AN ENHANCED SCENARIO APPROACH ASSESSING UNCERTAINTIES IN THE REALIZATION OF NEW AIRCRAFT AND TECHNOLOGIES

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Abstract

The successful definition and realization of aircraft and its technologies is imposed by many factors, which are hard to foresee or to control due to their complex and dynamic, often competitive environment.
Traditional scenario methodologies allow a-priori to assess these uncertainties by creating relevant scenarios to derive alternative conclusions and recommendations. However, they have deficiencies producing and visualizing dynamic behavior of the influencing system and fall short to highlight scenarios of higher-than-average quality and value, which restrains the ability to address uncertainty.
The presented enhanced scenario approach addresses this need with a technique to generate scenarios stepwise into the future obtaining system dynamics to understand the driving developments. It uses integrated indicators for results and implications to improve qualities of scenario characteristics and significance.
Results of a sample process demonstrate evolutions over time and scenario specific profiles of descriptive indicators.

1 General Introduction

Foreseeing long-term evolutions of market, product or technology environments surpasses the capabilities of methodologies based on quantitatively exact, model orientated methods. Especially in pretended steady environments, unexpected changes cause a high degree of disorientation and lead to costly deviations, if the originally planned path into the future has to be left without alternative strategies at hand.

1.1 Scenarios as Methodology

Real developments are not exactly to predict and, thus, underlie uncertainty. Uncertainty can be divided into events or occurrences, for which no probabilities can be assigned (unknowns), for which probabilities can be subjectively assigned, if this is tolerable, and for which probabilities are objectively assigned, for example by statistics. The latter two are also referred to as risk.

Dealing with this uncertainty, Hermann Kahn's future-now thinking in the 1950's and 60's introduced a combination of analysis and imagination to give a view on the future, motivating the expression "Scenario". Later, the oil shock and rapidly changing environments in the 1970ies marked the breakthrough of formalized scenario processes as a holistic approach to address strategic uncertainty. These considered both qualitative factors setting up systems and the dedicated creation of multiple futures to cope with uncertainty in a way of "what-if"-thinking. The method proved its worth at companies like Shell, that used scenarios already years before the oil crisis and pushed itself on the world top by having answers on the changed environment earlier at hand than its competitors. Breaking past mental blocks and thinking in alternatives were the key advantages over the one-dimensional path into the future. Nowadays, scenario techniques are adopted in larger scale to support strategic planning and evaluation processes. They are increasingly integrated in technology and project evaluation and provide references for product definition and development [1].

1.2 Some Aircraft and Technology Issues

Successful realization of new aircraft technologies into serial applications depends on many different factors. High uncertainties exist during the first technology life cycle phases regarding, for example, the evolution of the potential and complexity of the technology itself, the definition of robust requirements to comply with market needs or the bandwidth of aircraft for integration. Multidimensional and dynamic influences increasingly complicate the prediction of the growth path of a new technology. The US General Accounting Office GAO [2], for example, schematically grades the gap between the performance of a technology in development and the product requirements it has to meet using technology readiness levels (TRL) and assigns risk levels.

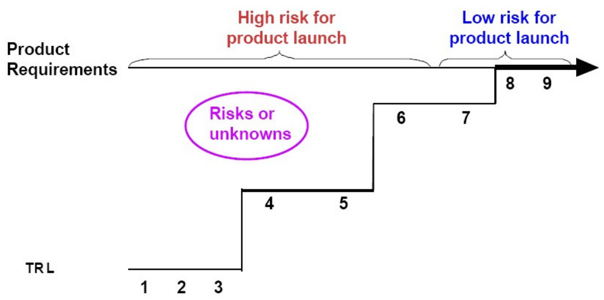

Fig. 1. Requirements, Risk and Technology Readiness

Once in service with TRL9 maturity, technology life cycle periods even go beyond that of aircraft programs, as they establish the technological platform for design. As for aircraft programs, supporting new technologies against the background of changing market environments, regulatory restrictions or customer preferences impose considerable and additional risks, since impacts from these external developments can hardly be controlled by the developing companies' internal decisions.

To systemize the relevant influences on the realization of technologies and aircraft, a schematic model from a system integrator's point of view is presented for further discussion. It shows the generic evolution of a new technology from TRL 1 to TRL 9 through different, but dominating environments, in which the TRLs have assumed positions. The basic, overall Macro field represents the general environment which considerably influences all other areas with factors as for example economic growth, energy prices or regulations. Herein, four Meso fields and two Micro fields are located. Meso 1 covers factors from the air traffic market environment, like air traffic growth, airlines business models or network structures. Meso 2 is the OEM & supplier environment in which factors like OEM technology strategy, competitive situations or supplier structures reflect the surrounding manufacturers' markets. Meso 3 defines the product environment with aircraft related factors such as technology standards, aircraft requirements or product strategies for existing and new aircraft. The field is strongly influenced by the Macro, Meso 1, 2 and Micro environments. Dedicated technical topics like aircraft size, system architecture or standards are a focus as well. Similar to the product environment, the Meso 4 field puts the research environment in context and interaction with the other fields. Influenced from these areas, it establishes the conditions for research with factors as research quality and efficiency, patent situations or research funding.

