# Requirements and Concepts of Operations for a Personalized Air Transport System in 2050

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**Long product life cycles paired with a high degree of uncertainty about the state of the long-term future make the product development process very challenging in the aviation industry. Future customer needs and environmental constraints must be anticipated, which severely increases the risk of failure when developing a new product. This paper presents a scenario-based approach to product development with the goal to better handle uncertainty and mitigate the risks. By exemplarily exploring the potentials of a more personalized air transport system, three alternative future scenarios in 2050 are created. The subsequent derivation of high-level requirements reveals a clear individualization trend of the mobility needs of future customers. Two key customer groups are determined: elderly people whose travel plans are merely motivated by leisure activities, and businesspersons who require a flexible and reliable air transport system with reasonable trip costs. Concepts of operations that were specifically developed for each scenario to meet the respective market constraints and customer needs expose a high potential of a more automated transport system that is able to seamlessly combine several transport modes without the traveler's interference.**

## I. Motivation and Scope Definition

THE modern experience of air travel has only little to do with the prestigious air journeys of the fifties and sixties of the last century when flying used to be a part of an upper-class lifestyle. Today, most citizens of developed countries can afford to fly. The sharp decline in ticket prices and a great extension of the flight route network since that time have caused enormous growth in civil aviation and made it become a major player of the modern transportation industry. However, aviation has also developed from a transport provider that was originally focused on an elite clientele into a mass transport system with only a limited consideration of the needs of the individual traveler.

With the increasing air traffic volume and extensively rising energy costs, further challenges face the future of civil aviation. Especially on short routes, ground-based means of transport are becoming critical competitors that are able to operate in a more energy efficient way and that can thus raise the pricing pressure in this market segment. A future-oriented, sustainable transport system will have to combine the strengths of every means of transport with the ultimate goal to minimize travel time, energy consumption, and environmental damage.

In this context, the European Union has published a position paper in which a vision of the future of a seamless, intermodal transport system in Europe is defined.[1] Among other goals, it is envisaged that 90% of all travelers within Europe will have travel options available to reach their final destination within four hours door-to-door. Furthermore, all travel segments are supposed to merge smoothly into each other in order to increase the efficiency (with respect to time and energy consumption) and reliability of the entire transport chain.

What role will future aviation play within this integral transport system? What technology and product options exist to meet the challenges of tomorrow? Who is the future customer? What are his needs and preferences? In order to find conceivable answers to these kinds of question, we conducted a future forecasting study. By creating alternative scenarios of the future in 2050 that contain statements both at a global socio-economic macro level and at an aviation-specific micro level (e.g. consumer behavior, air traffic market situation, technological options), a set of scenario-

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specific requirements for a more personalized air transport system was derived. The description of these future requirements and constraints from the traveler's perspective (user narratives) through a definition of alternative concepts of operations helped to better understand and communicate the findings of this study.

This paper provides an overview of our approach that we propose in order to derive requirements and concepts of operations necessary within the product development process from a set of multiple future scenarios (section II). It additionally summarizes the major findings and results of the foresight project (section III) and eventually evaluates the depicted approach to requirements elicitation (section IV).

## II. Scenario-Based Product Development

Eliciting, defining, and analyzing requirements are among the first steps of any product development process. 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. In this section, a theoretical overview of how to approach this task is given.

### A. Problem Formulation and Solution Approach

Delivering a *good* product at the right time to the right market is probably one of the most challenging tasks of profit-oriented enterprises in a highly competitive world. That is why numerous research institutions, private companies, and authorities have developed theories and procedure models to support engineers and designers in developing good products.[2] In this context, a product can be defined as the (im-)material outcome of a development and design process, with the design being the graphical depiction of the arrangement of all elements of the product.[3]

The product development process is usually divided into a number of distinct phases, as illustrated by Fig. 1.[4] An initial requirements analysis phase is followed by the system design phase where cross-domain solution concepts are identified. The subsequent domain-specific design phase is characterized by an in-depth development of subparts of the product. Eventually, the system integration phase is executed. This is where all subparts are put together to form the actual product.

