Journal of the Bavarian Building Authority

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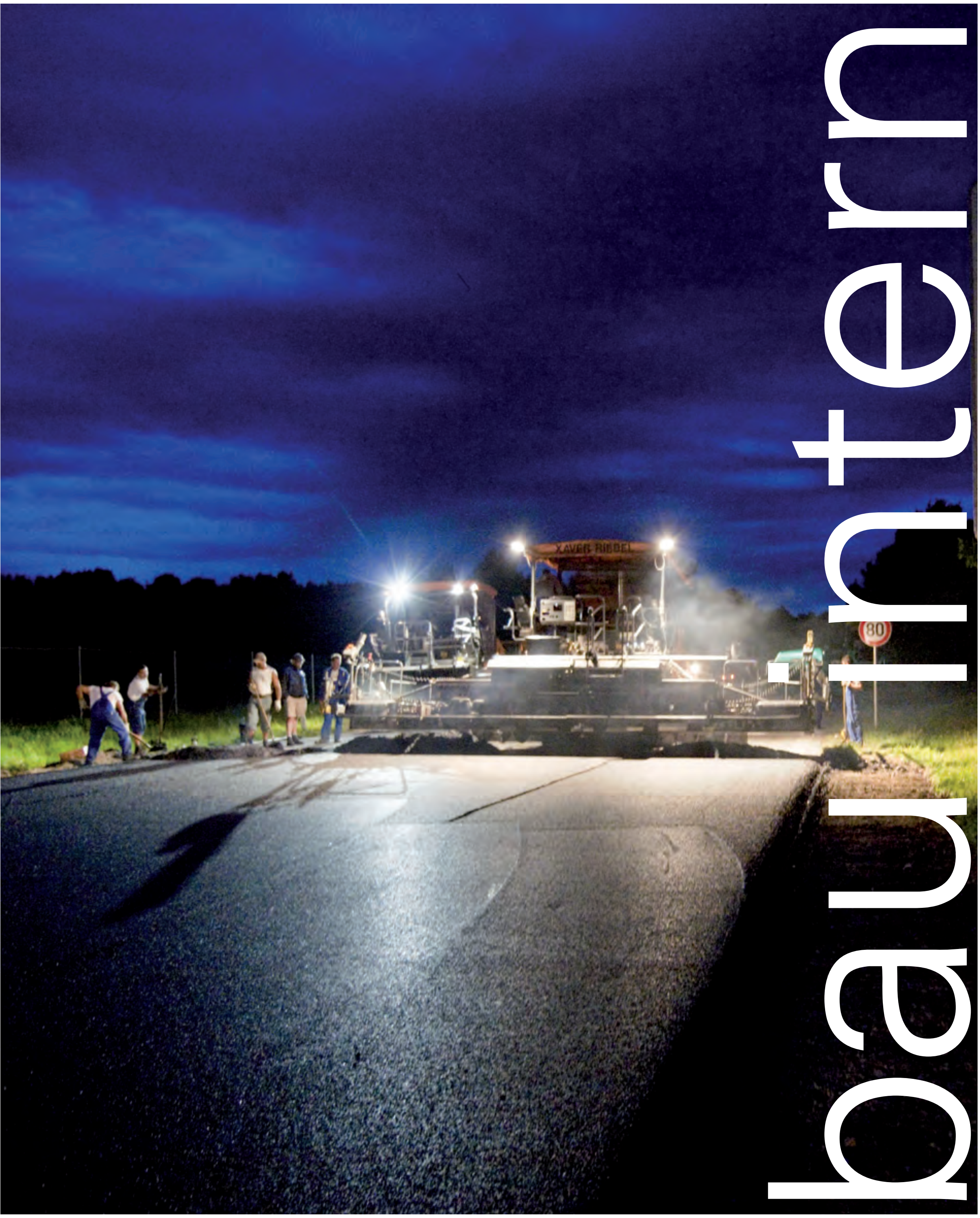
Maintenance management for Bavarian roads



Special edition August 2011
second, updated edition

Content

Preface

The Bavarian Road Administration has initiated relevant tools for maintenance management and is one of the leading national authorities in the further development of maintenance strategies.

The special journal "Maintenance management for Bavarian roads", which appeared in November 2009, has given specialists and interested citizens some insight into this work, explaining developments in Bavaria.

The first edition of our special journal is in the meantime out of stock. In total we distributed more than 3,300 copies, among others to professionals in this industry, delegates, districts, government authorities, universities, associations, construction companies and engineering offices.

The response to this publication was very positive, which is why we have decided to compile a second, revised edition. The concept and structure of the first edition have been retained. Current trends and figures on further developments in maintenance management in Bavaria and new findings have been incorporated, for example how to improve the visualisation of maintenance planning. The latest results of the monitoring and evaluation of pavement condition of federal motorways dating from 2009 have also been included.

The Bavarian Road Administration has developed modern maintenance management tools. We do, however, have to ensure that adequate funds are used for the overall maintenance of the road network, especially against the background of increasing traffic loads. Road traffic remains the most commonly used transport medium.

To ensure the high infrastructural standard on Bavarian roads, the Bavarian Road Administration has invested an average of 260 million euros per year over the last ten years to maintain the Bavarian road network. Despite the additional funds invested in recent years, we would actually have to invest even more in maintenance, but the financial scope is limited. The aim is thus to make the most efficient use possible of the available budget. This is why we need maintenance management tools. This is the only way in which we can guarantee the safe state of our roads and bridges in the long term, while achieving an optimal cost/benefit ratio and ensuring mobility in our country in the long term.

We thank everyone who has participated in the new edition of this special journal. Our special thanks go to Heller Ingenieurgesellschaft mbH for its perspective beyond the borders of Bavaria, as well as to the Civil Engineering Office of the city of Erlangen for its overview of structural maintenance planning from a communal point of view.

The first edition has met with a great deal of interest even beyond German borders. This is why we have published the present English version of this special journal.

Aufbruch Bayern
Zukunft Bauen

Joachim Herrmann, Member of the State Assembly

Bavarian State Minister of the Interior

Gerhard Eck, Member of the State Assembly

State Secretary at the Bavarian State Ministry of the Interior

Maintenance management -
Why it is important not only to think superficially

Dipl.-Ing. Roland Degelmann

Road networks have organically grown over time - not only in the Free State of Bavaria - and therefore include sections with different construction standards for routing, width, frost protection, carrying capacity of the road pavements as well as engineering structures with different designs and carrying capacities. A considerable part of the assets in the old federal states dates from the 1960s and 1970s as a result of the specific, economic development of Germany. In the years to come, the pavements and structures of this part of the road network will require additional maintenance measures in order to meet future traffic requirements.

Maintenance as a task

Maintenance of road traffic systems (roads, engineering structures, other system parts) is important to ensure the safety and performance of the road infrastructure in the long term. Increasing stress on roads, for example by heavy traffic, as well as a worsening age distribution and restrictions on budgets, increasingly force road administrations to use systematic, network-wide maintenance planning in order to use the means available in a technically and economically optimised manner according to the requirements.

The results of the most recent monitoring and evaluation of the pavement condition in Bavaria show a generally better road condition for federal roads when compared to state roads and a minor improvement of the usage value for federal as well as state roads. The usage value is relevant for driveability and traffic safety. However, the survey also showed a significant deterioration of the substance value, which is an indicator of the development of the asset value of roads. It can be concluded that in the last few years, the Bavarian Road Administration has managed to provide traffic participants with an infrastructure that shows a slightly improved surface quality overall, in spite of budget constraints. However, sustainable maintenance of the whole network is not possible in this manner, as the continuous deterioration of the substance will imply more frequent maintenance measures with clearly increasing costs per road kilometre.

Figure 1: Road damage on a state road

Providing an appropriate infrastructure in future in spite of these unfavourable conditions requires detailed information on the current condition of system parts and their expected condition development. This information must be integrated into a closed process cycle for maintenance.

The key tasks of such a maintenance management cycle for the road sector are:

- Evaluation of the network quality (situational analysis),
- Evaluation of the condition development,
- Planning of maintenance measures at network level,
- Compiling a medium-term maintenance programme,
- Implementation of the maintenance programme at operational level.

Based on these components, a description of a closed process cycle for the important administrative tasks in an efficient maintenance management system (EMS) for planning maintenance measures on roads in Bavaria was compiled (Fig. 2). It takes into account the road pavements as well as the bridge and engineering structures.

The work that has to be completed within the framework of the process cycle is still being handled with a variety of software-based tools, ranging from Pavement Management Systems for strategic applications to operational building and budgeting programmes.

Tools for maintenance management

The term **Pavement Management System (PMS)** refers to systematic planning of maintenance measures for pavements based on comprehensible criteria. It refers, in particular, to software-based tools for maintenance planning. This software supports the road administration in planning its maintenance work. A PMS is only a planning tool and cannot replace the technical work of a competent road-

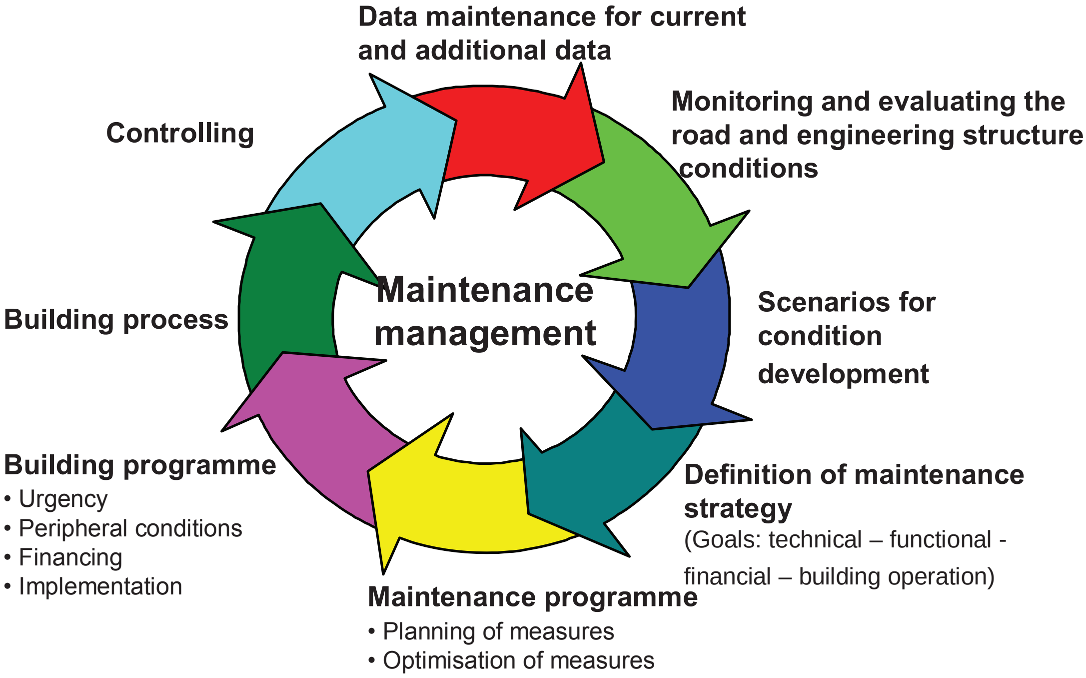


Figure 2: Process cycle for maintenance management

building engineer.

The PMS takes into account a set of input data to determine the most efficient measures:

- Road condition (transverse and longitudinal evenness, grip, substance characteristics), including the current situation and a prognosis
- Road structure (layer type and thickness and year of construction)
- Traffic data
- Financial resources
- Accident data
- Lists of measures.

The requirements for operational maintenance planning with pavement management software are currently not sufficiently fulfilled for all federal and state roads in Bavaria. Consistent use of pavement management software by the Bavarian Road Administration is therefore limited to motorways. The use in state building offices with responsibilities for road building is to date limited to a few pilot offices[1].

The use of the PMS in pilot offices showed that a comprehensive maintenance management system must cope with the data available. Consistent additional surveying of the current road structure is still associated with an extremely high technical effort and corresponding costs. This lack of information concerning the actual road structure implies that essential maintenance measures such as pavement reinforcements or other measures to secure the road superstructure must still be based on the results of the road condition survey and evaluation (e.g. crack formation, major longitudinal unevenness, etc.) and on individual samples taken. Alternative maintenance management solutions that can be adapted to the available data were therefore developed to remedy this shortcoming of the planning tools. These solutions primarily include the **"improved maintenance planning system" (VEP)**. The VEP considers the data of the monitoring and evaluation of pavement condition (ZEB) as well as the total and heavy-duty traffic load in the respective road section to generate a priority ranking for maintenance measures. The VEP system was developed by the Bavarian Road Administration in cooperation with Heller Ingenieurgesellschaft in Darmstadt and has been introduced on a comprehensive basis in 1999 and 2000.

The VEP already uses fairly sophisticated methods, but it cannot completely fulfil the increased requirements for efficient maintenance management. For this reason, the Bavarian Road Administration has consistently improved the method and developed the **"Coordinated maintenance and building programme" (KEB)**.

The KEB uses additional, basic information that leads to a considerable extension of the data available. The respective basic maintenance lists of the KEB for federal roads and state roads were first distributed to the relevant state building offices in Bavaria in 2008 after the results of the ZEB 2007 had become available.

Thereafter the KEB was directly used by the state building offices. Its current main application is the operational maintenance management performed in the offices.The systematic use of all currently available information concerning the road network is supplemented by a search for cost-efficient ways to collect more information on the existing road structure and its carrying capacity and to use this information for maintenance management. In recent years, two methods for **carrying capacity measurements** have become established in the federal area: the Benkelman beam and the Falling-Weight Deflectometer (FWD). Both methods allow conclusions concerning the deformation behaviour

[1] Additional information on these methods (PMS, VEP, KEB) is provided in separate articles in this special issue.

Figure 3: Pavement construction on a motorway

of the bound and unbound layers under load. Both methods work locally, i.e. they provide information for a specific measuring point. Statements concerning linear structures or areas are not possible. It was therefore attempted to develop methods that allow higher measuring point densities and higher driving speeds while measuring the carrying capacity. One of those is the ARGUS method (Schniering Ingenieurgesellschaft), which uses lasers to measure the deformation of the road surface when stressed by the load of a truck tyre. A similar method has been applied for several years in Spain. It uses a chain with acceleration sensors instead of the laser **(Curviametro method)**. The purpose of these methods is to derive information on the road surface as well as characteristics of the whole road superstructure. The data are intended for optimising the road maintenance measures. The Bavarian Road Administration has already used the Curviametro method on individual road sections and will implement it on a larger scale when the data are found to be appropriate.

Building programmes and controlling

Current analyses of the complete data material available show regional differences in the condition levels of the roads. This was one of the main reasons for the further development of the current distribution key for asset preservation of federal and state roads, which facilitates a more efficient and appropriate use of the budget available, based on objective criteria. The distribution keys for the asset preservation funds obtained in this manner were first used in 2009 and will be retained until the results of the current monitoring and evaluation of pavement condition are available. These results will then be used to evaluate the benefits of the distribution keys and to adapt them to new framework conditions.

The introduction of the KEB for federal and state roads in the whole

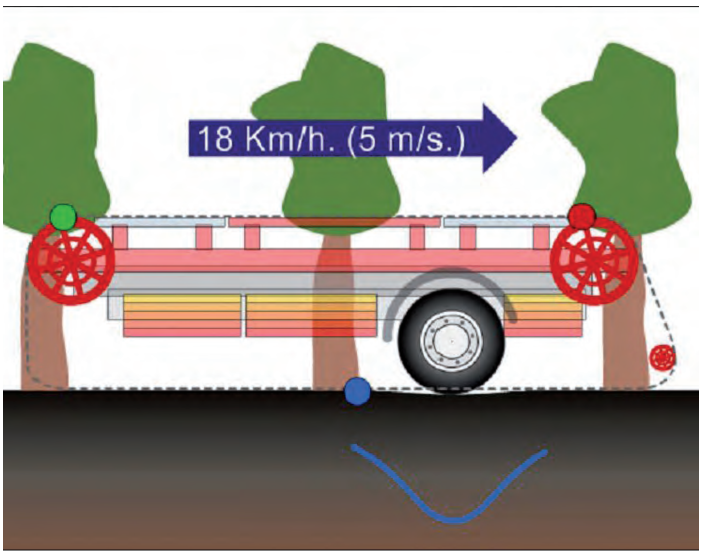


Figure 4: Curviametro methods

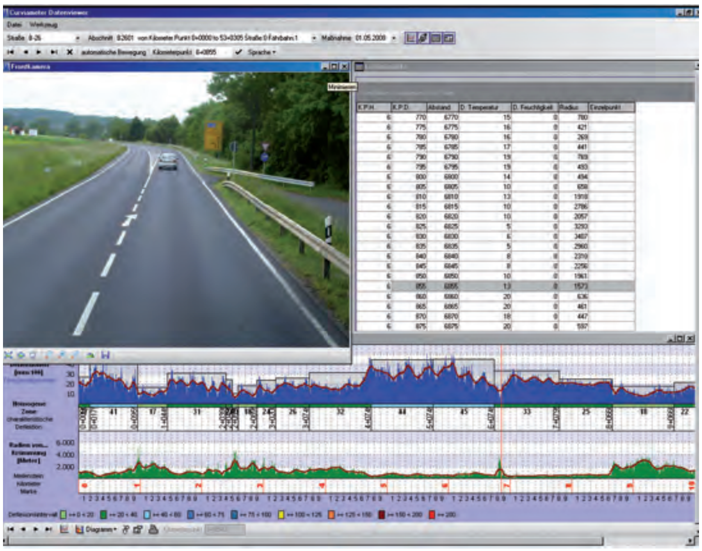


Figure 5: Curviametro measuring results

Figure 6: Maintenance measure (surface treatment)

of Bavaria facilitates analysis and **controlling** of the maintenance programmes of the state building offices. Controlling is primarily focused on the strategic goals (Are the right things being done?). A detailed analysis of the individual project plans (Are things being done in the right way?) to support the operational work of the construction offices has still only been performed for a few, selected cases by the Bavarian Building Authority.

It has already been shown that the KEB facilitates target-orientated handling of road maintenance for carriageways and engineering structures, even when the peripheral conditions change in the short term - e.g. by the provision of additional funds as part of economic recovery packages.

Conclusion

The traffic participants only require carriageways with sufficient surface quality for safe driving. However, the construction offices can only provide such an offer in a sustainable and economic manner when they do not only consider the usage properties of the surface but also the condition and the development of the substance of the whole road structure, the engineering structures and other system parts that are essential for providing good surface properties in the long run. This requires an improvement of the maintenance management tools used. Superficial thinking - in this case focusing exclusively on the surface - will not be sufficient to provide sustainable solutions.

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Results of the monitoring and evaluation of pavement condition of motorways, federal and state roads in Bavaria

Dr.-Ing. Olaf Weller

A system for the monitoring and evaluation of pavement condition of carriageways

The "Monitoring and evaluation of pavement condition" (ZEB) is a standardised procedure that was established jointly by the federal government and the state governments. It has been applied since the beginning of the 1990s and is aimed at measuring the road surfaces of federal roads and state roads with fast-moving vehicles in flowing traffic on a network-wide basis and to provide a subsequent evaluation.

Figure 1: Vehicle for measuring longitudinal and transverse unevenness and substance characteristics

Figure 2: Vehicle for measuring road grip

The results of several measuring surveys on the regional road network in Bavaria are now available (Fig. 3). They form the basis for predicting condition developments and making a prognosis for future trends. The ZEB is therefore an important part of maintenance management. It makes it possible to align the maintenance strategy according to specific and verifiable goals and ensures effective controlling.

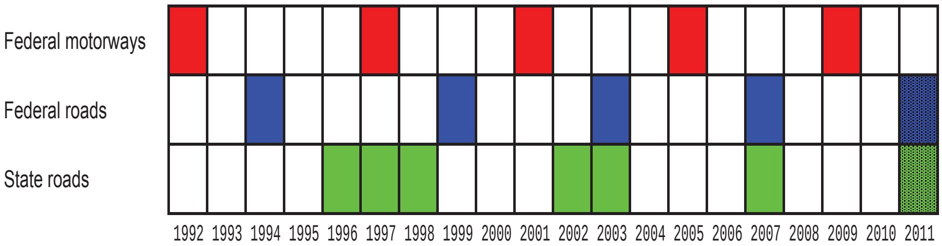

Figure 3: Completed and on-going ZEB surveys in Bavaria

ZEB surveys are performed in several sub-projects (TP). Once the basic data have been provided by the road administration, they are prepared and checked by the contractor (TP 0). Thereafter, the longitudinal and transverse evenness (TP 1), grip (TP 2) and substance-related surface characteristics (TP 3) such as cracks and mended places on asphalt roads can be measured. When all elementary data are available, they are processed and evaluated (TP4). The whole process is subject to strict quality management.

Two groups of characteristics are calculated for the evaluation of the road condition: the usage and the substance-orientated characteristics. The measured condition values are allocated to these two groups as follows:

Usage-related characteristics:
- General unevenness
- Rut depth
- Virtual water depth
- Grip.

Substance-related characteristics (for asphalt pavements):
- General unevenness
- Rut depth
- Cracks
- Mended areas.

