KNOWLEDGE MANAGEMENT CONCEPTS FOR AIR TRANSPORT SYSTEMS ARCHITECTING

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Abstract

The capacity and performance of the Air Transport System (ATS) is one of the critical factors for the development of aviation. In order to accommodate the estimated demand, the capacity of the air transport system has to be increased considerably in the next years. In order to accomplish this, the architecture of the ATS has to be reviewed and adapted to the new requirements. Due to the complex nature of the ATS architecture, all system elements – infrastructure as well as procedures and aircraft – have to be taken into account. This complexity makes the application of analytical models difficult. A new approach for the evaluation and architecting of the air transport system is the application of principles from the field of knowledge management. Of central interest are findings about the processing of structured and unstructured data as well as the derivation of rules of system behaviour. These results are applied to the further development of the air transport system architecture.

1 Background

Most available scenarios project a doubling to tripling of aircraft movements until the year 2025. The current infrastructure of the air transport system will hardly be able to accommodate this demand and therefore will pose constraints to the further growth of air transport (see [1][2] and [3]). The building of new infrastructure is difficult since this is expensive and – especially in dense populated areas – hardly accepted by the public. In many parts of the world, the capacity of the airspace reaches its limits – at least at current operating strategies. This leads to the quest of an improved architecture for the air transport system that uses the available resources more efficiently.

The analysis of the capacity and performance of the air transport system is a task, which could not solved by means of analytical models alone today, because of the complexity of the system. A variety of Simulation models do exist for several components and subsystems of the air transport system (an overview can be found in [4]). However, an analysis of the complete system with a gate-to-gate perspective is still difficult. A new approach for the evaluation of the infrastructure capacity and the interactions between the aircraft and the air transport infrastructure is the application of methods and systems from the field of knowledge management.

2 Principles of knowledge management

In order to understand the aims and methods of knowledge management, two definitions of the field should be presented, which are cited from [5]:

- “Knowledge is the combination of data and information, to which is added expert opinion, skills and experience, to result in a valuable asset which can be used to aid decision making. Knowledge may be explicit and/or tacit, individual and/or collective.”
- “Knowledge Management is the management of activities and processes for leveraging knowledge to enhance

competitiveness through better use and creation of individual and collective knowledge resources."

In a broader understanding, knowledge management incorporates the methodological analysis, processing, storage and presentation of knowledge about structures, context, interactions etc. within a social or technological system. Especially in an engineering context, this broader perspective shows the benefit of the application of knowledge management.

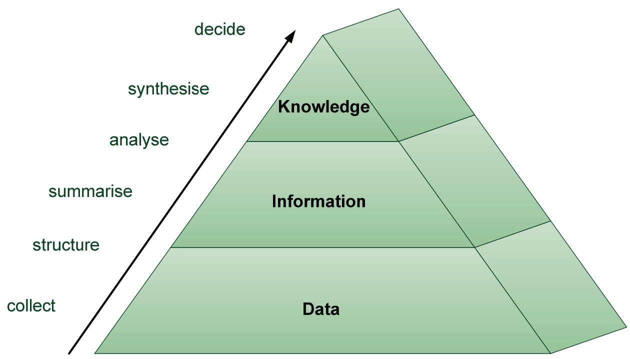

Fig. 1: Knowledge Pyramid

This view can be visualised by means of the knowledge pyramid diagram (see Fig. 1). It depicts that knowledge is an important foundation for decisions. In order to be able to use it, one has to transform data into knowledge. There is a large amount of data incorporated in every system or organisation. In order to obtain the bases for decisions out of these data, they have to be collected and structured. By that, the contained information becomes visible. This information can be summarised and analysed in order to discover interrelations and to generate knowledge. This knowledge can originate from several contexts and sources. One has to synthesise and evaluate it for the preparation of decisions.

For every knowledge management effort, it is important to be aware that knowledge is not necessarily available explicitly in an organisation. Moreover, an important part of knowledge has tacit character. This means it is "embedded" in the brains of the people or within the processes of the organisation. It is a challenge to integrate this tacit knowledge in to a knowledge management concept.

