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# AUTOMATION IN FUTURE AIR TRANSPORT: A SCENARIO-BASED APPROACH TO THE DEFINITION OF OPERATIONAL REQUIREMENTS

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## Abstract

*A thorough definition and analysis of requirements is the crucial first step of any successful product development process. Yet, anticipating the right requirements to meet the future market needs is a very difficult task that requires abilities to precisely understand problems and make robust decisions without knowing the future. In the aviation industry, long product lifecycles make this task even more vital for a successful product policy on the one hand, but also more challenging on the other hand. This paper demonstrates how scenario planning techniques can be applied to support the requirements elicitation phase under uncertainty when developing new products by portraying the methodical approach and obtained results of a recently completed foresight study. The thematic focus was on the future potential role of automation in civil air transport with a time horizon until 2050. Three alternative future scenarios were developed, forming the basis of a detailed analysis of the future traveler's characteristics and needs in order to derive high-level requirements for more automated air travel operating processes.*

## 1 Problem Statement

Extensive cost pressure is and will remain a major driver of the future of the aviation industry. Besides fuel costs and expenses for fees and charges, crew costs (i.e., cockpit and cabin crews, and ground personnel) represent the most important part of the direct operating costs of airlines.[1] In this context, automation technologies are considered as a chance to reduce these costs.

Already today, ground-based operations of unmanned aerial vehicles are possible from a technological viewpoint. In addition, large parts of cabin services could also be automated. As such, the automation of passenger handling, airline, and airport operating processes appears to be attractive from an economic perspective, as automated systems are able to replace manual work at numerous points along the transport chain. Examples like the widespread introduction of automatic check-in machines at many airport terminals have demonstrated the potentials and impact of automation on the air transport industry already.

Although there are various technological options for introducing more automated transport systems and processes into the travel chain, a vast number of challenges and obstacles exists regarding their actual application. Would passengers accept to pay for more or even fully automated air transport services including unmanned aircraft? How would emergency situations be handled? How would certification standards and procedures need to be adapted?

Obviously, a more automated air travel chain needs to comply with a large number of requirements and constraints imposed by numerous stakeholders throughout the system and its environment. Yet, it is difficult to anticipate how they will evolve in the future. From the point of view of a system design engineer, the management and integration of respective requirements and constraints presents a significant challenge, in particular when considering their uncertain future development. In this context, companies require a practical and application-oriented approach to cope with this challenge in order to ensure a successful product development process.

Especially in the aviation industry that is characterized by extensive product lifetimes, a robust decision-making process with regard to the definition of product requirements is vital for sustainable success.

This paper presents an approach to requirements elicitation under uncertainty using selected scenario planning techniques. It summarizes the methodical approach and obtained results of a foresight study named “Automation in Air Transport 2050” that was conducted at the Institute of Aircraft Design of the Technical University of Munich (TUM) in summer 2013. By developing three alternative scenarios with regard to the future role of automation in air transport, scenario-specific requirements and constraints were derived, enabling a multiple-future-based product innovation and architectural design process. The paper is organized as follows: section 2 focuses on the theoretical background of the scenario study. It defines important terms and depicts the methodical approach to scenario planning and requirements elicitation. In addition, it provides an overview of the major organizational characteristics of the foresight study. Section 3 summarizes the most important study results obtained for each scenario while section 4 evaluates the proposed approach and obtained results. Finally, section 5 provides an outlook on future projects at the institute.

## 2 Scenario-based Product Development

Eliciting, defining, and analyzing requirements are among the first steps of any product development process.[2, 3] The requirements must be derived from the customer needs and comply with the constraints imposed by the environment that the product will be operated in. Considering the definition of what a product development process is supposed to achieve, the relevance of the customer and his needs are well apparent: “Development includes the activities required to evolve the system from customer needs to product or process solutions.” [4]

Generally spoken, in order to ensure sustainable profit, a company is required to initiate the development of a new product in one of the two following situations: either the market (i.e., a relevant customer) has a newly arising need that has not been satisfied yet – this is called a demand-pull situation. Alternatively, a novel technology suddenly becomes available, inducing a new demand that the market has not known before – this is named a technology-push situation. In the literature, there is an ongoing debate about which of the two factors, technological progress and market demand, actually trigger off and support product innovations, and whether one should actually consider and treat the demand-pull and technology-push situations separately.[5] In today’s dynamic world of ever changing customer needs and technological progress, however, the true and reliable knowledge of what the customer really wants is neither available nor accessible to a company, regardless of the prevailing situation. This case becomes even worse when the customer does not know himself what he actually needs; some authors argue that because customers are sometimes unable to articulate sophisticated needs, they may hinder rather than support corporate innovation.[6]

One possible solution approach to this problem is to base the product development process on multiple future scenarios [7, 8] rather than on only the most likely image of the future that is found by extrapolating currently prevailing trends as frequently done in practice. In this context, Tidemann suggests to create a “design environment that is a valid representation of the world relevant to the product” prior to actually creating a new product.[9] This design environment is then used to define multiple scenarios, in which the new product is operated. In other words, the key idea of scenario-based product development is to take into account the uncertain dynamics of the customer requirements and the environmental conditions by creating multiple futures in order to enable the creation of more robust product architectures.[10]

### 2.1 Terms and Definitions

In order to clarify how the most important terms in the context of scenario-based product development were interpreted and used in the case of the foresight study presented here, the following sections briefly define them.