The Micro 1 field represents the given company environment, in which internal and external factors affect the realization of technologies and aircraft. These can be the long-term company's normative, operative and strategic targets, risk & revenue sharing or availability of resources. Decisions taken here are focussing on strategic and tactical measures necessary to prevail in the competitive struggle.

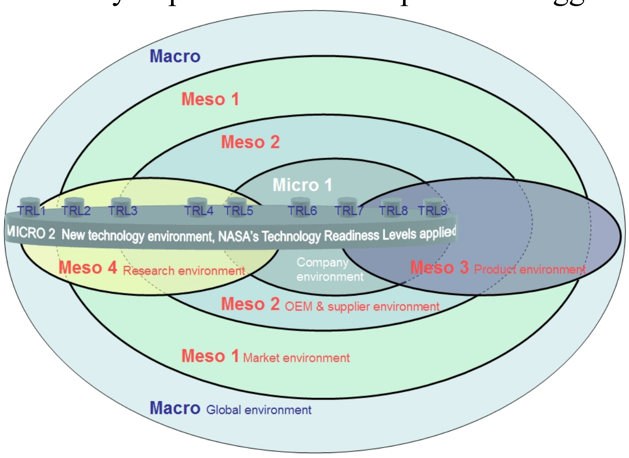

Fig. 2. Schematic of Influencing Environments

Micro 2 encompasses the environment of a dedicated new technology, which is brought forward by research and development aiming for the deployment in defined aircraft. It travels through the research environment via the company into the product (Meso 3), interacting with all other fields as well at a given time. Factors herein deal for example with the technology potential, bandwidth of applications or maturity of critical subtechnologies. With this model, the respective fields reflect the influencing environments a new technology passes in its evolution to turn into an innovation.

In this way, the schematic supports the selection of factors to arrange the relevant system to build alternative scenarios upon and derive specific conclusions and implications to answer questions regarding strategic uncertainty.

1.3 Current Scenario Approaches

To build scenarios several approaches are available. To analyze the differences, a general phase model of the overall scenario process is given which highlights the phase where single scenarios are generated according to different techniques. The model covers most current phases within scenario approaches.

Phase 1 contains the analysis and definition of the problem, including the selection of a time horizon. Phase 2 investigates and builds the relevant environment (for example according to the proposed schematic of figure 2), searching for key influencing factors and selecting them according to dedicated qualities. Phase 3 details the selected factors and defines plausible, alternative projections, which are the possible developments of each factor respectively (see figure 6). In Phase 4 these are put into correlation with each other, which can be realized either with an intuitive logic or a more tool based approach. Latter uses consistency or cross-impact matrices supported by computer tools, linking all possible combinations by numeric formalisms. Partially, cluster algorithms are used as well. According to the logic chosen, scenario frames are generated consisting of one defined future projection per factor each. On the basis of the frames, scenarios are written to address the future environments of the defined problem. Phase 5 derives relevant conclusions and implications from the scenarios and transfers it to subsequent processes like strategy planning.

The approaches can be classified in a first step according to their dependence on (computerized) tools.

On the one hand, representing nowadays the largest fraction of scenario processes without the assistance of tools, Intuitive Logic was pioneered by Stanford Research Institute SRI and Shell using a systematic and formalized approach.

On the other hand, current mainstream tool-based approaches use logics of consistency or cross-impact relations and mostly are computer-aided to deal with the complexity of the system. They became widely accepted in the 1980ies and 90ies.

In this paper, the proposed enhanced scenario approach is tool based. For this reason, the characteristics of two basic tool-based techniques in producing scenarios using consistencies or cross-impacts are shortly outlined to subsequently lead over to the specifics of the enhanced approach.

1.4 Scenario Generation Techniques

Consistency based approaches decide by pair-wise comparison of projections in the consistency matrix how well they can coexist or cause a consistent relationship. Early approaches were pioneered by Zwicky at the California Institute of Technology (CalTech) as a method for structuring and investigating the total set of relationships contained in multidimensional, non-quantifiable, problem complexes [3], known as Morphological Analysis (MA). A large number of different and highly consistent scenarios can be generated in that way with good acceptance of results by decision makers due to the outstanding performance of the technical quality indicator "consistency". In the German speaking regions, von Reibnitz and Geschka followed and introduced this approach at Battelle in

Frankfurt, which used the consistency based logic here, and spread it after having left Battelle. Probabilities to quantify projections can be used to assist the processes based on MA, but in general, they are not processed within the generation of scenarios. Consistency based MA is not designed for system evolutions, as system causality is quasi non-existent, offering only rudimentary possibilities for computation of time series of scenarios. As a static approach, its logic creates scenarios which are aiming to reflect the situation at the defined time horizon. Ways to and beyond this point are subject to interpretation backed by the experts' feeling and experience.