Substance-related characteristics (for concrete pavements):
- General unevenness

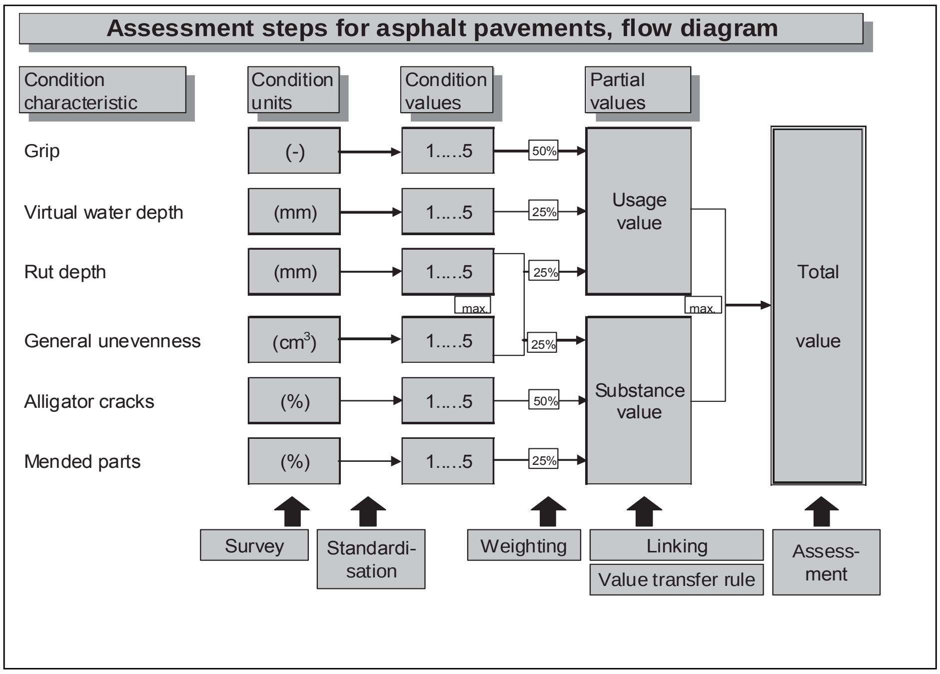

Figure 4: Flow diagram for the current assessment of the total value (for road sections with asphalt pavements on open roads)

- Rut depth
- Longitudinal/transverse cracks
- Broken-off corners
- Edge damage.

Once the survey has been completed, the measured data (elementary data) are used to calculate condition characteristics. Standardisation functions are used to convert the values into dimension-free and therefore comparable condition marks ranging from 1 for "very good" to 5 for "very bad". The marks characterise the state of the road regarding the different condition characteristics and can be combined to form a **usage value** and a **substance value**, using defined calculation and weighting rules (Fig. 4). The usage value takes into account the safety and comfort of the road users. The substance value describes the surface condition of the road as seen by the road-building authorities and provides important information for road maintenance. The substance value is exclusively determined from surface condition characteristics and is therefore also referred to as "substance value (surface)". The usage value and the substance value are combined to form the **total value**.

The road condition and the need for renovation are evaluated by using 1.5 values, warning values and threshold values.

- The 1.5 value (mark = 1.5) usually corresponds to the acceptance value after performing construction measures.
- Roads that reach or exceed the warning value (mark = 3.5) are in a condition that requires intense observation and analysis of the causes. When the value is exceeded, suitable maintenance measures might be planned.
- Roads that reach or exceed the threshold value (mark = 4.5) are in a condition that requires construction measures. Traffic restrictions have be considered.

The ZEB includes statistical evaluations and extensive visualisation of the condition data on maps and condition profiles. They are used as a basis for systematic maintenance planning at network and object level. They are intuitively comprehensible and are therefore well accepted among the users (Fig. 5 and Fig. 6).

Figure 5: Excerpt of a condition map for motorways (total value)

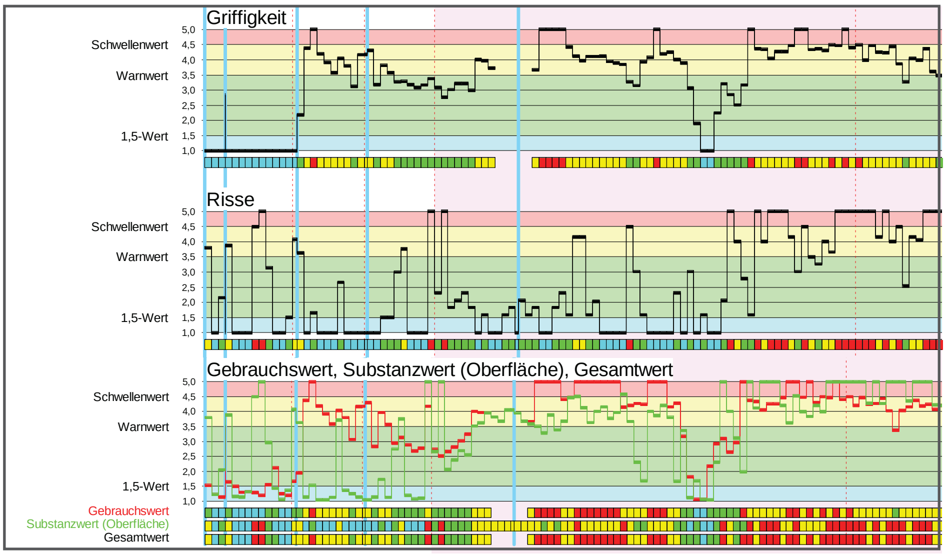

Figure 6: Section of a condition profile

Figure 7: Map of the 29 ZEB traffic areas on federal motorways in 2009

Results of the ZEB 2009 on motorways

The most recent, completely available evaluations of ZEB measuring surveys in Bavaria concern the ZEB 2009 in motorways. In contrast with the measuring surveys on two-lane federal roads and state roads, which only include one driving direction, surveys on motorways include driving along and separate evaluation of all lanes in both directions. These lane-specific driving tests take into account the different traffic loads on the individual lanes and the resulting, unequal condition devlopment across the carriageway. They serve as the basis for lane-specific maintenance planning. For the first time, the statistical evaluation of the ZEB 2009 took into account smaller areas of the network, which were called traffic units. This facilitates differentiated analysis of the condition and the condition development of individual, interlinked route sections for the purpose of maintenance planning (Fig. 7).

In addition to compiling the most current results, the data of the last three measuring surveys on the Bavarian motorway network during 2001, 2005 and 2009 were prepared and combined. This made it possible to describe the development of the road conditions over the last 8 years and to assess their dependence on various budget scenarios.

Concrete pavements have a share of well over 15% in the Bavarian motorway network, which makes them rather important. The results of the ZEB 2009 were therefore prepared to allow differentiation between the two construction types concrete and asphalt. This is advantageous, as they have different patterns of damage development and service lives and thus require different maintenance strategies.

Condition development in the whole of Bavaria

A review of the results of the network sections covered during all three measuring surveys in 2001, 2005 and 2009 (intersecting set) shows that the usage value relevant for driveability and traffic safety has significantly improved from 1.96 (2001) to 1.71 (2005) and 1.56 (2009).

The substance value, which is an indicator for the development of the road assets, developed in the opposite direction. It had a value of 1.58 in 2001 and deteriorated to 1.78 in 2005 and 2.09 in 2009. The total value has therefore slightly deteriorated from 2.26 in 2001 to 2.22 in 2005 and 2.35 in 2009 (Fig. 9).

The results were more favourable when the whole network covered in each survey was taken into account. This is due to the fact that a relatively large number of motorway routes has been newly built during the last decade. All of these are still in good condition, but they are ignored when only the intersecting set of all surveys is analysed. However, even a consideration of the whole network shows a continuous deterioration of our motorways (Figure 10).

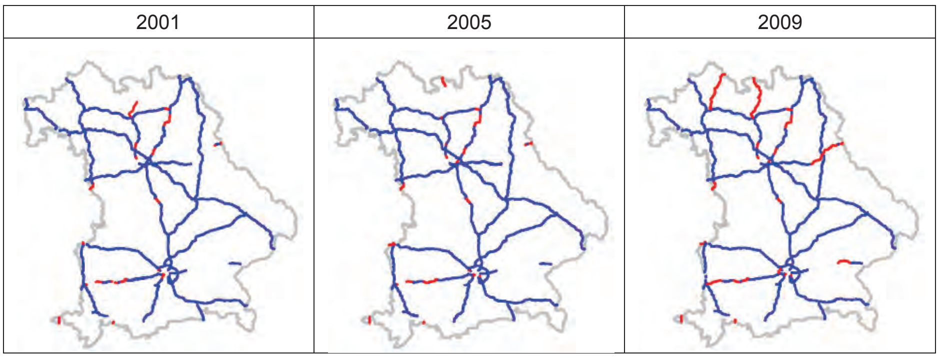

Figure 8: Motorway networks of the ZEB 2001 - 2005 - 2009. The red areas show sections outside the reference network used for the evaluation of condition developments. Blue sections = routes covered in all surveys

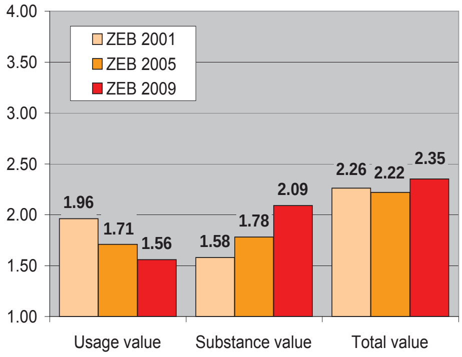

Figure 9: Survey comparison ZEB 2001 - 2005 - 2009. The averages relate to the routes covered in all surveys.

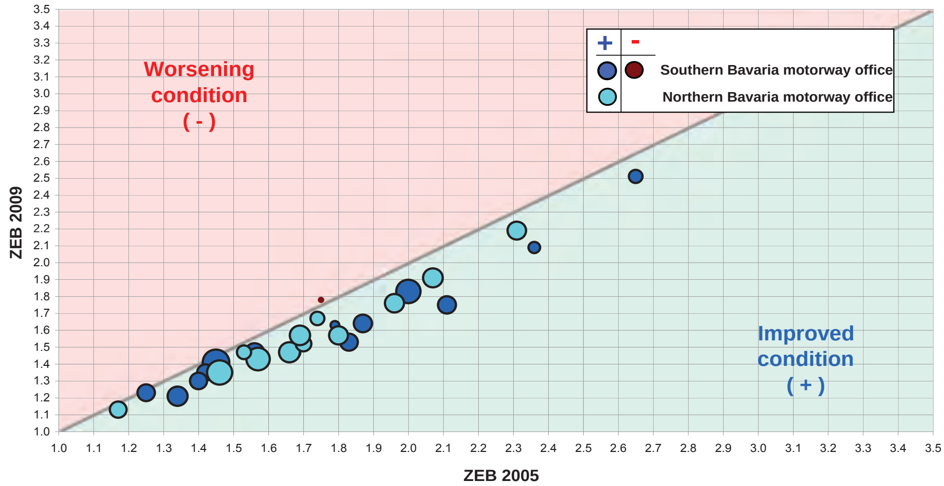

Figure 13: Averages of usage values of the traffic units 2005 - 2009

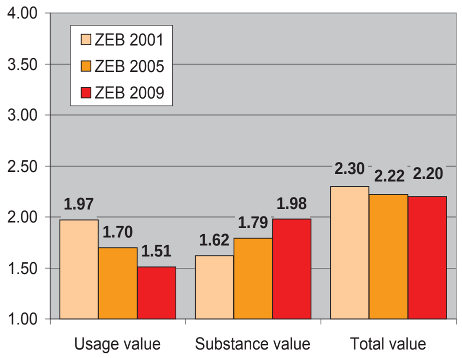

Figure 10: Survey comparison ZEB 2001 - 2005 - 2009. The averages relate to all the routes covered in the respective survey (total network).

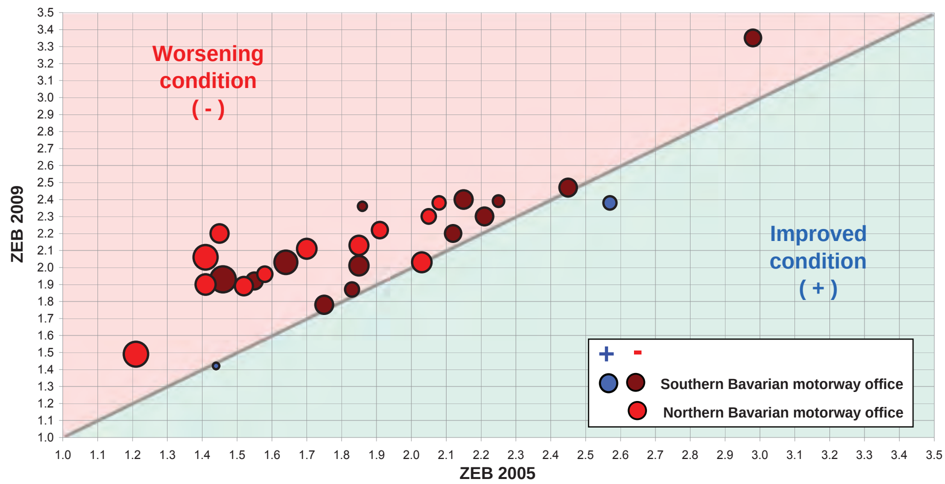

Figure 14: Averages of the substance values of the traffic units 2005 - 2009

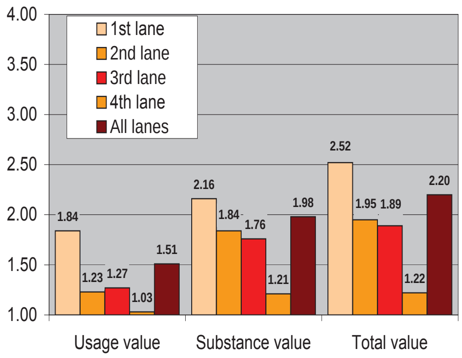

Figure 11: ZEB 2009. Averages for traffic lanes (total network).

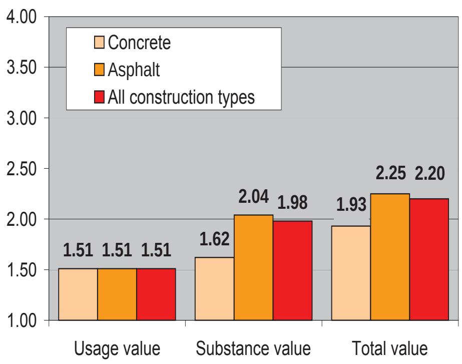

Figure 12: ZEB 2009. Averages for the construction types asphalt and concrete (total network).

ZEB results by driving lanes and construction types

The lane-specific evaluation of the current ZEB results for the whole of Bavaria shows that the right lane (1st lane), which is most frequently used by trucks, is in worst condition (Figure 11). This was to be expected.

The evaluation of the two construction types asphalt and concrete shows that the concrete pavements score better with regard to substance and total value than asphalt pavements. The average usage value is currently at a good level for both construction types (Fig. 12). It should be mentioned that the average age of concrete pavements in Bavaria at the time of the survey was approx. 24 years, while the average age of the asphalt pavements was approx. 17 years.

Condition development of the various traffic units

Bubble diagrams are used to show the changes in the averages of selected indicators between two ZEB surveys for several sub-networks per diagram. The size of the bubble is proportional to the network length. The bubble diagrams show an improvement in the usage values for nearly all traffic units, although the degrees of improvement differ (Fig. 13). The substance value also shows a fairly consistent development. However, there is generally a concerning deterioration of the substance between the measuring surveys in 2005 and 2009. There are only a few exceptions. In particular in the area of the Northern Bavarian Motorway Office, deterioration of the substance value is taking place at a concerning speed, although it started out at a relatively good level (Fig. 14).

Results of the ZEB 2007 on federal roads

For the first time, the results of the ZEB 2007 for federal roads and state roads were evaluated to show the development of their conditions. The results of the two previous surveys were prepared and combined with the latest results, as was done in the evaluation of the ZEB 2009 for motorways. In addition, the ZEB 2007 was statistically evaluated with regard to all country districts, state building offices, government districts and the whole of Bavaria.

The results of the last three surveys of the Bavarian federal road network in 1999, 2003 and 2007 show a slight overall improvement of the usage value from 2.28 in 1999 to 2.33 in 2003 and 2.23 in 2007. The substance had an average value of 2.31 in 1999, improved insignificantly to 2.28 and then deteriorated significantly to 2.61 in the last measuring survey in 2007. The total value has therefore continuously deteriorated during the whole observation period, from 2.83 in 1999 to 2.85 in 2003 and 2.98 in 2007 (Fig. 15).

A comparison of all state building offices in bubble diagrams shows that the usage value has improved from 1999 until today for approx. two thirds of all state building offices (Fig. 16). During the same period, the development of the substance value was only positive for approx. one quarter of the building offices (Fig. 17). The fact that the substance value deteriorated for all building offices between the surveys in 2003 and 2007 is particularly concerning (Fig. 18).

The analyses of the conditions by using means for the usage, substance and total value are supplemented by using the frequency distributions of the individual indicators. The frequency distribution of the substance value allows conclusions concerning regional backlogs with regard to maintenance. The frequency distribution is most unfavourable for the Lower Bavarian government district, while Swabia, Upper Franconia and Upper Palatinate show the most favourable distributions (Fig. 23).

Results of the ZEB 2007 on state roads

The results of the three measuring monitorings and evaluations of the pavement condition in 1996/98, 2002/03 and 2007 on the Bavarian state road network are as follows:

The usage value had an average of 2.98 in the first monitoring and

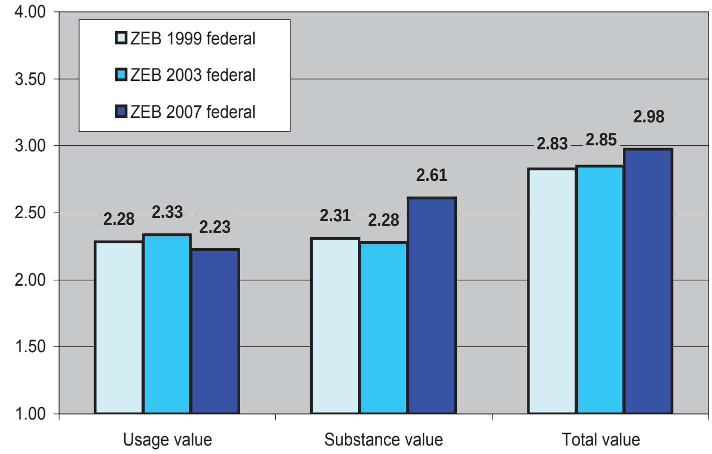

Figure 15: Survey comparison ZEB 1999 - 2003 - 2007 on federal roads. The averages relate to the routes covered in all surveys.

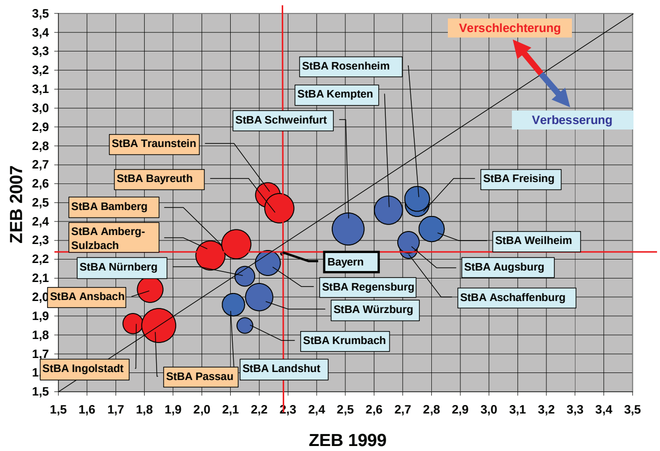

Figure 16: Averages of the usage values by state building offices 1999 - 2007 for federal roads

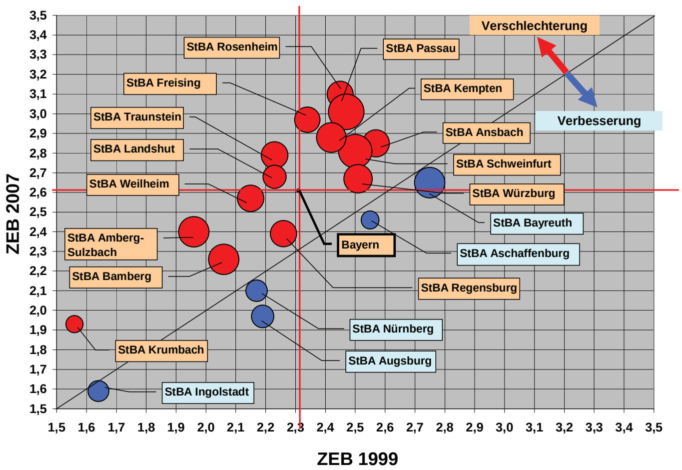

Figure 17: Averages of the substance values by state building offices 1999 - 2007 for federal roads

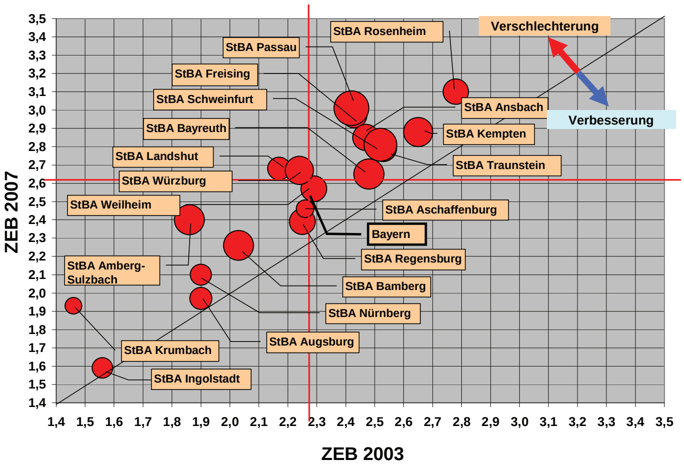

Figure 18: Averages of the substance values by state building offices 2003 - 2007 for federal roads

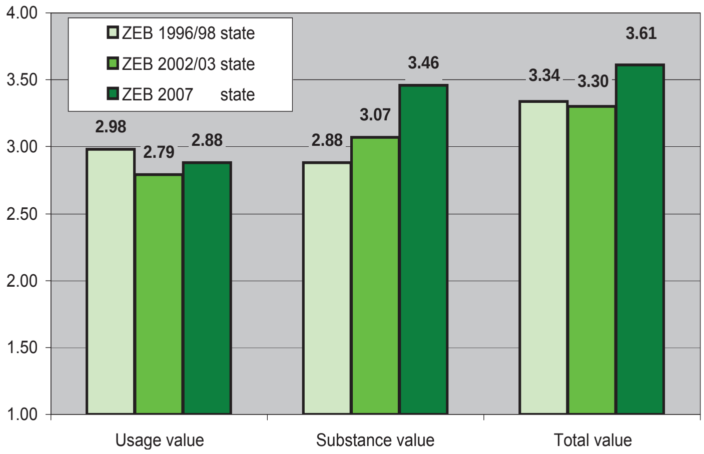

Figure 19: Survey comparison ZEB 1996/98 - 2002/03 - 2007 on state roads. Averages relate to the routes covered in all surveys.

