APPLIED SCENARIO PLANNING AS A BASIS FOR THE ASSESSMENT OF FUTURE AIRCRAFT TECHNOLOGIES

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Overview

The civil air transport sector is facing considerable challenges with regard to its future perspectives: enormous growth rates on the one hand and constrained infrastructural adaptation measures on the other hand require an integration of new technologies and aircraft concepts. Furthermore, rising energy prices call for significant efficiency improvements in energy usage. Yet, the actual benefit of new technologies strongly depends on the characteristics of the operational environment. For a profound analysis of this benefit, the impact of new technologies on the aviation sector needs to be evaluated. This can only be accomplished by simultaneously considering future environmental conditions. This paper depicts a scenario-based approach that is able to provide comprehensive, alternative pictures of the future (scenarios), forming the foundations of a sound technology assessment technique.

1. MOTIVATION

A sound and comprehensive approach to future-oriented technology assessment should not only include a comparison and quantitative evaluation of the respective technology itself relative to other technology options, but also comprise the consideration of the operational environment the technology will be applied in, since the effectiveness of a new technology largely depends on the operational environment. In the aviation industry, due to the long product life cycles, the definition of a future operational environment consequently has to consider potential long-term development options. This presents a major challenge within the overall assessment task since long-term predictive statements are generally apt to become somewhat imprecise and mostly remain on a qualitative rather than a quantitative level.

Major aviation stakeholders try to cope with this problem by elaborating and publishing market forecasting reports. [1] [2] In many future-oriented, aviation-related scientific studies, these reports serve mostly as the quantitative basis e.g. for the prediction of future air traffic growth rates, evolving air transport markets, future customer needs etc. However, these reports do not always clarify the methods and tools behind the forecasting process to a satisfying extent. Moreover, specific parameter developments required for technology assessment are usually not directly provided.

In this paper, a scenario-based approach to develop alternative long-term operational environments for aircraft technology assessment is proposed. Against the background of an increasing uncertainty of predictive statements with a longer time horizon, it is assumed that the obtained results become more robust once the assessment process is based on multiple, alternative futures.

In section 2 of this paper, an overview of how alternative pictures of the long-term future were developed with the help of scenario planning techniques within a future forecasting study is provided and the elaborated scenarios are explained. Section 3 then outlines the proposed method to use the scenarios as a basis for the definition of future operational environments. In section 4, the applicability of the proposed method is demonstrated by briefly depicting a case study in the context of runway capacity-related future technology assessment. Finally, section 5 summarizes the core messages of this paper.

2. SCENARIO-BASED FUTURE FORECASTING STUDY: APPROACH AND RESULTS

The following section provides an overview of the scenario development approach that was designed and applied in the context of technology impact evaluation. Techniques and tools of the scenario planning methodology used as well as scenario-specific results will be briefly explained in the following.

2.1. Study Goals and Topics Covered

The main goal of a future forecasting study is to develop multiple, consistent, and detailed operational environments for the civil air transport system with a certain time horizon. In the context of the specific study, a time horizon until the year 2050 was chosen. All future scenarios for this study were elaborated with the focus of "Operational Perspectives of Civil Aviation 2050." The scenarios were especially intended to serve as the basis for the two following current research projects at the Institute of Aircraft Design:

- The impact of future aircraft concepts (e.g. blended-wing body aircraft) on runway capacity is analyzed and evaluated on a global level.
- Potential paths of introducing alternative, non-fossil renewable fuels into the air transport system and quantify emission reduction potentials thereof are examined.

The following key questions had been formulated as a basis for the forecasting study:

- Airport Infrastructure: What possibilities exist for airport airside infrastructure expansions and what implications for air traffic development and aircraft types used can be derived from that?

- Airline Market: How will air transport networks develop globally and on a regional level? Which types of airline network structures and airports will evolve? How will airline business models develop and what is the role of airline structures (alliances)?

- Environmental regulations: How can aviation-related environmental regulations (particularly emissions and noise restrictions) develop regionally and globally?

- Technology: Which new aircraft concepts and propulsion techniques can be imagined and what is the degree of their availability and market penetration?

- Alternative Fuels: In which regions can alternative fuels from renewable resources be made available? What is their substitution potential compared to fossil fuels?

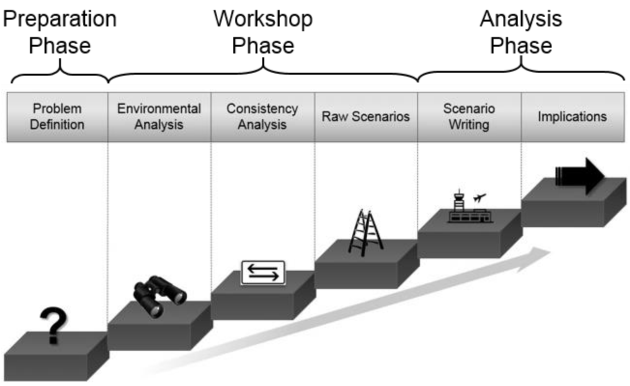
These questions were taken into account when preparing the thematic scope of the future forecasting study and formulating the problem statement (cf. Fig. 1: *Preparation Phase*).