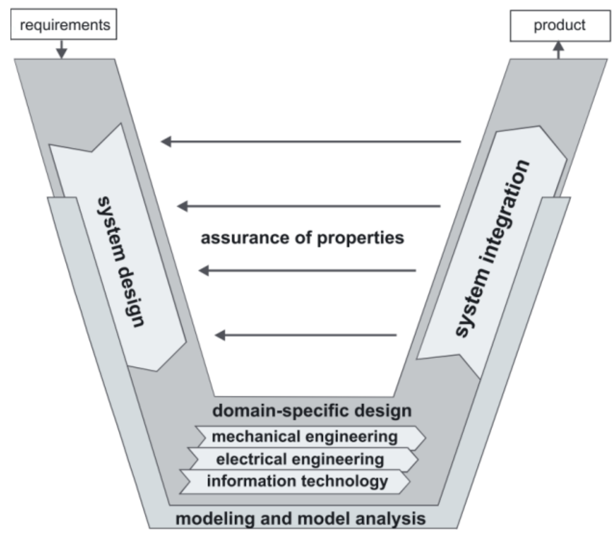


**Figure 1. V-Model describing one way of a generic product development process.** *Image from [4].*

Fig. 1 additionally reveals the iterative nature of the product development process, i.e., process results must be crosschecked continuously against the predefined requirements and the overall system design to ensure that the product delivers the expected features and performance.

All in all, the product development process can be defined as the sum of all activities "required to evolve the system from customer needs to product or process solutions."[5] This definition underlines the central importance of the role of the customer within the entire process. According to the ISO 9001 norm (and other quality management models), satisfying the customer is the central mission of any product development activity and is to be ensured by the top management of the organization.[6]

The development of a new product can be triggered off in two distinct situations:[7] in a "market pull" situation, a new customer need becomes apparent which causes a novel, unsatisfied market to rise. Thus, the product development process is aimed at delivering a product to satisfy the new market. In simple words, the problem is known, and the product is expected to solve the problem. In opposition to that, a "technology push" situation is characterized by the availability of a novel technology or technological potential. In this kind of situation, the customer need is not yet known and must be identified before actually starting to develop the new product that involves the newly available technology. Here, the problem for the solution needs to be established.

Both the market pull and the technology push situations have in common that the customer needs (i.e. the problem formulation) present the starting point of the product development process (Fig. 1). Thus, prior to the actual design of the product, a comprehensive analysis of the customer needs is vital. In this context, however, there are two major problems:

(1) *Who is the customer?* This question is actually not easy to answer as today's understanding about the customer goes beyond the classical definition of the customer being the person that actually *uses* the product (i.e. the user, the operator, or the key customer).[5] It is more common to talk about stakeholders and their various interests.

(2) *Uncertainty*: once identified, customer needs will not remain at steady state. Instead, they are apt to great changes over time. The significance of this phenomenon within the product development process increases with an increasing lifetime of the final product.[8]

In order to deal with uncertainty within the product development process, Tideman proposes a fundamental distinction between two types of product development processes.[7] Type 1 is characterized by the presence of a problem that "can be clearly and reliably described in the early stages of the design process, and the subsequent stages are aimed at finding adequate solutions." In contrast, in type 2 processes, the problem "cannot be clearly and reliably described in the early stages of the design process," which forces the product developers to simultaneously describe the problem *and* find adequate solutions. It is obvious that type 2 product development processes are much more difficult to manage. Tideman has identified four major global trends[§] that cause type 2 processes to occur much more frequently today than in the past. In the study presented in this paper, we focus on this type of process.

A major challenge of a typical type 2 product development process is portrayed in Fig. 2. It reveals the gap between the expenses for activities during the product development process (lower line) and the costs of the final product that are established by the design decisions of the product developers (upper line).[9] During the system design phase (Fig. 1), the overall product architecture and functions are established, which in turn stipulates the costs of the final product. In the further product development phases, only minor changes to the overall product design and costs can be made. However, the detailed system design and integration phases require a high degree of committed work, which causes the development costs to rise exponentially.

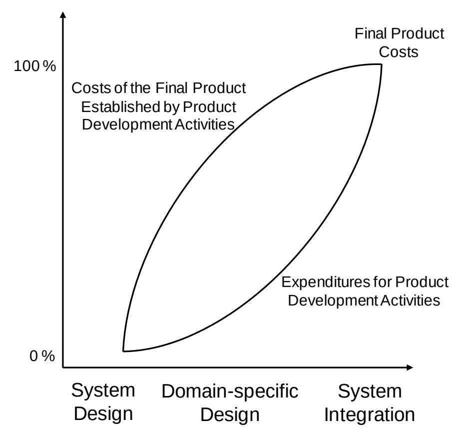


**Figure 2. Costs and expenditure gap along the product development process.**

Fig. 2 implicitly suggests that it is highly favorable to identify the requirements the final product must meet in the early stages of the product development process. In the unpleasant case of requirements becoming invalid or inapplicable during the process, a major change to the product design will immediately lead to tremendously higher development costs. Again, this underlines the importance of robust requirements elicitation when developing a new product.