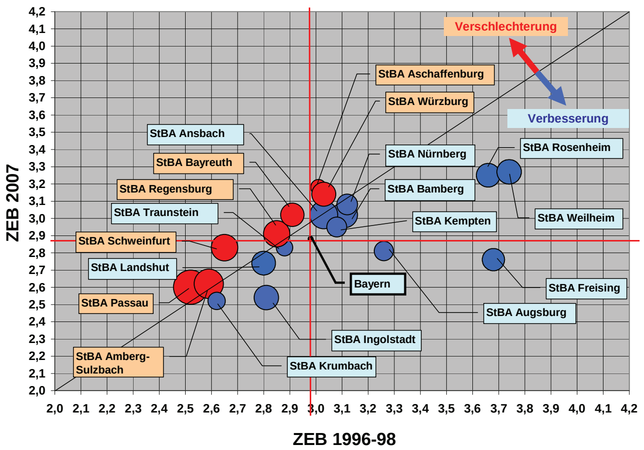

Figure 20: Averages of the usage values by state building offices 1996/98 - 2007 for state roads

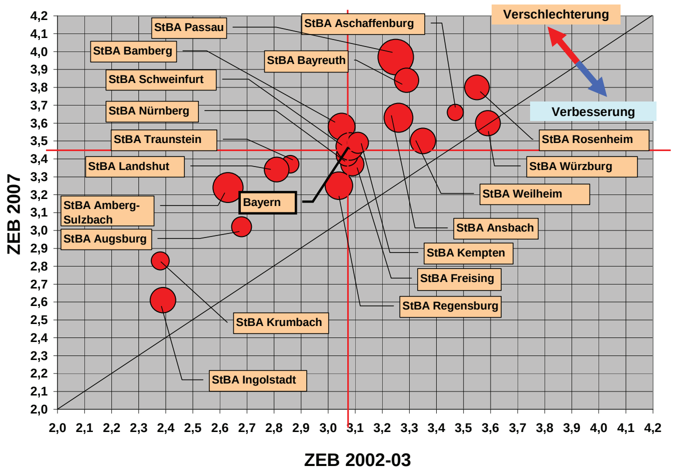

Figure 21: Averages of the substance values by state building offices 2002/03 - 2007 for state roads

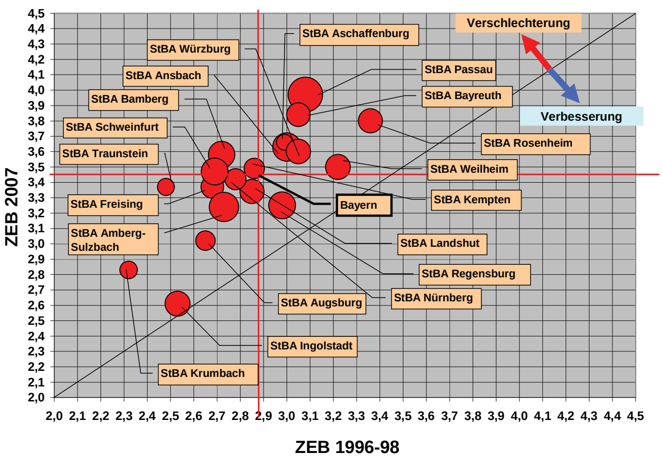

Figure 22: Averages of the substance values by state building offices 1996/98 - 2007 for state roads

evaluation in 1996/98. In the period to the next measuring survey in 2002/03, this improved to 2.79. In the last measuring survey in 2007, an average usage value of 2.88 was determined, which is slightly better than in the condition survey in 1996/98.

However, the substance value continuously deteriorated from 2.88 in 1996/98 to 3.07 in 2002/03 and finally to 3.46 (2007). This means that the total value during the monitoring period deteriorated from 3.34 (1996/98) to a current value of 3.61 (2007), after improving slightly to 3.30 (2002/03) (Fig. 19).

Comparison of the state building offices shows considerable differences between the averages. Approx. two thirds of all building offices could improve the usage value between 1999 and 2007. Improvements in some regions like the Freising building office district were very pronounced (Fig. 20). However the substance value deteriorated for all building offices in the time between 1996/98 and 2007 and also in the time between 2002/03 and 2007. The broad range of this deterioration is concerning (Fig. 21 and Fig. 22).

Consideration of the frequency distribution of the substance value shows that more than a third of the state roads in Bavaria exceed the threshold value. The worst-affected region is Lower Bavaria, where approx. half of the road networks exceed the threshold value. The situation is best in Swabia, with approximately one quarter of the road above the threshold value (Fig. 24).

Comparison of the ZEB results on motorways, federal roads and state roads in Bavaria

The road condition values and the condition development for all three road classes could easily be compared, as the evaluation of the ZEB measurements on motorways, federal roads and state roads used the same evaluation scale, i.e. the same standardisation function for the conversion of measured condition values.

The comparison shows that the level of the averages increases with the value of the importance of the road class (Fig. 25). This implies that the road condition of motorways is significantly better than that of federal

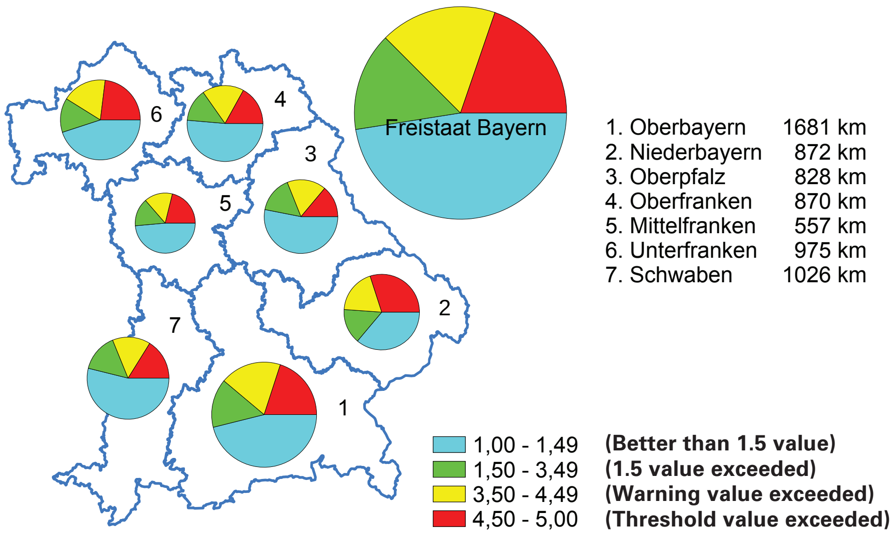

Figure 23: Frequency distribution of the substance value in the government districts on federal roads in the ZEB 2007

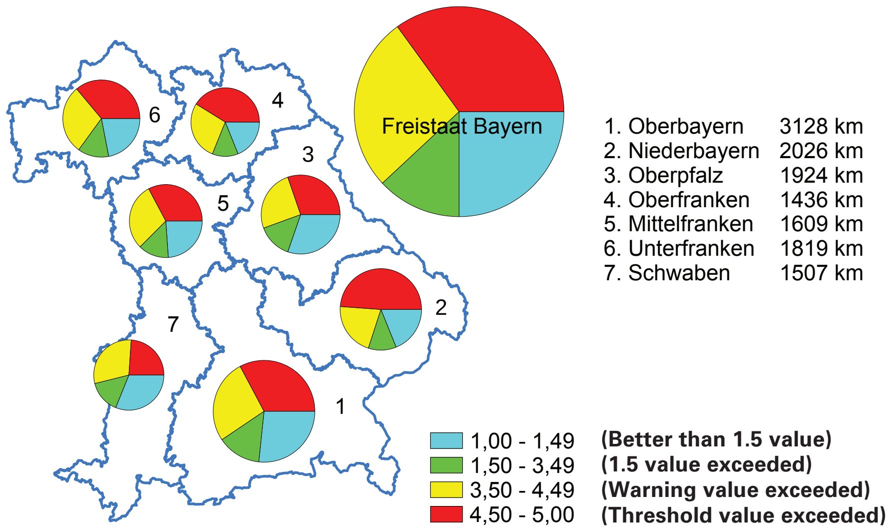

Figure 24: Frequency distribution of the substance value in the government districts on state roads in the ZEB 2007

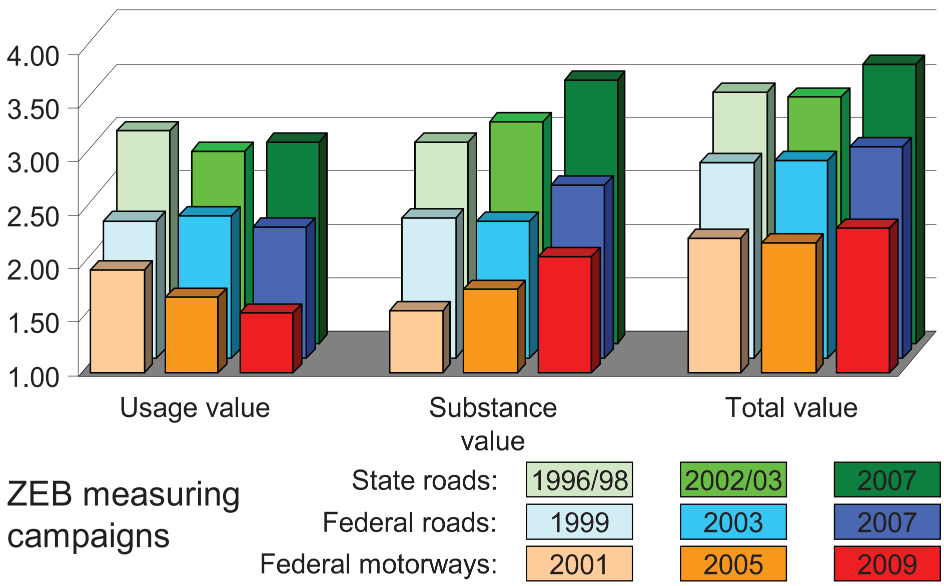

Figure 25: Condition development for motorways, federal roads and state roads in Bavaria

roads. This seems justified, given the higher speeds driven and higher requirements for motorways. The condition of the federal roads is in turn clearly better than the condition of the state roads. The significantly worse state of the state roads is concerning, as the speeds driven and the traffic safety levels are comparable for both road types.

Interpretation of the ZEB results

Insufficient resources used

These developments indicate the consequences of resource utilisation in recent years on the condition of the roads. An average of 119 million € per year was used in the years from 2001 to 2010 to maintain motorways. This is clearly less than is required according to generally accepted findings. The "Standard prediction of maintenance requirements for the highway infrastructure until 2015" (Project No. 28.004/199 Maerschalk/RS-Consult Rübensam), for example, which was commissioned by the former Federal Ministry of Transport, Building and Housing and completed in 2002, provides different scenarios concerning maintenance requirements. The maintenance requirements for sustaining the condition of engineering structures, carriageways and other system parts of the Bavarian motorway network at the level determined in the ZEB 1997 were assessed at 187 million € per year on average. This figure did not include building price increases and the increase in value-added tax, which has come into force in the meantime.

This study also estimated a requirement of 123 million € per year or 2.09 €/m² [1] for sustaining the conditions of the federal roads in Bavaria at that time. However, the real expenses for asset preservation of federal roads during the last decade (2001-2010) were only 75 million € per year on average. Given the current length of the network, this corresponds to less than 12,000 € per kilometre per year or approximately 1.40 €/m² [1].

Only 67 million € per year were on average invested in the whole of Bavaria on state roads in the years 2001 to 2010. This corresponds to

[1] The cost information includes the demand or the expenses for road carriageways, engineering structures and other system components.

less than 5,000 € per kilometre per year or 0.80 €/m^2 [1]. Between the measuring surveys in 1996/98 and 2007, this amount was on average only approximately 50 million € per year. The maintenance requirements based on investigations of the Bavarian General Accounting Office in 1995 for pavements alone amounted to 85 million € per year, which currently corresponds to 100 million € per year or 1.17 €/m^2 when the development of the building prices is considered.

The insufficient means for asset maintenance during the last decade forced the motorway offices as well as the state building offices to postpone due maintenance measures or to delay overdue, basic renewal with superficial repairs.

The Bavarian Road Administration managed to keep the surface properties, which are essential for traffic safety and driveability, at a constant level or to improve them in some cases. However, the substance value of the roads could not be maintained. These findings indicate that the road substance will deteriorate further in future when the means available remain unchanged. Maintenance of the whole road network is not sustainable in this way, as the continuous deterioration of the substance due to increasing load on the roads, in particular by heavy traffic, leads to an increasing demand for repair measures, which is associated with increasing costs per kilometre. This is not an economical maintenance practice. Even "minor" events such as frequent frost-thawing changes in winter in connection with normal traffic load will increasingly lead to massive damage to the road structure (e.g. potholes) that can only be repaired with relatively high financial effort.

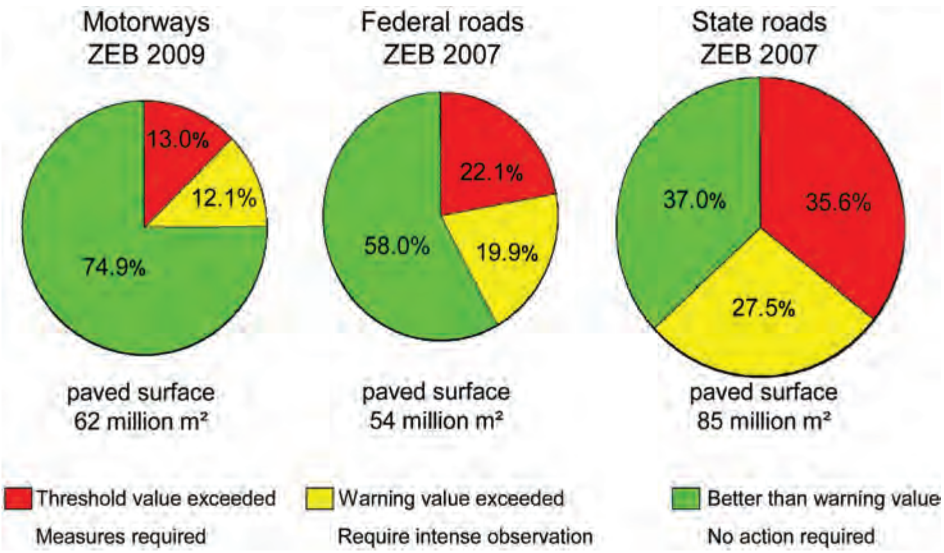

Figure 26: Frequency distribution of the total value on motorways (ZEB 2009), federal roads (ZEB 2007) and state roads (ZEB 2007) in Bavaria. The size of the circles is proportional to the paved surface.

High and increasing maintenance backlog

Continuous underfinancing increases the backlog for asset maintenance, i.e. the part of the road network that is overdue for construction measures. In the ZEB 2001, 9.3% of the road sections covered in the survey had a total value above the threshold value (mark $\geq$ 4.5). In the ZEB 2005, this part had already increased to 11.6% and in the ZEB 2009 it included 13% of the motorway network (Fig. 26). This implies that currently approximately 1,450 of the total of 11,200 motorway lane kilometres in Bavaria are in a state that requires basic renovation with appropriate financial means or measures to restrict traffic. Renovation costs for these road sections are estimated at more than 300 million € In addition to the network sections due for renovation, a further 12.1% of the routes, i.e. more than 1,350 motorway lane kilometres, require intense observation. This implies that maintenance investment will be required in the mid-term. These renovation requirements do not include engineering constructions, which have also continuously deteriorated in recent years due to the difficult financial situation. The pending backlog for bridge renovation considerably exceeds that for pavement renovation, as the bridge area proportion in motorways is very high and the age structure of the motorway bridges is very unfavourable.

The proportion of the federal road network that is overdue for construction measures has also noticeably increased in recent years, from 18.9% in the 2003 survey to 22.1% in the ZEB 2007. In addition, the warning value has been exceeded on 19.9% of the federal road network, which implies appropriate maintenance measures in the mid-term (Fig. 26).

The backlog for state road maintenance is even more considerable. The ZEB 2007 shows that the total value of 35.6% of the state road network exceeds the threshold value (Fig. 26). The state road network for which the Free State of Bavaria is responsible includes 13,500 km of roads. This share of the network was still 27.5% in 2002/03. The ZEB 2007 shows that approximately 4,800 km of Bavarian state roads require renovation. The renovation of these road sections alone would require on average 150,000 €/km, resulting in a total investment of 720 million €. The backlog for pavement maintenance, which was assessed at 450 million € in the ZEB 1996/98, has therefore significantly increased. Additional funding of at least 70 million € per year would be required to work off the current backlog of 720 million € within 10 years. When adding the current maintenance requirements for the state road network of 100 million € per year, as described above, the annual maintenance requirements are therefore 170 million € per year for the next ten years.

In addition to the network parts that already require thorough renovation today, a further 27.5% of the state road network or approx. 3,700 km of road require intense observation, which implies maintenance investment in the mid-term. Only 37% of the state road network currently require no planning or performance of maintenance measures.

Provision of maintenance resources

The situation described makes it obvious that the funding for asset maintenance of all road types must be permanently increased to counteract the continuous deterioration of pavement and bridge conditions of the road network, which increase the chances of damage (e.g. "winter damage").

Economic recovery packages in 2009 allowed a significant increase in maintenance funding as compared to previous years (motorways: 238 million €, federal roads: 164 million €, state roads: 119 million €), but the funding for asset maintenance dropped in 2010 already (motorways: 118 million €, federal roads: 99 million €, state roads: 96 million €). Also in 2011, the expenditure for the maintenance of federal roads remained clearly below the demand specified previously. It will not be possible to reduce the maintenance backlog with this level of funding. One positive development is that the maintenance budget for state roads was significantly increased to a total of approx. 125 million € in 2011. This provides at least some opportunity to reduce the backlog in addition to covering the current needs.

Use of the current findings

Sufficient funding for asset maintenance on a continuous basis will be required in the coming years to prevent significant deterioration of the road conditions and to work off the backlog regarding road asset maintenance. It must also be ensured that the means available are invested in an optimal manner according to the locally recognisable demand. The Bavarian Road Administration has therefore further optimised its management concept for road maintenance to cater for different peripheral conditions (network length, traffic road conditions) in different regions. The resulting coordinated maintenance and building programme was first introduced in 2008 for federal and state roads. It supports the state building offices with medium-term planning of maintenance measures based on objective criteria such as the pavement and engineering structure conditions and provides a basis for controlling.

The distribution key for asset maintenance of federal and state roads was further developed to make even better use of the available budget based on objective criteria (see article "Coordinated maintenance and building programme (KEB) for federal and state roads" as well as "Condition-related granting of funds in the maintenance of existing constructions" in this special issue). The results of the ZEB for motorways are used in software-based maintenance planning using the Pavement Management System (see article "The Pavement Management System (PMS) on motorways" in this special issue). The Bavarian Road Administration will use these tools to handle the maintenance of pavements and engineering structures and will verify the resulting developments, based on future condition surveys and evaluations.

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Coordinated maintenance and building programme (KEB) for federal and state roads

Dipl.-Ing. (FH) Wolfgang Zettl

General information

The increasing usage of roads, especially by heavy-duty traffic, along with the ever more unfavourable ageing structure and scarce budget resources, are increasingly forcing road construction cost bearers to introduce a system for network-wide maintenance. Thus various computer-aided tools have been developed in recent years to link extensive information about road maintenance and to generate automated suggestions for road maintenance measures. The question of which tools are possible and suitable particularly depends on the data availability for the road network in question. The requirements for the generation of automated measure recommendations for carriageways by a Pavement Management System (PMS) are currently not always fulfilled when it comes to federal and state roads in Bavaria. The PMS is therefore being used for federal motorways in the Bavarian Road Administration. Thus far it has been restricted to a few pilot projects when it comes to state building offices with road-building responsibilities. The generation of automated recommendations for road maintenance as a basis for creating a maintenance management system (EMS) in Bavaria was thus mainly carried out on the basis of the improved maintenance planning system (VEP) by the state building offices. The VEP system was developed by the Bavarian Road Administration in cooperation with Heller Ingenieurgesellschaft mbH in Darmstadt in 1999 and 2000 and introduced on a broad scale. The Bavarian Road Administration has consistently continued with the development of the VEP system and - based on this - the so-called "Coordinated maintenance and building programme" (KEB). This bundles and documents the main information about maintenance planning. Thus far the KEB has been restricted to federal and state roads and has been implemented by the relevant state building offices since 2008.

The VEP system as the main basis of the KEB, the various procedural steps and an analysis of the KEB are provided in more detail below.

VEP section division

The VEP is based on the results produced by the ZEB. Within the framework of the VEP, maintenance sections are defined, consisting of several consecutive evaluation sections. In this case the term "evaluation sections" refers to 100 m or (for city roads) 20 m sections, for which the condition parameters, condition values and the ZEB sub- and total values are known.

In a first step, the urgency class (DK) of all evaluation sections is determined by means of a two-dimensional urgency matrix (Fig. 1). The input parameters for the matrix are the adjusted usage and substance values ($GEB_{mod.}$ and $SUB_{mod.}$), which are formed from the condition characteristics by applying weighting and linking rules.

As the 100 m or 20 m evaluation sections are not suitable for direct construction lots, they are combined in a second set of longer and homogeneous maintenance sections. The definition of the maintenance sections takes place automatically, taking into account the following tried and tested parameters.

- The length of a maintenance section must be at least 500 metres.
- Only maintenance sections with an urgency class rating between 1 and 5 are taken into account.
- A maintenance section may comprise 100 m evaluation sections (or 20 m sections in cities) in a better condition, provided that their total length does not exceed 20% of the length of the total maintenance section. The minimum length of the consecutive evaluation sections in a poorer condition must be at least 200 metres. The length of the consecutive evaluation sections in a better condition may not exceed 200 metres.
- Up to three evaluation sections are bridged by interpolation where no measuring data are available.