**Customer.** A customer is "the entity to whom the system developer must provide proof that the system developed satisfies the system requirements specified." [11] In the foresight study, the customer was thus considered as being any stakeholder that either employs or is affected by the product to be developed. A further distinction was made between the "key customer" being the "end-user" or "operator" of the product [4, 11] (i.e., the air traveler) and other customers who actually purchase the product (airlines, airports, and other service providers) or are affected by the product in other ways (e.g., the environment, regulative authorities).

**System.** A system is a collection of components, which cooperate in an organized way to achieve some desired result, i.e., the requirements.[12]

**Product.** A product is the physical or non-physical result of a creation process within an organization employing resources, which is offered to a customer in order to satisfy a certain customer need.[13] A system is referred to as a 'product' when it presents a certain value to the customer, resulting in a willingness to pay.

**Requirement.** In the literature, various definitions of different types of requirements can be found.[4, 14] In general, requirements must be formulated at different levels of abstraction.[12] At a high level, the overall needs that the product is supposed to satisfy are stated, and the stakeholder requirements are stipulated. At a lower level, requirements for the system, the system components, and the subsystem components are defined.

In the study presented in this paper, the focus is on operational requirements, i.e., requirements defining the basic needs of the operator of the product, or clarifying the "operational needs" [15] of the key customer. In principle, they define the mission profile, the operating environment, and the critical system parameters needed to accomplish the mission.[4] As such, they address the needs of the key customer at a very high level of abstraction and can thus be called "top-level system requirements" [2] or "high-level requirements." [12, 16] A well-formulated set of requirements should be unique, normalized, complete, consistent, bounded, modifiable, configurable, and granular.

Requirements comprise constraints that are imposed on the product "by force or compulsion and may limit or modify the design changes" [11] and that control "the way in which one or more capabilities are to be delivered." [12]

**Scenarios.** Scenarios are "focused descriptions of fundamentally different futures presented in coherent script-like or narrative fashion." [17] As such, they are "accessible to and sharable by diverse stakeholders in a design project." [18] Scenarios are neither "states of nature nor statistical predictions," [17] but "multiple, but equally plausible" [19] descriptions of potential states of the environment used to better understand future uncertainties thereof.

**Environment.** The environment comprises all "circumstances, objects, and conditions that will influence the completed systems; they include political, market, cultural, organizational, and physical influences as well as standards and policies that govern what the system must do or how it must do it." [11] As such, the environment is constituted by a compilation of all "environmental factors," [20] sometimes also referred to as "driving forces," [21, 22] that have a certain kind of influence or impact on the considered system. Depending on the respective scenario, each environmental factor holds a certain future state, "outcome," [22] or "projection." [23]

**Concept of Operations.** A Concept of Operations document (CONOPS) "focuses on the goals, objectives, and general desired capabilities of the potential system without indicating how the system will be implemented to actually achieve goals." [11] It is "a user-oriented document that describes a system's operational characteristics from the end-user's viewpoint." [24] It is not a requirements document, but is used for requirements derivation.[25] It may also be referred to as "use scenario" and presents "an aid to finding a complete set of requirements, by covering every aspect of operational use." [12]

In principle, a CONOPS describes in the form of a narrative from the perspective of a product customer, operator, or user how different elements of a product work together in order to achieve desired objectives.[25] Formulating a CONOPS document supports the product designer in better understanding the operational requirements and product capabilities from customer perspective, which facilitates the communication of requirements and desired product capabilities among customers and product designers.[15]

In the foresight study presented here, the formulation of scenario-specific CONOPS presented an essential step prior to the elicitation of operational high-level requirements. Within the scope of this study (i.e., the transportation sector), the CONOPS describes from the traveler's perspective the door-to-door travel chain, its respective travel segments, and their interaction to illustrate how the traveler gets from the place of departure to the desired destination.

## 2.2 Methodical Approach

The first part of this section is dedicated to a general overview and discussion of the methodical approaches to scenario planning. In the second part, the specific approach utilized in the foresight study is outlined. In addition, organizational aspects of the study are briefly summarized.

**Overview.** Organizations would usually consider using scenario planning techniques under the following circumstances: [26]

- A high degree of uncertainty underlies a certain corporate decision that has to be made
- The organization failed to adapt adequately to environmental changes in the past and wants to become more capable in this matter in the future.
- The organization generally lacks strategic thinking.

No matter which motivation for using scenario planning exists, the methodical approach has been an intensely discussed subject in the community for decades and is still a current research topic among futurists, economists, managers, and practitioners.

In fact, the research activities on scenario planning have greatly expanded,[27] which has led to the existence of an excessive amount of models, techniques, and good practice guidelines available. Some authors even call the current situation a "methodological chaos." [28] However, many of these approaches appear to be of little use for practical application since their authors have validated neither their effectiveness nor their applicability in practical test cases.[29] This paper does not attempt to provide an overview of all currently available approaches to scenario planning, but depict a pragmatic application-oriented method that has proven itself applicable for future-oriented requirements elicitation under uncertainty. For an overview of existing scenario planning techniques, the papers of Börjeson et al. [30] and Amer et al. [31] are recommended to the interested reader.