In this paper, we propose to use scenario planning techniques to get to know and understand the future customer and his needs, and to deal with the uncertainties of requirements elicitation within the product development process. Scenario planning techniques have proven to provide a useful way of dealing with uncertainty and complexity.[10] As such, the method presented here is based on the knowledge and experience of previous scenario studies at our institute when we used scenario planning techniques as a method to support corporate strategic decision-making.[11] We found that the method was especially useful in the air transport industry that is characterized by long product lifecycles including long development times. In this context, eliciting robust requirements becomes all the more important.

The key principle of the proposed scenario-based approach to product development is to elaborate multiple alternative, yet consistent pictures of the long-term future, containing both statements at a macro and an air transport market-related level. We then derive from these future scenarios (1) the scenario-specific needs, preferences, and characteristics of the future customer with regard to a certain sub-market (in the case presented here: the market of personalized air transport systems) and (2) the scenario-specific constraints of the market imposed by the scenario-specific environmental conditions. The availability of the scenario-specific future customer needs and constraints allows us to describe the use of the product to be developed from the key customer's perspective in a specific scenario with a *user narrative*. This way, the use cases of the product can be depicted. Finally, by identifying similarities and differences between the different scenario-specific use cases, all scenario-specific information can be translated into robust product requirements that are applicable through all predefined future scenarios.

[§](1) New technologies enter the market more quickly; (2) The functional range of products is steadily increasing; (3) The world is becoming more interconnected and interrelated; (4) Mass-produced goods are increasingly customized to meet the individual preferences of the consumer.[7]

### B. Requirements and Concepts of Operations

The approach to requirements elicitation and analysis under uncertainty is presented in the context of the perspectives of personalized air transport. It is adapted to the principles stated by the book *Systems Engineering Fundamentals* published by the U.S. Department of Defense Systems Management College.[5]

The definition of a requirement varies slightly from field to field. In the context of this study, similar to the terminology introduced by IEEE,[12] a requirement is defined as "a documented specification of a condition or system capability needed by a stakeholder in order for that stakeholder to solve a problem or achieve a desired objective." We have expanded the definition here to include all stakeholders in addition to users. Though this project considered requirements at every level, the focus was on high-level, i.e. solution-neutral, requirements.[**] An example of a high-level requirement for the transport sector might be "minimize land usage." Contrast this to the solution-specific "helicopters should be used in order to minimize the need for large ground-based road, rail, and airport infrastructure." By specifying a system solution (helicopters), the requirement, when phrased this way, unnecessarily restricts the design space for solving the underlying high-level issues.

Analyzing requirements is essential within the systems engineering process.[5] This task includes the definition of customer expectations and the identification of external constraints and operational scenarios.[13,14] The mission of requirements analysis is to support a clear understanding of the functions, performance, and interfaces of the product, while taking the needs of all customers of the product into account.[††] Usually, the results of the requirements analysis are documented using one of three different views: the operational view, the functional view, or the physical view.

A detailed set of requirements by itself does not define the system usage, though. A narrative that tells the story of how the system is used can describe how a set of capabilities defined by the requirements might be employed in order to achieve desired objectives. This narrative can be from the perspective of any stakeholder, though the most common is a narrative from the viewpoint of an individual user. The *user narrative* is often called an operational concept[5] or a Concept of Operations (ConOps)[15]. The ConOps corresponds to the operational view of the requirements analysis documentation that "describes a system's operational characteristics from the end user's viewpoint."[16]

In the approach presented here, we created scenario-specific ConOps to explain how product ideas can serve their users. For each scenario, we explored a typical journey from a traveler's point of view in order to gain a better understanding of (1) the traveler's characteristics, (physical, financial, etc.) abilities, and preferences, and (2) the operational environment the traveler is moving within. We considered the traveler as the key customer of our product.

### C. The Foresight Project: Activity Scheme and Scope

The approach to requirements elicitation and analysis under uncertainty with the support of scenario planning techniques depicted in the previous sections was accomplished within a "comprehensive foresight project" as defined by Bishop et al.[17] that we conducted at our institute in April 2013. Fig. 3 provides an overview of the main methodical steps of the project.