Cross-impact based approaches (CI) generate its scenarios by reflecting the causal interrelations between the projections of different factors. Depending on the specific practices, the positive and negative influences of projections on other projections are noted in a large cross-impact matrix (CIM, see paragraph 3). Two basic techniques are to be mentioned, upon which various derivatives have been developed.

The first, BASICS (BAttelle Scenario Inputs to Corporate Strategies) developed by Battelle, works with cross-impacts which transform a-priori-probabilities of projections into a-posteriori-probabilities by a mathematical function. For every factor, the projection with the highest a-posteriori probability per factor is selected to build the scenario frame.

The second on the contrary, KSIM [4], is not using probabilities as a selection criterion, but directly combines cross-impacts of projections from the CIM by summation of their CIM values in a linear way and selects the respective projections according to the highest sum. Both algorithms are capable of creating multiple futures, but latter is able to produce successive time layers as a time series development of scenarios. One of the latest approaches using the KSIM language is described in the Cross-Impact-Balances analysis of Weimer-Jehle [5] at the University of Stuttgart, Germany.

Other methodologies use cross-impacts for purposes other than creating scenarios. As an example, Godet's MICMAC[1] approach identifies key variables by processing influences and exposures of a factor in a system through cross-impacts. With an elegant mathematical operation of CIM multiplication it considers all indirect impacts of second and higher order of a factor as well and, thus, is able to identify the indirect active and passive forces in a dynamic system, which become only recognizable if the system evolves (see paragraph 2.1). As a helpful and important input, this is frequently used by CI and MA to categorize factors for their true impact potential.

1.5 Critical Review of Techniques

However, established scenario techniques are not free from critics. Liebl states that commonly practiced approaches are not able to deal with complex developments and trends, identifying blind spots especially in the handling of inconsistencies [6]. This means that current techniques aim for highly consistent scenarios and run the risk to possibly "ignore trends transgressing boundaries and contexts". This is caused, since scenarios with a too high number of inconsistencies or just too low consistency levels are ruled out by definition in most approaches. This fact is imposing a high additional complexity onto the selection of relevant scenarios. If surprising, but relevant combinations are not detected, decision making is influenced considerably as a consequence. Especially for systems going through phase changes this is an important point to be addressed.

A further issue of shortcoming is interpreted from Mietzner and Reger, who accentuate the need to distinguish between scenario content and process quality. Consequently, it is demanded to develop a stronger evaluation capability for this purpose [7]. Classic technical quality indicators, however, are mostly only based on scenario consistencies conflicting with Liebl's concern above.

[1] MICMAC: Matrice d'Impacts Croisés Multiplication Appliqués à un Classement [11]

2 The Enhanced Scenario Approach

According to the short review of some existing scenario generation techniques mentioned above, desired scenario qualities can be directly derived. They define the requirements for an enhancement of the current methodologies to support the notion and anticipation of strategic uncertainty.

Environments are increasingly understood as highly dynamic, which influence and drive the subsystems of corporate, market, product or technology developments, in which the realization of aircraft and its technologies is embedded. Therefore, it is adequate to favor a dynamic scenario generation technique which can contribute to an improved system knowledge, understanding and, thus, scenario acceptance.

Also, it seems necessary to put an even stronger emphasis on efficient, quantitative analysis and visualization of scenario results, which can be achieved by enlarging the scenario base for numeric and statistic analysis.

Together with integrated, descriptive indicators reflecting system states, scenario results can be improved and communicated in a clearer way (see paragraph 3.5).

The mathematical techniques of the enhanced approach are based on the Evolutional Cross-Impact-Analysis, which is described in more detail in [8]. In this paper, the relevant steps are presented to offer a comprehensive view of the logic in the enhanced approach.

2.1 Methodical Solutions

Based on the above general requirements, the key functions of the enhanced approach comprise:

- evolution in discrete steps (Time Intervals (TI's), see figure 5) for system development
- high number of scenarios (some thousands) to provide the base for clustering and the sample for statistical analysis
- consideration of the relevant factors driving and initializing the system
- logic of single scenario generation similar to Battelle's CI logic, but with simultaneous and multiple processing of impacts
- cluster algorithms for scenario bundling
- visualization of total system, cluster, factor dynamics and technical indicator performances
- output of selected descriptive indicators enhancing scenario contents

To provide the methods of the technical solutions delivering the above functions, the core scenario generation process has to be defined and explained in order to understand the background and relationships in the enhanced approach.

2.2 Phases and Procedures

In general, the basic structure is similar to other scenario methodologies. Slightly aligned from the phases presented in paragraph 1.3 the phase model according to figure 3 points out the successive steps. In the following, the whole process is specified with its actions.