Especially in an innovative sector as aeronautics, it is important not only to store and manage existing knowledge but also to encourage the creation of new knowledge. Therefore, a knowledge management concept should support creative work and the connection of the stored information with the tacit knowledge of the users.

3 Objectives

For the further development of the air transport system architecture, it is necessary to have an improved understanding about the performance and behaviour of the infrastructure and the interaction between aircraft parameters and the infrastructure capacity. There are several studies about the capacity of the infrastructure and planned improvements (as e.g. [1][2] and [3]). Most available studies and models deal with the capacity of specific components of the infrastructure as airports or air traffic control. Other sources as [6] show the expected development trends of selected aircraft parameters. By use of the methods of knowledge management and knowledge discovery, different information sources could be evaluated in terms of the capacity of the air transport system and the interaction mechanisms between aircraft and infrastructure. Of central interest are findings about the analyses and the processing of structured and unstructured data as well as the derivation of correlations and rules of system behaviour.

4 Knowledge Management Research at TU Berlin

The section Flight Guidance and Air Transport of TU Berlin has worked under the direction of Prof. M. Fricke in the last years on several projects about the knowledge modelling and the building of knowledge bases of the air transport system. These projects have taken place in cooperation with governmental and industrial partners as well as universities and research establishments. Some examples will be described in this paper.

The research is integrated into the curriculum of aeronautics and astronautics by a course in knowledge management in aeronautics where students learn the methods of this field and the development of knowledge bases.

5 Examples of Knowledge Management Concepts

5.1 Research Information System FIS

An example for a knowledge management system is the research information system (FIS – *Forschungsinformationssystem*) developed for German Federal Ministry of Transport, Building and Urban Development (BMVBS). It is a global information system, which covers all topics within the responsibility of the ministry. This system is focused on the synthesis of results of current research for the policy development and the formulation of strategies. Since this system is intended especially for the senior staff as well as the experts in the departments of the ministry, complex political and technological issues have to be presented in a comprehensible form for the use in strategies.

More than a dozen universities and research establishments prepare since 2001 the contents of the knowledge bases of the system. The section Flight Guidance and Air Transport of TU Berlin is responsible within this consortium for the analysis and integration of information and research results about all topics of aeronautics into the system.

Technically, the system is based on the WebGenesis content management framework developed by the Fraunhofer Institute for Information and Data Processing (FhG IITB). This system provides a basic ontology for relations as between authors and documents. As a web-based application, the authors and users need only a web-browser to interact with the system.

Motivation of the ministry to sponsor this project was the awareness that there should be an improved access to research information for decision-making and the everyday work within the ministry. In addition, this should help the ministry to communicate decisions in a more transparent and scientifically sound way. These requirements called for a problem-based presentation of knowledge within the system. For example, if the user is researching the topic aircraft noise he or she should get access to information reaching from basic research on the origins of engine noise to aspects of new noise regulations at airports. In order to achieve the access of large information bases while maintaining a user-friendly and clear interface the system uses knowledge maps to show connections of topics and information.