2.2. Methodological Approach and Scenario Results

2.2.1. Overview

The future forecasting study was fundamentally split into three procedural steps: the preparation phase, the workshop phase, and the analysis phase, of which the workshop phase represented the core part of the study. The overall foresight process is schematically depicted in Fig. 1.

FIG. 1: Procedural scheme of the future foresight study.



As it can be observed in Fig. 1, the three procedural steps were further subdivided into six methodological steps: The *problem definition* step was destined to define the study scope and related research questions (cf. section 2.1). In addition, organizational work had to be conducted to prepare the subsequent steps (e.g. select and invite the project team members) for the workshop phase. The workshop phase was composed of an *environmental analysis*, a *consistency analysis* and the generation of *raw scenarios,* that provided the key output of the foresight study. These steps will be described in more detail in the next section. The concluding steps of *scenario writing* and *implications* of the analysis phase were conducted in order to prepare the obtained results of the workshop phase for the subsequent creation of the alternative operational environments.

The foresight study can be characterized with the activity scheme shown in Tab. 1, following [3].

TAB. 1: Foresight study activity scheme, adapted from [3].

Methodical Step	Activity Phase Character	Activity Description
Problem Definition	Procedural	Setting the scene.
Environmental Analysis	Procedural	Identification of relevant environmental factors. *)
	Discursive	Selection of key environmental factors. *)
Consistency Analysis	Procedural	Determining factor consistencies. *)
Raw Scenarios	Procedural	Generation of raw scenarios. *)
Scenario Writing	Discursive	Selection of scenario 'themes'.
	Procedural	Detailing of chosen scenario themes.
Implications	Procedural	Derivation of alternative operational environments.

Note that the activities marked *) were numerically supported by the "Risk Assessment and Horizon Scanning" (RAHS) toolbox, a comprehensive, web-based collection of scenario planning techniques developed by the German Armed Forces. [4]

2.2.2. Workshop Phase

Since the workshop phase presents the most relevant part of the future foresight study, it is depicted here in more detail.

All methodological steps of the workshop phase were conducted with a project team composed of industry and research professionals with aviation-related experience. This team contained nine members from a major German hub airport, a European aircraft manufacturer, two German aerospace research institutes, as well as from two German public universities. The interdisciplinary character of the project team ensured a widespread diversity of the project outcome, as suggested by Verity [5].

2.2.2.1. Environmental Analysis

The project team initially worked on the *environmental analysis*. In this step and with the problem definition set (cf. section 2.1) environmental factors that had a direct or indirect relationship to the stated problem, i.e., in this case the "operational perspectives of civil aviation", were identified. For this purpose, the considered environment was segmented into the STEEPV areas Society, Technology, Economics, Ecology, and Values with an additional environmental factor area "Aviation" specific to the problem statement. The STEEPV approach is a frequently utilized method for structuring and analyzing the relevant environment surrounding the analyzed problem [6], [7]. Twenty-one environmental factors were finally identified and are listed in Tab. 2. The corresponding factor definitions are provided in Tab. 3.

TAB. 2: List of environmental factors categorized by STEEPV+A, consecutively numbered.

STEEPV+A	No.	Factor Name
Society	1	Environmental awareness of society
	2	Demand for mobility
	3	Urbanization
Technology	4	Revolutionary technologies
	5	Capacity of air traffic control systems
	6	Operational procedures
	7	Aircraft fleet mix
	8	Regional availability of alternative fuels
Economy	9	Economic development
	10	Stability of the financial sector
	11	Energy price
Environment	12	Environmental regulations and fees
	13	Climate change
Politics	14	Armed conflicts
	15	Political influence on mobility
Values	16	Globalization vs. regionalization
	17	Intermodal transportation
Aviation	18	Expansion of airport infrastructure
	19	Air transport network structures
	20	Airline business models
	21	Major air routes

TAB. 3: Environmental factor definitions.