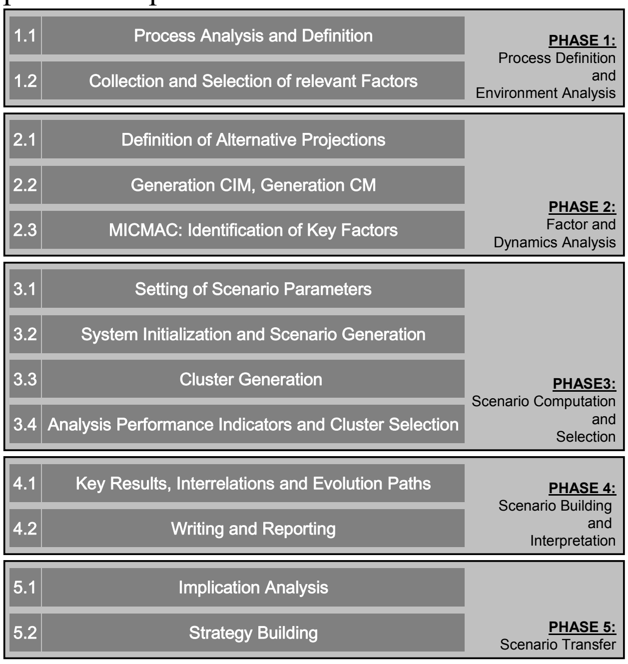

Fig. 3. Phase Model and Major Steps

Phase 1 analyzes the problem and defines the project (1.1) by topic and time horizon. In the environment analysis (1.2), relevant factors are collected and numerically rated according to their assessed uncertainty and impact in the system. Manual classification selects the desired number of factors with the highest impacts and uncertainties, defining these to be so called descriptors or variables. Phase 2 defines the alternative projections for the identified variables (2.1), which in general is 2 to 4. For every projection of a factor the a-priori probability is defined, analyzed or assumed according to expert opinions, surveys, analysis of time series or other statistics. With the projections, the CIM can be developed bringing all projections into relation with each other (see figure 6, compare to [1]). To evaluate the generated scenarios for their level of consistency later on, also a consistency matrix (CM) is generated. With a special logic, the CM can be derived from the CIM (2.2). With the CIM, the direct influence (activity) and exposure (passivity) potential of the variables is derived and plotted into the system dynamic grid of figure 4. In this way, the system relevant drivers can be identified. However, as the enhanced approach is performing multiple steps into the future, referred to as Time Intervals (TI), indirect influences are gaining on importance considerably.

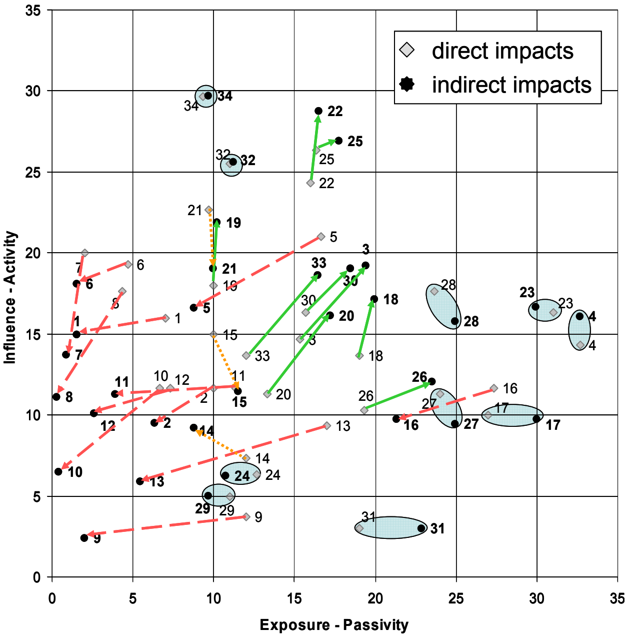

Fig. 4. MICMAC: Dynamics with Indirect Impacts

To still identify the correct dynamics of the variables, the MICMAC method captures the indirect influences and exposures (see paragraph 3.2).

The scenario parameters controlling the generation of the scenarios are defined subsequently. These are the number of TI's of the scenario evolution (3.1) and the driving variables for system initialization as well as some other technical parameters, which are not explained in detail here (see [8]).

The system initialization (3.2) with selected driving variables from the MICMAC result directs the creation of respective scenario starting points and so the total number of scenarios. It is realized by determining all possible combinations of projections of the selected driving variables and setting each as a unique starting point. As an example, if 8 driving factors were identified with 3 projections each, a total of $3^8 = 6561$ scenarios would be set up. Each of them develops uniquely stepwise until the predefined number of TI's (see figure 5). Obviously, the number of driving variables is limited to 10 to 12 due to computer power, memory space and consequently computing time. Thus, the selection of driving variables is of high importance. In contrast to most other CI methods, the inconsistency of using starting points with little or no influencing potential on the system is eliminated here. As an example, to generate scenarios upon the strongly driving variable 22 (see figure 4) is vital, whereas variable 9 is so inactive in the system, that additional scenarios shouldn't be initiated from this point.