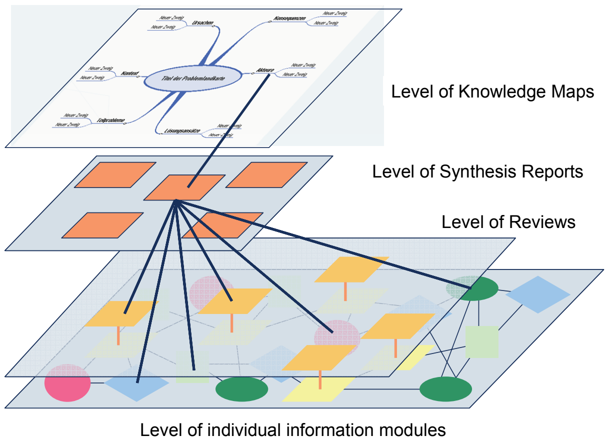

Fig. 2: Levels of information within the FIS

The FIS has different system levels which allow several navigation strategies of the users (see Fig. 2). The top-level is build by the knowledge maps, which allows a quick visual overview over a topic or the solutions to a specific problem. The knowledge map allows a visual navigation through the available pieces of information. The branches of the knowledge map are linked to synthesis reports. These reports summarize a part or section of the topic in a short and concise text and build up the second level of the system. An important characteristic of these syntheses are the clear traceability of the used sources of information. Reviews with a standardised structure make cited research reports more accessible and allow a classification according to the status of research. The class of reviews build up the third intermediate level of the system. The so-called information modules build up the lowest level within the system. They provide bibliographical information about the used sources and show the user how to obtain the documents. In addition, as many research reports and cited literature as permitted by copyright and digital availability are provided as digital documents for downloading. Besides the navigation by use of knowledge maps, a full-text search function with several search options can be used. The user can tune the depth of the search according to his or her needs.

The portal page of the system gives easy access to four primary searching strategies:

- Graphical navigation through the information base by use of knowledge maps,
- Access to information by subject area according to the topical classification system of the ministry
- List of current topics
- Full-text search with options.

Our experience has shown that experts prefer the full text search while generalists make extensive use of knowledge maps. The topics of the knowledge maps have been chosen according to the needs of the ministry. Examples of available knowledge maps are:

- Main overview knowledge map air transport
- Health aspects of air transport
- Air transport infrastructure
- Air transport safety
- Air transport security
- Competition and Economics of air transport
- Intermodality / air and rail transport systems
- Research in aeronautics
- Aircraft technology
- Air transport policy
- Air transport and sustainability
- Astronautics
- Satellite Navigation
- Capacity of the air transport system
- Logistics and interactions of the air transport system
- Reduction of aviation emissions
- Reduction of aviation noise.

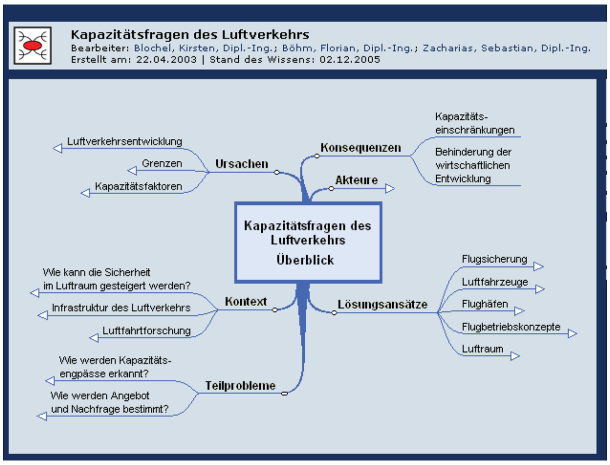

Fig. 3: Knowledge Map
“Capacity of the air transport system”

An example of the knowledge map based user interface is shown in Fig. 3. The arrows at some branches indicate links to sub-maps. Each knowledge map consists of a network of terms. It visualises the interrelations within a subject, a problem or a system and allow to navigate through the information graphically. There are two main types of knowledge maps: problem-based maps and subject area maps. The problem-based maps visualise a concrete question of the political discussion. It shows the causes, consequences, actors, possible solutions and sub-problems. The subject area maps can be seen as taxonomy and visual reference map of the topic. They are intended to give a quick overview over a subject. They allow a thematic orientation.

All nodes and branches are linked to synthesis reports (see example in Fig. 4). They summarise in compact form a (often complex) subject. Therefore, they have a clear outline with subheadings and graphics. All used information must be traceable. Usually, the sources are linked to the report.