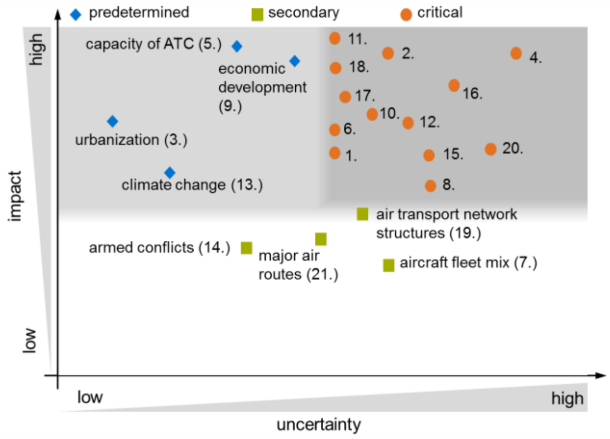
Factor Name	No.	Definition
Environmental awareness of society	1	The degree of environmental awareness of the society is described by this factor. It contains an indication for the sensitivity of the population towards aviation's impact on the environment. Since environmental awareness and acceptance of air traffic can be closely linked, this factor shall also be an indicator for the degree of acceptance of the impact of air traffic on the environment.
Demand for mobility	2	The factor describes the degree of how frequently people are travelling from one point to another. Trip lengths considered here can vary from short to long haul. The factor takes both business and private trips into account and includes all transportation modes available (land, sea, and air traffic). Intermodal transport characteristics may be defined in the projections of this factor.
Urbanization	3	The factor defines how widely urban ways of life have expanded, or in other words, how many people live in metropolitan areas (physical urbanization). Projections may describe regionally distinct developments.
Revolutionary technologies	4	The factor describes how quickly revolutionary technologies are developed and how strongly they substitute conventional systems (i.e. engines, aircraft concepts, energy usage). Is there a step changer or a rather evolutionary development?
Capacity of air traffic control systems	5	This factor addresses the air traffic control system(s), their structure, and underlying techniques. It shall mainly provide an indication for the ability of the air traffic control system(s) to handle the traffic volume. The factor also provides information about capacity considerations of potential new structures considered (such as SESAR) in the projections.
Operational procedures	6	This factor addresses the operational procedures used in an air transport mission, particularly focusing on approach and departure flight procedures. Non-conventional types of procedures (such as a CDA or other noise abatement procedures) and their degree of use shall be considered.
Aircraft fleet mix	7	The factor describes the composition of commercial aircraft fleets operated by airlines worldwide. The factor focuses on the aircraft mix on a global level rather than on an airline specific level and considers aircraft categories rather than single aircraft types (e.g. long-haul aircraft instead of Airbus A330). Projections may define the overall number of aircraft in operation as well as e.g. the percentage of regional, mid-, and long-haul aircraft.
Regional availability of alternative fuels	8	The factor describes the availability of alternative fuels (i.e. fuels that are derived from regenerative energy sources) with a regional focus. Alternative fuels covered in this scenario study have drop-in capabilities with respect to conventional aircraft engines. Although fuels for the entire transport sector can be taken into account, the factor especially considers fuels destined for civil aviation.
Economic development	9	The economic development (with the GDP as an indicator) is described by this factor. Since there are considerable differences in the degree of economic development worldwide, three different groups of countries shall be taken into consideration: industrialized countries, BRICS, and N11. Moreover, the relation of economic development and air traffic growth shall be indicated in the projections. The economic development in different regions shall also provide information about major traffic corridors worldwide.

Stability of the financial sector	10	The factor describes the ability of the financial sector to provide the real economy (i.e. the part of the economy that is concerned with actually producing goods and services) with loans. Currency and exchange rate fluctuations are included in this factor as well. Projections of this factor may describe how sustainably banks can offer credits and how stable currencies are.
Energy price	11	This factor describes the price for energy on the world market (e.g. $/barrel).
Environmental regulations and fees	12	This factor describes the extent of effective environmental regulations and fees worldwide, taking noise and gaseous emissions into account. It shall also consider the area for which the respective regulations are in effect (regional vs. global) and their degree of harmonization.
Climate change	13	The factor describes how quickly and strongly the global climate changes. This may have severe consequences for some regions of the world, while others may even benefit from that. The factor includes meteorological long-term effects (e.g. global warming) as well as the occurrence of extreme weather events (tropical cyclones, floods, extreme heat,...) caused by climate change.
Armed conflicts	14	The factor describes how frequently armed conflicts happen in a certain region or globally. These conflicts can occur due to various reasons, including religiously or politically motivated riots and terrorism. The projections of this factor should give a statement about the geographical and political extension of conflicts as well as reasons for their occurrence (e.g. fight between local armed forces for fresh water in parts of Africa).
Political influence on mobility	15	Mobility is influenced by political action. Hence, this factor describes to what extent air transportation and its boundary conditions are determined by politics. Possible influences could be specific regulations or fees introduced (such as night curfews or air transport taxes), which can affect the air traffic development and its attractiveness towards society. This may affect the modal split.
Globalization vs. regionalization	16	The factor describes the status of the globalization process with a special focus on global economics and transportation. While globalization would mean a continuation of the process of liberating markets and opening national borders, regionalization would describe the opposite development. Projections of this factor may be positioned in between those two extremes.
Intermodal transportation	17	The factor defines the degree of how strongly the transportation modes (land, sea, and air traffic) are interwoven locally and globally with each other in order to optimize travel time for passengers and goods, and reduce the use of resources (energy, time etc.). Projections of this factor should also describe where and how every transportation mode is contributing to the overall transportation process (= intermodal split).
Expansion of airport infrastructure	18	This factor describes the possibility to expand airport infrastructure in order to meet present and future demand. Many airports worldwide already reach their limit of runway capacity and require further expansion. Airport expansion heavily depends on the political and social environment. Airport expansion can be difficult or even impossible in certain world regions.
Air transport network structures	19	The air transport network in terms of its structure is described by this factor. Network structures can consist of well-known types such as hub & spoke or point-to-point structures. New or mixed types can be considered as well. As a direct link to the structure, different types of airports evolve, such as major hubs or origin and destination airports (new types may also be imagined). The factor shall consider both passenger and freight traffic.
Air transport business models	20	This factor addresses the development of airline business models and their share within the air transport market (i.e. the share of no-frills airlines in particular). The factor shall also give a statement about the development of larger airline structures, i.e. alliances.
Major air routes	21	The factor gives an indication about the major traffic corridors that are served by air traffic. Passenger as well as freight transportation are taken into account. The detail level of this factor is set on a regional level (i.e. connection between world regions instead of city pairs).

