A SCENARIO-BASED APPROACH TO DEVELOP REPRESENTATIVE TRAFFIC ENVIRONMENTS FOR OPERATIONAL AIRCRAFT EVALUATION

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Abstract

Combining scenario techniques and operational aircraft evaluation provides the potential to quantify plausible but highly uncertain future developments of required environment parameters for operational evaluation of aircraft concepts. It is crucial to assess these new concepts in their potential operational environment to enable efficient air transport in the future.

One of the main steps in the presented approach takes into account cluster analysis methods to determine representative sets of environment parameter values on a global scale. This reduces the wide range of operational parameter values to typical groups and enables a holistic operational evaluation assessment.

The abstraction and standardization is followed by a scenario process, leading to multiple qualitative future developments which serve as an input to determine plausible future developments of relevant parameters. The complex causality evaluation and quantification needs to be performed individually for each environment parameter and concludes the presented concept.

1 Introduction

Operational analyses for airports and airlines, such as noise or capacity simulation, are widely used for optimizing air transport. In focus are all processes related to air transport [1], mainly taking into account air traffic in its current fleet composition. These types of analyses are rarely concentrated on studying the effects of a single specific type of aircraft on operational processes, but rather the total system efficiency.

However, for developing new aircraft concepts it is crucial to determine their characteristics and influences in their expected future operational environment. Hence, aircraft focused operational evaluation plays an important role in ensuring an efficient air transport in the future. (This is also in line with ACARE strategies [2]).

The task of aircraft focused future operational evaluation can be split into two main issues: the evaluation methods used and the required parameterized operational environment. This paper focuses on the latter, while methods for operational analyses are considered as given. Such operational evaluation methods are, for example, the assessment of runway capacity influence of a new aircraft concept or the analysis of direct operating cost aspects, such as load factor or utilization, for new technologies. These methods are the main sources to specify operational environment parameter needs that constitute the boundary conditions of operational assessments. Since they have a considerable influence on the analysis results, their reasonable specification is crucial. Due to the multitude of environment conditions worldwide, a method is required that enables a reduction of operational cases to most representative ones in a global context. This is one of the main aspects addressed in the presented approach.

Instead of individually analyzing each possible evaluation method, it is advisable to take into account required environment parameters of several methods of interest simultaneously. This serves as a basis for a holistic operational

