Digitalisation in Infrastructure Management through BIM-based data models

Manuel Niever, M.Sc., Prof. Dr.-Ing. Markus Stöckner
Institute for Transport Systems and and Infrastructure (IVI)
University of Applied Sciences, Karlsruhe
e-mail: manuel.niever@hs-karlsruhe.de

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Modern and comprehensive methods of maintenance management are required for the operation and maintenance of the highly loaded road infrastructure in Germany. The basic prerequisite for this is the availability of the right data in a usable quality. Due to the economic importance of an efficient road infrastructure, the opportunities through digitalisation should be used by a holistic and area-wide application of Building Information Modeling (BIM). The aim is to achieve a consistent, digital exchange of information for the entire life cycle of a construction. In order to introduce BIM and the associated opportunities for maintenance management, this work focuses on process models for the maintenance management over the entire life cycle of road infrastructure. This creates a transparent representation of the future data requirements and should lead to better databases for the algorithms and calculations used by the pavement management.

Motivation

An intact and efficient road infrastructure serves to secure the mobility of our society. As the demands on performance and economic interrelationships continue to rise in Germany, the maintenance of road infrastructure is particularly relevant. Especially because the transport infrastructure is one of the most valuable fixed assets and the basis for successful economic development and quality of life. (Socina/Komma, 2015) This economic importance of an efficient transport infrastructure is illustrated by the corresponding gross investment assets of over 175 billion euros (Radke, 2018). On the basis of the 2015 maintenance requirement forecast of the Federal Transport Infrastructure Plan, it becomes clear that the required quality can only be achieved through a structured maintenance management.

In addition to the increased focus on maintaining the existing road infrastructure, the issue of digitalisation in the construction sector has also become a very high priority. The method of BIM enables a wide range of actors to work together during the design, planning, construction and operation of a building on the basis of common data exchange and multidimensional models. This increases productivity and prevents the loss of information that is often caused by the current transmission of information through printed blueprints or digital formats with limited usability. In building construction, BIM is already being used by several planning offices and construction companies. The demand for an implementation of the BIM method is also increasing in the field of traffic infrastructure. Based on process models for maintenance measures, this article highlights the opportunities and challenges of BIM in the maintenance management for the transportation infrastructure.

State of the art

Road Maintenance

Road maintenance is a summary of activities to maintain the value of traffic and ancillary areas as well as their environmental compatibility. The aim of maintenance management is therefore to enable the economic, sustainable and user-oriented provision of road infrastructure. (Socina/Komma, 2015) Accordingly, it serves the development of processes of a practice-oriented system and their data structures for the optimization of operational and strategic maintenance planning.

The overhauling and renewal of the german transportation infrastructure are dealt within the Pavement Management System (PMS) to optimise the maintenance planning (BASt, 2018). The basis for this is laid by a regular condition assessment and evaluation called “Zustandserfassung und –bewertung” (ZEB) (Stöckner, 2017). For an optimised, targeted maintenance strategy, detailed knowledge of the road network and its condition as well as other inventory data and parameters are essential. The efficiency and effectiveness of the PMS models are highly dependent on the quality of the input data. (Maerschalk et al., 2013) Since the ZEB as well as the PMS are theoretically subject to periodic intervals, a modelling of the current processes offers itself for further analysis.

BIM

With regard to the relevance of traffic infrastructure maintenance new digital solutions should be considered, especially BIM. (Stoeckner/Niever, 2018) The term Building Information Model refers to a software-based, three-dimensional digital twin of a building/construction with great depth of information regarding the geometry as well as non-geometric additional information of the individual components. However, the BIM method is not limited to the use of three-dimensional building models, but also includes digital document management for transparent and open collaboration. By linking the time and costs of the buildings, four- and five-dimensional building models are created that can be used over the entire life cycle (from planning and construction to operation and maintenance). (Borrmann et al., 2015) The use of BIM promotes cooperative cooperation and definition of objectives among all stakeholders, as well as open and transparent data exchange over the entire life cycle. These are important factors influencing the success of a joint project. According to the German Federal Ministry of Transport and Digital Infrastructure, the BIM method is defined as follows:

> "Building Information Modeling is a cooperative working methodology that uses digital models of a structure to consistently capture and manage the information and data relevant to its life cycle and to exchange them in transparent communication between the parties involved or to hand them over for further processing.” (Egger et al., 2013)