By mapping the factors on an uncertainty-impact diagram according to their relative impact on the considered problem as well as according to their relative degree of uncertainty with respect to their future development [7], twelve key environmental factors were subsequently found. They are marked “critical” in the corresponding uncertainty-impact-diagram shown in Fig. 2.

Note that the numbers and color code used for the factors in Tab. 2 to classify the three factor groups is identical to the color code of Fig. 2.

FIG. 2: Uncertainty-Impact diagram with 12 key environmental factors in the context of "Operational Perspectives of Civil Aviation 2050."



2.2.2.2. Consistency Analysis

In the next step, the environmental factors had to be analyzed further with regard to their potential future development: while factors with a relatively low degree of uncertainty can be treated with only one possible development option (since uncertainty is low the one projection is usually clear), key environmental factors must be further defined by considering at least two alternative future development options (cf. Tab. 4). In the scenario planning terminology, the potential development options of key environmental factors are called "projections." [8]

With the projection definitions of the key environmental factors available, a consistency analysis was executed next "to check the compatibility of combined variations" of the projections of the key factors (cf. Tab. 1). [9] Here, each projection of a key environmental factor was checked for consistency relative to the projection of another factor using a consistency matrix. For each pair of projections, the degree of consistency was quantified using a scale from 1 to 5 (with 5 - complete consistency, 4 - partial consistency, 3 - neutral, 2 - partial inconsistency, 1 - total inconsistency). This task was initially done in two separate sub-teams and then the two consistency matrices were consolidated to finally obtain a single one.

2.2.2.3. Raw Scenarios

The consolidated consistency matrix served as input data for a numerical determination of the most consistent combination paths of the projections of all key factors (i.e., the raw scenarios). With the help of the RAHS toolbox, it was possible to identify 318 distinct raw scenarios that were numerically grouped into 19 clusters, i.e. 19 consistent but different pictures of the future could be identified based on the elaborated consistency matrix. From these, a number of five raw scenario clusters were initially selected and finally the three that appeared most interesting and challenging with regard to the problem statement were filtered out.

The environmental factors that had not been considered in the consistency analysis were subsequently added to the raw scenarios. For this and in order to generate a quantitative statement level of the scenarios, some of the environmental factor projections had to be quantified. In section 3, more information on this task is provided.

The factor projections of the three final raw scenarios are depicted in Tab. 4. Note that the 13 key environmental factors are in bold.

TAB. 4: Final raw scenarios selected in the future forecasting study.

Factor Name	Raw Scenario A	Raw Scenario B	Raw Scenario C
Environmental awareness of society (1)	All negative impacts of air transport on people are not accepted		
Demand for mobility (2)	Long-haul focus: Strong regional ground transportation based competition, hence, less growth in short-haul segment (2.7%). Focus on long-haul in business/ leisure	Predicted development: approx. 5% global growth with +/-3% regional variation; similar development in all segments (short/long-haul, leisure/business)	
Urbanization (3)	100 megacities, globally distributed; Reference: United Nations demographic evolution; megacities >10Mio; 70% less than 100km from coast		
Revolutionary technologies (4)	Accelerated development with higher risk: Reduced development cycles; benefit not 100% secured; higher market risk and opportunities	Evolutionary development and market penetration: No step changes, but continuous improvement; planned innovation and introduction to markets; secured success	Disruptive innovation: Game changing technology development and operational principles; short transition phase and high market impact
Capacity of air traffic control systems (5)	In line with demand (technology, procedures and infrastructure)		
Operational procedures (6)	Revolution: formation arrival & departure procedures among others are performed at all major hubs	Evolution: No further changes except for the things already known (CDA, segmented approach, etc.)	Revolution: formation arrival & departure procedures among others are performed at all major hubs
Aircraft fleet mix (7)	WB: 25% NB: 25% RJ: 0% TP: 40% WBTP: 10%	WB: 25% NB: 40% RJ: 20% TP: 15%	WB: 25% NB: 40% RJ: 25% TP: 5% SS: 5%