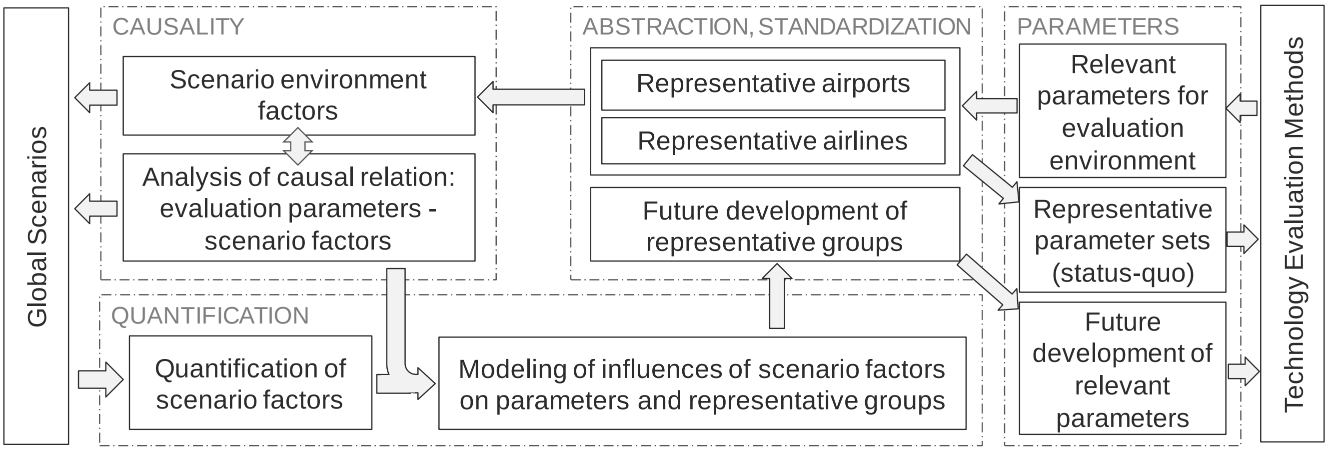


Fig. 1: Systematic approach to determine representative sets of current and future environment parameters for operational aircraft evaluation. Starting with the identification of relevant parameters to describe the evaluation environment (top right), the three main steps contained are the abstraction and standardization process, the scenario techniques and causality analysis and the quantification of the future parameter development.

evaluation, which covers more than a single field of impact evaluation. Moreover, several methods make use of similar environment parameters and, hence, a multiple application of the presented assessment in this paper is not required.

The environment parameters can usually be derived for the present, but specification of their uncertain future development is difficult [4, 13]. Industry forecasts and trends can only provide certain possible developments on a general level and do not offer specific values for all operational parameters required.

Hence, this paper presents a systematic concept for the future quantification of operational evaluation environment parameters using scenario techniques.

2 Approach Overview

The major steps to determine representative current and future evaluation environments are presented in Fig. 1.

Starting from the specification of relevant environment parameters on the top right in Fig. 1 an abstraction and standardization process will take place to enable a specification of representative parameter values and groups, handling the worldwide diversity of possible parameter ranges. These representative sets can already serve as an evaluation input if no future development is of interest.

The next step towards future values is the determination of suitable scenario factors and a subsequent scenario analysis process. This results in multiple qualitative future developments of scenario factors which will then serve as an input to determine the future development of environment parameters that are in a certain relation to the scenario factors (causality assessment). The quantification and modeling of the parameter development will result in future environment parameter sets that can directly be used for operational evaluation.

For each of the main steps shown in Fig. 1 a detailed description is provided in the subsequent chapters.

2.1 Environment Parameters for Operational Evaluation

Before the actual approach can be started, it is crucial to assess which input parameters of operational evaluation methods are of importance to describe the evaluation environment. In an analysis of currently applied evaluation methods regarding their required total set of input parameters, the following general categorization of parameters was established:

- aircraft design specific parameters
- environment parameters (traffic, infrastructure and location related parameters)
- procedures and regulations

The approach presented in this paper focuses on the environment parameters only. Aircraft parameters are the actual parameters evaluated by the methods and are not of interest for this approach. Procedures are based on worldwide regulations and those are specified on a global basis with little local variations. Hence, they are not considered as environment parameters.

The need for relevant environment parameters has to be addressed separately for each evaluation method of interest. Exemplary environment parameters for different evaluation methods are given in the following:

- aircraft mix
- ratio arrivals/departures
- distribution of flights between day and night
- load factor
- utilization

3 Abstraction and Standardization

The majority of environment parameters identified as relevant for the evaluation methods taken into consideration typically show a large worldwide variation and a specification of common values is difficult. Hence, a method is required that is able to handle the multitude of parameter values in different operational environments worldwide and to reduce it to a limited number of typical representative cases that can also be viewed as a kind of standard.

This step, which is denoted “Abstraction, Standardization” in Fig. 1, is beneficial for operational evaluation since it reduces the number of assessments required. A large variation of operational cases worldwide could be considered as an analysis environment, but is computationally demanding. Hence, it is reasonable to limit the analysis to representative environments to get results in a generalized context of high global relevance. Böck et al. [4] described the need for an evaluation environment that ensures “to produce results that are not only valid for one airport operations case but have sufficient relevance for all important operational cases […]”. This issue is addressed in this paper on a holistic evaluation context. The methodological approach based on cluster analysis is explained in chapter 3.1.