This shows that BIM can be used on the basis of a multidimensional model for planning and information linking between the (interdisciplinary) project participants. It enables transparent and centralized communication and collaboration. In the course of the project, the existing building model can be supplemented with properties such as material, service life, environmentally relevant aspects, sound insulation or fire protection features by the relevant project participants. Accordingly, this data basis is successively expanded and managed over the entire life cycle. (BMVI, 2015)

Process Modeling

The consideration of processes is a very important part of the BIM method. A transparent process definition in combination with a systematic and correct description of which tasks are to be performed by which persons in which order, support the introduction of BIM substantially. According to the method Information Delivery Manual (IDM), the modeling language *Business Process Model and Notation* (BPMN) is often used to give a process-supported definition of model contents. All relevant elements that are necessary for the execution of individual tasks or measures are formally described and clearly represented. Using a graphical notation, the data exchange processes are described in so-called "exchange requirements", i.e. requirements regarding the model content to be exchanged. (Koenig, 2015).

For an explanation of the process modeling, an exemplary excerpt according to the principles of BPMN is shown in figure 1.

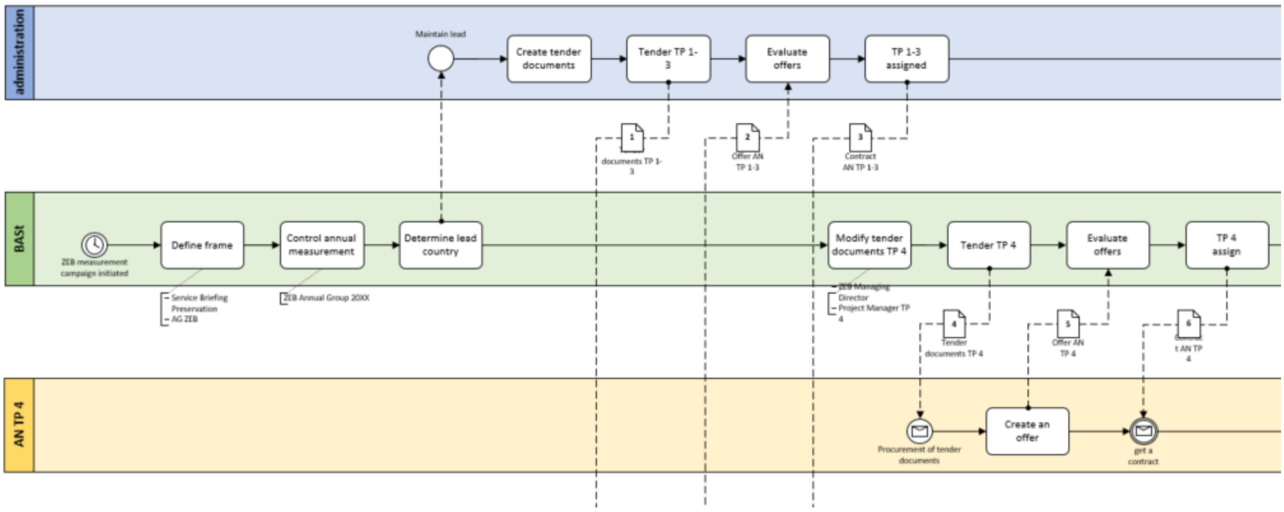

Figure 1: BPMN exemplary process

The example shows that the actors involved (e.g. companies, administrative units) are represented in so-called "pools". If there are several responsibilities, roles or persons of this actor, this pool can be divided into several "lanes". The activities that occur (work steps and activities) are represented by rectangular boxes. The sequence and the connection between the individual steps is described with the help of "Connections". These are displayed as continuous arrows. The information or data flow is represented by dashed arrows. Data objects are visualized within the data flow as "Artefact" and embody an information carrier such as documents, e-mails, letters or the like. (Koenig, 2015)

Objectives and Research Methodology

The state of the art shows promising effects on sustainable mobility and the possibility to achieve a consistent, digital exchange of information for the entire life cycle of a construction through the systematic implementation of BIM. Regarding the three pillars of sustainability it will especially impact the economical and socio-cultural aspects, through the efficiency improvements in the road maintenance.

Based on the Design Research Methodology (Blessing/Chakrabarti, 2009) a research program was set up to answer the question, how the implementation of BIM in traffic infrastructure can be supported through the methodological support of process models.