Regional availability of alternative fuels (8)	USA, Arabia and China possess the major fields for energy plants and/or storages and gather their bio-fuels		Global bio-fuel market, available everywhere, the price regulates the dispersion
Economic development (9)	Average growth of 3%, regionally different, volatile till 2050		
Stability of the financial sector (10)	Free, highly speculative financial market, thus high ups and downs		The financial sector's self-understanding: financing the real economy. Thus, very stable
Energy price (11)	Energy crisis: Price explosion: 10€/l or equivalent; no viable alternatives to fuel		Energy paradise: Availability of new energy sources; consumer energy price determined by infrastructure, service costs and taxes;1€/l
Environmental regulations and fees (12)	Very stringent regulations (noise + gaseous emissions); worldwide night curfews; very few exceptions; high charges for non-compliant aircraft	Incentive-based regulation: staggered and more stringent regulations, but compensation opportunities; giving strong incentive for new technologies	Very stringent regulations (noise + gaseous emissions); worldwide night curfews; very few exceptions; high charges for non-compliant aircraft
Climate change (13)	Change as the majority of scientists predict: Rise of sea level, stronger storms, deserts growing, agricultural areas diminishing, clear water is getting sparse		
Armed conflicts (14)	Conflicts on a regional level possible due to lack of fresh water	As predicted; local conflicts; critical in middle east	Very peaceful world
Political influence on mobility (15)	Market distortion: Local political influence on preferred and available means of transport leads to market distortion between different transport modes; risk of non-compatibility		Global harmonization; full transparency; no need for political intervention; fair comparison between all means of transport; no local political preference
Globalization vs. regionalization (16)	Global economy; strong ongoing globalization; free market		
Intermodal transportation (17)	All routes below 600km are solely served by ground transportation		The air transport is fully embedded into a seamless transport system
Expansion of airport infrastructure (18)	In certain regions (BRICS, N11, Middle east) hub airports can expand almost without any constraints	Hubs can expand, but the expansion must obey certain constraints (e.g. curfews, operation of new aircraft only...)	
Air transport network structures (19)	Point-to-point: 40% Hub and spoke: 60%	Point-to-point: 45% Hub and spoke: 55%	Point-to-point: 50% Hub and spoke: 50%
Air transport business models (20)	Consolidation: All service carriers in global alliances with 3% profit margin; no frills in separate alliances. Customer differentiation		Fragmentation: Highly competitive global environment for flag carriers as well as no frills; very little margin
Major air routes (21)	EU: 5% AS: 15% NA: 10% NAAS: 10% AFAS: 5%	AS: 25% AFAS: 5% NAME: 5% EUME: 5%	Innerregional total: 50% NAEU: 10% NAAS: 15% EUAS: 15%

2.2.3. Analysis Phase

The initial goal of the analysis phase was to further transform the raw scenarios (Tab. 4) into clear, communicable storylines. In addition, in the implication phase, the elaborated scenarios were taken as a basis for the definition of alternative operational environments for technology assessment (see sections 3 and 4 for further details).

2.2.3.1. Scenario Writing

In the scenario writing phase (cf. Tab. 1 and Fig. 1), prosaic descriptions of the raw scenarios were developed in order to obtain a clearer understanding of the key statements, the storylines, and the causal chain of each scenario, and to enable a better communicability of the core messages of each scenario towards external parties. Summaries of these descriptions of the three scenarios are presented in the following.

Scenario A: "Stringent environmental regulations"

This scenario is characterized by a society that strongly opposes the negative impacts of air transportation (emissions, noise). Politics react accordingly: Stringent limitations of health relevant emissions are implemented, making it impossible for a majority of airports to have their expansion approved. The capacity problems at airports as well as the environmental regulations force civil aviation to introduce revolutionary concepts in operational procedures: formation procedures in cruise and departure/approach are developed and put into action. This also helps to decrease the jet fuel demand and thus the effect of high energy prices that were a result of a highly speculative financial market. Within this context, strong politicians enforce a higher degree of intermodality that prohibits airlines from serving routes below 600 km. The remaining aviation market is focused on long-haul transportation where only a few strong alliances & carriers can survive (consolidated market). These developments had significant effects on the world aircraft fleet: due to their energy efficiency, turboprop-motored aircraft have an overall market share of 50%, replacing regional jet-engine aircraft and parts of the wide body long-haul fleet.

