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Theoretical framework of systems design for the air transportation system including an inherently quantitative philosophy of scenario development

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ABSTRACT

This paper provides an overview of an inherently quantitative scenario philosophy for systems analysis and innovative concept design in the context of the Air Transportation System (ATS). A general perspective of the ATS is visualized in an “atomic model” with surrounding external scenario factors and the aircraft as the key connecting element between the main stakeholders: manufacturers, airlines, air navigation service providers (ANSPs) and airports. An iterative waterfall model is presented, which serves as a mental model of integration and decomposition over cascades of levels of detail from global scenario level to a single technology. The difference between classical scenario technique and a quantitative, yet participatory methodology of developing scenarios for the ATS is described. In order to integrate and decompose over a large span of levels of details, concept design and synthesis is as important as analysis. Further, quantitative scenario development may be considered as the synthesis of a skillful manipulation of a model deck. Scenario Gaming can be a method to simulate the settlement on requirements of complex socio-technological systems with multiple stakeholders and conflicting perspectives under radically changing boundary conditions. Scenario thinking can be an innovative and explorative instrument of participatory futurology, if not reduced to a mere “input for a tool chain”.

1. General introduction

Previous research on scenario development in aviation science was mainly focused on qualitative scenario technique, quantitative technology assessment for preliminary aircraft design or attempted to link these two concepts in a sequential way as in Strohmayer (Strohmayer, 2002) and Phleps (Phleps, 2011). The theoretical framework presented in this paper is meant to encompass an approach and a view on the ATS which enables us to integrate previously disjointed theories, approaches and partial solutions into one overarching theory. The theoretical framework for systems design including systems analysis of the ATS and concept design with an integrated approach to participatory futurology is fundamentally different from approaches that can be found in the works of Meussen and Becker (Meussen and Becker, 2004) (Meussen et al., 2008) as well as Eelman (Eelman, 2006). As an instrument of choice for participatory futurology we use scenarios. Herman Kahn, as a founder of modern term scenario, defined scenarios as “hypothetical succession of events with the objective of drawing attention to causal relationships and working towards decisions” (Kahn and Wiener, 1968) (Pillkahn, 2007). Classical scenario technique based on consistency matrices inherently lacks the quantification which is required by systems and aircraft designers. Quantification is also needed in order to conduct systems analysis for socio-technological planning on ATS level. We present a way of building “inherently quantitative” scenarios for the ATS as whole. The goal is a systematic and consistent framework for the ATS which is sufficiently abstracted in order to model and organize (in the ideal case) every possible research question concerning the ATS. To think the ATS as a whole does not mean to think *every* detail at once, but to understand the main driving interrelationships between stakeholders and external scenario factors. Because every systems analysis is different, a flexible framework is needed. This can only be realized by an extreme form of abstraction. Previous approaches using scenario methods in preliminary aircraft design (Strohmayer, 2002; Phleps, 2011; Meussen and Becker, 2004; Meussen et al., 2008; Eelman, 2006) were almost exclusively based on sequential

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thinking with a quasi-linear process. During our research we gained the insight that this way of thinking is problematic for various kinds of questions which could not be answered satisfactorily. It was not possible to integrate partial analyses, models and design studies in a plausible way into the big picture we actually wanted to produce. The framework presented in this paper is highly non-linear as well as iterative in order to deal with complexity. On the one hand, the complexity is resulting from the long-term scope of futurology with the related timeline dynamics of scenario parameters. On the other hand, the scenario methodology needs to cope with great mental leaps from one level of detail to another, i.e. from single technology to the entire socio-economic system of the world and vice versa.

2. General view on the ATS

The "atomic model" of the ATS (see Fig. 1) is a visualization of the core ATS consisting of the set of manufacturers, airlines (or aircraft operators in general), airports, and air navigation service providers (ANSPs), namely the 4-stakeholder model as described in Weiss et al. (Weiss et al., 2011). Within each stakeholder group, greatly different aspects like sub-elements, processes and infrastructures are consolidated. The 4-stakeholder-model is one perspective on the core ATS and ATS-specific internal interactions. Surrounding external scenario factors (Housing Industry Association of Australia (2011)) whose changes may influence the structure of the ATS (e.g. how aircraft are designed) or who may be influenced by a change of the ATS are depicted orbiting the core ATS. In one single analysis, both ways need to be considered. For example, a change in politics and technology may lead to changes of the core ATS and thus, the change of the ATS influences the environment in a positive and/or negative way.