The approach to scenario planning applied in the foresight study presented here can generally be assigned to the "intuitive logics school" of scenario planning that stems back to the activities related to scenario planning of the Royal Dutch Shell oil company of the 1960s-80s.[20, 32] The key idea is to develop between two and four scenarios, all being both equally plausible and probable, and explore with them the "limits of possibility" with regard to how the future may evolve.[22]

The approach to scenario development is rather "qualitative in nature," [32] relying on the "disciplined intuition" of the scenario team that builds the scenarios.[33] As the scenarios usually comprise detailed descriptive narratives of a broad range of aspects of the future environment, a scenario team is required that unites a large scope of multidisciplinary expertise and experience in the respective fields. As a result, the "selection of the team members is important." [19] The presence of "remarkable people" may help to "overcome the availability bias in scenario construction." [22]

In the context of analyzing and describing the scenario-specific environment, a "STEEP" or "PESTEL" approach is often applied, covering social, technological, economic, ecological, political, and legal environmental factors.[22, 32]

Scenario development processes of the intuitive logics school may be composed of roughly eight methodical steps, starting by setting the thematic agenda, and ending with formulating scenario narratives or "storylines" and analyzing implications if necessary.[22, 34] Some authors recommend between five [35] and twelve [36] steps. In the foresight study presented here, six steps are applied (Fig. 1).

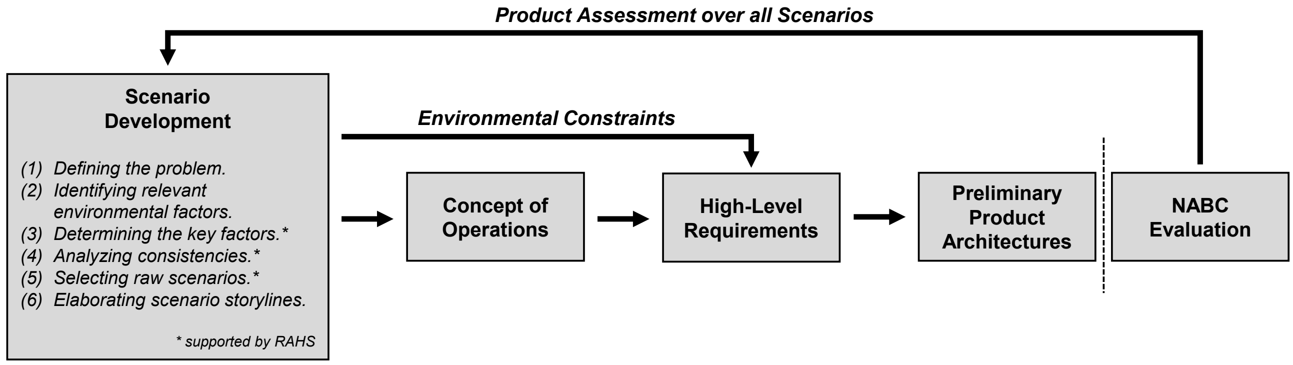


**Fig. 1. Methodical steps of the foresight study.**

The outcome of the scenario development process is "a set of logically linked scenarios in discursive narrative form […], often embellished with pictures, newspaper clippings, and vivid graphics for effect, most of which are contrived." [32] Many scenario developers seem to generally avoid integrating numerical facts and statements in their scenarios such as rates of market growth, interest rates, energy prices, etc. (depending on the thematic scope of the scenario study).[37] However, in the field of product development, quantitative scenarios are needed as only those can support a solid requirements definition process. A reason for the creation of predominantly qualitative scenarios described in the literature may lie in the fact that utilizing scenarios for purposes of product development is not the primary use case when applying scenario planning. Instead, most scenario studies are conducted to support strategic corporate decision-making.[27] Another reason might be that the creation of quantified scenarios requires extensive numerical models that are able to project the complex interaction schemes between the environmental factors into the future.[37]

The experience of several scenario consultants has revealed, however, that at the end of many scenario studies, the results obtained seem to be too "soft" or "vague" in order to be implemented in the corporate decision-making process.[37] This is an observation that is confirmed by the authors of this paper.

The creation of scenarios presented in this paper is aimed at providing a solid basis for the elicitation of quantified operational requirements for automated systems in future air transport. The key idea is to derive quantitative operational requirements from the qualitative scenarios by formulating scenario-specific CONOPS documents from the traveler's perspective.

**Specific Approach.** Fig. 1 provides an overview of the methodical approach to the foresight study "Automation in Air Transport 2050." At first, it reveals the six methodical steps applied to develop the scenarios (Fig. 1: *Scenario Development*): in the problem definition phase (1), the project leaders stipulated the thematic scope and the goals of the foresight study. Relevant literature and data input were scanned, and the scenario team was compiled. Subsequently, in order to identify environmental factors relevant to the scope of problem (2), the scenario team conducted an in-depth analysis of the environment with a STEEPV approach. The key factors or "critical uncertainties" were identified (3) by classifying all environmental factors within a "driving force ranking space." [19] Here, the factors were intuitively evaluated concerning their relative strength of impact on the problem considered as well as their relative degree of uncertainty with regard to how they may evolve into the future.