Scenario B: “Development as predicted today”

This scenario can be considered as the “baseline scenario” that is characterized by a development that most of today’s analysts expect. As part of these predictions, there is a globalized world with global markets where energy prices are high and environmental consciousness among people plays an important role. In this world, the Far East has become a strong global player where the inner-regional air traffic has a share of roughly 25% of the global air transport capacity. As far as technology is concerned, no revolutionary development is taking place in the transportation branch. Politics have a strong influence on air transportation, particularly affecting aircraft operations at airports: environmental regulations (emission and noise fees) privilege green aircraft, hub airport expansions are only allowed if airports commit to “the green standard”, a certificate granted for fulfilling certain environmental protection standards. Politics also define the modal split: ground-based vehicles serve short routes, while air traffic is destined for routes greater than 600 km.

Scenario C: “Energy paradise”

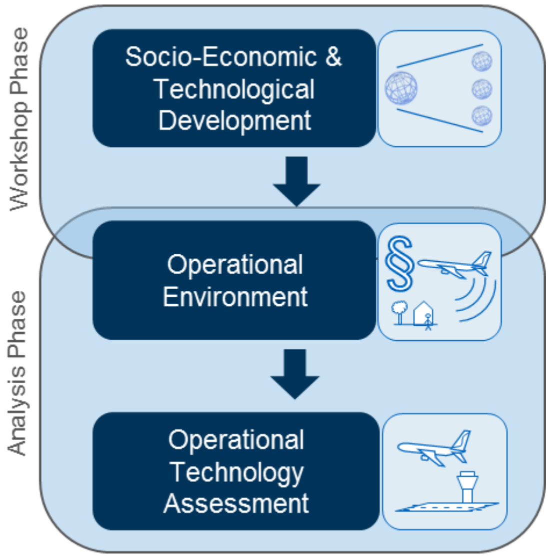
Energy (liquid fuels, electricity etc.) has become very cheap in this scenario. In particular, alternative fuels are globally available. In this world, where the economy is widely globalized and the financial market rediscovers its original purpose, airlines are able to focus on their individual business strategies and oppose their competitors. A central topic in society is the negative effect of the transport sector on the environment. Politics react accordingly and introduce stringent environmental regulations including restrictions for airport expansion. Revolutionary technologies in aircraft operation are introduced to meet the requirements set. In terms of aircraft technology, only an evolutionary development is taking place. A central goal of politics is to organize a seamless intermodal transport system where all means of transport are well coordinated. As a result, unnecessary redundancies of transport capacity (routes served in parallel by different means of transport) are avoided. Due to the low energy prices, the share of energy-efficient turboprop motored aircraft in the global fleet is decreasing. Instead, the energy-demanding market of supersonic air travel is reviving for the ultra-long-haul transport sector.

3. SCENARIO PLANNING AND TECHNOLOGY ASSESSMENT

An objective and thorough comparison of technologies can only be accomplished by using quantitative rather than qualitative metrics. Thus, within a consistent process of technology assessment, a quantified operational environment is required. However, the elaborated scenarios (see section 2) contain mainly statements on a qualitative level. Therefore, the scenario factors (Tab. 3) are used as a basis to develop quantified operational parameters.

Three basic steps to combine scenarios with technology assessment are proposed (Fig. 3). The scenario descriptions are the basis for this process. In this context, it is beneficial to include quantified factor projections in contrast to the usual qualitative statements as early as possible in the scenario development process (Fig. 1) in order to facilitate the subsequent definition of operational environments. As an example of the study presented here, a quantified projection of the factor intermodal transportation (Factor 17, Tab. 4) was defined, restricting all routes below 600 km to ground based means of transportation. This was already accomplished within the workshop phase to ensure the sound and collective definition of the future development.

FIG. 3: Methodical steps towards technology assessment in potential future operational environments.



Depending on the type of technology assessment pursued, distinct parameter requirements exist in order to describe the operational environment. Higher-level environmental factors of the scenarios do not necessarily cover the specific parameter needs directly. Therefore, in the analysis phase the environmental factors of considerable impact on the corresponding assessment task are identified. Where possible, further interrelations between environmental factors and operational parameters are intuitively elaborated (see example in section 4). This will eventually enable the sound definition of the input parameters that describe the operational environment for the subsequent assessment procedure.

4. APPLICATION CASE: RUNWAY CAPACITIY IMPACT ASSESSMENT

The methodology and resulting scenarios presented in this paper were applied in the context of impact assessment of new aircraft types on the capacity of an airport's runway system.