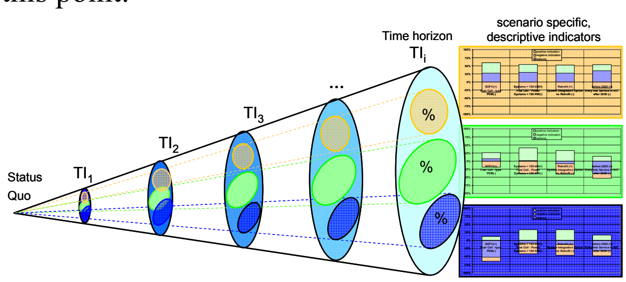

Fig. 5. Evolutional Cross-Impact-Analysis

The high multiplicity of scenarios makes a manual selection of relevant scenarios impossible. Therefore, a cluster algorithm has been developed, which determines according to the dissimilarity of each scenario how to bundle similar scenarios together (3.3) into a small number of clusters. These are then manually selected (3.4) for their both content and technical quality. The content quality is analyzed to meet qualitative issues like applicability, anticipation of the defined problem or dissimilarity, whereas technical aspects have to comply with technical indicators like scenario frequency, probability, consistencies or system evolution characteristics over TI's. Latter is to be analyzed, as a plausible and coherent system dynamic supports the elaboration of scenario stories and process reports (4.2) for the defined time horizon. Based on the produced results, the descriptive and technical indicators at hand as well as the reasoned scenario writing, implications for the given problem are derived and classified throughout the selected scenarios (5.1). As a final step, the total package of results from problem analysis to implications is post-processed to form the basis for a clear strategy input (5.2) and further technology management methods like [9].

3 Specifics of the Approach

3.1 Systems Thinking and CIM Notation

Scenario methodologies are often applied for complex problems, a fact which strongly recommends the use of basic principles of systems theory. In the following, the fundamentals of systems theory are adopted for the CIM notation.

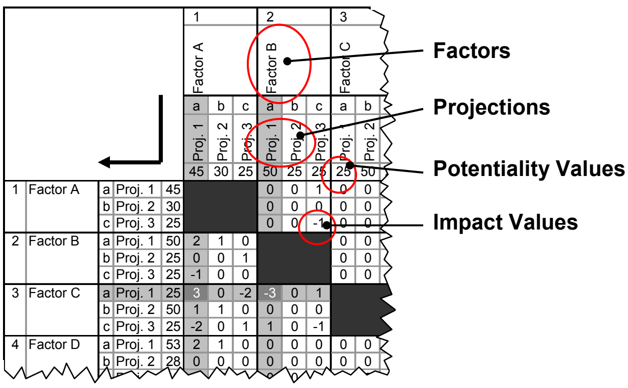

Fig. 6. CIM – Element Notations

The core of the systems theory is to study systems as a whole, but analyzing and decomposing them in their sets, elements or parts, states and interrelations. The arrangement of elements and relations defines the system structure. Considering this in the CIM, all factors with their projections are regarded as elements and are arranged in rows and columns to allow relations to one another (see figure 6).

Each projection is defined as possible development of a factor and the state of a projection is its Potentiality Value (PV). The PV of a projection is defined as a probability like value, which indicates the potential of a projection to occur, ranging from 0 to 100. All PV's summed up per factor are exactly 100, which denotes the correlation to real probabilities in percent. The interrelations between the projections are represented by Impact Values. As a unidirectional impact only, a column projection of a column factor influences all row projections of row factors by the respective Impact Values in the CIM. Negative Impact Values decrease the PV of a projection whereas positive increase it. The Impact Values range from -3 to +3, decreasing or increasing the original PV's.

For the first TI, the PV's are equal to the probabilities, which are derived from statistic analyses, for example. Through the evolution of the system into higher TI's, however, the nature of mathematically exact probabilities is not maintained any more. Still having the character of probabilities, PV's are classified as a-priori PV before system interactions take place and a-posteriori PV after the system interactions in a given TI.

During the generation of scenarios, no other factors or projections are in- or excluded to stay within the defined system. Only for the integration of wild cards or predefined developments, system boundaries are aligned to obtain the relevant conditions. This can be realized by adding factors in the CIM or manually setting dedicated projections to occur over several TI's (see paragraph 3.4).

3.2 MICMAC and Driving Variables

The knowledge of the indirect influences in a system is vital to indicate how strong a factor impacts the system over multiple TI's.

MICMAC is a good method to select the driving factors for scenario initialization.