The urgency class ($DK_{Erh.}$) is subsequently defined for the resulting maintenance sections. For this purpose, the average modified usage value and the average modified substance value are calculated. The two average values are then again linked via the two-dimensional urgency matrix (Fig. 2), in the same way in which the urgency class for the evaluation section is defined.

As previously mentioned, a maintenance section may comprise up to 20% better sections than urgency class 5. The urgency class for a maintenance section ($DK_{Erh.}$) may thus be determined as 6, 7 or even 8 on the basis of the calculated average and/or in the case of a very heterogeneous

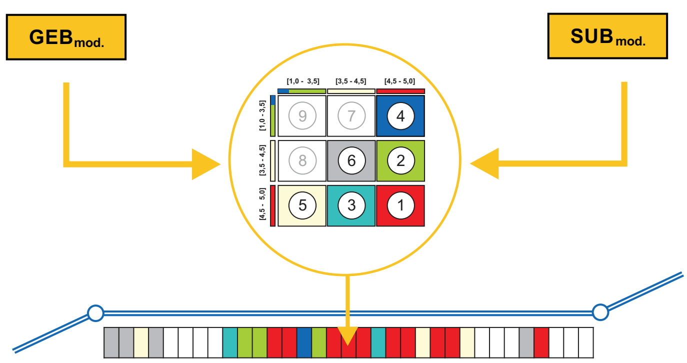


Figure 1: Determining the urgency class for each evaluation section

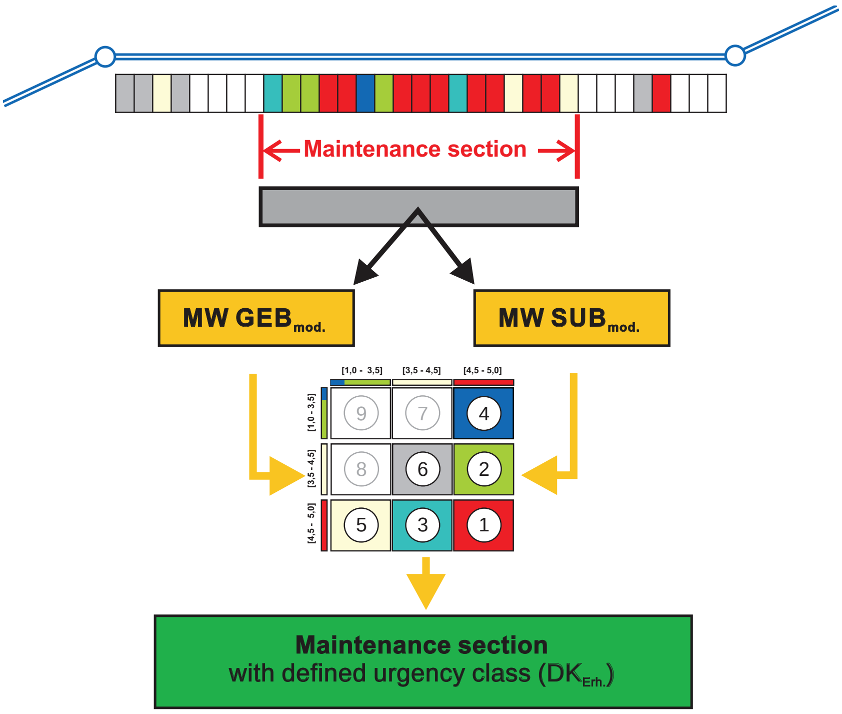
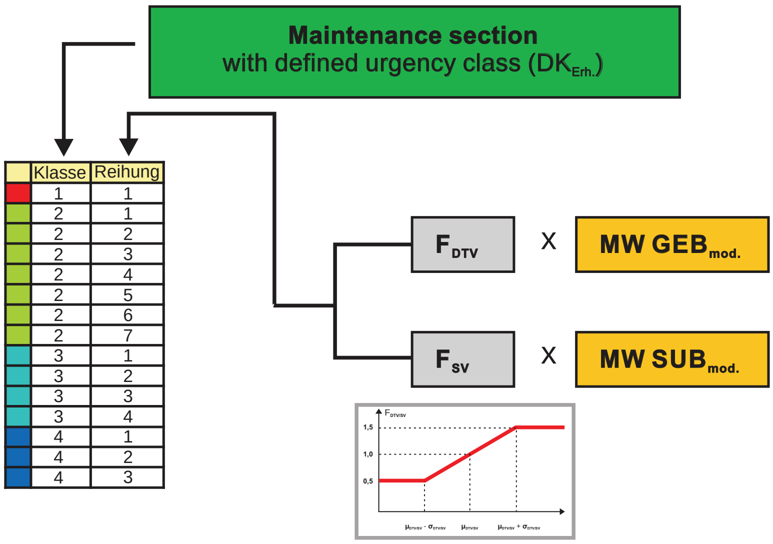


Figure 2: Generating the maintenance sections and determining the urgency class



Klasse	Reihung
1	1
2	1
2	2
2	3
2	4
2	5
2	6
2	7
3	1
3	2
3	3
3	4
4	1
4	2
4	3

Figure 3: Urgency ranking, taking traffic load into account

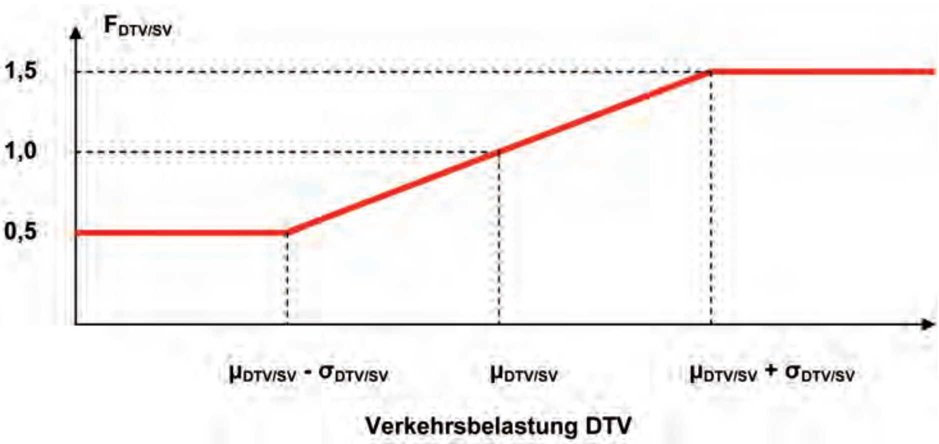


Figure 4: Function to calculate the weighting factors F_{DTV} and F_{SV}

condition distribution.

Urgency ranking of VEP

The urgency ranking of the defined maintenance sections within the same urgency class takes into account the significance of its traffic and the use of this road by heavy-duty traffic. Sub-values are defined for each maintenance section, i.e. the average modified usage and the average modified substance value, with a factor F_{DTV} which is supposed to reflect the traffic significance of the section and F_{SV} to take into account the heavy-duty traffic load, multiplied and subsequently added to obtain a weighted total value. This weighted total value is then used to calculate an internal ranking within each class. The higher the weighted total value, the more urgent the classification of the maintenance section (Figure 3).

The factors F_{DTV} and F_{SV} are calculated on the basis of the traffic load and its standard deviations. If the average traffic load exerted by passenger and heavy-duty vehicles within the maintenance section is regarded as equal to the national average (μ_{DTV} or μ_{SV}), the factors F_{DTV} or F_{SV} are deemed to be equal to 1.0. For sections with a traffic load greater than or equal to the national average plus the calculated standard deviation, the factor is F = 1.5. For sections with a traffic load less than or equal to the national average minus the standard deviation, F = 0.5. A linear interpolation is made between these values (Fig. 4).

System for coordinated maintenance and building programmes (KEB)

The system for coordinated maintenance and building programmes (KEB) takes into account the experience gained at all administrative levels, both from a strategic and an operational point of view. Various bases such as the ZEB and construction tests and aids such as the above-mentioned VEP are used, all of which have been compiled at considerable expense. The aim is to optimise the maintenance of the carriageway pavements and the constructions, making use of a coordinated maintenance and construction programme to render them more transparent. This is associated with the following expectations and requirements:

- Consistent utilisation of the existing bases, aids and data
- Systematic processing of the automatically recommended measures
- Taking into account the perspectives of third persons (e.g. communities)
- Documentation of the decisions made
- Traceable urgency ranking (including for publicity work)
- Controlling
- Systematic observation of condition developments

An Excel list forms the central work base of the KEB. This Excel list provides an overview of all relevant maintenance planning information of a state construction office. The basis for compiling the KEB list is constituted by automatically generated recommendations for route sections and constructions that require renovation. The KEB Excel lists are separately maintained for federal and state roads by each state building offices, with the structure of the Excel lists being the same for the federal and state roads. The automatically generated measure recommendations in the basic Excel lists of the KEB were centrally entered by the Bavarian Building Authority to reduce the effort required from the state building offices, although the basic Excel lists had been distributed to all state building offices. The recommended measures for the carriageway correspond to the maintenance sections formed on the basis of the ZEB 2007 results with the aid of the VEP. As soon as the recommended measures resulting from the current ZEB 2011 are available, they are correspondingly taken into account the next time the KEB is updated. When it comes to constructions, the recommended measures included in the basic KEB tables are those for which the construction test has resulted in an overall condition mark ≥ 2.8. The selection criterion for constructions is limited to the general condition mark for constructions, as the overall condition mark already contains a weighting for the various component groups and only damage that has a significant effect on the condition of the overall construction should receive an overall condition mark ≥ 2.8. Each of these potential carriageway or construction measures is shown as a recommended measure on a line of its own in the basic KEB list.

The ranking of the recommended measures for carriageways corresponds to the urgency ranking according to the VEP system. The urgency ranking for constructions depends on the overall condition mark. Other criteria relevant for decision-making, such as the road composition or the last measure carried out, as well as the perspectives of third parties (e.g. communities) are not taken into account when automatically generating the recommended measures. In the same way, no concrete types of measures or costs are as yet allocated to the recommended measures. This allocation only takes place when the construction programme is compiled by the state building offices. Engineering criteria are most important in this regard.

When the construction programme is compiled by the state building offices, the first step is to check the automatically generated recommended measures for plausibility in the basic lists. The recommended measures might then be supplemented or their urgency level changed, citing reasons. In addition, the limits of the maintenance sections might be adapted to local circumstances and the types of measures allocated to the sections in accordance with engineering criteria. The cost of the measures will be determined and the number of years required for implementation defined on the basis of the specified budget. This implementation ultimately results in a concrete construction programme for carriageways and constructions with an internal urgency ranking based on automatically generated recommended measures. Documentation of the decisions taken is of primary importance. The framework for the KEB is formed by strategic objectives such as the budget framework of the maintenance media or the desired road condition.

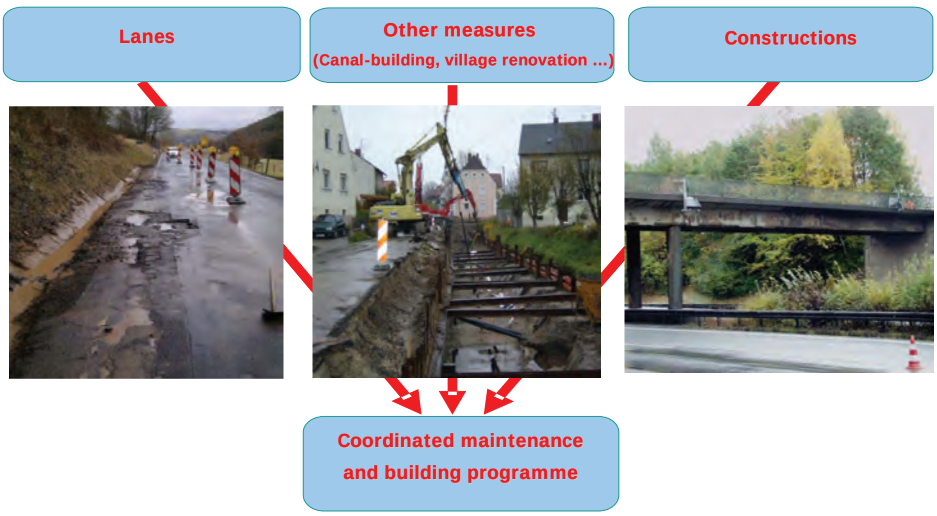
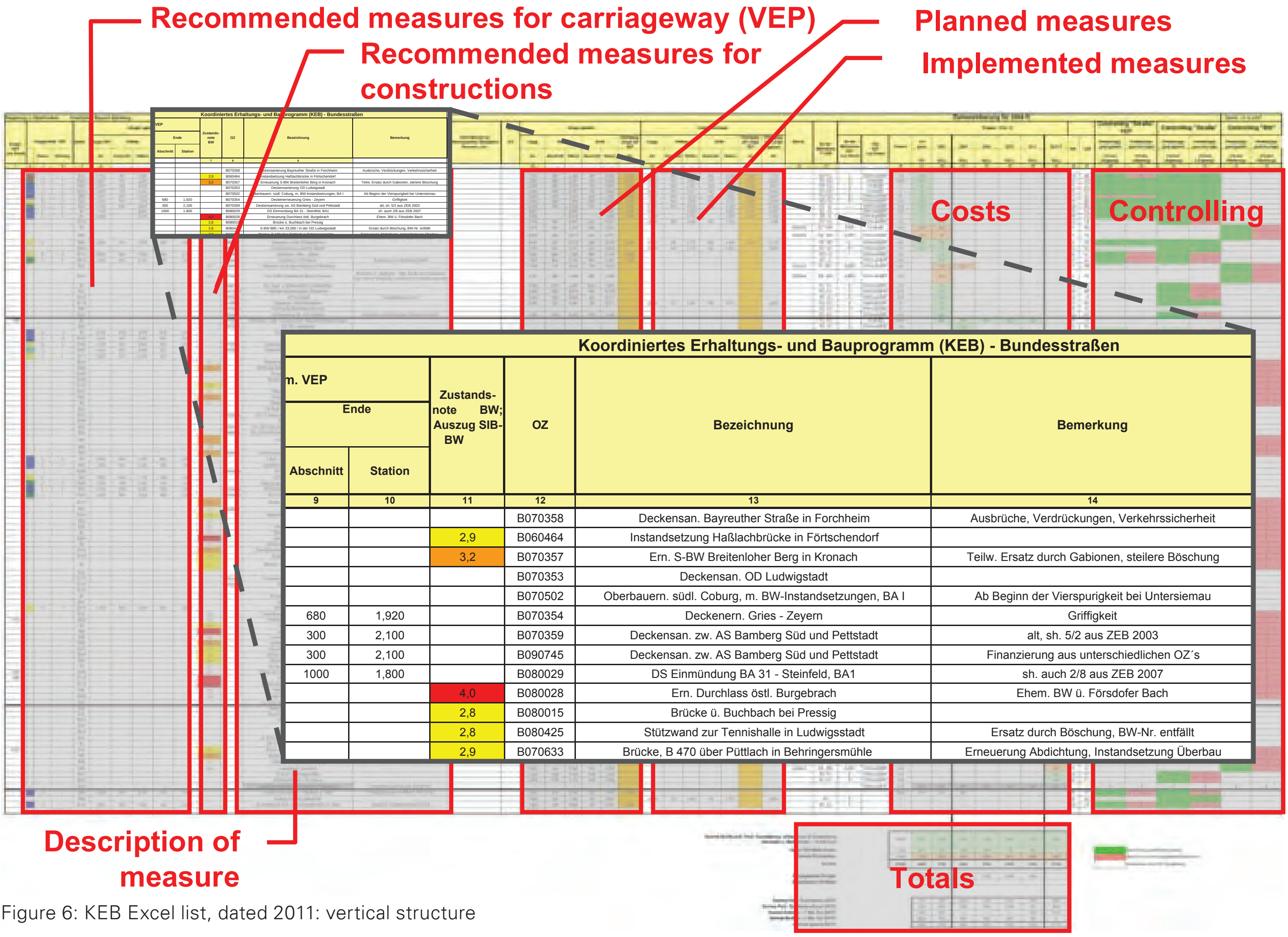


Figure 5: Bundling the information in the coordinated maintenance and building programme (KEB)

Structure of the KEB Excel list

The vertical structure of the KEB list consists of various blocks (Fig. 6). The vertical structure of the first two blocks of the KEB Excel list contains the VEP sections recommended for renovation and the constructions for which maintenance measures appear to be required on the basis of the overall condition mark. The other blocks show the planned and executed measures. The cost columns result in an initial ranking for implementing the measures, with the colour coding in the controlling section indicating the percentage to which such implementation has taken place. The totals block below the costs of the individual measures is used as an indication whether the available budget has been adhered to.

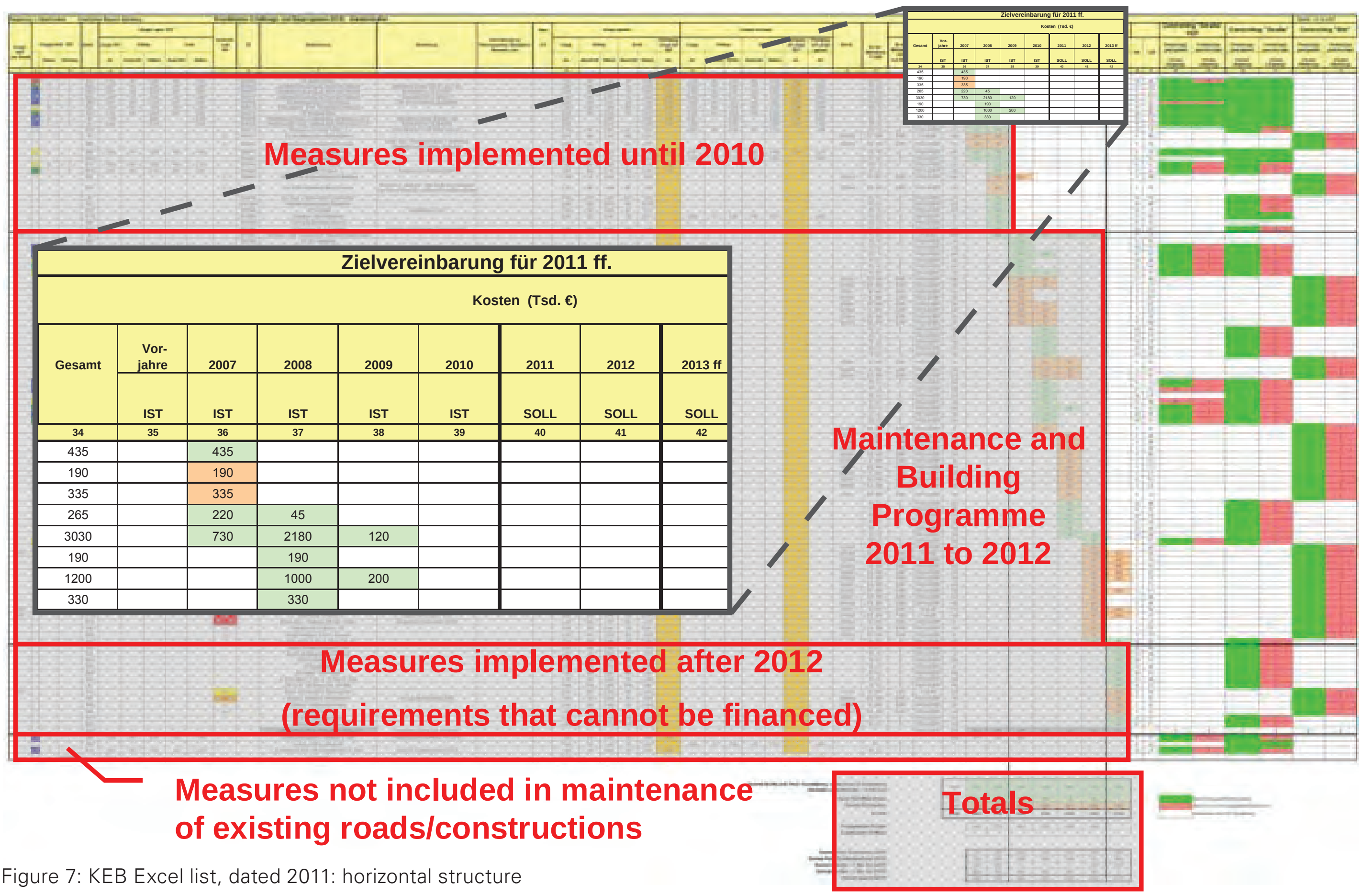
Various abbreviated views have since been added to improve the individual visual presentation of the KEB Excel lists. These abbreviated views make a rapid reduction of the column size of the KEB Excel lists possible, depending on the requirements of each user.



Koordiniertes Erhaltungs- und Bauprogramm (KEB) - Bundesstraßen

m. VEP Ende Abschnitt	Station	Zustands-note BW; Auszug SIB-BW	OZ	Bezeichnung	Bemerkung
9	10	11	12	13	14
			B070358	Deckensan. Bayreuther Straße in Forchheim	Ausbrüche, Verdrückungen, Verkehrssicherheit
		2,9	B060464	Instandsetzung Haßlachbrücke in Förtschendorf	
		3,2	B070357	Ern. S-BW Breitenloher Berg in Kronach	Teilw. Ersatz durch Gabionen, steilere Böschung
			B070353	Deckensan. OD Ludwigstadt	
			B070502	Oberbauern. südl. Coburg, m. BW-Instandsetzungen, BA I	Ab Beginn der Vierspurigkeit bei Untersiemau
680	1,920		B070354	Deckenern. Gries - Zeyern	Griffigkeit
300	2,100		B070359	Deckensan. zw. AS Bamberg Süd und Pettstadt	alt, sh. 5/2 aus ZEB 2003
300	2,100		B090745	Deckensan. zw. AS Bamberg Süd und Pettstadt	Finanzierung aus unterschiedlichen OZ´s
1000	1,800		B080029	DS Einmündung BA 31 - Steinfeld, BA1	sh. auch 2/8 aus ZEB 2007
		4,0	B080028	Ern. Durchlass östl. Burgebrach	Ehem. BW ü. Försdofer Bach
		2,8	B080015	Brücke ü. Buchbach bei Pressig	
		2,8	B080425	Stützwand zur Tennishalle in Ludwigsstadt	Ersatz durch Böschung, BW-Nr. entfällt
		2,9	B070633	Brücke, B 470 über Püttlach in Behringersmühle	Erneuerung Abdichtung, Instandsetzung Überbau

Figure 6: KEB Excel list, dated 2011: vertical structure



Zielvereinbarung für 2011 ff.