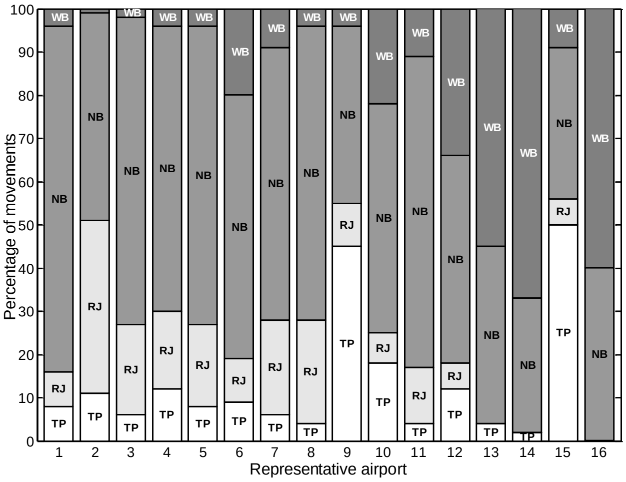
One of the most limiting determinants of airport capacity is the runway system [10]. In order to ensure efficient processes at airports it is important to know about the impact that new technologies and aircraft concepts have on the runway capacity. The term capacity in this context refers to the definition of ultimate capacity of the runway system, being the maximum throughput that is theoretically possible. In [10] a method was developed to determine the runway capacity envelope from airport simulation runs by varying demand and arrival/departure ratios. This envelope serves as a basis for impact assessment, where the capacity impact is defined as change in movements per hour that can be handled relative to a reference case.

The capacity of a runway system is largely influenced by the operational environment, which consists of the runway infrastructure as well as the traffic. Of particular interest for capacity assessment is the daily average traffic mix at an airport as well as the traffic mix in peak hours.
Since there is a worldwide variety of traffic situations, it is not straightforward to select those of highest relevance. Limiting an impact analysis to a few specific airport situations is also not reasonable, since it questions the general significance of the results. In order to determine the capacity impact of a new technology on a global level it is necessary to derive the most relevant worldwide traffic situations.

This was accomplished by use of cluster analysis applied to traffic patterns at the 287 largest airports worldwide [11] that were determined from OAG flight data for one week in summer 2008. This set was selected to consider all airports that account for 90% of worldwide movement and passenger numbers. In order to apply a cluster analysis, the operational environment, i.e. the traffic, needs to be parameterized. The main set of parameters describes the traffic mix in terms of aircraft types. To offer sufficient granularity 10 aircraft weight classes were specified in this context (see also [10]).
The cluster analysis resulted in an optimal number of 16 representative airport types for the daily traffic and 19 representative peak situations. These limited parameter sets cover most relevant traffic patterns worldwide without the need to include a large variety of traffic situations in the assessment.

Fig. 4 shows the resulting daily aircraft mix for the 16 representative airports derived from status quo flight data, ordered by their cluster size from largest (left) to smallest (right). Aircraft weight classes were combined for clarity (TP…turboprop, RJ…regional jet, NB…narrow body, WB…wide body). Since not all detailed weight classes are shown, some of the clusters appear rather similar. For a more detailed insight, refer to [11].

FIG. 4: Daily aircraft mix for 16 representative airport clusters and status quo flight data (based on [11]).



Depending on the type of technology or aircraft concept to be evaluated in the context of airport capacity impact, a certain share of the traffic mix will be substituted by this new technology. For the aircraft concept examples considered in [11], all heavy aircraft above 245t MTOW were substituted by a blended-wing-body aircraft concept.

The mix specifications as in Fig. 4 can directly feed into capacity impact analysis and result in a range of impacts to be expected under current traffic conditions.

Apart from considering current traffic data, it is important to take into account potential future developments of the operational environment. A new technology is most likely to be introduced at some future point in time for which conditions might have changed. Therefore, addressing the future development of the derived representative airport traffic environments is crucial. However, this is a complex task. The long period and high uncertainties in the development do support the application of scenario techniques in this context.

The three developed scenarios presented in this study were incorporated for this application. As explained in section 3 (Fig. 3), the scenarios that contain both qualitative and quantitative factor projections serve as a basis to determine the future development of the operational environment. In order to accomplish this, it is necessary to select scenario factors that have a significant influence on the aircraft mix. Certainly, quantified environmental factors are most useful in this context, since their projections are already provided in a specific metric. Nevertheless, quantification of the influences is complex and no standardized approach is available.

Environmental factors considered to have a significant influence on the aircraft mix at an airport are:

- Aircraft Fleet Mix (7)
- Intermodal Transportation (17)
- Air Transport Network Structures (19)
- Air Transport Business Models (20)

Although the airline network structures and business models highly influence the aircraft mix at airports, it is not manageable to consider these factors with all their influences. The representative airport clusters contain a set of real airports that all follow their individual strategy that influences the type of traffic. Hence, a general conclusion for an influence cannot be drawn, particularly for the long time horizon.

Since both Aircraft Fleet Mix and Intermodal Transportation are provided in a clear and quantitative way, their influence on the aircraft mix at airports was estimated.
For raw scenarios A and B, it is stated that no routes below 600km are served by air transport anymore. Therefore, the aircraft mix for routes of this type was determined from status quo flight data, along with the share of these routes for each airport cluster. For simplicity, the respective share of routes smaller 600km was simply cut off for each aircraft category and airport cluster and the remaining total mix was stretched to 100% again.