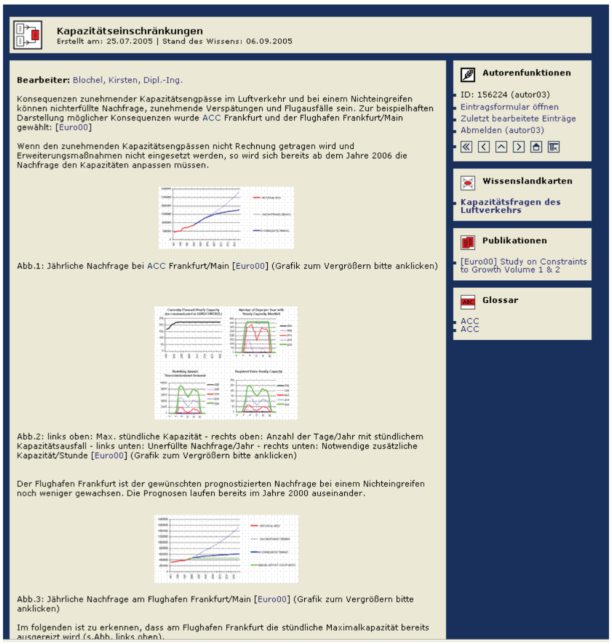

Fig. 4: Synthesis Report "capacity limitations"

An example of the presentation of the information about a source document is shown in Fig. 5.

Fig. 5: Review "Calculation of Aircraft Noise"

The common bibliographical items include here a link to the information about the author of the document, which are available within the system. In case of the document, which is shown in Fig. 5, a review of the research report is added. This review summarises the research report and classifies it in terms of significance for the advancement of research and relevance for policy formulation. Therefore, it is more informative than an ordinary summary.

The links between the different entries are produced automatically by the content management system WebGenesis. This mechanism is based on an ontology, which models the relationship between the classes of entries. The principle of this ontology is shown in Fig. 6.

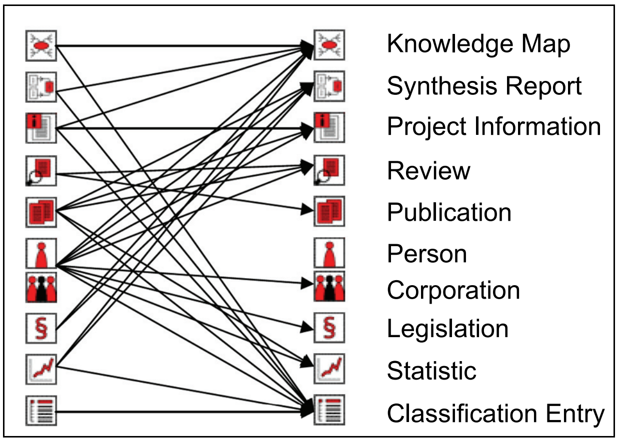

Fig. 6: Ontology of the FIS
(Source: FhG IITB, altered)

The FIS is currently used intensively within the BMVBS and other federal institutions in Germany. It supports methodically the knowledge-based work in policy definition and contributes to a modernisation of administrative processes. It contributes to a higher efficiency of these processes and a cost reduction. In addition, it makes the foundations of decisions transparent.

The knowledge of the system users is integrated by use of commentaries and additional reviews provided by them. Regular meetings between the universities, research institutions and the ministry ensure the quality and relevance of the system for the work of the ministry.

5.2 Air Transport Infrastructure Knowledge Base

Another example for a knowledge management concept is a knowledge base on the interactions between aircraft parameters and the air transport infrastructure, which has been built up for Airbus Germany. Project partners were the DLR Institute for Flight Guidance, the TU Berlin – Section Flight Guidance and Air Transport and the TU Munich – Institute for Aeronautical Engineering. This knowledge base is intended for engineers in the domains of aircraft design, future projects and technology evaluation.

One of the aims of the knowledge base is to present an analysis of all aircraft parameters, which have an influence on the capacity of the air transport infrastructure. This allows a deeper understanding of the interaction mechanisms and the effects of design changes on the air transport system capacity. This knowledge can be used for the development and integration of technologies for capacity enhancements as well as to incorporate infrastructure issues into the design of new aircraft.