Kosten (Tsd. €)

Gesamt	Vorjahre IST	2007 IST	2008 IST	2009 IST	2010 IST	2011 SOLL	2012 SOLL	2013 ff SOLL
34	35	36	37	38	39	40	41	42
435		435						
190		190						
335		335						
265		220	45					
3030		730	2180	120				
190			190					
1200			1000	200				
330			330					

Figure 7: KEB Excel list, dated 2011: horizontal structure

The horizontal structure (Fig. 7) divides the KEB into

- measures already started or implemented during previous years,
- measures to be implemented in the medium term,
- measures that cannot be financed in the medium term, although they would be required. These measures are shown in the KEB so that the technical maintenance requirements can be documented,
- there may be recommended measures that are not deemed to be urgent and can therefore be postponed,
- measures that are covered by the recommendations but cannot be financed from the budget resources available for maintenance (measures for reconstruction and extension).

The horizontal structure thus provides a good time overview of the maintenance planning at state building offices.

Coordination of the KEB

The KEB Excel lists are updated at regular intervals, usually on 15 February of each year. The Excel lists are stored in a distributed file system (DFS) by the state building offices. Access rights have been regulated as follows in the DFS:

State building offices

- The office manager, divisional manager for road construction and departmental managers are given reading rights.
- The sectional manager for maintenance management and/or the person responsible for maintenance management are given reading and writing rights.

District governments

- The person responsible for maintenance management is given reading rights.

As part of an efficient maintenance management system, the district governments are responsible for the technical and organisational coordination of the KEB. Once the KEB lists have been compiled and updated by the state building offices, the district governments have the task of analysing the building offices' programmes according to the agreements concluded, thus preparing the ground for other targeted decision-making.

The district governments forward the main results of the controlling process to the Bavarian Building Authority.

Where adjustments and additions to the KEB Excel lists are required, these are centrally implemented by the Bavarian Building Authority for reasons of standardisation. To ensure the best possible continuity in keeping the KEB Excel lists, they are restricted to the absolute essentials.

KEB analysis

The introduction of the KEB for federal and state roads in Bavaria makes it possible to analyse and control the maintenance programs of the state building offices. The controlling system is mainly restricted to strategic goals ("Are the right things being done?"). A detailed individual view of the project planning (e.g. selected types of measures) is currently only provided by the Bavarian Building Authority in selected individual cases.

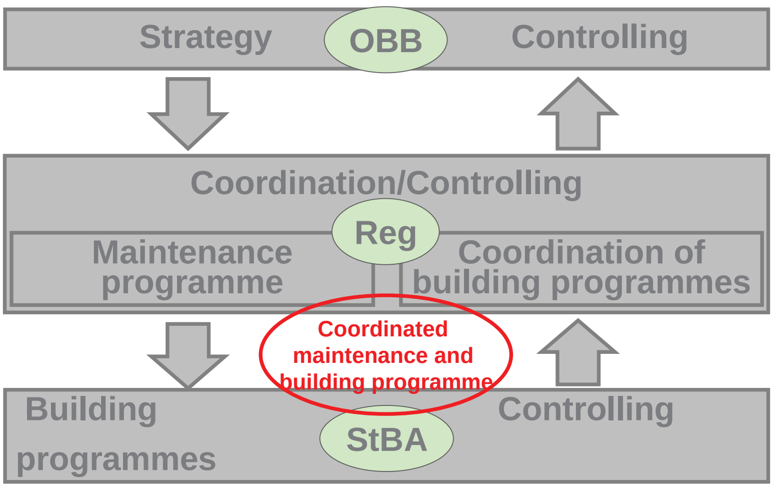


Figure 8: Flow chart for the coordinated maintenance and building programme (KEB)

The most important basic premise for meaningful controlling is a uniform database. For the KEB, it is a priority to analyse whether motivation and documentation have been adequate,

- why recommended measures are being delayed,
- why the recommended urgency of measures is being changed, or
- why new projects are given priority over recommended measures.

When it comes to additional analyses of the KEB lists, the database requirements increase along with the quality requirements and the requirements for the scope of evaluation.

The analysis of the KEB lists has to date been summarised and documented by KEB data sheets. A separate data sheet is compiled for each KEB list (Fig. 9). The data sheets are structured as follows:

General information (data set)

The need for improvements to the data base has been summarised below. The better the data base, the better and more reliable the maintenance information will be.

Key information

The key information provided for the maintenance planning of the relevant state building offices is displayed here. This includes information on whether the urgency ranking of the projects has been adequately documented and what the main cost factors for maintenance planning are.

Reference figures

Reference figures provide rapid information on the areas in which funds have been invested or are to be invested. The evaluation of the reference figures has been restricted to a few relevant key data that make a comparison of the various offices possible (benchmarking). Because of changes in the distribution of funds, approximately half of the maintenance funding is allocated according to the recommended measures and thus the basic lists of the KEB. This can be used for controlling purposes, among other things to derive the targets for implementing as many recommended measures as possible in the various budget years. The cost of the recommended measures as a percentage of the total budget has

Data sheet for the federal coordinated maintenance and building programme – Date: 15/02/2011

State Building Office A-Stadt
Road-Building Division

General information (database)

Both the database and its structure were jointly optimised with the building office.

Core statements

- All plausible traffic development measures have been taken into account in the programme and carefully assessed with regard to their urgency.
- Additional measures have been adequately motivated.
- Unfortunately the cost framework requires bridges with condition marks ≥ 3.0 to be classified as non-financable.
- Superstructure replacement south of A-Stadt is not a traffic development measure and binds significant asset maintenance funds.
- 75% of the non-financable requirements are constructions (constructions are postponed).
- In deviation from the original planning for 2010, the renovation of the bridge across the Oberbach in B-Stadt was postponed until 2011. Two additional measures not related to traffic development were realised instead.

Individual consideration (reference figures)

	2009 current	2010 target	2010 of which realisedt	2010 realised in deviation	2011	2012	Orientation value (percentage of allocated office budget)
1. VEP-measures							
Number of projects	7	5	5	0	5	3	
Budget amount (€ '000)	2305	675	700	0	1000	700	
Percentage of budget (%)	30	13	14	0	20	14	18
2. Non-VEP-measures							
Number of projects	13	8	8	2	10	12	
Budget amount (€ '000)	2428	1580	1600	500	2000	2500	
Percentage of budget (%)	32	31	32	10	40	50	
3. Construction							
Number of projects	4	5	4	0	5	3	
Budget amount (€ '000)	1750	1950	1400	0	1500	1400	
Percentage of budget (%)	23	39	28	0	30	28	35
Σ (Percentage of budget of 1.-3. above)	85	83	74	10	90	92	
Expenditure / budget framework (€ '000)	7640	5060	5000		5000	5000	
• Non-financable requirements for planned measures 2013ff							approx. 30 million €

Figure 9: Example of a data sheet (abbreviated)

thus been mainly used as a determining factor. Since 15 February 2011, a target/current comparison has also been carried out for the past year (Fig. 9).

In addition, the KEB Excel lists also make further data evaluations possible. For example, the average cost of implementing measures can be separately determined for each type of measure and for federal and state roads. A rapid overview of the maintenance plans of the state building offices is also very useful when answering enquiries about the maintenance of existing roads and constructions.

Our experience thus far has shown that the KEB can be used for targeted implementation of the maintenance programme for carriageways and other constructions even when conditions change in the short term, for example when additional financing becomes available.

Visualising the KEB lists

Since October 2010 it has been possible to generate map info relations online from the KEB-Excel-lists of the state building offices, making use of an application for the BAYSIS intranet (Fig. 10). The online platform is updated each year, as the period for the construction programme also changes on an annual basis. The indications of the planned and implemented measures compiled by the state building offices on various key dates are also regularly integrated into the BAYSIS card window, usually after the update deadlines (Fig. 11).

In addition, this tool can also be used by the offices for compiling theme cards. A corresponding manual and sample card is made available to the offices on the intranet.

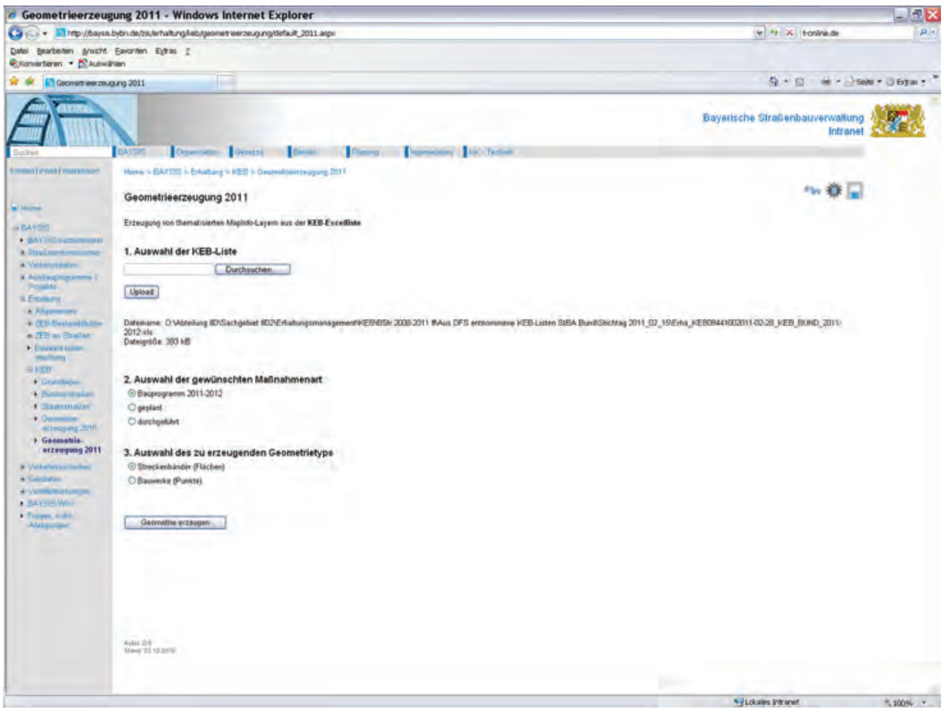


Figure 10: Online display platform

KEB in MaViS

MaViS is a central project management and controlling tool for managing infrastructure projects. In future, the maintenance planning data and the data for other technical programmes are to be entered into the MaViS project information system. It is nevertheless possible to compile the KEB lists in their conventional form using MaViS. In MaViS, this takes place via a so-called report generator.

Summary

The systematic condition survey of the carriageway pavements as part of the ZEB and the constructions as part of the regular inspection system are the basic requirements for systematic maintenance planning and the "Coordinated Maintenance and Building Programme" developed by

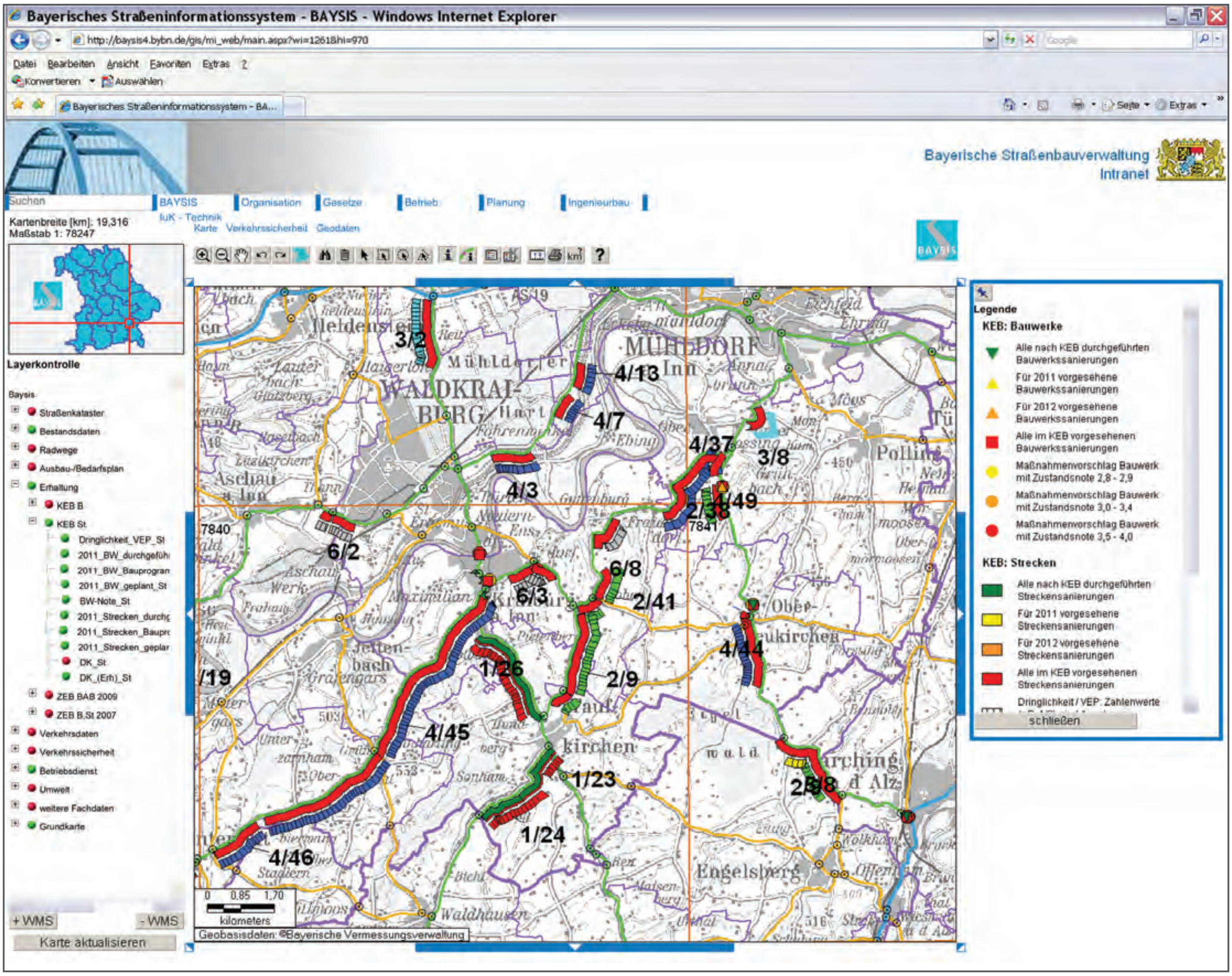


Figure 11: KEB in the BAYSIS card window

the Bavarian Road Administration. This has enabled the state building offices to conduct their maintenance management on a motivated, traceable basis. As a further step, the maintenance and building programmes compiled allow for more consistent analysis with regard to the planned implementation of the programmes and thus of the controlling system. This may also result in the inadequate provision of maintenance media.

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The Pavement Management System (PMS) on motorways

Dipl.-Ing. Rupert Schmerbeck

The Southern Bavarian Motorway Office manages some 33 million m² of motorway pavements, including connection points, parking lots and other auxiliary spaces. The average age of the pavements is currently approximately 17.3 years. Our oldest existing pavements date back to the 1960s.

An asphalt pavement lasts on average 15 to 20 years, while a concrete pavement has a service life of 25 to 30 years. On average, this results in a potential service life of approximately 20 years. A simplified calculation would yield the result that each year about 5% of the pavements, i.e. about 1.5 million m², would have to be renovated for the average age of the pavements to be about 10 years. In practice, however, just under a million m² per year have been renovated on average.

The reason for this is that maintenance funding is limited. The relationship between budget underfunding and pavement age can be clearly seen in Figure 1. Thus far it is only in 2009 that it has been possible to reverse the progressive aging of the existing pavements. The federal budget programme with its high level of maintenance funding has thus proven effective. This effect has been further increased by the completion of the A8 extension between Augsburg and Munich as part of the operator model. This, too, has resulted in a slight decrease in the average age.

The aim of compiling a pavement management programme is to take into account the specified budgets, while optimising pavement maintenance for the entire network of the Southern Bavarian Motorway Office. The Pavement Management System (PMS) is an important tool in this regard. It was used for the first time in 1999 as part of a research project concerning the two motorway offices, as well as in the capacity of a pilot project by the former Weilheim Road building office.
From 2001 onwards, the PMS results served as the basis for the pavement construction programme of the Southern Bavarian Motorway Office.

Although the keyword PMS has been ubiquitous, many people do not know what lies behind the term. The term "PMS" is used in two contexts. First of all, the PMS refers to the entire cycle of road maintenance. In a narrower sense, this now refers to computer-aided maintenance planning.

The road maintenance cycle consists of several steps, which are completed each year (Fig. 2).

The first step is to monitor and evaluate the pavement condition (ZEB). The continuous driving lanes are surveyed by measuring vehicles with laser monitors and video cameras and subsequently evaluated, i.e. the motorway is given a mark. This ZEB is also carried out on federal and state roads at regular intervals (also see the article "Results of the monitoring and evaluation of pavement condition on motorways, federal and state roads in Bavaria" in this special journal).

The condition data are then liked to the construction of the pavement (type, thickness and age) and the required construction class, which results from the traffic load according to the guidelines for standardisation of the superstructure of traffic surfaces (RStO 01). The linked data are used by the PMS program to calculate a recommendation how the overall condition of the network can be maintained as well as possible or even improved. The relevant procedure is as follows:

- The road condition values calculated in the ZEB are used to compile a future prognosis.
- The predicted damage is used to divide the various sections into damage classes.
- The damage classes stipulate the various possible measures for each individual section, sub-divided by year in which it is to be taken, the type of measure to be taken, the costs involved and the potential improvement to be expected in the condition of the road.
- All the potential measures are then combined and a mathematical optimisation function that makes the best use of these measures to maintain the overall road network

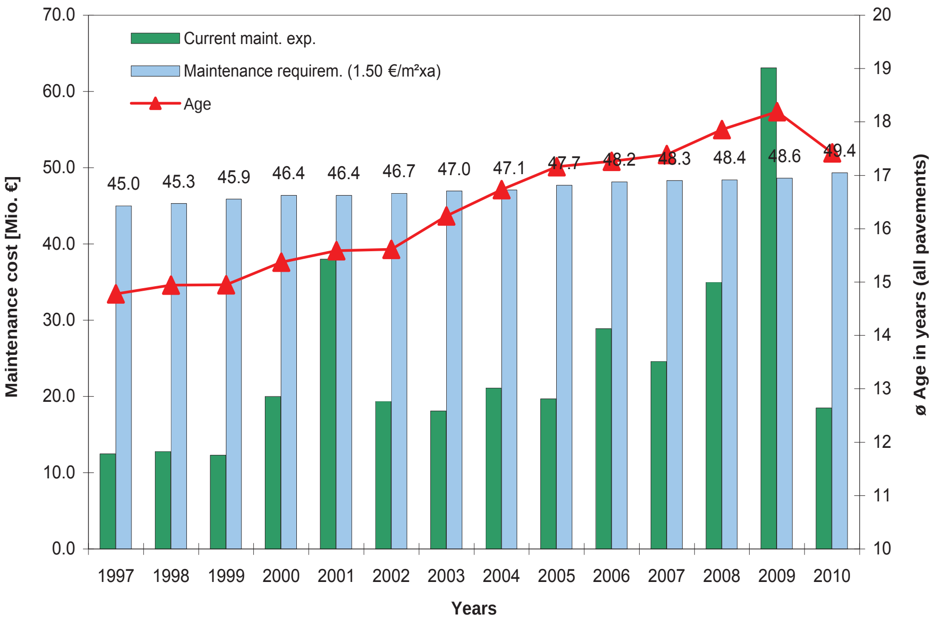

Figure 1: Pavement age and maintenance funding for the pavement superstructure within the area covered by the Southern Bavarian Motorway Office (always on 01/01 of each year)

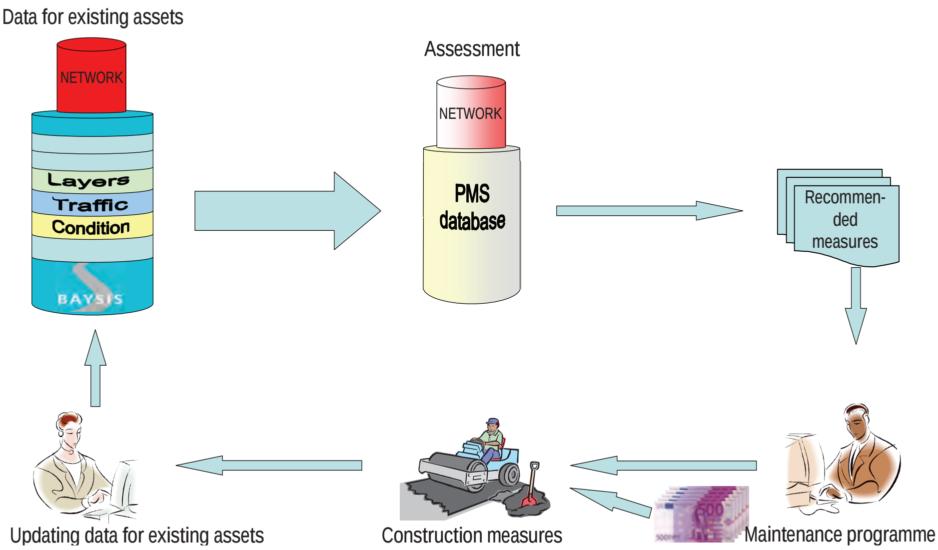

Figure 2: The road maintenance cycle

is applied, taking a budget into account.

The measures selected as part of the PMS optimisation (see Fig. 3) are only the same as the technically optimal measures for the individual sections when adequate funding is available. The list of measures calculated by PMS then serves as a basis for compiling the Coordinated Maintenance Programme (KEP) for the next 4 years. The following aspects are also taken into account:

- Checking the plausibility of the recommendations,
- Accident hot spots,
- Coordination with bridge construction, and
- Planned extensions.