Taking into account possible developments of each environment parameter individually in this approach would lead to a very complex assessment. Therefore, this abstraction step tries to combine parameters into standardized sets of reasonable groups rather than using them individually. As part of the abstraction process, it is intended to also simultaneously consider environment parameters of several operational evaluation methods where applicable. This facilitates a holistic operational assessment, since these sets of relevant input parameters enable a one-time specification of the required scenarios that are used to describe the future development of these input parameters. Scenarios are usually customized to the respective task and are not generally applicable [5]. Hence, different evaluation assessments would not require reassessment of the entire scenario development for this approach.

The abstraction and standardization process will lead to a set of representative groups of environment parameters for the current (or a past) day that can already be used for status-quo evaluations.

3.1 Cluster Analysis

For abstraction and standardization, cluster techniques are applied. Cluster analysis belongs to the data mining methods of unsupervised learning [6], being applied in many different research fields like engineering or life sciences.

Clustering should not be confused with classification, for which predefined classes exist (supervised learning). For the environment parameters analyzed usually no predefined categorizations exist. As it was demonstrated in [11], existing classifications of airports, for instance, do not cover the parameters required for operational evaluation and are usually formulated in a qualitative manner only. Hence, for the application in this paper, clustering techniques are applied, since no predefined classes are taken into consideration.

Clustering techniques offer the possibility to identify similarities between data objects in a systematic manner, enabling a data organization into groups that are well separated, but close internally. Deriving a representative data object in each group enables the handling of data diversity and reduction to most relevant cases needed for this approach.

An overview of the clustering process used for this paper is provided in Fig. 2.

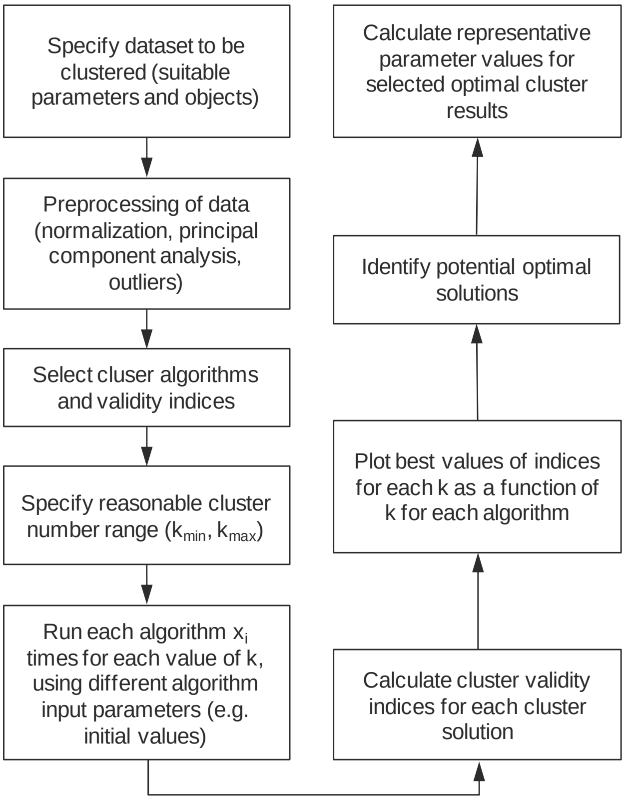


Fig. 2: Cluster analysis process steps to find an optimal cluster solution and representative parameter sets ([11], identification process of potential optima simplified).

First, the dataset to be clustered, containing various objects (e.g. airports) with different parameters, needs to be collected. Before the actual clustering can be applied, a data preprocessing is necessary. The different parameters should be evaluated individually beforehand to determine whether they are suitable for finding distinct clusters. Calculating the correlation between parameters can help to reduce the number of parameters to a minimum, which increases the quality of cluster results. Application of a Principal Component Analysis can improve the clarity of cluster results, since the original data is linearly transformed into principal components representing the data dimensions with highest variances, while eliminating correlations between them. Outliers can distort the results and should also be removed. Different detection algorithms can be found in the literature. In the presented approach the Local Outlier Factor (LOF) [9] was applied.

After the preprocessing, the applicable cluster algorithms and cluster validity indices have to be selected. There is a large variety of cluster algorithms, based on different theories, with distinct similarity measures and depending on the type of data. An extensive overview is provided in [7].