By summing up the absolute Impact Values of a factor per column in the CIM, its value for activity (influence on others) is derived. Likewise with rows, its value for passivity (exposure from others) is derived. Combining both values for each factor in a so called system dynamics grid establishes a classification showing the activity and passivity profile of a factor in the system. This method, however, only considers the direct, first order influences (see figure 4, rhombs). According to Godet's MICMAC approach [11], the analysis of indirect system dynamics (2.3) is analyzable as well. By multiplication of the CIM with itself, a new matrix is created which entails the first order indirect influences, which for example is an influence of variable A on C via B. Similar summation as before and normalization to fit into the existing system grid displays the variables with indirect influences. Further multiplication of the new matrix with the original CIM delivers the second order indirect influences (e.g. A on D via C and B) and so on. Variables are for every loop ranked according to their activity and passivity value. Loops are performed until the ranks of activity and passivity of all factors is not changing any more (mostly around 5 to 7 loops). This marks the end of the MICMAC analysis. However, the system dynamics grid in general has significantly changed for around 20% of the factors, assigning a different activity and passivity profile to the system. Every MICMAC loop can be compared with one TI, which means that the scenarios have in general 5 to 7 TI's to evolve before the full nature of the system complexity is visible.

The system dynamics grid for indirect influences (see figure 4, bullets) illustrates that the factors 19, 33 and 20, for example, are obviously underestimated in their activity in the system after multiple TI's. If one would choose these according to their direct activity, it is clear that without MICMAC the wrong system initializations would have been made, causing that scenarios generated do not fully reflect the relevant systems behavior.

3.3 Scenario Generation Technique

After having identified the initializing variables, scenarios are generated according to the logic of Evolutional Cross-Impact-Analysis [8]. With the cross-impact model as fundamental technique, all projections are processed by the alignment of the respective PV's within one TI at the same time.

The a-posteriori PV's for the current TI are the a-priori PV's for the next TI. This process is repeated until the defined number of TI's is reached. For all other initialized scenarios, the procedure is equal. Thus, every scenario starting point (3^8 in the example) evolves with one scenario frame at every TI and has been calculated from its preceding TI. Hence, the system can be tracked step-wise into the future, reflecting the dynamic behavior of the analyzed system. The evolutional model enables the processing of parallel impacts in one TI and serial impacts over several TI's. The multiplicity of impacts from the CIM together with the necessary evolution over time causes feedback of influences resulting in developments that experience gains, dampings and cycle developments by variables in the system. A-priori defined probabilities have a major influence on results and evolutions.

As a natural behavior of complex systems, scenarios are heading towards attractors during the evolution, which are robust states in the system. From the original number of different scenarios only a share remains different, which is measured by the level of convergence (see paragraph 4.1).

3.4 Disruptive Events or Wild Cards

A strength of the proposed approach can be seen in the adoptability of highly uncertain but disruptive events. These wildcards can be introduced in the CIM easily, for example, as new variables with only one projection, quasi as premise. The modification concerns only steps 2.1, 2.2 and 2.3 of the phase model in paragraph 2.2. Under the new conditions, the entire process of scenario generation is performed again. The most powerful scenario cluster based on the wild card can be compared to all other before identified scenario clusters to conduct a sound "what-if" analysis. With the step-wise scenario evolution over the TI's, the response of the system to a disruptive event can be analyzed. Phase changes of factors (see paragraph 4.1) allow assessing the time delays of certain developments within the system and, thus, its criticality.

3.5 Integration of Descriptive Indicators

To obtain more information about the development of single issues, descriptive indicators are embedded in the CIM. These are additional factors, which are only passively influenced by the projections of the regular CIM-factors. They are noted in the CIM equally as the other factors, but do not have an active impact on or feedback in the system. Consequently, they are only noted as row factor (compare to figure 6). Descriptive indicators can be selected and defined to build up subsystems, which are of interest. For example, to identify if the conditions in a scenario would support a realization of a dedicated technology, one could define a descriptive indicator "Entry into Service until 2015". Column projections with positive Impact Values on this indicator in the CIM would give signs that the goal can be reached, whereas negative ones would inform that conditions are difficult. Together with other indicators, complex issues can be derived directly from the scenarios in a quantified way and internal developments are recorded. First conclusions about the sensitivity of system specific developments are extracted and visualized in this way. Additionally, scenarios can be selected and clustered according to a relevant or required indicator profile.

Indicator models implemented in a similar way will produce comparable results to the generic one presented hereunder, so that the exact mathematics behind it is not described.

In general, after a TI of a scenario has been calculated and the winning projections are selected according to the highest a-posteriori PV per factor, only these column projections change the values of the descriptive indicators.

Descriptive indicators can have values between -100% and 100%. They start with an initial value of 0%. The score of an indicator after each TI is calculated by separately summing up all positive and all negative Impact Values, which influence the indicator due to the winning projections of the CIM, and balance them. Hence, the respective Impact Values increase the initial 0% indicator value, if it is a positive influence on the indicator, or decrease the value, if it is a negative influence. The visualization, however, shows both the positive, negative and balanced score to create an objective overview of the indicator (see figures 9, 10 and 11).

4 Results from a Sample Scenario Process

4.1 General Results of the Evolutional Cross-Impact-Analysis

The methodic proposed in this paper has been applied to a scenario process dealing with the realization of fuel cells for commercial aircraft up to the year 2020 [10]. Focus of the project was to identify which fuel cell types and applications would be opportune dependent on alternative developments in aircraft, technology, markets, global and other environments. The process served as sample to evaluate the results with regard to content and technical quality. Without presenting details, the major findings visualize the quality of results.