As mentioned above, a unified model of the air transport system could not be of a pure analytical or numerical character. For example, the regulatory influence on the operation of aircraft or airports has as much importance as technical issues. However, it is difficult to model this regulatory influence in an analytical way. On the other hand, models for physical interaction mechanisms are available. The challenge is to bring together knowledge from different domains in order to gain a better understanding of the behaviour of the air transport system. The available knowledge of different domains as aircraft design, flight dynamics, airport planning, flight operation and Air Traffic Management has to be linked and to be seen within the appropriate context.

In order to build up the knowledge base , a system identification of the air transport system has to be conducted. The elements of the air transport systems are identified and described. Their impact on the aircraft and operational parameters (constraints) is estimated at all flight phases. Since capacity is more than the number of the possible movements within a given time interval quality functions (as safety/reliability, delay, security, environment, cost and comfort) have to be taken into account. The structure of the knowledge base is shown in Fig. 7.

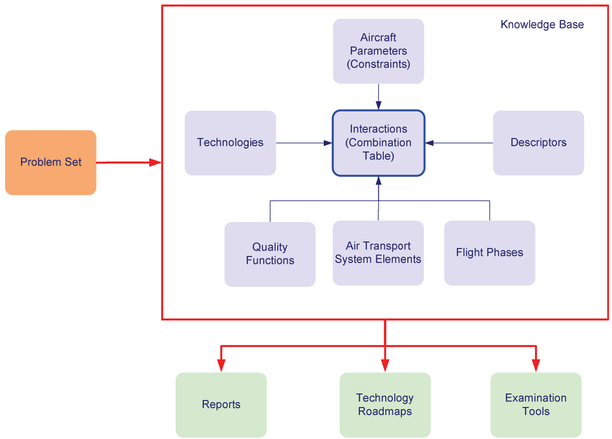

Fig. 7: Schematic diagram of the Air Transport Infrastructure Knowledge Base

Core of the knowledge base, which was implemented by the project partner DLR, is the combination table where all possible interactions of quality functions, system elements and flight phases are stored. These combinations of interactions are evaluated in terms of their plausibility (Is there an interaction in reality?), the involved constraints (e. g. aircraft design parameters) and the strength of influence on capacity. If there were an interaction with considerable effects on capacity, a list of available tools for a closer examination of the interaction and a descriptor would be added. This descriptor gives an explanation on the mechanism of action and references for the individual interaction.

Technologies, which have a beneficial influence on the capacity, are identified according to the interaction mechanisms and the related constraints. These technologies are evaluated in terms of their maturity (Technology Readiness Level), necessary development effort, effect on the capacity of the air transport system and the estimated year of availability.

The user can interact with the Knowledge Base by the input of a problem set of constraints, flight phases and quality factors to describe an area where an increase of capacity is intended or the effects of larger aircraft should be compensated. (e. g.: Which consequences on capacity have the wake vortex strength of an aircraft and which technologies are available for the mitigation of the effect?). The Knowledge Base returns reports on the interaction mechanisms, on the available examination tools and a proposed technology roadmap for the mitigation of the effects on the capacity of the air transport system. Fig. 8 shows the principle, how a roadmap with priorities for the application of technologies is generated out of the database.

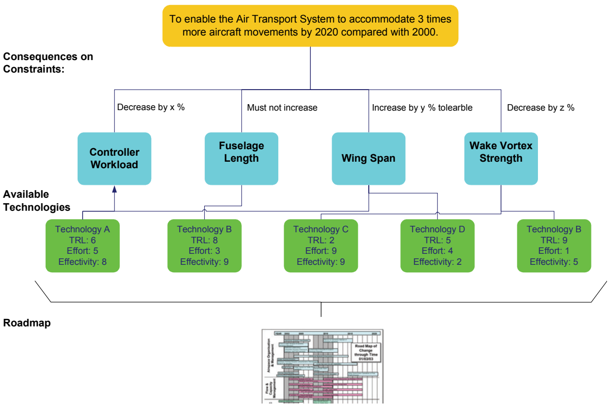

Fig. 8: Generation of technology roadmaps

6 Integration in Knowledge Based Engineering Environments

The air transport infrastructure is a key enabler for aviation. The interactions between aircraft parameters and the infrastructure have a strong impact on the infrastructure. Therefore, it is sensible to use the knowledge about interactions between air transport system infrastructure and aircraft parameters for conceptual aircraft design.