Unfortunately, there is no best clustering algorithm to use. It always depends on the data and therefore, it is recommended to use several algorithms and compare the results [8]. K-means, k-medoid (PAM) and agglomerative hierarchical algorithms have been selected for this approach. They are widely used, easy to implement, computationally inexpensive and perform well for the rather small datasets taken into account here.

Cluster validity indices are used to evaluate the quality of a clustering result and determine which number of clusters is a potential optimum. A wide range of indices can be found in literature [6, 10]. The focus here is on relative indices that can be used to compare cluster results. Examples for indices taken into account are Calinski-Harabasz, Davies-Bouldin, Dunn and I-Index.

For the types of algorithms taken into consideration, the optimal number of clusters is not an algorithm result. Therefore, a range of reasonable cluster numbers for the respective application has to be defined, for which the algorithms are applied and the optimal number of clusters can be determined.

In a next step each algorithm is repeatedly run with different algorithm input parameters (mainly initial conditions for clusters). Cluster validity indices can then be calculated for all runs and algorithms. To determine an optimal solution, the best index values for each cluster number k over the range of cluster numbers is plotted (per algorithm). As an example, Fig. 3 shows the highest CH-index values for three different cluster algorithms plotted over a range of cluster numbers.

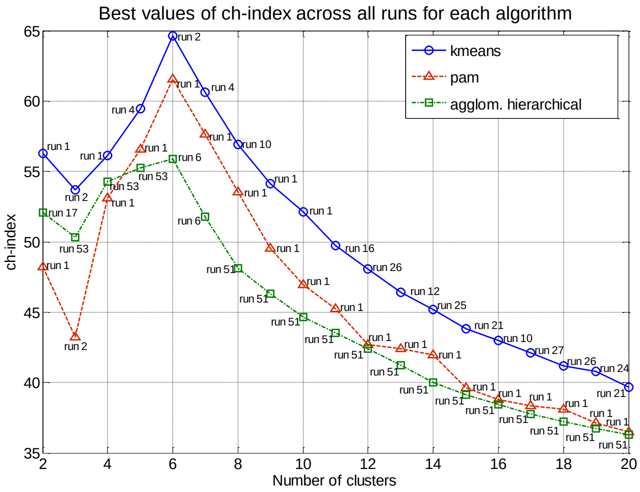


Fig. 3: Calinski-Harabasz (CH) –indices for different runs of three cluster algorithms. The total maximum indicates the optimal solution, which is clearly at k=6 clusters.

If the resulting graphs do not show a continuous increase or decrease with k, either the maximum or minimum value of the plot indicates an optimum (depending on the index definition). For the example in Fig. 3 a clear global optimum for the 6-cluster solution can be determined. (CH indicates an optimum at its maximum [12]).

If a minimum or maximum cannot be easily detected, the graphs have to be analyzed regarding “knees” or significant local changes. In case any such feature can be identified, this can also indicate an optimum. If both types of indications do not appear, it can be interpreted that the data does not contain any cluster structure.

In the final analysis step, representative values for parameters in each cluster are specified by calculating the median values.

A more extensive description of the process steps is contained in [11], along with an application for runway capacity related technology evaluation.

3.2 Representative Environment Parameter Groups

The cluster process described above can now be applied to the environment parameters. Depending on the total amount of parameter values, it is not necessarily possible to include all parameters in a single cluster assessment. Hence, reasonable groups of parameters are needed that can be addressed separately. During the analysis of environment parameters for different evaluation methods (such as runway capacity analysis, noise impact analysis or direct operational cost assessment), it has been found that an assignment of parameters to being either airline or airport related is a useful step in forming logical groups of parameters that can be clustered simultaneously. Combination of parameters into reasonable groups of similar context is also beneficial for the future development assessment described later.

Application of the cluster analysis process to airport related parameters for runway capacity evaluation, such as the daily movement distribution at an airport or the aircraft mix, has shown that it is possible to identify similarities between worldwide traffic situations, reducing it to a limited set of 16 representative cases. A detailed assessment of airport traffic related parameters is presented in [11]. Depending on the complexity of the set of parameters analyzed, further subdivision of reasonable groups of parameters might be required [3][11].