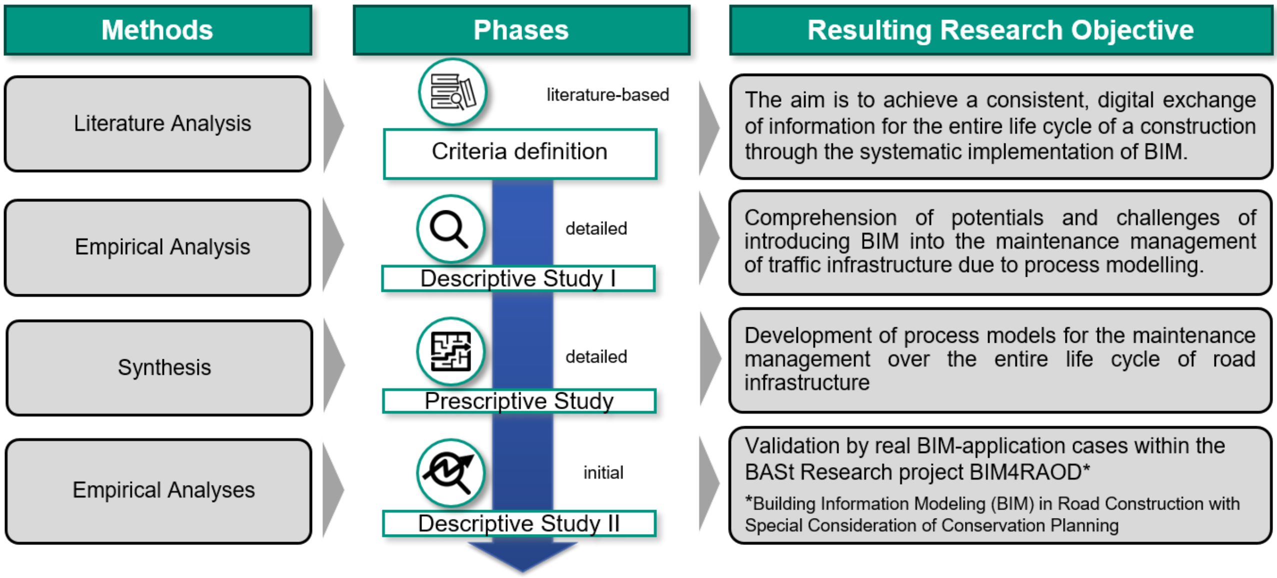

Figure 2: Research Framework according to Design Research Methodology

Figure 2 shows the applied research framework with its Methods, Phases and the respective objectives. First, a literature based *criteria definition* resulted in a clear understanding of the research area and the overall research objective. The aim of the BIM method is to provide the right people with the right information at the right time. In order to find out who needs which data and information at which point in time, the essential processes of maintenance management were first analysed and documented by a literature analysis and a descriptive study with expert interviews and own observations in several infrastructure management projects with various district offices. The *descriptive study I* led to a comprehension of potentials and challenges of introducing BIM into the maintenance management of traffic infrastructure due to process modelling.

Within the *prescriptive study* the individual process steps of the ZEB, the PMS and other local activities were described in detail and modelled formally according to BPMN. Based on these process models, the potentials and challenges of introducing BIM into the maintenance management of traffic infrastructure could be demonstrated. BIM-based data models were developed for supporting the implementation of BIM over the entire life cycle of road infrastructure. Finally, the generated process models were validated by the application within the real implementation of BIM-Application cases, which are realized in the BASt research project "Building Information Modeling (BIM) in Road Construction with Special Consideration of Conservation Planning". This project is currently being carried out by a consortium of the Ruhr University Bochum (Prof. König, Prof. Radenberg), the Technical University of Munich (Prof. Borrmann) and the Karlsruhe University of Applied Sciences (Prof. Stöckner). Due to the ongoing validation the only internal interim results cannot yet be reported and therefore the results of the *descriptive study II* will not be part of this paper.

Results

A fundamental finding of our research is that the detailed process analysis of the individual activities and data transfer points leads to a more accurate description of the data flow processes and the storage of actually relevant data. This initially has advantages in the object-orientated planning and construction process, but then in particular also in the later maintenance and operation phase. Especially at this late stage, the question arises which data are actually required, which were available in the previous process steps but were often not stored or only insufficiently stored and made accessible. For example, when applying systematic maintenance management as part of a life cycle analysis, it often occurs that the data on actually installed layers and their qualities are missing. Even though these data are essential for the calculation models in maintenance management in order to make appropriate predictions.