The inputs and settings of the process are summarized in table 1. According to the environments of the schematic in figure 2, relevant variables were selected to mirror the technology push and pull factors which drive the development of fuel cells in commercial aircraft.

Number of variables	34
Number of projections	101
Number of initializing factors	8
Number of generated scenarios	4374
Number of formed scenario clusters	3
MICMAC required number of TI's	6
Effective number of TI's	8

Table 1. Scenario Inputs and Settings

The a-priori probabilities of 17 of the in total 34 variables were derived from experts within an undisclosed survey conducted for this purpose. One variable was analyzed statistically whereas the rest were assumed by the scenario core team. To obtain the full system dynamic developments, 8 TI's were performed, as the MICMAC analysis demanded for a minimum of 6 TI's. With 8 initializing factors, 4374 scenarios were generated.

Figure 7 gives an overview over all scenarios. The optimum consistency of 100% depicts the best scenario according to the consistency matrix (see paragraph 2.2), which is completely independent from any cross-impacts and, thus, is used as reference only. The general trend shows a steady improvement of average scenario consistency throughout TI's, which occurs due to attractors in the system fitting together consistently. At TI 8, it reaches 80%.

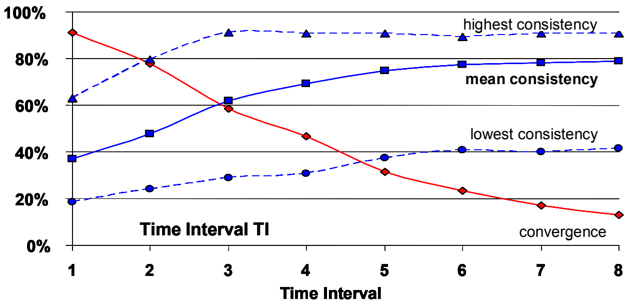

Fig. 7. Consistency Characteristics

Small inconsistencies prevent optimal consistence levels, but do not diminish the scenario credibility. This observation is underlined by true systems, which always contain a few partial inconsistencies. An example for this is the currently increasing oil price, which is partially inconsistent with the ongoing strong growth of air traffic and rising ticket prices. Especially dynamic system changes often produce inconsistent modes during transitions.

With increasing TI's more and more scenarios find robust and identical final states which are an indication of strong attractors in the system. It seems to be a characteristic of the enhanced approach that these attractors have good chances to develop in the given complex system. The behavior has been observed in other processes as well.

The results over all scenarios show non-linear, complex system evolution. From the 34 variables, three kinds of characteristics are extracted and visualized in figure 8. Emergence of projections was observed, in which a new system state (projection) occurred after several TI's. Oscillating as well as complete phase transitions showed which variables in the system evolved related to other impacts at a certain time. Also, the movement of the system towards attractors became visible. With these findings, scenario developments can be reasoned well.

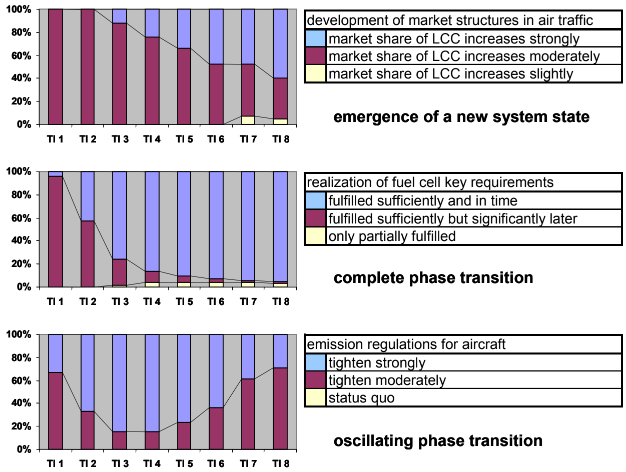

Fig. 8. Complex System Behavior

The behavior in single clusters is similar, but their scenario frequency affects how smooth changes and transitions occur. The fewer scenarios are bundled in a cluster, the more discrete the changes are.

4.2 Scenario and Indicator Results

Three clusters were selected according to content quality and a desired dissimilarity between each other (see table 2) to form the foundations for the three alternative scenarios "Go, Fuel Cell, Go", "Tie Break" and "Powerless".

Cluster	1	2	3
1		28	22
2	28		11
3	22	11	

Table 2. Dissimilarities Between Cluster

Depending on the defined cluster parameters, the scenario frequency within clusters ranged from a single one (extreme scenario) over a few dozens up to over 2000 for the “trend” scenario. The clusters consistencies were over 70 % and together with scenario frequency it underlined the scenarios’ plausibility.

Four descriptive indicators were defined to extract specific information for the given topic:

- Fuel cell type
- Fuel cell power range
- System integration (retrofit)
- Entry into service until 2020

Per cluster, a clear indicator profile was established, fitting consistently in the overall environmental conditions of the scenarios.

