the current work status.
installation elements and wiring mass are not yet considered. It becomes obvious information acquisition is here difficult in practice.
The presented evaluation metrics only cover a small part of the A/C avionic system architectures and has to be completed to get an overall assessment
In general, the stake holders have to check the plausibility of the results and the validity of the model assumptions and the model results.

6. SUMMARY AND OUTLOOK

An evaluation with multiple criteria requires an understanding and information from many specialists.
However, an evaluation could be conducted for the proposed exemplary architectures.
benefits of the approach are the identification of design drivers and the derivation of advantageous trends for architecture design.
Next steps are the consideration of module functionality and aircraft geometry. A functional model is necessary to treat the safety criterion and geometry data is a needed for the calculation of wiring.
The architecture scenarios should also be compared for different aircraft types. Each aircraft programme requires a unique architecture solution.
Short term potentials of the method are the support of the every day engineering process by transparent trade-offs and the derivation of platform requirements.
In a future scenario the analytic evaluation model can be the basis for an automatic architecture optimization. Tool supported architecture generation could lead to new generation of technical solutions which are not feasible manually.

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