This programme is then updated on an annual basis.

This list is then detailed even more for the year to come. In particular, site visits, drill cores, georadar measurements, carrying capacity measurements, etc. are used to achieve this. The programme is then discussed with the local service authorities, at which point an urgency ranking is also defined. This results from the technical efficiency of the measure, calculated using PMS and taking into account the local knowledge of the service points and the potential prioritisation of individual measures due to increased accident rates. This list then serves as a basis for requesting funding for maintenance during the following year. As the list usually contains more measures than can normally be financed, a rapid response is possible when additional funds are allocated.

It must be taken into account, however, that fund allocation in autumn is meaningless, as the measures still have to be put out for tender and contracted, i.e. normally a 3-month run-up period is required, which means that construction can only take place during the following year.

The next step is then to write out a tender, award it and carry out the construction work. Once the measure has been completed, the new construction data are incorporated into the road database to serve as a basis for future maintenance planning.

The system has been successfully used for 8 years and has significantly simplified the work of optimising network-wide maintenance cover. The link to the Bavarian road database (BAYSIS) will be facilitated by new software in future (also see the article "BAYSIS as a tool for maintenance management" in this special journal). In future, too, qualified engineers will be required, with the necessary specialised knowledge in superstructural and maintenance technology, to put the computerised recommendations into practice.

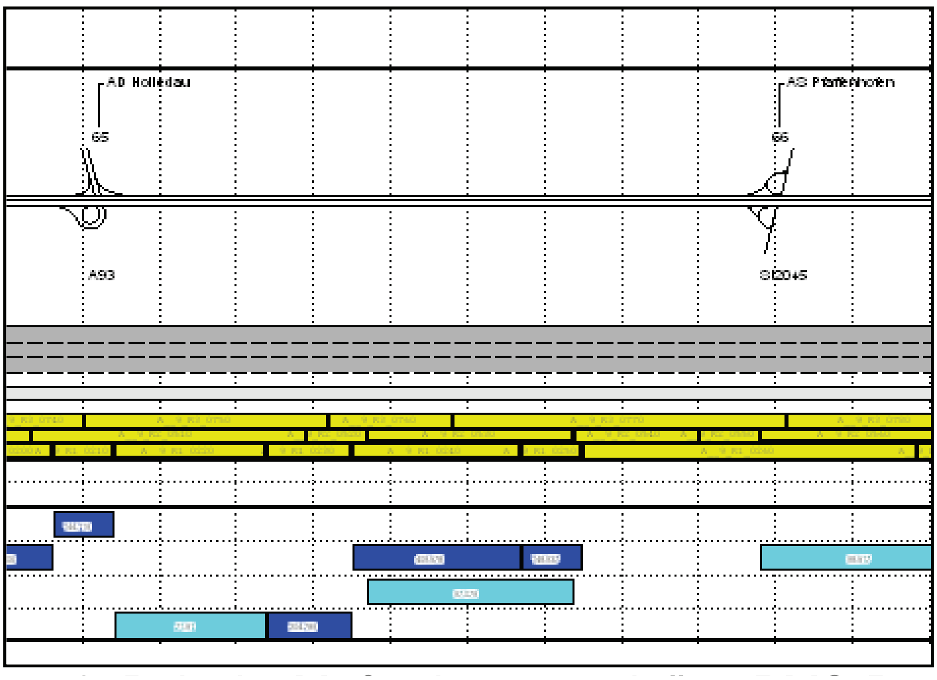

Figure 3: Example of measures recommended by the PMS programme

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BAYSIS as a tool for maintenance management

Dipl.-Math. Georg Ertl

BAYSIS

The BAYSIS Bavarian Road Information System is the central information platform for the Bavarian Road Administration. It achieves three goals:

- Contents from different departments are linked to each other
- Facts can be displayed on maps
- All information is available in a user-friendly way

The core element of the system is a representation of the road network. The motorways, federal roads, state

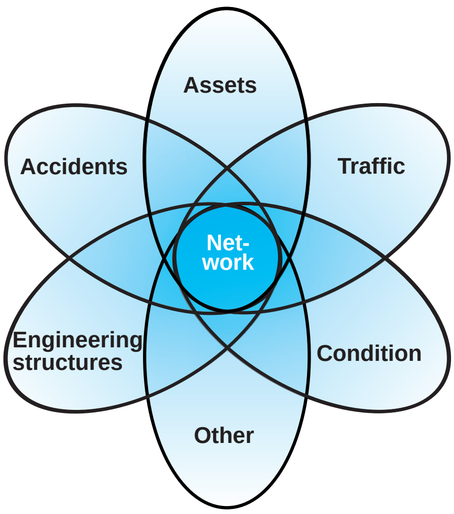

Figure 1: Rosette showing the BAYSIS themes

and district roads are shown in their accurate geometrical form and with their exact length and these data are continuously updated. All specialised information is linked to this road network. Correct localisation is ensured with the station sign, which includes the information "road", "section" and "station" and allows the accurate location of each position on the road.

Figure 2: Station sign at the roadside

The specialised information includes road assets (e.g. responsible office, cross-section, structure), maintenance (e.g. condition values, variables, ZEB condition images), traffic (e.g. traffic survey data, annual evaluations), traffic safety (e.g. accident type section maps) as well as extension and requirement planning (e.g. overview maps).

BAYSIS is provided, coordinated and further developed by the Centre for Information Systems (ZIS) at the Southern Bavarian Motorway Office. The motorway offices and state building offices maintain the specialised data within their areas of responsibility. Their BAYSIS operators access the central database through a Web application. BAYSIS operators report changes in the road network to the ZIS, which maintains the country-wide road network information.

The road information system takes the relevant, federal and European standards into account. The data capture is based on the technical specifications of the Road Information Database Ordinance (ASB) and the modelling corresponds to the Object Catalogue for Road and Traffic Systems (OKSTRA) and the INSPIRE geo-data infrastructure.

The monitoring and evaluation of the pavement condition (ZEB) is tightly integrated with BAYSIS. The BAYSIS road network is used as a basis for the survey. The first step includes the creation of an empty results database in Sub-Project 0 (TP 0). After the driving survey, the results are transferred to BAYSIS. This includes the condition values and parameters, the ZEB condition images as well as the section diagrams and condition maps.

Figure 3: Table of contents on the BAYSIS intranet

Maintenance in the BAYSIS intranet

The BAYSIS intranet provides this information without installation effort or licensing costs. The complete data for all staff members of the Bavarian Road Administration are available at http://baysis.bybn.de.

The following text describes the content for the part "Maintenance". maintenance. When a specific section of a road is selected, the system displays a front image, two lateral images and one back image. By clicking on the images they can be enlarged and printed. The navigation buttons can be used to move forwards and backwards or to see the current position accurately on a map. It is furthermore possible to get detailed profile information. The "ZEB inventory images" are also accessible from the map window (see below). The "ZEB on roads" menu point shows the results of the monitoring and evaluation of the pavement condition. Maps relating to different condition characteristics can be called up for the whole of Bavaria or separately for each building office. The condition profiles are available in graphic form for each individual road. The "Development" sub-point shows the frequency distributions for the current survey and comparisons with previous surveys.

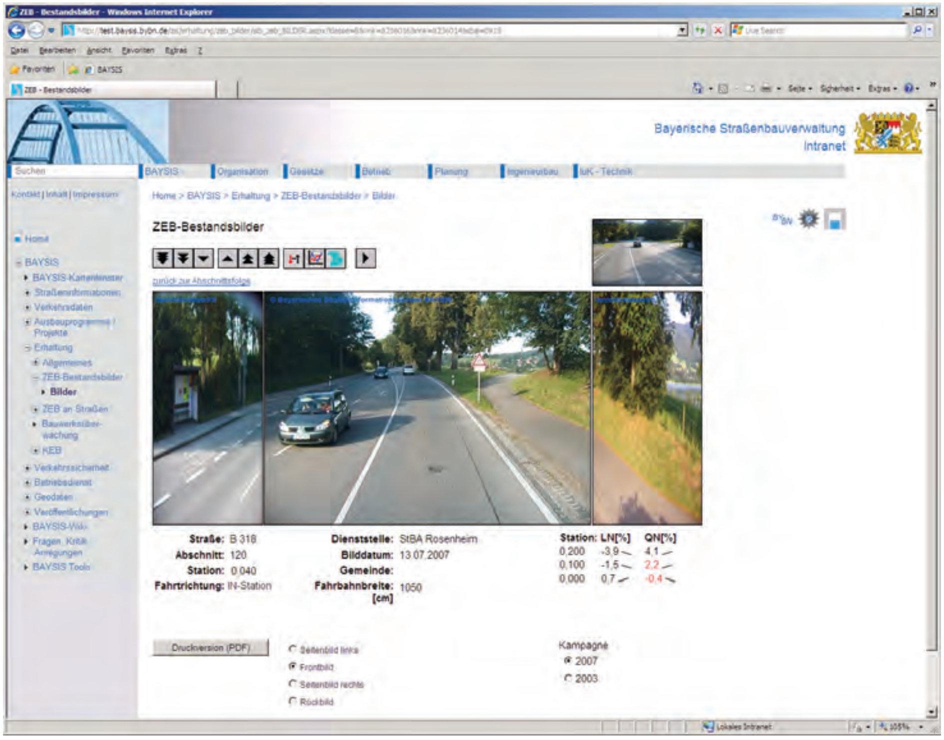

Figure 4: ZEB inventory images

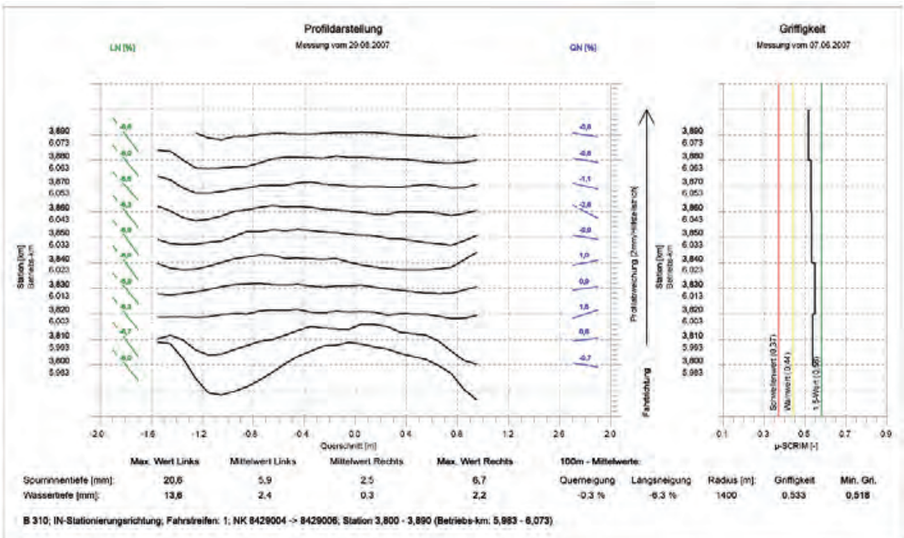

Figure 5: Profile presentation and grip

The "General" part includes a definitions of terms as well as seminar documentation of the annual workshops.

The "ZEB inventory images", which are taken every 20 metres on all motorways, federal roads and state roads, are of particular importance for

The coordinated maintenance and building programme ("KEB") is supported by a function that shows the maintenance sections of the KEB lists in geometrical form. Completed maps can be selected for each building office and a KEB route band is available for each road. Technically simplified information is available to the public on the internet at www.baysis.bayern.de.

Map window in the BAYSIS intranet

The map window in the BAYSIS intranet provides the benefits of a geographical information system (GIS). New technologies allow for extensive functions. User-defined sections of various basic maps (e.g. topographical maps, digital cadastral maps, aerial photographs) can be called up for the whole of Bavaria. Navigation on the map can be done manually and searches can be performed according to building, office, municipality or road.

Several thematic layers can be placed on top of a basic map, similar to the way in which slides are placed onto an overhead projector. This includes asset data (e.g. wearing course age), traffic data (e.g. road traffic survey) or traffic safety data (e.g. accident type route map). Clicking on one of the thematic objects displays the associated thematic information (e.g. detailed traffic data). A link to the SIB structures database facilitates viewing of engineering structures. External thematic layers can be incorporated using WMS technology. This allows, for example, direct access to the FHH (fauna/flora habitat) layers of the Bavarian State Office for the Environment.

Individual condition indicators from the maintenance area, such as quartiles of road grip, rut depth and general unevenness, can be overlaid as well. It is furthermore possible to access the ZEB inventory images described above. Each of the point symbols shown indicates an imaging location. Clicking on the symbols opens the ZEB images associated with this location.

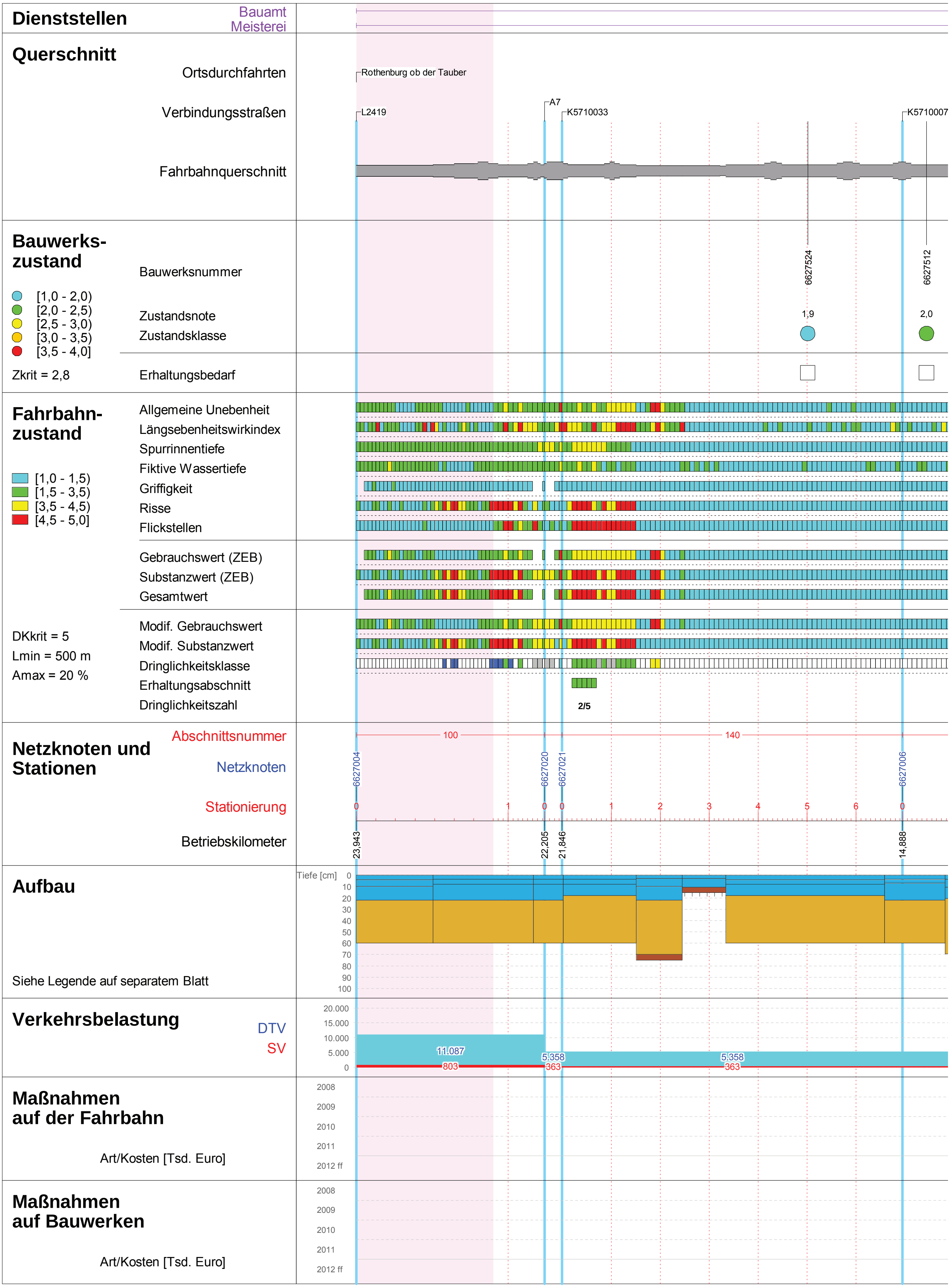

Figure 6: KEB section band

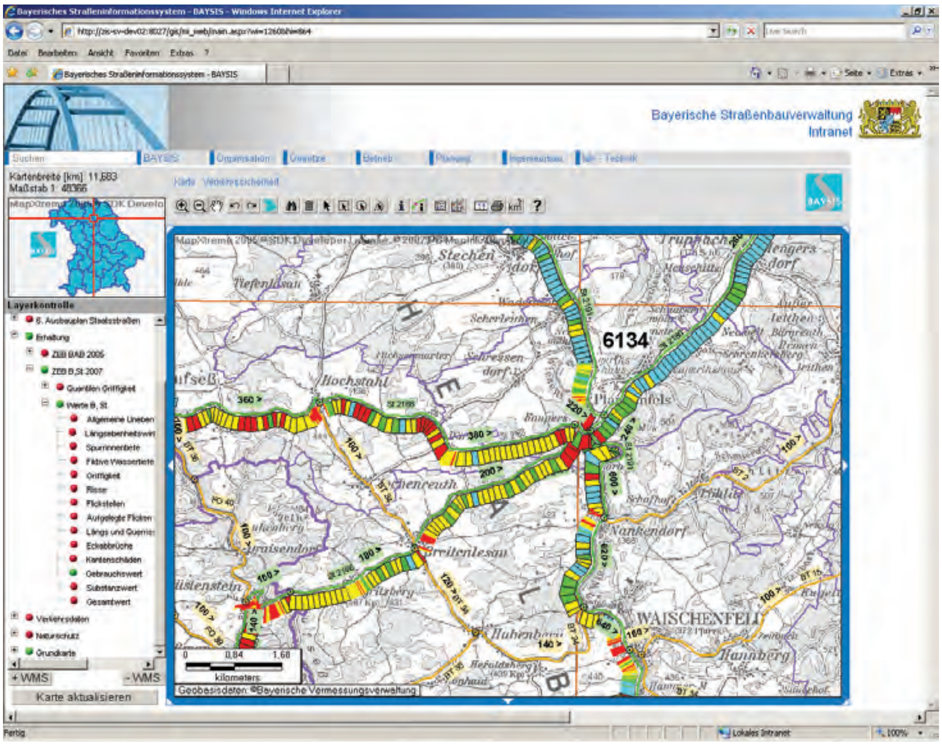

Figure 7: Map window showing usage value

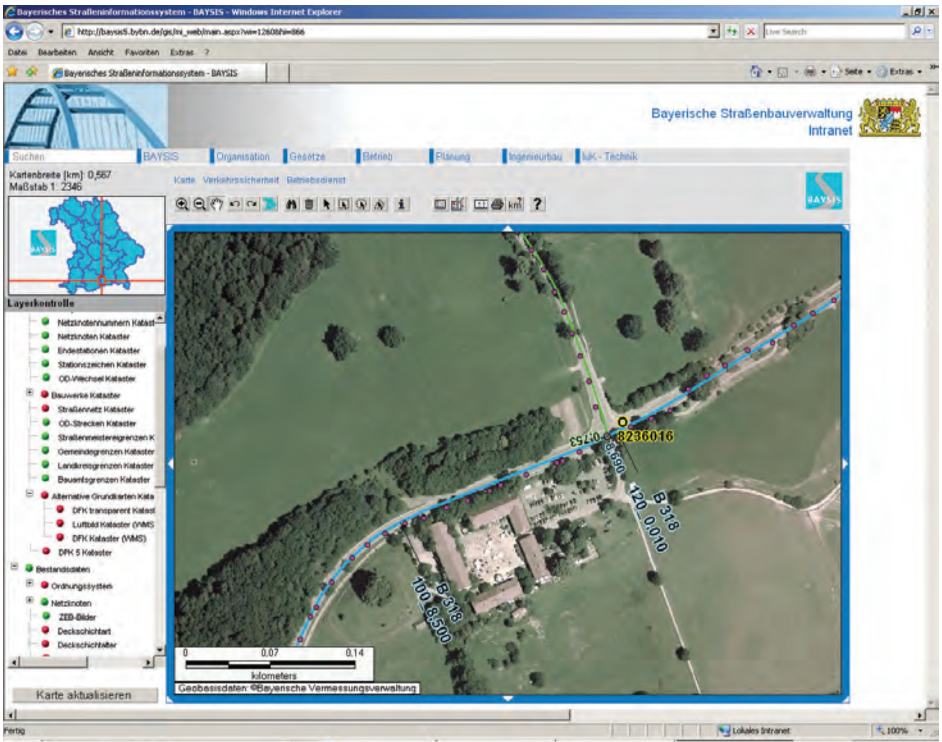

Figure 8: Map window with aerial photograph and point symbols for the imaging locations

Further processing

One of the systems that rely on BAYSIS is the Pavement Management System (PMS). All data required are supplied by BAYSIS: the road network is directly updated, the condition data are available from the driving surveys, the traffic data are provided by the traffic surveys and the structural data are entered by the offices responsible. The quality of the PMS evaluation strongly depends on the quality of the structural data.

The ability to link information is a particular strength of BAYSIS. The theme rosette (Fig. 1) indicates that information from a wide range of fields can be combined by relating it to the shared road network. Appropriate tools can be used, for example, to combine data for structure, traffic and condition and to search for routes with high pavement age, high traffic load and bad condition characteristics. It is also possible to take accident data into account. The results of all these evaluations can be displayed in map form.

It can be concluded that the BAYSIS information system provides a wide range of information that is particularly relevant for maintenance. The evaluation tools available have considerable potential to support technical decisions and contribute to efficient and economic use of the resources available.