One of the major influences on the aircraft mix at airports is due to the worldwide fleet mix specified in environmental factor 7. Before an influence can be modeled, it has to be taken care of the fact that the fleet mix provided is not equal to the aircraft mix discussed, since the latter refers to aircraft movements and not to number of aircraft in operation. Therefore, the two representations had to be mapped. This was done by assuming that the relation between number of aircraft in operation and aircraft movements worldwide will stay the same as for the status quo situation.

Tab. 5 shows a comparison of the worldwide movement-based OAG aircraft mix for status quo with the status quo fleet mix from the ACAS database. The relations were used to determine the aircraft mix for the three scenarios. As an example, fleet mix and aircraft mix for scenario A are also provided.

TAB. 5: Comparison of worldwide fleet mix and movement-based aircraft mix for status quo and scenario A.

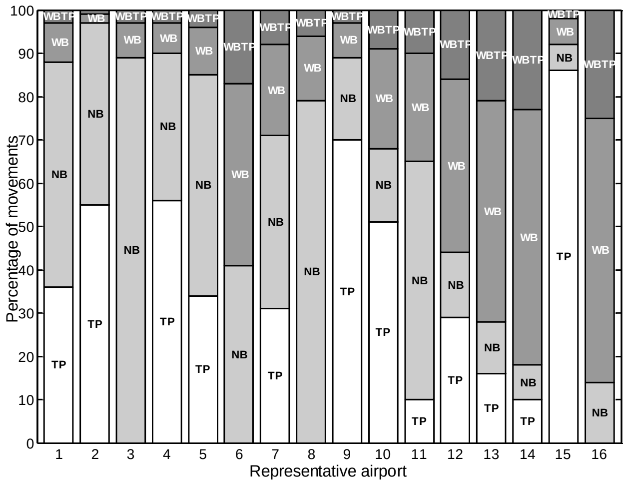
Status quo	TP	RJ	NB	WB+WBTP
Fleet mix	20%	15%	48%	17%
Movement-based mix	16%	19%	56%	9%

Scenario A	TP	RJ	NB	WB+WBTP
Fleet mix	40%	0%	25%	25+10%
Movement-based mix	40%	0%	37%	16+7%

The worldwide mix per scenario now has to be transferred to each airport cluster. The aircraft mix of the 16 representative airports resembles well the worldwide mix, which was also demonstrated in [11] by calculating a weighted average mix incorporating the cluster sizes. Thus, it can be assumed that this holds true for the future scenarios. Therefore, an inverse weighted average was applied. Apart from the worldwide mix and the assumption that cluster sizes remain the same, further relations between aircraft types of airport clusters had to be specified based on the status quo case in order to solve the inverse weighted average.

Fig. 5 provides the resulting representative airport clusters with adapted aircraft mix for scenario A. Comparing it to the status quo case in Fig. 3, it can be easily observed that the share of propeller aircraft increased significantly, while regional jets completely vanished. This is in line with the worldwide developments in this scenario. The share of heavy type aircraft also increased slightly, since the short haul traffic below 600km is no longer served. As a special feature in this scenario a new wide body aircraft type is introduced – the wide body turboprop (WBTP), taking over a certain share of wide body traffic.

FIG. 5: Daily aircraft mix for 16 representative airport clusters adapted for raw scenario A (based on [11]).



The resulting adapted aircraft mix for the representative airports in all scenarios can be directly used again for capacity impact assessment. This leads to further ranges of impact in comparison with the status quo case, which allows a valuation of the total range of impact to expect for the technology examined. Compared to considering only specific local and current traffic situations, this supports the global significance of the impact results.

Further information on the example application is provided in [11].

5. CONCLUSION

In this paper it was demonstrated how qualitative scenario planning techniques and quantitative technology assessment methods can be reasonably combined to generate robust future-oriented evaluation statements on a global, system-wide level.

With the goal to develop a range of distinct plausible future operational environments, a comprehensive future foresight study was conducted with a team of interdisciplinary industry and research professionals. As a result, three consistent future scenarios of the world in 2050 were obtained. These were the basis for the quantification of operational input parameters for technology assessment.

The proposed combination of scenario techniques and technology assessment was demonstrated for the example application of runway capacity impact evaluation. The scenarios were used as a basis to derive future developments of airport traffic environments required for capacity evaluation. For the complex step of modeling the influence of scenario environmental factors on operational parameters a particular example was presented, showing that a standardized approach is not feasible. Hence, the development of operational environments from qualitative scenarios cannot be generalized and needs to be designed according to the individual assessment need and method.

The application-specific future variations of airport traffic conditions derived by the help of the approach of this paper resulted in ranges of capacity impact to be expected in the future. These can differ from the status quo impact range and cases of only selected local environments. Hence, the global relevance and significance of the evaluation results is increased. This again points out the importance of thorough definition of relevant environment conditions to determine a reasonable estimate of technology impact that is not only based on given current conditions.

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