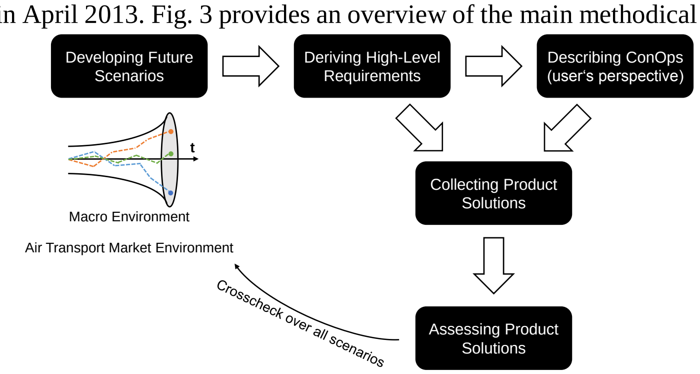


**Figure 3. Methodical steps of the foresight project.**

The starting point of the project was the development of the future scenarios. This step was divided into five subtasks following the "generic scenario planning workshop model" defined by Franco et al.[18] (1) In the *problem definition* phase, we defined the thematic scope and the goals of the scenario project, scanned and filtered relevant literature and data input, and compiled the workshop team for the subsequent project steps. (2) With the entire project team, we then conducted an in-depth *environmental analysis* using a STEEPV approach[‡‡] to identify environmental factors

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[**]High-level requirements can also be referred to as "top-level system requirements" and address system capabilities to ensure performance attainment.[13]

[††]In this context, the customers are considered as those who perform the "eight primary life cycle functions": disposal, training, verification, operation, support, development, deployment, and manufacturing/production/construction.[5] Special emphasis is put on the operator.

[‡‡]STEEPV is the abbreviation for the environmental areas Society, Technology, Economics, Ecology, Politics, and Values. These areas are frequently used during environmental analyses to support a broad analysis horizon.[19] In the foresight project depicted here, we added an aviation-related environmental area to address all aviation-specific factors.

relevant to the problem. We compared these factors mutually according to their relative impacts on the problem and simultaneously evaluated their degree of uncertainty concerning their future state, which eventually helped us to extract the key environmental factors with the support of a "driving force ranking space" developed by van der Heijden.[20] (3) In the *consistency analysis*, we defined several alternative future states for each key factor and intuitively evaluated how well the different future states of one factor would fit to the ones of another. (4) With the results of this analysis, we were able to determine numerically a range of *raw scenarios*, i.e. a set of combinations of key factors with one future state specific to each raw scenario. (5) We finally selected the three most interesting raw scenarios, expanded them by adding the remaining factors from the environmental analysis, and developed a storyline for each scenario to make it more comprehensible and communicable. This is how we eventually achieved to obtain three comprehensive and consistent pictures of the future with statements at both the macro environment as well as at the air transport market-related micro level.

The next step in the foresight project was to derive high-level requirements from each of the three scenarios. We did this by dividing the project team into three sub teams of equal size and assigned one scenario to each sub team. Because the foresight project was specific to the air transport sector, each sub team had a scenario to work with that described a future where there would in fact exist a need for transportation with some level of personalization at the aviation-specific micro level. This is not always a given for every possible future scenario, but it was assumed for the sake of this project.

Given the generic need for transportation, more specific requirements for that transportation and the personalization thereof were needed. This involved deriving high-level requirements, and each sub team sought to define high-level requirements specific to their scenario. Requirements were defined based on the problems and objectives of several stakeholders, including transit-providing public and private businesses, individual users and user groups, non-traveling citizens, and government regulators. Some stakeholder objectives can be rather obscure, while others are well defined and even documented today, for example the European Union's Flightpath 2050 defined goals for the future of European aviation.[1]

Once the sub teams had defined a reasonable set of high-level requirements, they were then tasked with creating a vision for a single possible user narrative (ConOps) per scenario. The user narratives describe not only how the user could fulfill his high-level requirements during the account of a single journey or set of journeys, but also how the journey meets many of the high-level requirements of other stakeholders present in the scenario.

Finally, the sub teams identified one or more systems or subsystems necessary for carrying out the user narrative as described. That is, a system that provides one or more capabilities defined in high-level requirements. As a short and informal engineering design exercise, other possible system attributes were envisions and sometimes sketched, spurring on visions for new product ideas.