In the consistency analysis (4), hypothetical states in 2050 of each key factor were defined. Then, all factor states were assessed on a pair-by-pair basis with respect to their mutual consistency. The overall assessment result was then placed into a "consistency matrix" [23] that served as input data in order to numerically determine a range of "raw scenarios," i.e., a set of key factors with one future state per factor specific to each raw scenario.[31] The project leaders then selected the three most appealing raw scenarios (5) out of tens of available raw scenarios that had been numerically determined. The scenario team subsequently expanded these raw scenarios by defining hypothetical states of the remaining factors from the environmental analysis (2) specific to each one of the three scenarios that had not been identified as key factors (3). Eventually, storylines and graphical illustrations were elaborated for each scenario (6). For this task, the entire scenario team was split into three sub teams of equal size, one responsible for each scenario. Every sub team was asked to include contents about the following issues in their scenario:

- Global level:
  - Economy and business
  - Society and demographics
  - Ecology and energy
  - Politics, legislation, and regulations
- Air transport level:
  - Infrastructure
  - Air traffic market
  - Passenger behavior
  - Technology options

The prior definition of these topic areas was supposed to ensure a subsequent comparability among the three scenarios.

Steps (3), (4), and (5) were numerically supported by the "Risk Assessment and Horizon Scanning (RAHS)" toolbox, a "web-based foresight platform" destined to "facilitate systematic horizon scanning and long-term analysis of the strategic environment." [38] The RAHS toolbox and its development is a current research project of the strategy department of the German Federal Armed Forces.

The next step was to create one CONOPS for each of the three scenarios. At first, each sub team was tasked with defining a generic traveler representative for their scenario (i.e., gender, age, travel motives, travel preferences, size of travel group). Next, the sub teams had to describe one specific door-to-door travel chain (including at least one air travel segment) that the representative traveler would undertake in the respective scenario, including a precise definition of the places of departure and destination, and taking into account the traveler's scenario-specific time and financial constraints as well as individual travel habits and preferences. Special attention was put on describing how automated systems may contribute to satisfy the traveler's needs during the trip, revealing possible roles of automation in the respective scenario.

With the CONOPS at hand, operational high-level requirements were derived for each scenario that the travel chain would have to meet in order to fulfill the stated CONOPS, taking into account the representative traveler's scenario-dependent characteristics, needs, and preferences. Here, the focus was on the air travel segment of the overall trip, taking into account possible roles of automation. In addition, constraints imposed by the respective scenario environment and its various stakeholders on the travel chain and its system components were deduced directly from the scenarios (Fig. 1). The sub teams were asked to split the high-level requirements found into requirements for in-flight and on-ground system components of the air travel chain.

Finally, the sub teams had to design one or more preliminary product architectures (i.e., systems and processes) necessary for carrying out the scenario-specific CONOPS as described. That is, a system that provides one or more capabilities defined through the high-level requirements. The product ideas were then evaluated for each scenario using the NABC assessment method proposed by the Stanford Research Institute (analysis of needs, approach, benefits, and competition/challenges).[39] A final cross-scenario evaluation of all created product ideas was conducted, revealing the robustness of the product ideas towards environmental change imposed by the scenarios.

To help better understand the role of the CONOPS within the requirements elicitation process in this project, Fig. 2 again illustrates the methodical approach by referring to the "requirements layer" concept of Hull et al. [12]. In this study, the most important stakeholder was considered to be the traveler.

**Organizational Aspects.** The foresight study was conducted at the Institute of Aircraft Design of TUM in the summer term of 2013. Six workshop days were held together with the entire scenario team. Additional time was available for the sub teams to work on their scenario storyline, CONOPS, high-level requirements, and product ideas.