Process model and data exchange using ZEB as an example

By means of the established processes in maintenance management, it can be shown for which activities or data transfer points the BIM method can help to ensure that the calculations currently used by pavement management are based on better data in future. First of all, it should be noted that the maintenance management process in the BIM reference process is to be classified under operation and maintenance. Due to the scope of the descriptive study for the analysis of process models in maintenance management, only the results of the ZEB process analysis are described in this article. Figures 3 and 4 show the actual situation of the process steps of a ZEB on federal highways. The process model according to BPMN shows the four pools for the actors administration, BASt, contractor subproject 4 (AN TP 4) and contractor subproject 1-3 (AN TP 1-3). All activities of the actor are displayed within the respective pool. In order to maintain clarity, all these activities are grouped according to established phases of the ZEB and subdivided into the phases of *preparation of the ZEB*, *transfer of data*, *condition recording and condition assessment*.

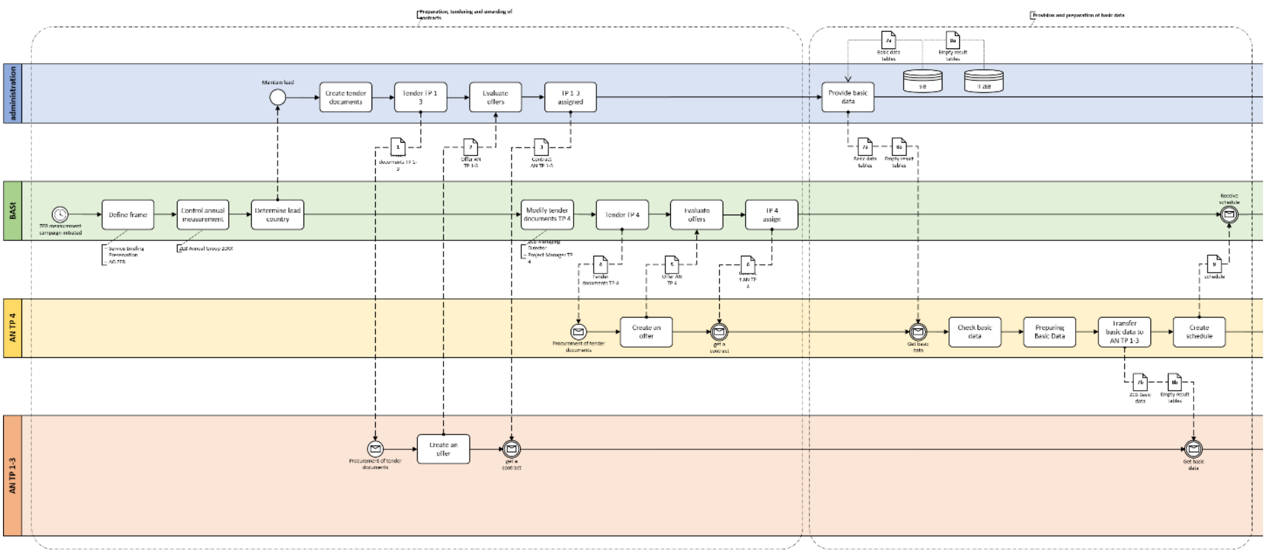

Figure 3: ZEB Process Model: Preparation and transfer of data

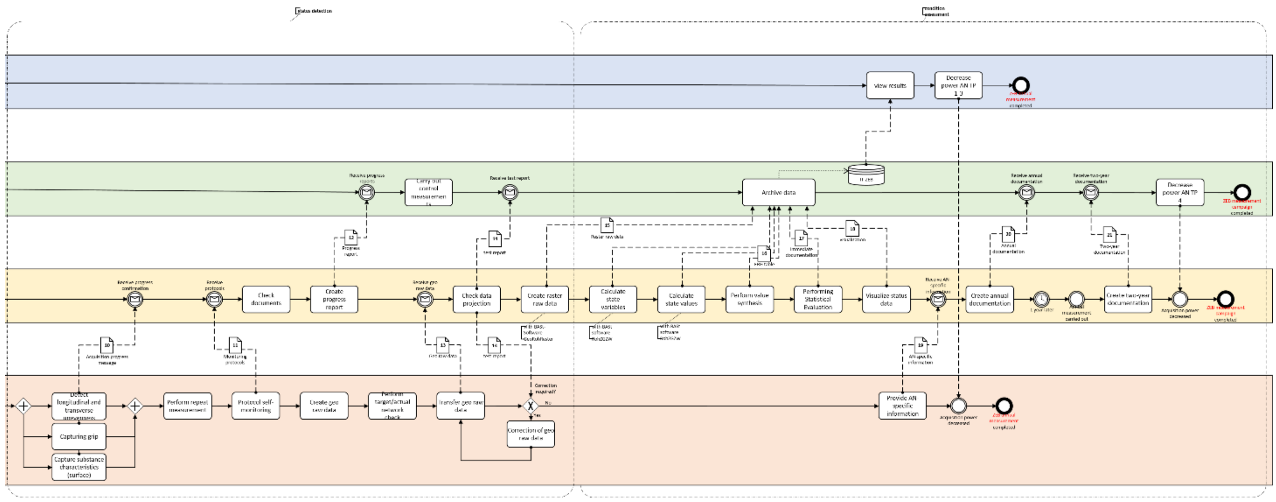

Figure 4: ZEB Process Model: Condition Recording and Evaluation

Data objects that are transferred or exchanged between the actors are arranged in the space between them. According to the IDM method, these data objects are numbered and listed in a separate table describing their data and model content requirements.

Using the process model, the individual data requirements and data transfer points are presented transparently, thus enabling a uniform understanding of all participants as the basis for close cooperation.

Concept for a BIM-based data model

The process model is then used for the conceptual implementation of the BIM method. The pool "BIM data environment" is inserted in the modeling, in which the entire data exchange as well as the BIM model are mapped. In this extended process model it becomes apparent what potentials and challenges an open and transparent exchange of information and data has for all participants.

For example, the "as built" model is successively created during construction. The "as built" model allows digital building documentation over the entire life cycle. Changes to the building object can be entered in the "as built" model. With the maintenance and updating of the model by all involved parties the advantage arises that a digital image is available which reflects the current object condition digitally. For future questions or upcoming construction work, all information is stored centrally in the model, eliminating the need to search in different storage media such as project folders and digital folders. The digital representation of the entire inventory therefore serves as a basis for future planning. However, this requires continuous "model maintenance". For every construction project on the object, the changes must be incorporated into the existing "as built" model and a structured, clear and comprehensible object history must also be created.