However, no matter how compatible a new product idea is with one future scenario, a developer should first check to see if the new concept has a place in most of the possible future scenarios before kicking off a formal development process. If the concept does not fit into the existing user narratives for the other two scenarios, a new ConOps may have to be created. The new idea and its usage can then be checked for consistency with the high-level requirements for each of the other scenarios.

The ultimate goal of the evolving foresight project is to be able to use the techniques described in this paper to derive specific system requirements for a new product. Once an idea has been vetted and determined to be compatible with most future scenarios, those specific system requirements can begin to be formally defined, resulting in a specification document that designers and engineers can use to develop a new product. However, the project described in this paper, due to some project constraints, ended with the identification of the necessary systems step, leaving the compatibility check and requirements refinement phases for future projects.

### D. Boundary Conditions of the Foresight Project

The foresight project was executed under several boundary conditions and constraints. By briefly depicting them in this section, we would like to enable a better understanding of how the project was conducted and how the project results were achieved.

*Time and place constraints*

The foresight project was executed during a period of two weeks in April 2013. Nine full working days were available, seven of which were dedicated to the workshop with the entire team, and two of which were available for the sub teams to work on their respective scenario, high-level requirements, and ConOps. All participants of the project were instructed to deliver results and complete the entire project within this period. The project took place at the faculty of mechanical engineering of the Technical University of Munich (TUM).

*Infrastructure available*

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 as well. A major numerical support utility was provided by the “Risk Assessment and Horizon Scanning” toolbox for scenario planning developed by the German Federal Armed Forces.[21]

*Input Data*

The project participants were given access to the data bank resources of the university library of TUM. In addition, they were pointed to relevant data and literature by the project leaders. They were also instructed to do their own literature and data research.

*Team structure*

The project team consisted of 16 people in total, nine of whom were students of TUM enrolled in undergraduate and graduate programs of mechanical engineering, aerospace engineering, and automotive engineering. The remaining seven participants were professionals and Ph.D. students in aerospace engineering, computer science, industrial design, and economics, four of whom were not employees of TUM.

## III. Project Results

The following section gives an overview of the raw scenarios. It also depicts the storyline of each scenario briefly with a focus on the air transport market-related statements. Based on these results, sector-specific high-level requirements are depicted and ConOps from the user perspective are shown with the intention to better understand the future needs of relevant customers. The results presented here are based on the final documentation of the foresight project that is publicly available through the internet.[22]

### A. Raw Scenarios

Each raw scenario is described by the environmental factors with a unique combination of one future state per environmental factor.[§§] The combination of these future states provides a good first impression of the scenarios. Table 1 contains a list of the key environmental factors selected within the foresight project, as well as a detailed description of each key factor used within the foresight project, and the associated future states for each scenario.

### B. Scenario Storylines

Based on the raw scenarios, a storyline for each scenario was developed in the foresight project in order to gain additional insight and enable an improved communicability of the scenarios. The storylines are depicted here, focusing on the air transport market-related scenario statements.

In *scenario A*, the aviation industry maintains its key role within the transport sector. Due to a high degree of privatization, globalization becomes a key driver for the increase in air traffic growth. Unpredictable volatilities in the energy price affect the demand for mobility. To cope with these conditions, the stakeholders engage in merging activities and the market structure develops towards an oligopoly. Aircraft-to-aircraft routing as well as automated systems are examples of new sector-specific technologies. Not all customers are willing to rely on automation, subject to demographical and geographical dependencies. High differences in the median disposable income amplify the personalization of travel preferences in correspondence with the customer’s financial situation. A decentralized infrastructure as well as enlarged public transport and new air traffic management systems, enabling aircraft-to-aircraft routing, provide the necessary capacities to satisfy this demand. In the face of highly volatile fuel prices, the air transport sector attempts to reduce its dependency on crude oil. The availability of recently developed high performance batteries leads to a great opportunity for changing the energy supply of flight propulsion. The new batteries are characterized by a high degree of operational safety and satisfactory performance for an acceptable volume and price.