In a different assessment, airline related environment parameters for direct operating cost evaluations (as in [13]) have been analyzed. The list of airline related parameters can be seen in table 1, along with the cluster analysis result for one exemplary cluster.

Parameter	**Custer I**
Average utilization	2872 h/year
Average load factor	69.8 %
Average flight distance	1293 km
Percentage heavy category aircraft	4 %
Number of aircraft models in fleet	2
Share of turboprop+piston aircraft	2 %
Average fleet age	9.4 years
Network type indicator (Kurtosis of airport frequency)	23.8

Table 1: Exemplary representative parameter values for one cluster of the airline related parameter set.

The validity index plot determined for this parameter set is shown in Fig. 3.

This example demonstrates that there is a clear optimal solution for the determination of groups of similar characteristics. The considerable worldwide variations in the input dataset of 225 airlines could be reduced to only six representative types, containing the values of highest relevance.

Since the number of parameters is low for this airline related example, it is also used for some of the following steps in this paper.

4 Scenarios

The abstraction and standardization process provides representative status-quo environment parameter sets. The possible future development is then assessed by application of scenario techniques.

In general, scenario techniques are powerful methods for mid- to long-term elaboration of plausible alternative future developments that have proven their potential for strategic planning purposes with high uncertainties [15].

Two main reasons support the application of scenarios in the context of this paper:

First, the time horizon of interest for parameter developments is similar to other aircraft design related evaluations in the industry field [13] and manufacturer forecasts (e.g. [14]). It can be considered around 20 to 30 years. This long term development cannot be evaluated precisely with mathematical prediction methods. Moreover, the manifold of uncertainties in this long period questions a single specific prediction, while scenarios handle uncertainties in a structured manner.

Second, since many external and internal causalities and influences form a complex network, direct mathematical modeling of the long-term parameter development is extraordinarily complex, if not impossible.

Hence, scenario techniques offer a possibility to still determine future developments without the necessity of precise models of the entire system.

Due to the described features scenario techniques can be used to elaborate consistent evaluation environments [13].

4.1 Scenario Development and First Causality Assessment

A mixture of model based and intuitive scenario approaches [13] is used to develop scenarios. An overview of the main steps in scenario creation is provided in Fig. 4, being based on the process described in [15].

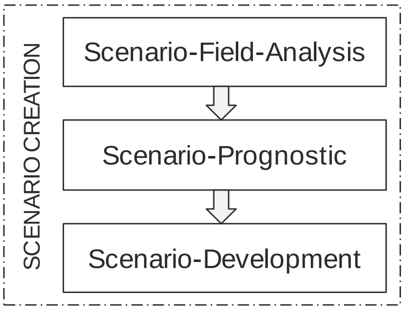


Fig. 4: Scenario development - main process steps [15]

Scenario analysis requires so-called scenario or environment factors that will be evaluated regarding their qualitative future development. To handle the complexity of the air transport system, it is common to define different system levels where factors belong to. These are the macro, meso and micro level [13]. Macro factors describe the socio-economic environment like politics, economy or society. The meso level incorporates factors specific for the air transport system as a whole, while micro factors are usually problem specific.

Which factors to take into account needs to be specified in a first major scenario development step that can also be referred to as “Scenario-Field-Analysis” (Fig. 4).

A particular feature of the proposed approach is that the actual environment parameters in the representative datasets are not necessarily scenario factors themselves, hence, there are no micro-level factors. In contrast, factors are selected that serve as a basis to describe the behavior of the environment parameters. These factors are of the macro and meso type only.