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Synergy effects of the introduction of double-entry bookkeeping for the development of a maintenance management system in Erlangen

Dipl.-Ing. (FH) Christian Müller

Initial situation

On 21/11/2003, the Conference of State Ministers of the Interior (IMK) decided on a reform of the municipal budgeting laws that required detailed proof of financial status with value specification and documentation of depreciation (imputed costs) for all areas of a municipality. The City of Erlangen therefore decided to change its single-entry bookkeeping system to double-entry bookkeeping. This decision was initiated by the expiry of the contract for the financial software used at the time.

In summer 2007, the Civil Engineering Office of the City of Erlangen conducted measurement-based and visual evaluations of the road conditions to document and evaluate the road infrastructure assets as part of the introduction of the New Communal Financial Management for Erlangen (NKFE).

All roads within the scope of responsibility of the city were investigated. This monitoring and evaluation of pavement condition was based on and conducted according to the working papers of the German Road and Transportation Research Association (FGSV) and their recommendations for the maintenance management of inner city roads (E EMI 2003).

The Evaluation Directive for Bavaria - Draft (BewertRBayern - E), which was applicable at the time, required a road condition survey for the initial evaluation and balance sheet, as possibly severe construction flaws and damage to traffic structures would require extraordinary depreciation. After discussion with the project managers responsible at the treasury of Erlangen, it was agreed that only condition classes 4 and 5 (see below) were to be considered for extraordinary depreciation of 80% and 100% respectively.

Monitoring and evaluation of pavement

The road network of the City of Erlangen that was to be surveyed and evaluated covers approximately 430 km when the dependent pedestrian and cycle paths (e.g. partially public paths, field and forest paths) are included. The network was divided into evaluation sections, which would later serve as maintenance sections, by using a node and edge model.

A certified company was contracted to drive 82 road kilometres (150 driving lane kilometres) for measurement and evaluation purposes. The evaluation and processing as well as the integration of the driving survey result files into the GIS Smallworld system of the City of Erlangen were handled by an external engineering bureau.

Visual condition surveys according to the damage catalogue compiled for the City of Erlangen were performed on the subordinate existing road network by in-house staff of the Civil Engineering Office, who were trained by an engineering company competent in the field. Evaluation teams consisting of two persons were formed. They evaluated the individual road sections defined in the node-edge model by walking on site and entering the data into recording devices (PDAs). The visual assessment was performed according to a 2-step model. In a first step, a condition class (ZSK) from 1 to 5 was allocated to the respective cross-section element (Table 1).

Condition class	Extent of damage
Condition class 1	Very weak damage pattern, pavement new or equivalent
Condition class 2	Weak damage pattern, e.g. individual, small damaged areas
Condition class 3	Clear damage pattern, maintenance measures required in approx. 8-10 years
Condition class 4	Strong damage pattern, maintenance measures required in approx. 4-5 years
Condition class 5	Strong damage pattern, short-term maintenance measures required

Table 1: Step 1, condition class and extent of damage

Condition class	Extent (Proportion of total area affected in %)	Surface condition
1	≤ 10	Very weak damage
2	10 to ≤ 20	Weak damage
3	20 to ≤ 30	Clear damage
4	30 to ≤ 40	Strong damage
5	> 40	Very strong damage

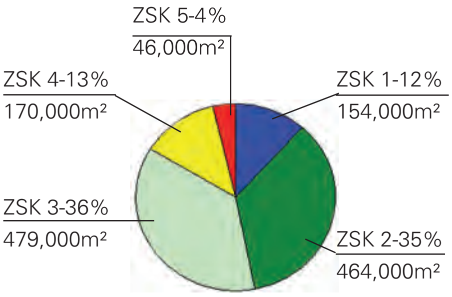
Table 2: Allocation of condition classes and extent of damage

When the condition class was worse than 3, detailed condition variables in different groups were recorded. These included cracks and open joints (in %), inserted and added patched areas (in %), surface damage (in %), rut depth (in mm) and general unevenness (extent). For example, ruts with a depth of less than 4 mm were allocated to ZSK 1, with approx. 10 mm to ZSK 2, with approx. 15 mm to ZSK 3, with approx. 20-30 mm to ZSK 4 and with 35 mm or more to ZSK 5.

Auxiliary surfaces, pedestrian and cycle paths, bus bays, bus stops, public squares and pedestrian path areas along the roads measured were solely recorded and evaluated according to Step 1, i.e. the overall extent of the damage (proportion of the affected area). Substance descriptors such as cracks, open pavement joints, mended areas and surface damage were used as evaluation parameters.

The allocation of the extent of damage of auxiliary areas to individual condition classes is described in Table 2.

Pedestrian and cycle path



Pavements of subordinate roads

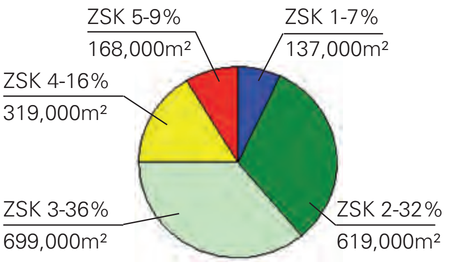


Figure 1: Evaluation of the visual condition survey

The visual as well as the measurement-based condition surveys were subject to quality assurance by the supporting specialised engineering office.

Maintenance management

The condition classes and condition values obtained provide the basic information for determining the extension and renewal requirements for the road network in Erlangen. In 2008 already, these values were used to determine the concepts for the evaluation and selection of maintenance and repair measures. They were also used as an effective instrument for processing renovation applications and queries from citizens and city council committees.

The Civil Engineering Office of Erlangen intends to achieve sustainability, in addition to optimising the daily work processes with this currently unique, high-quality database that covers the complete road traffic network. The high quality of these data encouraged the Civil Engineering

Figure 2: Road section in Erlangen requiring renovation

Office to consider the development of systematic maintenance planning with a Pavement Management System (PMS).

The following factors provided additional motivation for the City of Erlangen to introduce and implement a PMS:

The introduction of a systematic road maintenance management is intended to support the City of Erlangen in the technical, economic and organisational coordination and optimisation of its asset preservation measures.

The Civil Engineering Office intends to use the PMS to assess the benefits of selected maintenance measures, to evaluate medium-term maintenance measures and to optimise the use of resources in the long term.

The solution is intended to reduce the maintenance effort through focused, requirement-orientated use of resources without loss of quality and by avoiding wrong investments through better, IT-based planning of measures. It is furthermore intended to improve the city's internal, inter-office cooperation with regard to road-building measures as well as the coordination of measures with the municipal utilities of Erlangen and other supply companies.

Additional, relevant data must be collected, prepared and processed during the next phase to make the PMS more efficient and relevant. For example, the road structure and pavement layer data and the resulting building classes are only available in connection with construction measures performed during the last 25 years. Most of the road network of Erlangen (approx. 70%) is older and still requires a road structure analysis. This information will mainly be obtained by evaluating available and future data from earth works.

Traffic load and road function (usage by public transport, industry and heavy-duty traffic, etc.) are further, important factors to be considered. It is intended to perform additional, comprehensive traffic load surveys at strategically important points.

Repeats of the whole monitoring and evaluation of pavement condition at regular intervals of 3-5 years are planned, as the structural state changes continuously. This will make it possible to control and optimise the time of intervention for maintenance measures, depending on the importance of the road and the budgetary means available.

The overall goal of maintenance management is the integration of all road-related factors into a 5-year maintenance programme that can compile optimised maintenance strategies and show the budget required as well as its impact on the maintenance of the municipal infrastructure assets of Erlangen.

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Predictions of the condition development of pavements

Dipl.-Ing. Roland Degelmann

Prediction is very difficult, especially if it's about the future.
Mark Twain (1835-1910)

Knowledge of future condition development is an important prerequisite for optimal maintenance management. The best time at which specific measures are most economical for the total system can only be determined when the condition development can be clearly described.

Condition predictions today

The description of the condition development with performance functions - which is commonly used these days - assumes the following:

- The currently measured condition data reflect all effects of material properties, installation conditions, traffic, climate, building maintenance, interference (e.g. earthworks), etc.
- The time of the recent evaluation as well as the time at which the condition was optimal, are known.
- The type of the respective behaviour function - i.e. the type of condition development - is known.

Performance functions are defined for individual condition characteristics in order to describe the condition development. They differ by showing slow, medium or fast deterioration of the condition after maintenance measures have been performed. The determination of the specific function parameters is, for example, performed with stochastic methods. The qualitative progression of the function must be determined in advance (Figure 1).

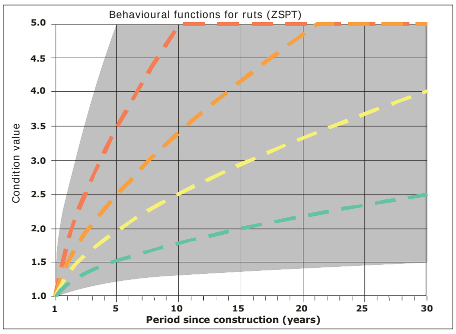

Figure 1: Performance functions for ruts

The methods described as well as the progression of the performance functions are usually considered to be reliable. However, they have some inherent shortcomings. Predictions based on corresponding functions do not allow a direct combination of different condition characteristics. It is not possible to describe how the unevenness of a pavement will develop when the surface has a high proportion of alligator cracks, or when the proportion of alligator cracks increases rapidly or slowly. This leaves considerable room for improving prediction methods in future.

Approaches to further development

Since 1992, condition surveys and evaluations of the relevant road network have been performed at regular intervals. They form the basis for presentation of the condition development and the prediction of future trends. After the completion of the condition survey in 2007, the results of the last three condition surveys were prepared and combined. This made it possible to view the dynamics of the condition development of individual route sections (100-metre sections in each case) over the last eight years, in addition to the current condition. A three-survey comparison is now also available for motorways. It

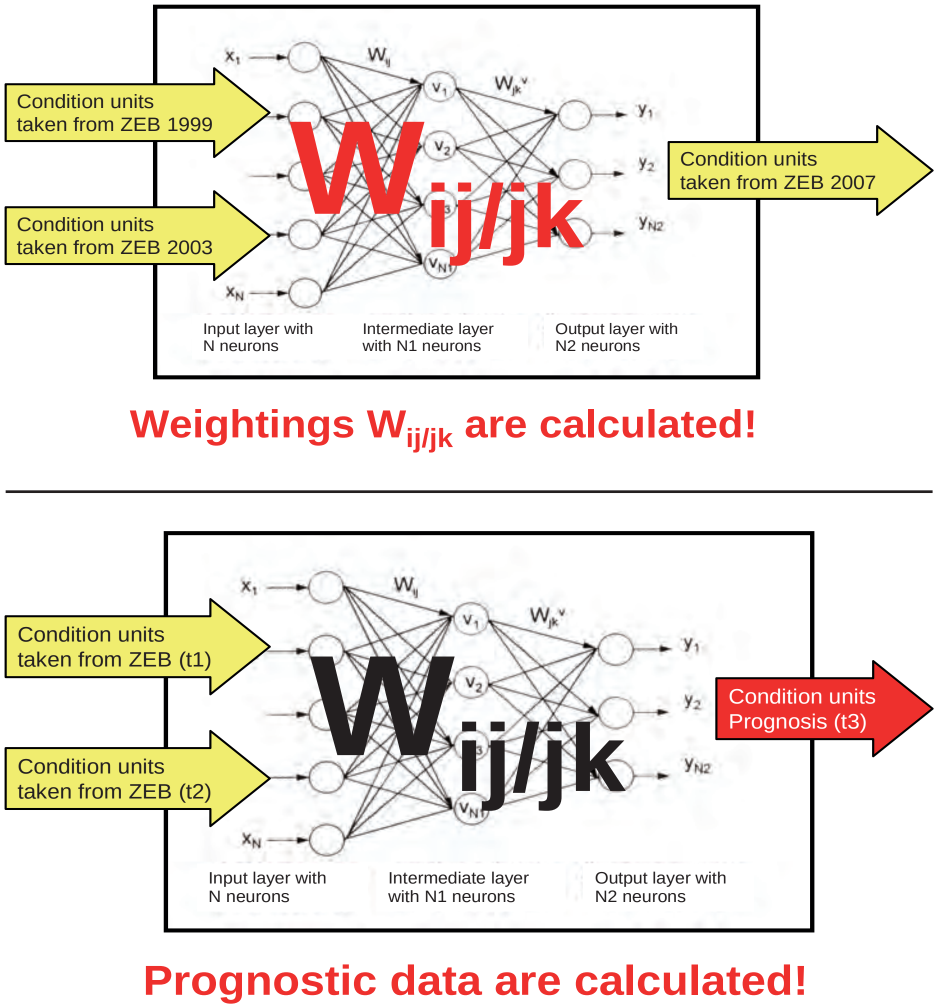

Figure 2: Training of neural networks and prediction

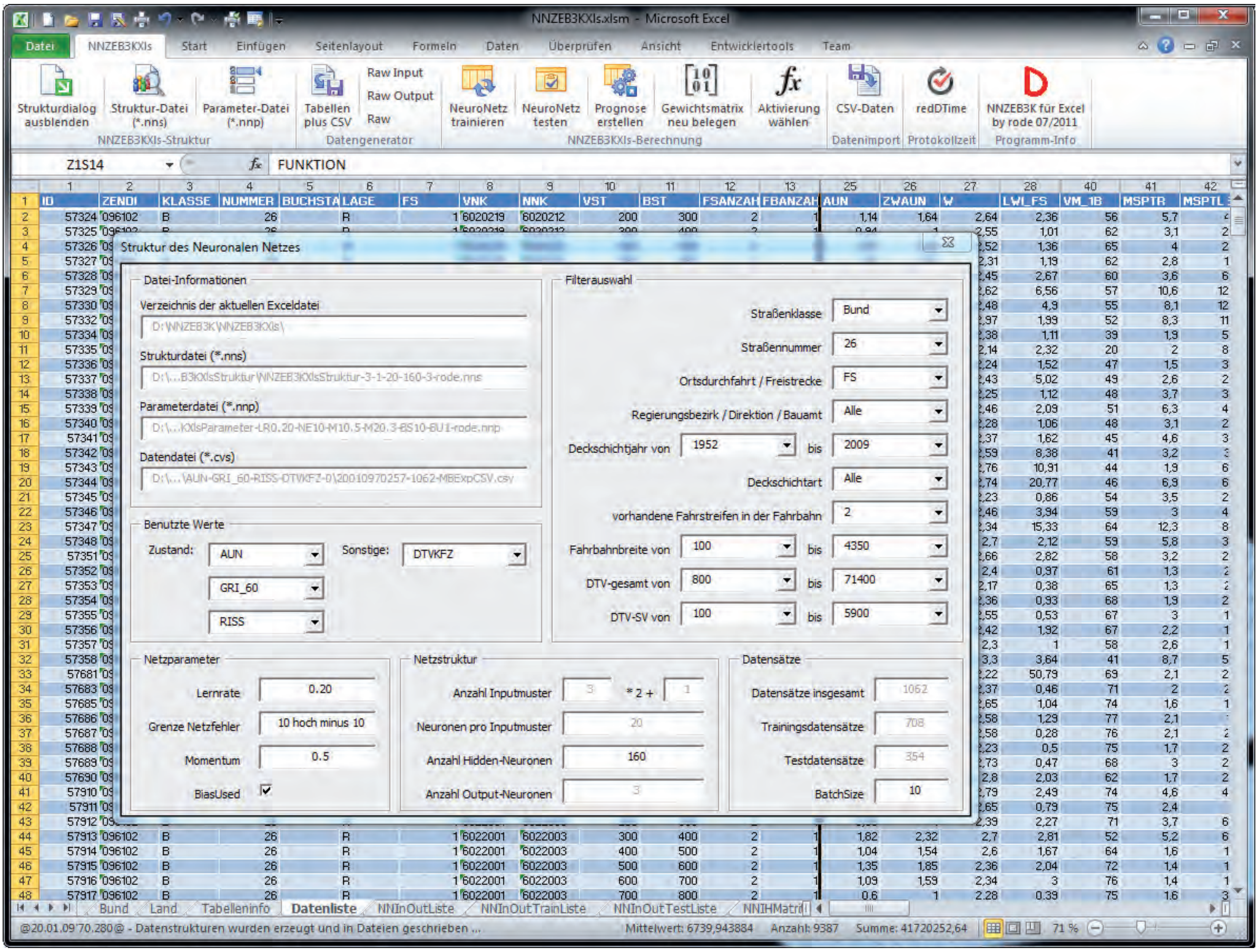

Figure 3: Computation of neural networks with Excel

includes the evaluations performed in 2001, 2005 and 2009.

The data available make it possible to verify the performance functions used, as the knowledge of three measuring values at a multitude of survey sections can be used to check the progression of the curves. The data can be used to combine different condition characteristics for additional evaluations. They also allow more complex condition predictions using neural networks in addition to conventional analysis methods.

Condition predictions with neural networks

The neural network method is based on biological information processing in the brain, which explains its name. Neural networks can independently discover structural patterns in any type of measuring data (e.g. condition data, financial data, sales data, etc.) and predict their development. They are therefore flexible tools for prediction purposes

These neural networks contain artificial neurons (nerve cells) as basic elements of information processing. They are arranged in layers and each neuron is connected to other neurons, usually to those in the subsequent layer. This makes it possible to model highly non-linear and complex interaction between a multitude of variables without previous knowledge of the direction and extent of their interactions. The neural network is first provided with observed data to learn the relevant structures in a training phase. After the training phase, the network has been configured and can now be used for the analysis of new data (Fig. 2).

Back-propagation networks were used for the learning procedures concerning asset maintenance. The individual sample data were provided to the network and the target outputs were compared with the actual outputs. The error values were used to correct the weighting of the individual neurons.

The implementation of appropriate computing runs can now be performed with standard tools such as Excel, which has to be extended by software modules for neural networks. The investigations concerning the condition predictions were performed with separate function libraries (Fig. 3).

The data of the last three condition surveys on federal and state roads, which have been available since 2008, can be used in addition to the corresponding data from surveys on motorways to predict condition development with neural networks. Fig. 4 shows the result of such a computing run. The standardised target and actual values of a condition variable are compared along a road section.

A particularly useful aspect of

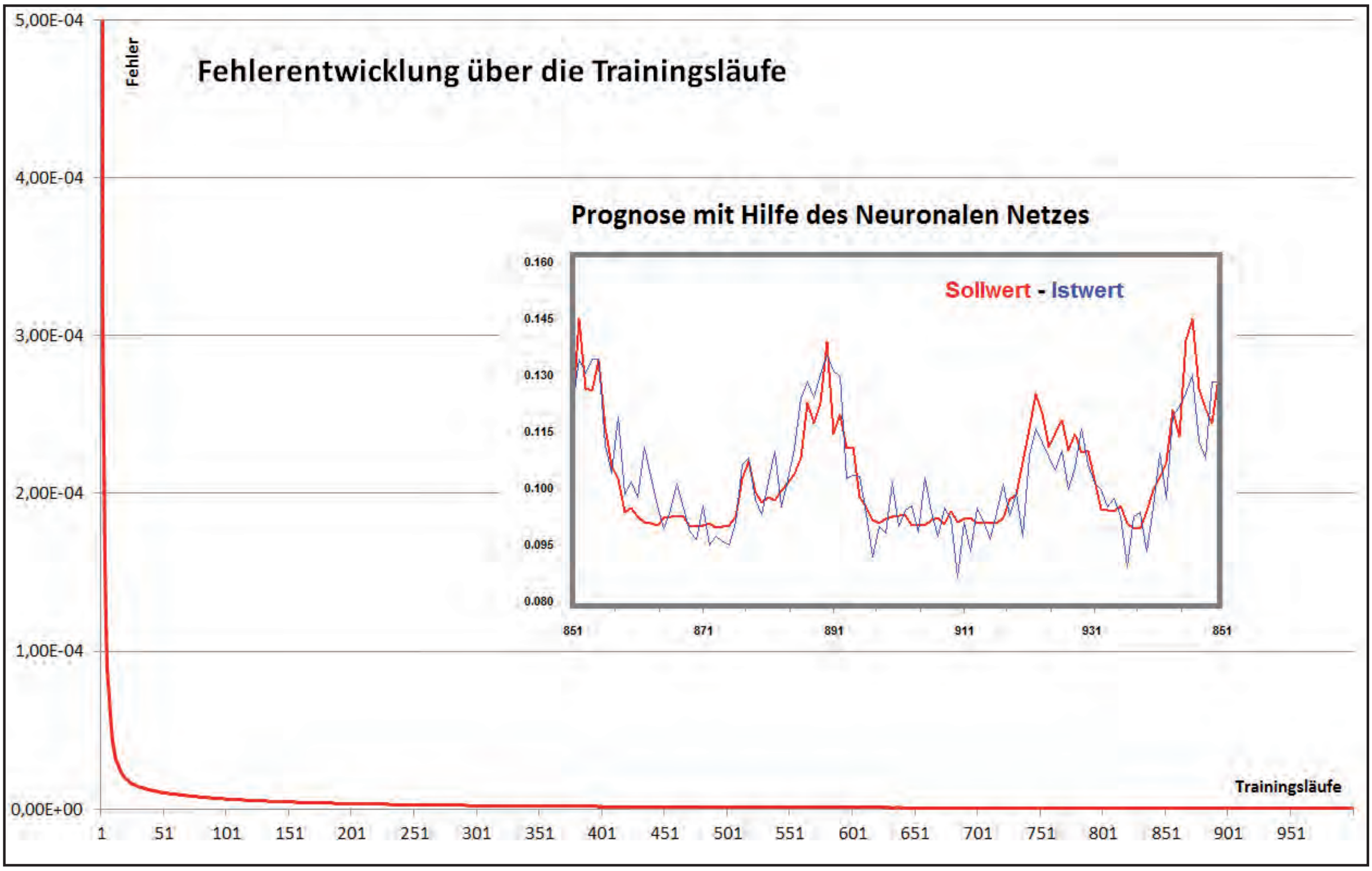

Figure 4: Computation output with condition prediction (target/actual comparison)

using neural networks is that several condition parameters can be combined with each other for a prediction. Mutual dependencies of different parameters can thus be taken into account in the predictions.

The investigation results available thus far indicate that the approaches selected are suitable for predicting the development of road conditions in a realistic manner.