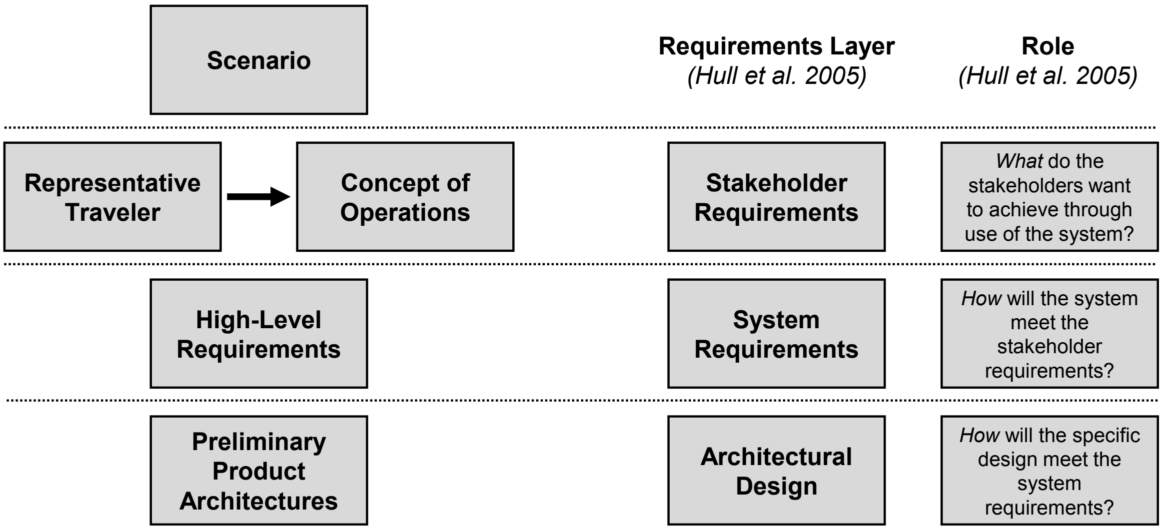


**Fig. 2. Methodical approach to requirements elicitation and requirements layer concept.**

A central classroom was available for the workshop with the possibility to access the internet and to present data and results using a whiteboard, flipcharts, and a computer with a digital projector. In order to enable the sub teams to work separately and independently, several smaller seminar rooms were available in the faculty. The project participants were given access to the data bank resources of the university library of TUM. In addition, the project leaders pointed them to relevant data and literature. The team was also instructed to do their own literature and data research.

For all team members, RAHS accounts were created, enabling every member and sub team to independently work with the scenario tools available in RAHS, as well as use the data and interim findings produced during the course of the study at any time. To access RAHS, only a personal computer with an internet connection was required.

The scenario team was composed of 18 members in total, eleven of whom were students of TUM enrolled in undergraduate and graduate programs of mechanical engineering, aerospace engineering, and business administration. The remaining seven participants were professionals and scientists in aerospace engineering, ergonomics, automotive engineering, computer science, and economics, five of whom were not employees of TUM.

## 3 Project Results

This section provides an overview of the three raw scenarios including the key factors identified in the context of the perspectives of automation in future air transport. In addition, the core messages of each scenario are given to enable a better imagination of the scenarios.

More importantly, the three scenario-specific CONOPS are depicted, including a short description of the traveler representative for each scenario. The corresponding high-level requirements for in-flight and on-ground system components of the travel chain are subsequently specified.

The results presented here are based on the comprehensive final report of the foresight study created under the supervision of the project leaders by the student members of the scenario team. The report is publicly available on the internet.[40]

**Raw Scenarios.** As described in section 2, raw scenarios are constituted by a unique combination of future states of the key environmental factors. As such, they provide a helpful first impression of the scenarios and allow an easy comparison of one scenario with another. Tab. 1 presents the three raw scenarios selected in the foresight study.

**Scenario Core Messages.** For a brief characterization of the main contents of the scenarios,

**Tab. 1. Raw scenarios – key factors and corresponding future states in 2050.**

| Key Factor | Comments | Scenario A | Scenario B | Scenario C |
|---|---|---|---|---|
| Changes in air transport demand based on income disparities | Describes the relationship between the population's poor-rich ratio and the composition and amount of air passengers | Big middle class | Widespread poverty | Big middle class |
| Development of aviation legislation and certification | The boundaries in the certification process are defined by the legal framework | No restrictions | Legislation restricts development of air transport sector | Technical complexity hinders fast development until 2050 |
| Acceptance of automated technology | Trend towards a purely natural life without any machines vs. trend towards more automation and more use of machines. Acceptance of a more machine-handled and engineered life. Impersonal procedures during check-in, flight, and arrival may lead to discomfort and anonymity | Open to technological progress and changes | Skepticism towards further automation in automated air transport systems | Open to technological progress and changes |
| Investment-willingness in the aviation sector | The readiness of the aircraft industry and airlines to invest in research and development, and implementation of technologies in the aviation sector | More investments | No investments in the development of automated air transport systems | More investments |
| Degree of automation of transport services around airports | Degree of automation of intermodal passenger transport services between the cities and their airports. Embedded check-in systems at public transportation and various spots in and around the cities. | Completely automated rail transport services | Partially automated rail transport services | Completely automated road- and rail transport services |
| Medial representation of automation | The picture of automation in the air transport industry in general as drawn by the media. The reputation of the role of automation in the air transport industry as discussed in general and especially in social media. | Media hypes technological innovations positively | Media hypes technological innovations negatively | Media hypes technological innovations positively |
| Degree of automation in airline services | Aircraft operators (e.g., airlines) have to decide whether they want to automate their services or whether they stick to the traditional means of passenger handling. | Different business models compete on the market | All airlines automate their services in large parts | All airlines automate their services in large parts |
| Progress in software reliability and security | Software reliability is the probability of failure-free software operation for a specified running time in a certain environment. Software security describes the ability of a software system to resist against external attacks | Software security is near 100% | Software security is worse than in 2013 | Software security is near 100% |
| Perception of air travel | Describes the way people perceive air travel in general, but also by comparison with other means of transportation | Automation is another example of the innovative image of the air transport sector | Environmental issues cause air travel to receive an ever-growing negative image | Environmental issues cause air travel to receive an ever-growing negative image |
| Communication standards and procedures | Describes to what extent communication takes place between the automated systems as well as between the systems and human operators | No communication between airline personnel and PAX/plane | "Mother Plane" controlled by human pilot | On-ground control centers steer aircraft and onboard services |

five core messages were formulated for each scenario. They are reproduced here:

*Scenario A: "An Automated Revolution."*

1. Automation is necessary to cope with the most important challenges of the 21st century like the growth of the world population.