There are different approaches on how to identify suitable scenario factors (see [13], [15]). In many cases a brainstorming in an expert workshop provides a list of plausible factors. For the presented approach, typical factors that have already been frequently used in scenario creation processes for air transport related topics were taken into consideration as a basis. This extensive list of macro and meso factors had to be reduced in order to be able to handle the complexity of the scenario creation. Identification of most relevant scenario factors was supported by input of experts in the evaluation fields and by roughly analyzing causal relations between factors and environment parameters. This step refers to the upper part of the "Causality" block in Fig. 1. Causal relations between environment parameters and scenario factors will later have to be evaluated in more detail for the quantification process (see chapter 5 below).

As an example, the Scenario-Field-Analysis was performed for several evaluation areas, taking into consideration typical environment parameters needed. 24 macro and meso factors could be identified as a result (see table 2).

Macro factors	Meso factors
Global economic growth (GDP)	Air traffic growth
Development of Emerging Markets	Airline network development
Purchasing power	Airline business models
Political stability	ATC infrastructure development
Population growth	Airport infrastructure development
Globalization	Environmental regulations and fees
Stability of financial system	Global harmonization of environmental fees
Use of novel means of communication	Night curfews
Environmental awareness	Liberalization of air traffic
Development of fuel price	Ticket price
Acceptance of air traffic	
Urbanization	
Mobility of population	
Competing alternative means of transport	

Table 2: List of identified relevant macro and meso scenario factors. Macro factors describe the socio-economic environment, while meso factors are specific to the air transport system.

This set of scenario factors is used to create the scenarios in a later step. Before this is possible, reasonable projections for each factor have to be specified. This is part of the so-called "Scenario-Prognostic" step according to Fig. 4. Usually, three to four projections per factor are used, taking into consideration the whole range of plausible developments.

In the "Scenario-Development" phase (Fig. 4) a consistency matrix is set up, which specifies the compatibility of factor projections. From this matrix the most consistent scenario bundles among all projections are determined.

It is common to identify three final consistent scenarios out of all results. For these, the scenario prosaic description completes the scenario creation process [13]. These scenarios are characterized by an interconnected description of the driving environment rather than an arbitrary or subjective selection and combination of inputs [5].

It has to be mentioned again that the scenario creation process is done on a holistic level, taking into account environment parameters of different operational evaluation methods. This means that the scenarios do not have to be newly created for every particular type of evaluation done.

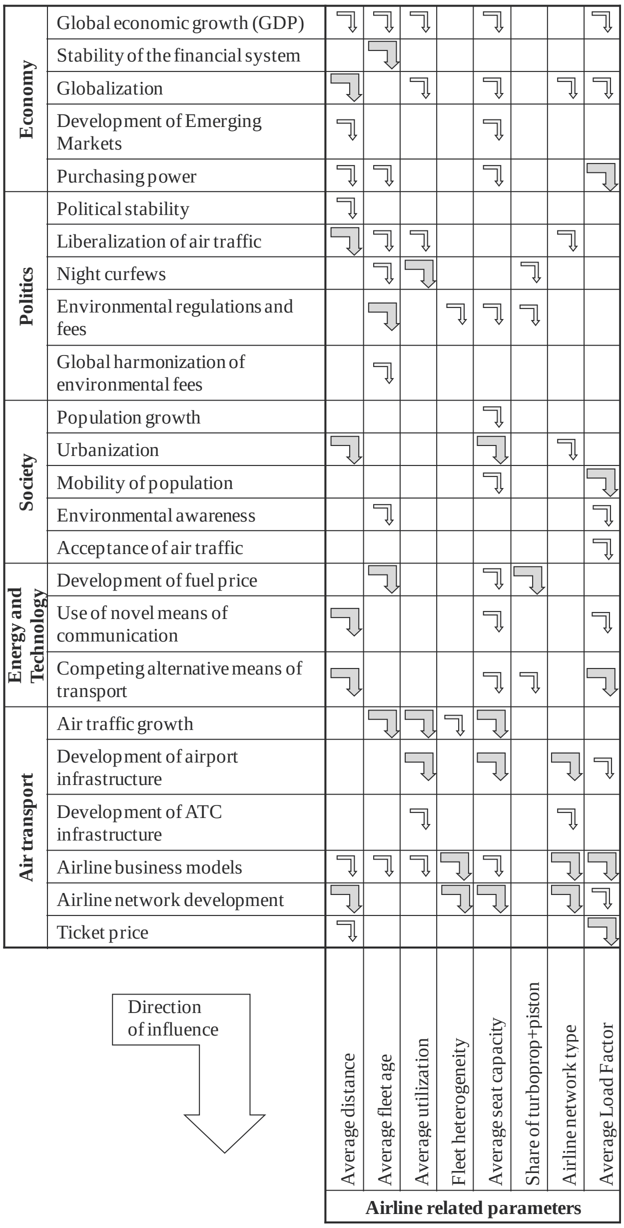
The final scenario development step has not been performed yet. However, the scenario development process is clearly defined and direct application is possible and planned for the near future.