In *scenario B*, the profit margins of the air transport sector remain at low level. Companies tackle this stagnation with the effort to reduce costs as well as the intention to create oligopoly enterprise structures in order to reduce the rough competition in the market. In terms of customer profiles, the size of travel groups decreases due to a low birth rate and the smaller size of families, whereas the number of individually traveling businesspersons increases. Especially older travelers become more relevant for airlines when it comes to meet the expectations of different customer groups. The global traffic infrastructure remains unchanged. There is no improvement of the degree of

[§§]Note that sometimes, potential future states of environmental factors are also referred to as “projections”.[23]

**Table 1. Raw scenarios: key factors and associated future states in 2050.**

| Key Factor | Description | Scenario A | Scenario B | Scenario C |
|---|---|---|---|---|
| Energy storage technologies | Technologies which store energy in order to be used for propulsion | High performance batteries available | Nothing better than liquid hydro-carbons | Game changer |
| People's trust in automated systems | High acceptance and trust that all tasks assigned to an automated system will be handled safely and reliably | Heterogeneously distributed trust | High trust | High trust |
| Political influence on mobility sector | Subventions, regulations, and limitations within the mobility sector introduced by the responsible political institution | Neo-Liberalism | Status quo | Highly regulated |
| Energy costs | Price of each energy source used for transportation | High volatility | 200% increase | 50% reduction |
| Intermodal transport system | An intermodal transport system is characterized by the existence of a chain of different means of transportation that are providing the traveler with efficient and effective transport. | Enlarged public transport system | No change | Enlarged public transport system |
| Median disposable income | Median of the available income taking into account tax deductions and fixed costs | Increasing differences | Increasing differences | World divided into two parts |
| Individualization in mobility | Possibility to satisfy personal travel needs and preferences by being able to decide individually how to get from one point to another within a desired amount of time | Free choice of transportation system | Degree of personalization similar to 2013 | Standardized and regulated transportation system |
| Air traffic management systems and procedures | All processes and practices as well as safety regulations required to manage and control the air traffic volume | Satellite based aircraft-to-aircraft routing | GPS/Galileo successfully implemented | Satellite-based aircraft-to-aircraft routing |
| Travel constraints | Presence of unpredictable events with significant impact on the air traffic system, e.g. political tensions, pandemics, natural disasters, etc. | Political conflicts, military interventions, and global terrorism prevail on global level | Global peace | Global peace |
| Airport infrastructure | Functional layout of an airport to ensure security and to enable ground operations including baggage and passenger handling, refueling, and servicing | Take-off and landing possible from many decentralized airfields | Airport layout similar to 2013 | Airport layout changed to meet requirements of personal air vehicles |

intermodality, neither of airport layout characteristics. The successful implementation of the European satellite-based navigation system Galileo provides additional capacities becoming necessary due to air traffic growth. The importance of liquid hydrocarbons as supreme energy source increases further, even though their production costs greatly rise. Engineers put huge efforts into efficiency improvements of aircraft propulsion systems. Other technologies, e.g. composite materials, become a standard in aviation.

In *scenario C*, highly regulative politics affect the mobility sector after liberal economic mechanisms have failed to establish appropriate measures to prevent further environmental pollution. The aviation industry thus faces plenty of restrictions and regulations that lead to a high degree of standardization and the enlargement of public transportation. Global efforts in research and development of alternative energy sources and efficient energy storage finally lead to the outcome of a revolutionary technology. The success of this development results from a commendable collaboration of the wealthy countries. Due to the rise of this game changer in energy technology as well as a reduction in the energy costs by 50 percent compared to 2013, air transportation becomes the common and politically promoted choice of mobility for distances above 200 kilometers. The profitability of the air transport sector rises continuously due to the low operating costs combined with global air traffic growth. This increase leads to low prices that in turn enable people, especially those among the elderly affected by poverty, to travel as well. The predominant role of the air transport sector within the overall transportation industry necessitates to consider several socio-economic trends. The high trust in automated systems within the society enables the development of satellite-based aircraft-to-aircraft routing. Besides that, many infrastructural changes have occurred since 2013. Nearly every airport has changed its functional layout on the land- and airside, influenced by urbanization and the ageing society. Air travel achieves an outstanding level of safety since the prevailing political system has led to a fast implementation of safety regulations.