2. Especially in the air transport sector, automation is being strongly supported by politics, media, and society.

3. In 2050, passengers are benefiting from automation as it makes air travel simpler, faster, and more comfortable.

4. Fair economic conditions and the presence of globally acting stock companies have

**Tab. 2. Representative traveler and scenario CONOPS.**

| Scenario A | | Scenario B* | | Scenario C | |
|---|---|---|---|---|---|
| *Male, age 35, business traveler, travels alone* | | *Male, age 40, business traveler, travels with his father-in-law* | | *Male, age 67, job: teacher, weekly commuter, travels alone* | |
| *Munich, Germany to Shanghai, China* | | *Starnberg, Germany to Southampton, England* | | *Shanghai, China to Hiroshima, Japan* | |
| 13:00 | Starts working in his office in Munich after lunch. | n/a | Leave home. | 06:50 | Leaves home. |
| 13:30 | Gets an invitation from the office in China to a meeting tomorrow at 13:00 (local time) in Shanghai. | n/a | Get to the airport by partially automated train. Individual selection of in-flight catering services during the train ride. | 06:57 | Boards the metro which takes him to the airport shuttle transit station. |
| 13:35 | Buys an e-ticket for the connection at 20:00 from Munich to Shanghai. | n/a | Arrive at airport. Proceed to automated security checks and border control procedures. | 07:05 | Boards high-speed train to Shanghai airport. |
| 19:55 | Arrives at nearest train station with connection to the airport. Walks with his baggage and his e-passport through the security and check-in gate. | n/a | Proceed to the boarding gate, guided by airport navigation system. | 07:18 | Arrives at the airport and proceeds directly to the gate. |
| | | | | 07:25 | Passes numerous shops on the way to his gate. |
| 19:58 | Takes a seat in a single-traveler transport unit (STU) in the train and stores his baggage beneath the seat. Meanwhile, he is welcomed personally by the STU. | n/a | Arrive at waiting lounges in front of the gate. Can work there. | 07:30 | Arrives at the gate and boards the aircraft. |
| | | | | 07:32 | Takes a seat and starts correcting students' exams. |
| 20:00 | Confirms his flight data and orders dinner and drinks for the flight. The train leaves the station. | n/a | Board the aircraft and are guided to their seats. | 07:40 | Take-off at Shanghai airport. |
| | | | | 07:55 | Eats a light breakfast. |
| 20:13 | The "stay on your seat" sign illuminates and he hears friendly voice announcing the arrival of the train at the airport. | n/a | Catering is being delivered by cabin crew. | 08:12 | Working without being disturbed by turbulences. |
| | | | | 08:30 | Gets current information about the upcoming travel segments. |
| 20:15 | Recognizes that the STU leaves the train and is positioned onto an aircraft. | n/a | Work on board the aircraft. Entertainment services available. | 08:45 | Landing at Hiroshima airport. Leaves the aircraft and has a short coffee break. |
| 20:22 | Meets his new seat neighbor whose transport unit assembles next his one. | n/a | Arrive at destination after a one-hour flight. | 09:01 | Gets on a train to his working place. |
| 20:25 | Gets a message that his meal in the catering box on the STU is ready. | n/a | Leave the aircraft. Get on a train to the city center. | 09:15 | Lesson starts. |
| 21:00 | Finished dinner and had a delightful conversation with his seat neighbor. Switches his STU to "work-mode." Connects online to his company network. | | | | |
| 23:00 | Switches his STU to "sleep-mode." Falls asleep. | | | | |
| 12:00 Shanghai Time | Wakes up. A friendly voice tells him that he will arrive in 30 minutes. | ** Remark: Team did not stipulate time intervals.* | | | |

fostered the development of a big middle class that is wealthy enough and increasingly motivated to undertake air trips.

5. Transport aircraft are flying fully automated and are able to coordinate their energy-optimized flight trajectories almost only by communicating with other aircraft in their vicinity. Flight attendants are not on board the aircraft.

*Scenario B: "Error 404: Automation not found."*

1. Society has become more skeptic towards automation technologies due to increasingly prevailing software security threats.