5 Quantification of Future Development

In the final and most challenging step of the presented approach, the qualitative future development of scenario factors and their relations to the environment parameters need to be quantified.

The basic concept steps described are a system analysis to identify major influences, a derivation of analytical models for quantification, an identification of key indicators if required and the definition of status-quo initial values for quantification, as elaborated in [13]. These have been taken into account for the approach of this paper.

In line with the methodology described above, a more detailed causality analysis can be performed as a basic step towards the quantification of environment parameter development. Therefore, influences of scenario factors on the parameters are evaluated on an order-of-magnitude level first. An example for scenario factor influences on airline related environment parameters is shown in Fig. 5.



		Average distance	Average fleet age	Average utilization	Fleet heterogeneity	Average seat capacity	Share of turboprop+piston	Airline network type	Average Load Factor
Economy	Global economic growth (GDP)	↴	↴	↴		↴			↴
	Stability of the financial system		⬇						
	Globalization	⬇		↴		↴		↴	↴
	Development of Emerging Markets	↴				↴			
	Purchasing power	↴	↴			↴			⬇
Politics	Political stability	↴							
	Liberalization of air traffic	⬇	↴	↴				↴	
	Night curfews		↴	⬇			↴		
	Environmental regulations and fees		⬇		↴	↴	↴		
	Global harmonization of environmental fees		↴						
Society	Population growth					↴			
	Urbanization	⬇				⬇		↴	
	Mobility of population					↴			⬇
	Environmental awareness		↴						↴
	Acceptance of air traffic								↴
Energy and Technology	Development of fuel price		⬇			↴	⬇		
	Use of novel means of communication	⬇				↴			↴
	Competing alternative means of transport	⬇				↴	↴		⬇
Air transport	Air traffic growth		⬇	⬇	↴	⬇			
	Development of airport infrastructure			⬇		⬇		⬇	↴
	Development of ATC infrastructure			↴				↴	
	Airline business models	↴	↴	↴	⬇	↴		⬇	⬇
	Airline network development	⬇			⬇	⬇		⬇	↴
	Ticket price	↴							⬇
		Airline related parameters							

Fig. 5: Matrix of influences of scenario factors on selected airline related environment parameters. The order of magnitude of an influence is characterized by the arrow type: no arrow – no influence, small arrow ↴ – medium influence, large arrow ⬇ – strong influence.

An arrow is posted where a general influence was identified. The size of the arrow depicts the magnitude of the influence. It is important to mention that only individual direct influences have been considered and that the influence direction is only from scenario factors to the parameters. For the given example it can be observed that the majority of strong influences originate from air transport related scenario factors. Some scenario factors show only little influence on the parameters, while others have a strong influence on several of them.

Since the matrix of influences is large and quantification a very complex process that needs to be addressed individually for each scenario factor-parameter combination, starting with the most relevant is reasonable. Therefore, this order-of-magnitude causality analysis is used to identify scenario factor-parameter combinations of highest relevance for quantification assessment. It has to be kept in mind that for each environment parameter a set of status-quo representative values has been defined. Hence, quantification also has to take into account the different representative groups. The quantification of future developments can then be addressed by simply applying any parameter change quantified to all representative groups in a similar magnitude, for instance, which is used here. Differentiating the quantification for distinct representative groups could be imagined, but increases complexity even further.