The integration of infrastructure capacity metrics into the preliminary design process for aircraft could give an answer to the following questions:

- How does the infrastructure constrain new aircraft designs? Are there restrictions on the economic performance of the aircraft?
- Which changes to the infrastructure are necessary in order to operate a new (possibly unconventional) aircraft design? Can these changes be justified economically and politically?
- Which design decisions have impact on the infrastructure compatibility of the aircraft design?

In addition, the application of knowledge management concepts for the analysis of the air transport system show that capacity and architecture issues are an application scenario for knowledge based engineering (KBE) principles. It is possible to formulate design rules concerning infrastructure compatibility and capacity usage of aircraft designs for the use within KBE systems (as described in [7] or [8]). For example, if the distance between the nose wheel and the main gear exceeds a specific value the turning radius of the aircraft increases so much that it cannot use the taxiway system at several airports. The parameter “Turning Radius” is compared to the available infrastructure. Warnings or hints could be shown, if design parameters (constraints) or combinations thereof have unfavourable consequences in terms of infrastructure capacity. Therefore, it is feasible to integrate the infrastructure knowledge into an aircraft design environment.

In addition, optimisation rules can be derived from properties of the infrastructure, which allow an optimisation of design parameters to a given air transport infrastructure in terms of an effective utilisation of capacity.

Of course, the same can be done vice versa in order to define improvements to the air transport infrastructure, which are enabled by modified aircraft parameters (as performance) or new aircraft systems. Necessary alternations of infrastructure can be evaluated. This allows the development of air transport system architectures with improved performance and capacity.

7 Integration of Knowledge Models with Simulation Tools

Knowledge models of the air transport system are the starting point for more detailed simulations of interactions of aircraft with the infrastructure. These simulations can be used to validate the interaction mechanisms and to determine their effects.

Main challenge with the simulation of the interactions between aircraft and the air transport infrastructure is the linking of models of very different character. It spans from communication analysis of the interaction between flight crew / on-board systems and the air traffic service provider, the flight dynamics of the approach to process analyses of aircraft servicing at the terminal. They have to cover the aircraft, the airport as well as systems on-board and at air traffic control.

Knowledge models can support the connection of different tools and simulation models. Such a linkage of different simulation tools is currently realised in the ATS (air transport system) Simulation Network of TU Berlin. This network consists of a computing cluster for the simulation of the ATS, which is coupled with a database of traffic scenarios. This cluster will be connected with the different flight simulators and the ATC demonstrator (controller working positions) at the institute in order to able to study the influence of systems and human performance on the ATS capacity in real-time-simulations. The goal is the complete simulation of an aircraft in the airspace from gate to gate with exact modelling of traffic as well as flight dynamics and system performance and their impact on the capacity of the ATS.

8 Summary and Outlook

The air transport system is an interesting field for the application of knowledge management principles. This allows the integration of models and data of different origin and structure. Examples are a research information system for policy support or a knowledge base about interactions between aircraft and the air transport infrastructure.

These knowledge bases can be coupled with simulation systems and knowledge based engineering (KBE) applications. For example, infrastructure metrics can be used as additional inputs for knowledge based aircraft design systems in order to incorporate infrastructure aspects into these systems. The infrastructure knowledge bases can as well be used to build up models and scenarios for simulation systems as the Air Transport System Simulation Network of TU Berlin. The results of the analyses of the knowledge bases and the simulations are applied for the development and evaluation of new air transport system architectures with improved performance and capacity.

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