Two main ways of exploring interrelationships of future changes between ATS core and external scenario shell are conceivable:

1. Impacts of hypothetical alterations *of* the ATS on external scenario factors over time.
2. Impacts that hypothetical alterations or goals of external scenario factors will or should have *on* the ATS over time.

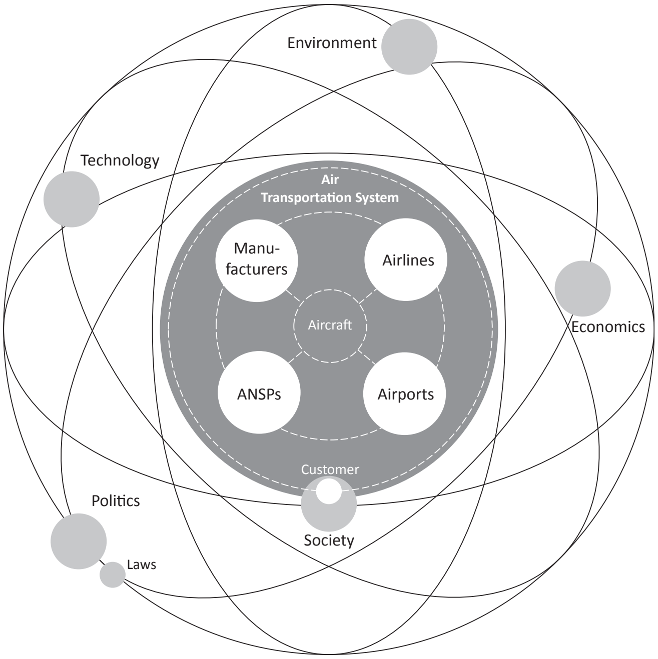

Fig. 1. "Atomic model" with the four core stakeholders, the aircraft as the connecting element, and external key scenario factors including the customer.

The aircraft may be understood as the key connecting element between stakeholders. But stakeholders may also interact independent of aircraft, for example if only airports and airlines discuss the evaluation of technologies that potentially enhance the service level at a hub. Thus, stakeholders can also be analyzed reclusively or in interaction with other stakeholders without the aircraft as the connecting element.

The aircraft manufacturer produces an aircraft with specific characteristics (flight performance, alternatively fueled, special maintainability, aircraft dimensions, passenger comfort, etc.). Future characteristics are settled upon with other stakeholders who impose constraints and requirements on the future aircraft from their perspective based on a given scenario. Note that in a future context (and to open the design space for innovative thinking), today's constraints and requirements may not apply in the future. In order to conduct innovative research, it may be even necessary to willingly ignore current constraints and requirements and "act as if" they did not exist. In order to design a useful scenario it may be also necessary adding new potential constraints to a static or dynamic scenario storyline,[1] even if it is not certain that they will be implemented. For example, we presuppose that a global climate target must be achieved or that peak-oil exists. We explore from that point in what way core stakeholders would be affected and how a holistic solution in such a scenario may look like. Under the postulated conditions, it then should be elaborated what key technologies at what performance figures would be needed to cope with the challenges of a scenario. Useful dynamic scenarios, which can be interpreted as chains of events, need a point of substantial change in their storyline, thus at least one key decision point. For the generation of decision scenarios it is favorable to act if one could change all parameters radically from a fictive omnipotent perspective. This includes the fictive implementation of global policies, the radical change of airport infrastructure as well as technological parameters (e.g. progress in battery technology enabling electric flight). Thus, it is helpful to act as the "principal engineer" or "architect" of the ATS, when in fact there is none, since it is de facto a self-organized complex system. This favors to elaborate the key decision points instead of relying on passive reactive analysis based on a forecast with an "incrementalist" mental model of the world. Following iterations of harmonizing between analysis and synthesis, goal setting and intermediate decisions, this will eventually end in the definition of requirements for e.g. aircraft design or airport concepts. This procedure will lead to a successive settlement on cost and performance requirements for single key technologies to make those very concepts work.

In Fig. 1 the customers are highlighted since transport demand is created by them. This can be customers of air freight or passengers. The customers are the reason why the ATS exists, but they are not deciding what kind of aircraft to buy or if the aircraft needs to fit into an infrastructure. This means that the customer is not involved in direct design or technology decisions of systemic relevance. The customer is *indirectly* involved in those decisions, but with no less importance to the ATS. Taking comfort as an example, passengers transfer their need for comfort through their choice to buy a ticket of a certain price, of a certain airline with a certain comfort proposition, but they will not negotiate with the manufacturer about seat pitch. Customer needs are indirectly connected through an interim stage over the airline or the airport

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[1] A definition of static and dynamic scenarios is given in Section 4.3.