According to [13], the quantification of parameters can either be directly derived from scenario factor developments or assessed by use of key indicators. The latter serve as additional descriptors to model the future parameter development. The necessity for use of key indicators will depend on the scenario factor-parameter combination in focus.

The development and final application of parts of the approach presented in this paper are still ongoing at the time of writing. In particular, the specific quantification of the future parameter developments can only be covered on a conceptual level rather than providing specific results.

To support understanding, a short quantification example is addressed in the following. The strong influence (see Fig. 5) of competing alternative means of transport on the average load factor was selected for this.

According to a modal split analysis by [16], air transport is competing considerably with other means of transport for distances up to about 500km. Analyzing the data behind the representative airlines mentioned in chapter 3.2 regarding their share of flights for distances ≤ 500km, the numbers in table 3 can be obtained. The numbers represent the cluster median of values obtained for each airline and are provided for two representative examples.

	Share of flights ≤ 500km (S_{500})	LF	LF_{new}
Cluster I	24.9	69.8	68.1
Cluster II	89.8	63.5	57.8

Table 3: Share of flights for distances ≤ 500km, passenger load factors and calculated new load factors for two representative airlines, all provided in percent.

The basic quantification idea is now to assume that a change in the use of alternative means of transport will directly change the load factor on flights ≤ 500km.

Due to data availability, average load factors per airline were used for this analysis. From these, median values for each cluster could be determined, defining an average load factor (LF) for each representative airline group (see example table 1).

If the share of flights ≤ 500km (S_{500}) will result in a reduced load factor, the new total load factor (LF_{new}) for all flights of this representative airline can be estimated as:

$$LF_{new} = LF \cdot S_{500} \cdot (1-\Delta) + LF \cdot (1-S_{500}) \quad (1)$$

where Δ is the relative change in passenger numbers using air transportation for travel distances ≤ 500km.

Assuming a 10% change ($\Delta = 0.1$) as one of the quantified scenario factor projections, the new average load factor for representative airline II (regionally focused) would result in 57.8%, while the new load factor for representative airline I (in the full service carrier category) would be 68.1%. The result shows that airlines with a high share of regional traffic are affected most by competing means of transport. Of course, this assessment example does not consider any cost related effects this situation of competing alternative modes of transport might have on load factors and possible consequences in a longer run, such as reduction of fleet or frequency if load factors decrease. Even though this issue is yet to be discussed, it is an example to outline the necessity for modeling causal relationships in order to quantify parameter developments.

Since the final parameter quantification process is complex and time consuming, it is recommended to pursue this step only for environment parameters required for the specific operational evaluation application. However, ideally, all parameters within the formed groups of airline or airport related parameters are addressed simultaneously, since interrelations between them are possible.

6 Conclusion and Outlook

In this paper a systematic approach to determine representative future evaluation environments for operational evaluation of new aircraft concepts was presented.

An abstraction process of environment parameters enables a reduction in the manifold of existing parameters worldwide to typical representative sets. This ensures a clear systematic derivation of environment input parameters and reduces computation time in analyses pursued, while still covering a range of typical environmental situations of global relevance. Applications of this abstraction and standardization process on specific research questions showed promising results ([3], [11]) and proved the suitability of applied methods.

Since the abstraction process can only be based on current or past data, a method for the future development of the representative environment parameter sets was added. This approach incorporates scenario techniques, which have shown their potential for assessing multiple future developments of complex systems.

The scenarios can only provide a qualitative future development. Quantification of these qualitative results remains a challenging task. The complex network of causalities between scenario factors and environment parameters needs to be investigated and parameter specific implications derived for quantification of parameter development. The quantification process step is still under development and a specific application example needs to be pursued to prove the entire concept.

Due to the complexity, it is recommendable to carry out the quantification step for application specific parameter requirements only rather than on a generalized level. Nevertheless, the holistic approach presented for abstraction and scenario creation steps, incorporating the parameter needs of several evaluation methods, can serve as a common standardized basis for application specific quantification approaches.

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