The scenario “Go, Fuel Cell, Go” has a positive research environment with technology leaps solving current deficiencies of high temperature solid oxide fuel cells (SOFC).

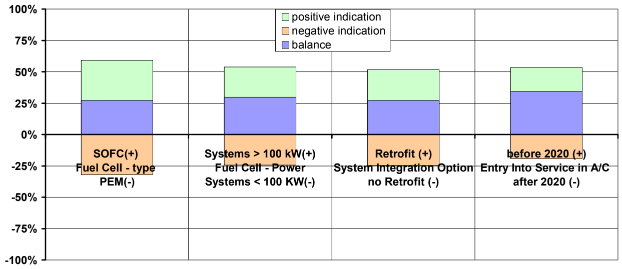

Fig. 9. Descriptive Indicators “Go, Fuel Cell, Go”

Aiming for larger fuel cell applications in aircraft with efficiency benefits, especially for small to medium sized long-range aircraft, is a driver, pushing the demand for retrofit systems of in production aircraft models and the earliest possible entry into service.

The scenario “Tie Break” describes a competitive environment, in which both conventional energy systems and new fuel cell technology fight a head to head race.

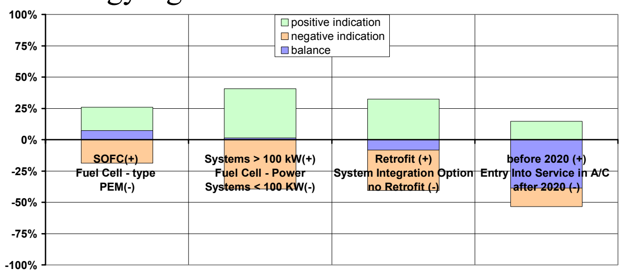

Fig. 10. Descriptive Indicators “Tie Break”

The fuel cells’ cost advantages for aircraft operators are not significant and hardly match roll-over requirements, which refer to the fierce competition between airlines and their business models. Still, due to environmental issues, the change to this technology is to happen in the longer term after the year 2020. Conditions did not favor the one or other fuel cell type. Also, the power range is undecided, since new aircraft architectures, undefined today, are to improve economics of maintenance and safety concepts.

The scenario “Powerless” develops a difficult environment for fuel cells to evolve in. Problems to realize serial SOFC technology turn into show stoppers, leaving the low temperature PEM fuel cell as the exclusive option. Shrinking research budgets for this technology prolong the planned road map for PEM fuel cells, limiting their bandwidth of application in aircraft to smaller systems. With operators demanding for higher reliability and lower complexity of aircraft, the entry into service of fuel cells is postponed after 2020 to comply with the technology readiness for the stricter customer requirements.

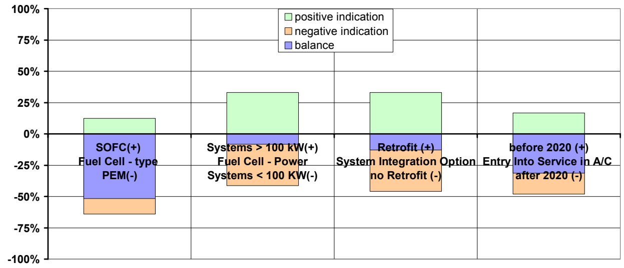

Fig. 11. Descriptive Indicators “Powerless”

4.3 Review of Paragraph 1.5

As the method is not designed to produce scenarios with the highest consistencies, but evolves for the most logical outcomes from a systems theory perspective, it does accept inconsistencies as long as these do not challenge the generated scenario. Thus, the concerns from [6] regarding effects on planning and decision-making are considered and with evolutional scenarios, especially the turning points of assumed steady developments are addressed.

Content and process are differentiated with the visualization of technical properties such as consistency, frequency and system evolution on the one hand and the respective descriptive indicators on the other. Scenario process characteristics in a broader sense are difficult to improve and largely rely on a sound process design. Descriptive indicators support the understanding of the content and can form an important interface to subsequent strategic instruments and processes.

5 Summary and Conclusions

A holistic and evolutional approach to produce scenarios for strategic planning is introduced. It combines and integrates established methodical standards and practices like MICMAC, consistence and cross-impact based approaches into one approach. The method relies on a novel, non-linear technique of generating single scenarios which are developed in discrete time intervals to reflect the complex and unsteady characteristics of dynamic, strongly influencing environments. The produced large sample of scenarios allows the identification of trends and extremes in a straight-forward way. Together with system inherent technical and descriptive indicators, clusters can be compared to each other. Especially descriptive indicators improve the understanding of scenarios and form an input to strategic instruments hereafter. From the schematic environments (figure 2), factors can be selected to establish the relevant system driving new aircraft and technologies, offering means to reduce strategic uncertainty.

Scenario processes are formed and filled by people who bring in experience and expertise as the backbone of every process. Together with the proposed method, future scenarios of decisive value can be developed herefrom to anticipate tomorrow's issues with today's decisions in a robust way.

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