**Table 2. High-level requirements derived from the three scenarios.**

| Scenario A: | Scenario B: | Scenario C: |
|---|---|---|
| High degree of personalized mobility needs individual to every customer | Minimization of air vehicle energy consumption | Large variety in size of travel groups |
| Free choice of transportation mode | Fulfillment of all environmental regulations | Age-appropriate systems for elderly travelers |
| Satisfaction of different target group demands | Elimination of human workload | Realization of door-to-door trips in Europe within 3.5 hours for 95% of EU residents |
| Securing protection against system failure, crises, and weather conditions caused by climate change | Trust-worthiness of transportation system | Capability of satellite-based aircraft-to-aircraft routing technology |
| Securing battery recharge infrastructure | Avoidance of unnecessary system malfunctions and interruptions | Take-off distance maximum: 1,000 meters |
| | Reduction of stress during the entire journey | Perceived noise emission reduction by 70% |
| | Fulfillment of personal desires | $CO_2$-emission maximum 30 g/km per PAX |
| | High value-for-money ratio in terms of quality and comfort during the journey | Aircraft turn-around time: max. 10 minutes per rotation |
| | | Workload reduction for aircraft operator |

### C. High-Level Requirements

High-level requirements were derived from each of the three scenarios based on the scenario storylines. Table 2 provides an overview of the scenario-specific high-level requirements as defined by the three sub teams.

### D. Concepts of Operations

The following paragraph contains a ConOps description for each scenario that corresponds to the high-level requirements shown in Table 2.

Taking into account the social differences present in *scenario A*, the concept of operations describes a journey from two perspectives: the wealthy and the poor customer's view.

A wealthy customer starts his journey entering his own small-sized aerial vehicle that is parked next to his home. Prior the actual journey, he selects his destination with an app on his smartphone. This process initializes flight planning and other necessary tasks. As soon as he takes a seat, the fully automated flight begins. During the entire flight, the customer can either work as all necessary connections to his workplace are provided (e.g. server connection), or enjoy leisure activities. Once arrived at the final destination, the customer exits the vehicle. While he takes care of his business or private obligations at the destination, the vehicle is automatically relocated and stored at a designated public parking space. At this location, an interface for recharging the high performance batteries is available. Prior to his subsequent journey, the customer selects a new destination via his smartphone. The vehicle is relocated from the public parking space back to a sector where the passenger can reenter it.

In contrast to this procedure, poor customers only have access to a standardized version of the vehicle, which they can book on short notice and pick up at one of the designated storage locations, that is, one of many decentralized airfields. These fields are embedded into a highly interconnected global network. The standardized vehicle versions are equipped with a basic level of comfort. Personalized seat configurations or server connections to the workplace are not implemented. The standardized vehicles are available at all decentralized airfields that the customer can reach via the public transport system.

Wealthy and poor customers can undertake long-haul journeys by docking onto one of the almost constantly flying carrier vehicles, which form a global air transportation network. In the interior of these vehicles, a wealthy customer is seated in a section with a high degree of comfort, whereas a poor customer is located in a compartment with a standardized configuration, completely separated from wealthy passengers during the entire flight.

A journey in *scenario B* begins for the customer with a short walk to one of the decentralized seat access stations, where he installs himself at a travel seat. He will stay in this seat throughout the entire journey until he reaches his final destination. The customer checks himself in for the flight to his destination at the seat and is able to select additional options, for example, the meal plan and the entertainment program as well as service options for the flight. The security check at the airport is performed automatically while the customer is seated. During the journey, the seat is moved forward automatically on a magnetic levitation rail system. At any point in time until take-off, the customer has the option to redirect the seat to certain locations, e.g. if he wishes to drink a coffee at the airport prior the journey. After departing from the airport, the small airplane that carries a group of seats heading into the same direction, docks with a long-haul aircraft circling over Europe. The small plane undocks itself at the point of the shortest distance to the airport that is located at the closest position to the final destination and takes the customer to the final airport. There, his seat leaves the small plane and enters the local public transportation system. After the customer leaves the seat at the seat station closest to his final destination, the seat autonomously moves back into a storage location.

This concept of operations requires that certain infrastructural facilities such as a seamless magnetic levitation rail system are available, and that there is a sufficient number of seats available that can be stored, redistributed, and maintained. The control and management system behind this global logistic effort is centralized and fully automated.

In *scenario C*, the ageing society leads to an increasing importance of the needs of older travelers. Hence, a personalized air transport system has to take into account the needs and preferences of this leisure-oriented customer group as well as the needs of business and other travelers.