2. No investments in automation technologies have been made in the last decades due to legislative restrictions.

**Tab. 3. High-level requirements for in-flight and on-ground system components of air travel chain.**

| Scenario A | Scenario B | Scenario C |
| --- | --- | --- |
| **In-Flight** | | **General** |
| - Aircraft taxi, take-off, fly, and land completely automated.<br>- Probability of collision is reduced to 10^-12 per flight hour.<br>- Aircraft deviate off their optimized flight paths with a probability threshold of 10^-9 per flight hour.<br>- Travel procedures are as simple as to allow a six-year-old child to undertake air trips. (Also consider handicapped and an elderly persons.)<br>- Medical onboard equipment is sufficient to handle health issues like heart attacks and simple injuries.<br>- Flights arrive within 1 minute of the planned arrival time regardless of the prevailing weather conditions.<br>- During flight, passengers have the possibility to work, be entertained, and relax.<br>- Passengers can communicate audio-visually with every person worldwide.<br>- Passengers have the possibility to order drinks and food during flight at any time.<br>- Baggage has to be accessible for passengers at all time during the trip. | - Maximization of space per passenger.<br>- Crew to passenger ratio:<br>First class: 1:6; Business class: 1:9.<br>- Control of the aircraft lies in the hands of the pilot.<br>- The aircraft follows an optimized air trajectory with minimum pilot input.<br>- Minimized noise emissions, especially during airport operations.<br>- Only direct flights available with minimum trip time.<br>- Air traffic management system is able to handle the increased number of airplanes in airspace. | - Increase the share of usable time (leisure or work) of the total travel time.<br>- Processes are self-explanatory to passengers of all age groups and all nationalities.<br>- Minimize costs for personnel.<br>- Personalize all interactions with the passenger (language, cultural background, personal preferences).<br>- Minimize the price for air travel in order to allow 99% of the world's middle class to undertake air trips.<br>- Ensure a certain service level.<br>- Create a green image of air transport-related products.<br><br>**In-Flight**<br>- Minimize delays and network disruptions caused by weather issues.<br>- Increase the number of direct flight connections available.<br>- Maximize the capacity of the air space.<br>- Increase the load factor (passengers, baggage, and cargo).<br>- Reduce energy consumption.<br>- Reduce noise pollution.<br>- Improved engine efficiency. |
| **On-Ground** | | |
| - The transfer time from train to aircraft or aircraft to aircraft is below 15 minutes.<br>- Passengers are directed to the right aircraft automatically.<br>- Passenger identification is without human personnel.<br>- All passengers and their baggage are scanned fully automated.<br>- Check-In is completed before rail-transfer.<br>- The maximum time for railway-airport transfers does not exceed 20 minutes in metropolitan areas.<br>- After entering the railway-transport system, the baggage follows its owner automatically.<br>- The maximum walking distance inside airports is 100m.<br>- Aircraft handling is done within 15 minutes after de-boarding.<br>- The time for aircraft maintenance is reduced by 75% relative to 2013. | - Emission-free taxiing.<br>- Time needed for check-In and security controls is minimized.<br>- Security controls detect every potential threat.<br>- Aircraft maintenance procedures are automated.<br>- Time spent on the airport is minimal for passenger and aircraft.<br>- Fast connections between airport and final destination.<br>- Baggage handling is fully automated.<br>- Passengers are accompanied and supported individually on their way to the aircraft.<br>- Individual catering is available before arriving at the airport. | - Enable a hassle-free and quick intermodal connection for passengers of all age groups.<br>- Ensure efficient processes especially for frequent travelers.<br>- Increase efficiency of passenger baggage logistics.<br>- Reduce of energy consumption by improving efficiency of ground operations.<br>- Decrease energy consumption of on-ground processes.<br>- Increase the number of passengers handled per hour. |

3. Environmental awareness in society is constantly increasing.

4. The proportion of travelers who can afford air travel is decreasing because of a growing social gap.

5. Due to some severe automation-related aircraft incidents and accidents, automation technologies, although available, are not being employed. Instead, proven technologies and procedures originating from the beginning of the century are still in operation.