Another advantage of the BIM model is the centralization of the object data. By linking the attributes with different contents, the search for required information in different storage media, e.g. documents in paper form, in folders or digitally stored on the office-internal server, is no longer necessary.

In addition to the BIM model, data exchange for managing the models and the resulting documents offers potential for open collaboration and better, more transparent project management. Through the use of a shared, digital data exchange as a storage medium for the documentation of contractual framework conditions, project descriptions, plans, accounts and other documents, the project-relevant information is made available centrally and freely accessible to all project participants. Centralisation enables all project participants to carry out their specific activities on the basis of a common database. If requirements for the building object change, they can be made available to all participants in real time. Thus the project participants are always kept up to date.

Due to the possible use of online data exchange as a digital storage and exchange medium for important and trustworthy documents, data security plays an important role. If data is stored online, there is always a risk that it can be hacked, viewed, disseminated or processed by unauthorised third parties. To prevent this, an increased level of safety must be ensured.

Further action is required in the area of standardisation with regard to the establishment of the AIA or the BAP. Uniform wording in this respect, particularly in the area of contracting authorities, would facilitate a faster and easier application of BIM. Standardized formulations of the content specifications, such as information on the file formats (IFC) or rules to be used, can be used to create a uniform, area-wide creation of AIA and BAP documents. However, it must be possible to adapt the uniform specifications to specific projects. If this is not achieved, there is a risk that, in the worst case, there will be as many different AIA formulations as there are public limited companies. This leads to a confusing and aggravating project processing.

Outlook

In summary, the consistent integration of the BIM method in the life cycle of transport infrastructures can lead to far-reaching advantages for all parties involved in maintenance management. In addition to the technical requirements, however, comprehensive organisational and legal framework conditions must also be regulated.

If the remaining hurdles are overcome and uniformly regulated, the advantages of BIM in infrastructure management clearly outweigh the disadvantages and the BIM method can lead to communicative and cooperative collaboration and thus to more efficient project processing. This will have a positive impact on the economic and social-cultural aspects of upcoming infrastructure management projects and thus increase the sustainably.

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