Due to a highly standardized mobility environment, the customer performs his journey, short haul, or long haul, in a kind of cabin in which he stays during the entire journey until he arrives at the final destination where he exits the cabin. The customer can either use the cabin by himself or share it with other persons traveling with him (e.g. traveling groups on leisure journeys). During the journey, the cabin itself performs various docking and undocking processes from one means of transport to another. Thanks to a universally standardized system, the cabin is compatible with the infrastructure framework of all transport modes. The customer does not actively participate in the docking processes, but can enjoy leisure time during the entire journey. The combination of transport modes depends on the distance traveled and is chosen automatically already during the booking process. The customer has no influence on this selection. However, he can select the travel group size, with the capacity of the cabin varying from one up to 60 passengers.

## IV. Conclusion

In this section, the major outcomes and findings of the foresight project are summarized. Finally, the foresight project and its results are evaluated according to the quality level achieved.

### A. Major Findings

As mentioned before, the actual foresight project ended with the identification and description of a set of scenario-specific high-level requirements and ConOps, leaving the compatibility check and requirements refinement phases for future work. However, a brief comparison of the three scenarios and their associated results is provided in this section to enable a broader view on the major findings of the project.

In all of the three scenarios, the trend towards more personalized travel needs of future customers is well apparent. Two different key customer groups were identified: elderly travelers going on trips to satisfy their individual needs for leisure activities, and businesspersons who travel because of professional duties. Elderly customers are more likely to travel in small groups instead of traveling alone. In addition, they are rather flexible with regard to trip constraints (e.g. required travel time, schedules offered). The opposite is the case for businesspersons.

According to the environmental analysis we conducted, political influence on the mobility sector, income disparities, and costs of energy are the main drivers that determine the future way of traveling. We will probably see a continuation of the consolidation process of the air transport market that is going to be dominated by only a few big transport companies. Furthermore, the scenarios demonstrate that the energy imperative is strongly linked to the success of technological development.

Looking at the high-level requirements corresponding to the three scenarios (Table 2), one can find it quite hard to compare the results achieved. This is mainly due to the different aggregation levels of the requirements. While some are defined according to a specific product solution, others stay at top level. Common to all scenario-specific results is the need for personalized transport solutions being addressed in the requirements lists ("free choice of transportation mode", "fulfillment of personal desires", "realization of door-to-door journeys in Europe within 3.5 hours for 95% of EU residents"). Other requirements are those addressing the needs of the key customer groups ("age-appropriate systems", "reduction of stress during the entire journey") and issues regarding the safety and security of the products involved in the transport chain.

The developed scenario-specific ConOps describe

- in scenario A, the operation of small, fully automated aerial vehicles that are part of a highly interconnected global traffic network,
- in scenario B, a travel seat that carries the traveler from the departure point to the destination, and
- in scenario C, a travel cabin that the traveler stays in during the entire journey.

It is evident that the technical principles of ConOps A, B, and C are very similar: a system of small vessels is described that autonomously combines different transport modes without the traveler's interference in order to seamlessly move the traveler from one point to another, based on his individual travel needs.

### B. Evaluation of Proposed Product Development Approach

The results obtained at the end of the foresight project consist of (1) the description of three alternative future scenarios of the world in 2050 with focus on the air transport sector, (2) the derivation of high-level requirements corresponding to the scenarios, and (3) the development of scenario-specific concepts of operations. The scenario descriptions provide useful hints to think about different perspectives of a more personalized future air transport system. Relevant environmental factors were identified and their potential future states were defined. We therefore conclude that the main goals of the scenario development process were achieved.

However, looking at the definitions of the scenario-specific high-level requirements and the corresponding ConOps, a lack of quality and usefulness is rather obvious. E.g., the high-level requirements are not always addressed at the same aggregation level, making it impossible to check them for compatibility over all three scenarios. Some of them actually cannot be considered as requirements making statements at "high-level." In addition, they are not defined with a satisfying degree of precision, which leads to some overlapping of the meaning of one requirement and another. Furthermore, some requirement definitions imply technical solutions or approaches, although they should have been described in a solution-neutral way. The ConOps descriptions can only partly be considered as user narratives that describe the operational characteristics of the transport system from the end user's perspective. Instead, the ConOps developed here consist of a mixture between descriptions of travel experiences, market characteristics, and technical solutions that may or may not satisfy the traveler's needs.

The project presented in this paper was the first of its kind that we conducted at our institute. While we had gained broad experience in applying scenario planning techniques in earlier projects, we did not have any experience in integrating these techniques into a product development and requirements elicitation process at the time when we started the project. However, the project presented here provides evidence that there are interesting fields and potentials to explore in future projects.

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