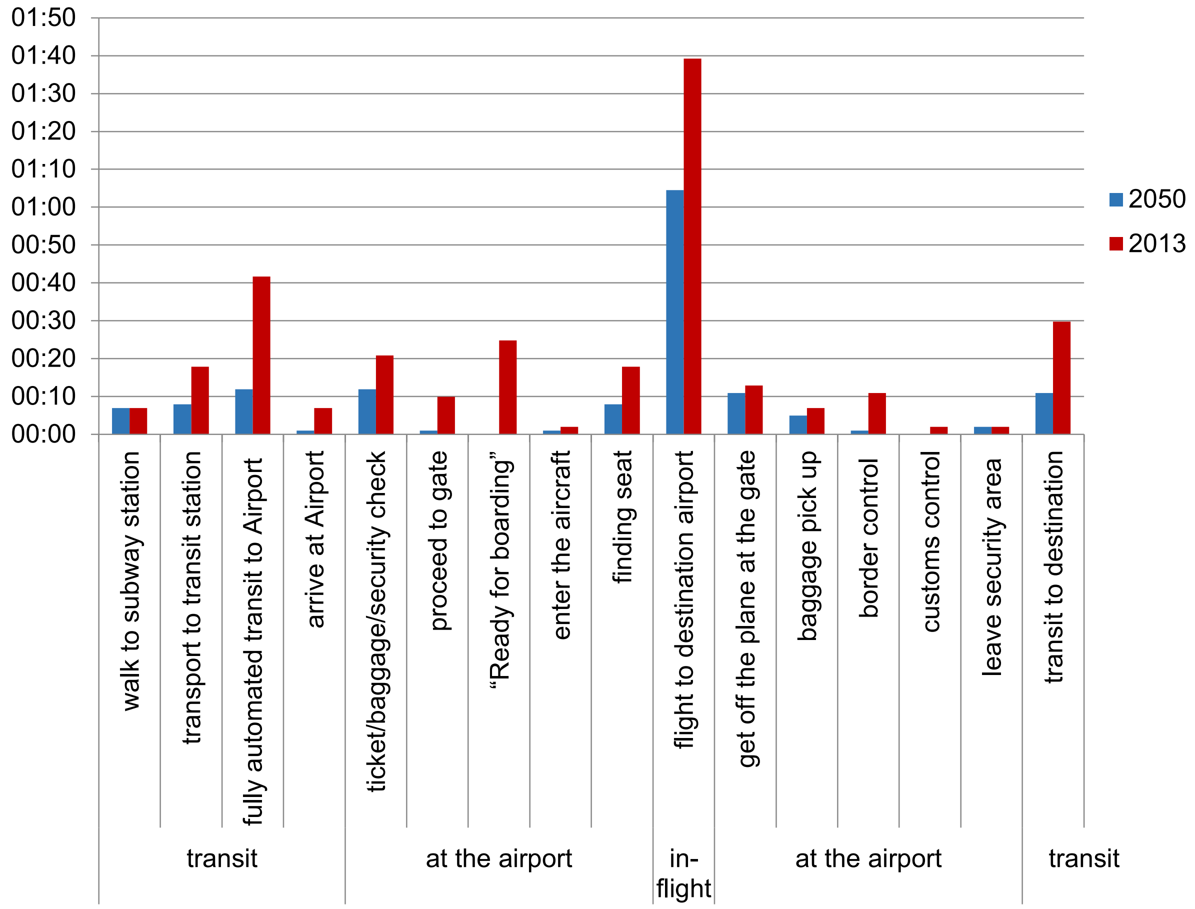


**Fig. 3. Time saving potentials in travel chain achieved through automation, scenario C. [40]**

*Scenario C: “Step by Step.”*

1. Completely automated public on-ground transport services have been established.

2. The air traffic market is being dominated by two large aircraft operators.

3. Despite the effects of climate change, the media is hyping technology (including automation technologies) and people are open towards technological progress.

4. A robust economic development has supported the development of a big middle class, leading to a high demand for air travel on routes between the global hotspots.

5. Although technically possible, fully automated flight operations are not yet admitted due to certification issues. Human pilots are still on board and control their highly automated aircraft.

**CONOPS.** The three scenario-specific CONOPS are depicted in Tab. 2, including a brief description of the representative traveler. In addition, Fig. 3 shows for scenario C an estimation of the time saving potentials in each travel segment that may be achieved through automation.

**High-Level Requirements.** Tab. 3 lists the high-level requirements for in-flight and on-ground system components for each scenario. For scenario C, high-level requirements that generally apply to the overall travel chain were additionally formulated.

## 4 Evaluation of Proposed Approach

Besides developing alternative scenarios for 2050 and analyzing the potential role of automation in future air transport, the foresight study presented in this paper intended to

(1) confirm the applicability and advantages of scenario planning in product development and requirements elicitation in general,

(2) create useful CONOPS and high-level requirements for a more automated air travel chain using the elaborated scenarios, and

(3) design and collect preliminary product architectures as system components of the travel chain to fulfill the respective CONOPS and high-level requirements.

In order to keep this paper short, the product ideas are not portrayed here. The interested reader is referred to [40].

Reviewing the study results, we conclude that goal (1) was reached. Due to the diversity of the elaborated scenarios, a broad horizon of the perspectives of automation in the air transport sector was scanned, enabling creative thinking about how future air travelers may be characterized, which needs they might have, and how automation may help aviation service providers to satisfy these needs. In particular, the elaboration of scenario-specific CONOPS from the traveler's perspective helped to thoroughly analyze the travel chains as well as to look at the interaction of its system components, and to better understand the traveler on the way along his trip. We state that in our study, the CONOPS were a helpful instrument to design operational high-level requirements for future air transport systems. We therefore conclude that CONOPS represent a suitable and easy-to-use method to derive operational requirements from scenarios.

Was goal (2) accomplished? This question is not easy to answer, as the foresight study was not followed by a real product development process. Thus, we cannot properly assess the quality of the CONOPS and high-level requirements, i.e., test whether they are actually able to support the development of successful products. A major flaw of the CONOPS developed here is certainly the fact that they partly include technical solution approaches although they should not.[25] This led to an unnecessary restriction of the design space. On the other hand, the CONOPS allowed a detailed look at different travel chains and enabled an analysis of potential integration points of automation on this basis (Fig. 3).

In our study, preliminary product architectures were actually designed and their role in the travel chain described, based on the CONOPS and requirements.[40] Thus, goal (3) was de facto reached, although we are not able to assess the quality of the product ideas at the current state.

In summary, we conclude that the proposed approach to requirements elicitation using scenario planning fosters future-oriented and creative thinking when creating systems and processes for the air transport system, and supports an in-depth analysis of potential needs of aviation stakeholders with the CONOPS descriptions. We also see that the quality of the obtained results strongly depends on the composition of the scenario team in terms of available expertise and experience. We thus confirm the high significance of the selection process of the team members for the output quality of a scenario study when being prepared, as stated in [19].

## 5 Outlook

The foresight study presented in this paper was the second of its kind conducted at the Institute of Aircraft Design at TUM. A previous study had dealt with "Personalized Air Transport in 2050" and had already proven general applicability of scenario planning in product development tasks.[41] IT thus motivated us to conduct the study presented here. Although there is still room for improvement, the methodical approach and organizational setup of the foresight study seem adequate to solve the problems considered.

An upcoming project at the institute is intended to extend the scope of application of scenario planning towards technology assessment. In this context, a recently developed aircraft concept [42] will present the test case for the design and evaluation of a scenario-based approach to stakeholder-oriented technology assessment.

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