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Future developments in maintenance management and the monitoring and evaluation of pavement condition

Dr.-Ing. Slawomir Heller

Introduction

Efficient maintenance of and accounting for the existing road infrastructure is one of the most important challenges for any modern economy. Maintenance management decisions are of high importance for the whole economy, due to the enormous amounts of capital tied up in road pavements. Modern maintenance management helps to maintain this infrastructure in a rational manner according to the requirements of the national economy. The pavement condition data collected in monitoring and evaluation (ZEB) are the most important sources of information. The quality, currency and completeness of the condition data directly affect the quality of the maintenance strategies and programmes based on them.

The ZEB is a specialised activity that is performed jointly by the federal government and the states and that is supported by the committees of the German Road and Transportation Research Association (FGSV). The term "ZEB" is commonly used to describe any activity connected to monitoring and evaluating the condition of road pavements. However, experts have agreed to use this term for a particular approach to systematic planning and implementation of measurement-based condition surveys, quality control and task-related processing and evaluation of condition data. The ZEB also includes numerous associated, continuous processes that contribute to ensuring the continuity, stability and high quality of all processes.

In which areas of the ZEB can progress be expected?

The ZEB has developed into a field of technology aimed at obtaining data concerning the condition of road pavements for a wide range of possible applications. Initially, at the beginning of the 1990s, maintenance management was the only application for the ZEB data. Consistent, focused measures have turned the condition survey into a largely task-neutral and general procedure. This strong **task neutrality** of the German ZEB is a special feature that discriminates it from comparable initiatives abroad. Another special feature of the ZEB is that nearly all relevant components are standardised. This **standardisation** guarantees that the annual ZEB measurements made by the federal government and the states can be handled on a routine basis and ensures reproducible results. The **transparency** of all elements of the ZEB method helps to improve quality. The main benefit is the strong integration of the states in the verification and validation of the data. Another positive side effect is increased acceptance and use of the data in routine work. The Bavarian Road Administration had initiated innovative methods by the middle of the 1990s and continues to contribute to further development. The methods for visualisation and plausibilisation of data used for Bavarian state roads are currently in routine use in nearly all other federal states.

Further development of the ZEB method with regard to task neutrality, standardisation and transparency will determine the direction of this discipline in the future. It can therefore be safely predicted that in the next few years, progress will be achieved in the following three areas:

- Increased task neutrality of the ZEB and extension of the application options outside maintenance management for road pavements.
- Completion of the standardisation of all ZEB services and a further increase in the stability of the method as well as extended use abroad.
- Increased transparency by active integration of the ZEB users in all relevant processes and targeted provision of data and results.

These three important characteristics are also goals of the ZEB and can only be considered when their mutual interaction is taken into account (Fig. 1).

It is obvious that technical developments in measuring technology, IT and other technical disciplines are likely to affect the ZEB. This is supported by the fact that the control of the ZEB is already based on a series of institutional measures that make it possible to integrate new, innovative technologies and methods into the ZEB without disturbing the process of the annual ZEB measurements or putting performance or quality at risk. It can be expected, for example, that Sub-Project 3 (TP 3) of the ZEB (video recording and sensitive evaluation of the substance characteristics of the surface) will achieve a breakthrough in automated damage detection that has been envisaged for a long time. The recent standardisation of this sub-project has made an important contribution to this

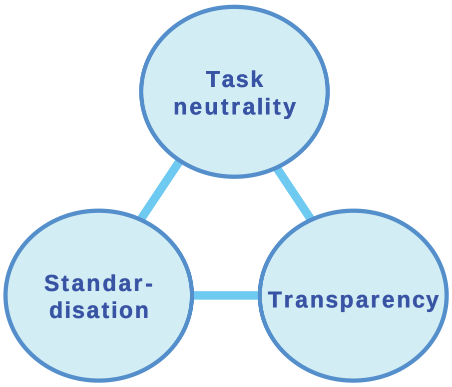

Figure 1: Interaction of the important characteristics of the ZEB

development.
It is hoped that the separate consideration of longitudinal evenness and transverse evenness will in future be replaced by imaging of the whole pavement surface, which would provide the basis for various multidisciplinary evaluations, including, for example, the analysis of water retention on the pavement. The first step in this direction, which is expected soon, will be the introduction of a second beam to measure the longitudinal evenness and an increase in the recording density for the

transverse profile from 1 metre to 10 cm.

It is furthermore considered to measure the structural properties of road pavements such as pavement construction data or bearing capacity on a regular basis, particularly for subordinate networks. More effective measuring methods, e.g. georadar or measuring vehicles for dynamic bearing capacity measurements, are already intensively used. There are pragmatic arguments for recording these characteristics within the well-developed organisational and infrastructure framework of the ZEB.

Task neutrality

The ZEB was created in the 1990s with the goal of providing pavement condition data for medium- and long-term planning maintenance programmes according to a uniform standard. The ZEB was instituted as a permanent undertaking by the general circular of the Federal Ministry of Transport (BMV) ARS-No. 27/1996 dated 09/08/1996.

In the early phases of the project, the elementary data served mainly as proof for the surveying work performed. At the end of the 1990s, these elementary data[1] were standardised and defined as the basis for all evaluation. The high-resolution elementary data became the interface between the **task-neutral survey** and the **task-orientated evaluation** of the data. This evaluation involves the following main steps:

- Determining the evaluation sections,
- Determining the pavement,
- Condition evaluation,
- Visualising the condition data,
- Statistical evaluation of the condition data and the evaluation results.

Fig. 2 shows the principle of these general changes to the ZEB in schematic form.

The requirements for task neutrality of the monitoring imply that the resolution and precision of the elementary data as well as the surveying frequencies will take all supported tasks and applications into account.

Initially, the survey ended with the delivery of the technical parameters for all evaluation sections of equal length (normally 100 m). Analysis of new or alternative condition parameters was not possible without accessing the internal database of the surveying company. Only once the elementary data had been standardised was it possible to perform evaluations according to individual and varied criteria. Until the later 1990s, a strongly conservative attitude prevailed with regard to the introduction of new condition indicators that were better suited to specific problems. This was justified by the fact that direct comparisons to previous ZEB monitoring and evaluation were not possible. After the standardisation of the elementary data, this was no longer a problem. It is by now rather common to introduce new indicators such as the longitudinal evenness index (LWI) or the evaluated longitudinal profile (BLP) and to calculate the respective values retrospectively for all previous ZEB monitoring and evaluation.

The elementary data are used as the "true" and task-independent representation of the pavement in the model. They are therefore a uniform, standardised basis for all further evaluations and are subjected to various transformations according to the objectives of the evaluation. "Conventional" ZEB evaluations, for example, make use of a fixed 100-metre grid in general and a 20-metre grid for cross-town links. Infrastructure assessments performed for the introduction of double-entry bookkeeping accounts aggregate the ZEB elementary data into sections of

[1] Longitudinal evenness profiles with 10 cm support point distance. Transverse profiles every 1 m with 10 cm support point distance. Sideway-force coefficient (SKM) values every 1 m. Surface properties per 1 m x 1/3 driving lane width.

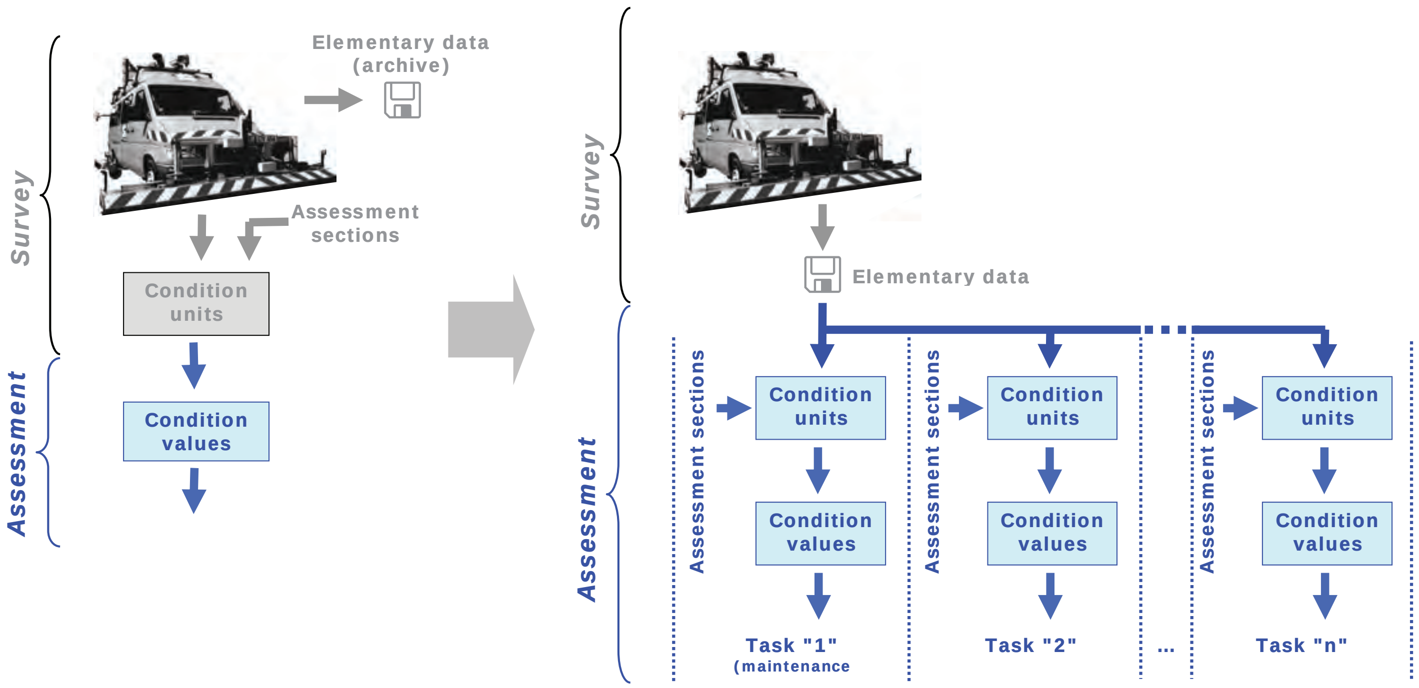

Figure 2: Transition to a task-neutral condition survey

variable length in order to make the sections as homogeneous as possible. The analysis for potential safety threats due to insufficient conditions uses evaluation sections with a constant length but variable locations by moving in 1-metre steps along the driving lane to be analysed. This eliminates the averaging of condition data, which is acceptable for most applications but is not appropriate for safety analyses. The elementary data of the ZEB collected on federal roads and state roads in the area of cross-town links can be directly used for maintenance management of urban roads, although the E EMI[2] requires a 10-metre evaluation grid. The appropriate transformation of the elementary data and determination of the condition indicators required for urban roads, for example planography simulation or the International Roughness Index (IRI), are now routinely performed and reduce the monitoring effort.

In the coming years, it can be expected that the ZEB will support an increasing range of tasks in road engineering and in other areas. This will benefit the established applications of the ZEB such as:

- Long- and medium-term maintenance planning on network level,
- Planning of measures and damage analysis at object level,
- Controlling of the maintenance goals,
- Accounting of road infrastructure,
- Construction type testing and material suitability testing.

The following new applications might also benefit from the task-neutral condition data:

- Determining and controlling the offer quality and the safety profile, support of the safety audit,
- Determining the unevenness and grip characteristics according to the needs of the transport and automotive industry,
- Creating an inventory of asset and geometry data for specific applications (e.g. inclusion of data concerning noise protection devices[3] or registration of PMS input variables such as carriageway width, number of driving lanes, location of additional information when the data in the road information database are missing or outdated).

In 2010, the ZEB could be used for surveying and evaluation of the condition data of bicycle paths along state roads in Lower Saxony with only moderate adaptations. This is a further confirmation that the task-neutrality of the ZEB provides considerable synergy benefits.

Standardisation

The standardisation of the ZEB includes processes, methods and data formats and contributes to on-going, sustainable stabilisation of the ZEB as a technical discipline.

The standardisation of the **ZEB processes** determines the rules for the preparation, tender, award, performance, quality assurance and billing of all ZEB services.

Most of the relevant **ZEB methods** have in the meantime been standardised as well. The most important ZEB methods standardised in recent years include:

- Allocation of the ZEB data to the network based on GPS coordinates (called "standardised network allocation"),
- Determining the condition parameters from elementary data,
- Verification of the basic ZEB data as well as the ZEB results.

The Federal Highway Research Institute (BASt) supports the ZEB by providing the companies involved with ZEB standard programs, which are free of charge and ensure that the ZEB methods are applied in a standardised manner and that the reproducibility and comparability of the ZEB results is guaranteed. The **ZEB data formats** (including the elementary data), **results** and other ZEB documents were standardised as well and are therefore suitable for additional evaluations and multidisciplinary applications outside the ZEB.

The standard documents of the ZEB include, in particular, the "Additional technical conditions of contract and directives for monitoring and evaluation of pavement conditions" (ZTV ZEB-StB) and the manuals of the respective annual surveys. These documents specify all relevant details concerning the processes, methods and data content and are not only used for federal arterial roads, but also for ZEBs on state roads, district roads and many municipal roads. The standardisation of the ZEB is unique in the world. German regulations, in particular the ZTV ZEB-StB, are therefore integrated as binding components in tenders abroad. The task neutrality mentioned above is of particular importance. It allows the use of the collected ZEB data according to the specifications of the relevant administrative unit.

The ZEB has been standardised to a large extent, but there is still some need for action that will determine the activities in the near future. Most of Sub-Project 3 (TP 3) of the ZEB (video documentation and sensitive evaluation of the substance characteristics of the surface) is still being performed according to the "old" principle. Data monitoring, i.e. taking images of the pavement surface (which are referred to as "macro-images") as well as the evaluation of the images according to stipulated rules are currently being handled by the surveying company, i.e. by the operators of the measuring vehicle. It is expected that consistent separation between data monitoring, which is in this case taking images of the pavement surface, and evaluation, i.e. engineering analysis of the images and registration of the surface damage, will be established as separate processes. This sub-project of the ZEB will then also fulfil the requirements for quality assurance.

Transparency

One of the most important requirements for the acceptance of the ZEB data for maintenance management as well as for applications in other application areas is a high transparency of all relevant procedures and data. Condition data will only be used in decision-making processes without objections when they can be

[2] E EMI 2003 "Recommendations for maintenance management of urban roads."

[3] The orientation and height of noise protection installations as well as traffic signs with speed limitations were photogrammetrically determined and evaluated using the ZEB route images. This was required to support the implementation of the EC Directive concerning the evaluation and reduction of environmental noise (2002/49/EC). The first analysis was performed for Bavaria, followed by Baden-Württemberg, Hesse and Lower Saxony. This procedure made it possible to avoid time- and cost-intensive on-site measurements.

verified and validated.

Four years ago, a method was implemented that allows online provision of the elementary data, the route images and the evaluation results to data users while the ZEB survey is in progress. This option of accessing the full set of condition data from different user perspectives is by now being routinely used in the whole federal area. It creates an opportunity for people with local knowledge to check the data (verification) and to comment on the correctness of the ZEB indicators (validation). The ZEB users are therefore included in the ZEB process during the "creation phase" and not only after delivery of the printed results. Numerous users have already taken the opportunity to point out certain plausibility problems and to make suggestions for the improvement of the evaluation functions. The suggestions are documented on an on-going basis and integrated into the ZEB method after approval by the relevant committees, in particular the ZEB coordinating group (KoG ZEB).

The expected spread of such methods and the participation of the ZEB users in a continuous improvement process transform the ZEB into a self-learning field with strong participation of the stakeholders.

Maintenance planning

Planning of maintenance measures at strategic and operational level is being performed with Pavement Management Systems (PMS). Strategic planning is mainly concerned with the requirements for maintenance funding to achieve predefined quality goals with a long-term planning horizon. Maintenance programs for short- and medium-term planning horizons are developed at operational level. Strategic planning therefore requires strongly aggregated data and predictions for road conditions. Operational planning requires effective and flexible access to the current condition data, including route images, elementary data and the macro-images from Sub-Project 3.

The development and implementation of the basic PMS models at strategic level as well as the performance of the research required will still be handled within the framework of federal projects. However, there is a clear trend towards additional evaluations that go beyond the standard calculations and are aimed at state-specific issues. It seems obvious that this trend will shape the future development of Pavement Management Systems. It can furthermore be expected that modular and flexible web services will prevail over comprehensive, inflexible PMS applications.

The trend towards evaluation according to pragmatic, transparent and comprehensible criteria, which is already clearly visible today, will increase further at operational level. The improved maintenance planning system (VEP), which has already been introduced in Bavaria in the middle of the 1990s, has been further developed during recent years and forms the basis for the coordinated maintenance and building programme (KEB) that was developed by the Bavarian Road Administration. Several federal states are currently using the Bavarian KEB with some state-specific modifications for practical planning work.

Summary

The author has been observing and contributing to the development of the ZEB since its early days. The predictions for the development of the ZEB in this article are based on the extrapolation of trends that are already clearly visible today. In recent years, the ZEB has developed procedures that are characterised by strong standardisation, transparency and a considerable extent of task neutrality. The last characteristic, in particular, will necessarily strengthen the interests of specialists in other fields and disciplines in ZEB data such as ZEB geometry data, route images and ZEB networks. The resulting dynamics will ensure progress and further development.

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Asphalt work on a motorway

Condition-related granting of funds in the maintenance of existing constructions

Dr.-Ing. Olaf Weller

Point of departure

The results of the current monitoring and evaluation of pavement condition (ZEB) on federal roads and state roads show that the condition of the carriageways in Bavaria is subject to strong regional differences. There are various reasons for this, for example regional differences in the construction activities in recent years. Also external factors that affect the road condition, for example climate and traffic load, vary considerably across Bavaria. Different maintenance strategies and engineering factors such as the construction type or the additives used in the material have long-term effects on the development of the road conditions. Furthermore, the maintenance funds necessary for extensions, renovations or unforeseen expenses related to winter services had to be reduced to varying degrees in the individual regions. In some state building offices, the need for costly renovation of some building structures considerably reduced the scope for additional maintenance measures.

The Bavarian Road Administration has further optimised its management concept for road maintenance to take these regional differences in road conditions and peripheral conditions into account. In 2008, the Coordinated Maintenance and Building Programme was introduced. It was to support the state building offices in their mid-term planning of maintenance measures based on objective measures such as road and structural conditions and to provide a basis for controlling (see article “Coordinated maintenance and building programme (KEB) for federal and state roads“ in this special journal). The previously used distribution key for asset maintenance on state roads and federal roads was further developed to use objective measures for a more effective and requirement-orientated way of allocating the available funds.

Previous distribution key for the asset maintenance funds

Until and including 2008, the distribution of the asset maintenance funds for state roads was based on the network length. During the last few years, the road conditions had been considered as well. The relative size of the network was weighted by means of the ZEB 2002/03 survey data. However, the effect of the weighting factors was reduced to prevent funding at district government level from strongly deviating from a distribution purely based on network length.

The distribution of the asset maintenance budget for federal roads was exclusively based on the “evaluation lengths“, which were derived from the network length and the streakiness.

Requirements for the improved distribution key for asset maintenance funds

The requirements defined for the development of a new distribution key for asset maintenance funds were high. It was particularly important to give areas with bad road and engineering structure conditions more support. However, the flow of funds to areas with considerable route lengths and engineering structure areas had to continue to enable the state building offices to pursue a sustainable maintenance strategy for their networks. It was furthermore intended to maximise the number of road users benefitting from the new distribution pattern without neglecting the rural areas. The staffing of the state building offices made it necessary to keep increases or decreases in the previous maintenance budget within limits. Finally, the key had to be easy to convey and transparent, in spite of the large number of factors and peripheral conditions that had to be considered.

These numerous and partially conflicting requirements created a need for compromise. Not all the factors that were initially discussed, such as the accident statistics or the extension level, were in the end used for the revised key.

New distribution key for asset maintenance funds for state roads

The improved distribution key for road maintenance funds deviates from the previous key by stronger weighting of the road condition, differentiation of the traffic load according to normal and heavy traffic and appropriate consideration of the extent and condition of engineering structures. The distribution of the state road asset maintenance funds to the state building offices will in future be performed according to the following key (Fig. 1):

- **40%** are distributed according to the evaluation length (route length and streakiness) and the respective traffic performance (network length multiplied by traffic load). The evaluation length determines half the result value and the traffic load due to normal traffic and the traffic load according to heavy traffic each determine a quarter.

- **40%** are distributed according to the carriageway condition. The distribution is based on maintenance sections that are calculated with the improved maintenance planning system (VEP) method using the ZEB 2007 data. This method filters the multitude of ZEB data to identify route sections with a minimum length of 500 m that require repair. These centrally calculated maintenance sections are also used in the Coordinated Maintenance and Building Programme. Maintenance suggestions that have to be handled by the state building offices are therefore associated with a basic amount of finance corresponding to their share in the repair work required in the whole of Bavaria.
  In addition, a factor for the condition development is taken into account. It is based on the last two monitorings and evaluations of pavement conditions in 2002/03

and 2007. State building offices with areas of responsibility in which the conditions deteriorated rapidly during this period, receive more funds.

The VEP maintenance sections do not receive additional weighting according to their traffic load, as this factor is already included in the basic requirements mentioned above. Comparative calculations have also shown that the consideration of traffic load for the VEP maintenance sections does not lead to a significant change in the results.

- **10%** are distributed according to the area covered by engineering structures. The higher maintenance requirements for engineering structures as compared to pavements are thus taken into account.
- **10 %** are distributed according to the condition of the engineering structures as determined during regular structure inspections. The basis for the distribution is the area of the bridges that have a total condition mark of 2.8 or worse. In the technical regulations, this mark corresponds to the worse part of the category "sufficient structure condition" (mark 2.5-2.9) or to the categories "insufficient" (mark 3.0-3.4) or "inadequate structure condition" (mark 3.5-4.0). This approach provides a financial response to short-term, costly structural renovations. These structures due for renovation are included in the Coordinated Maintenance and Building Programme mentioned above and have to be taken into account in the compilation of maintenance programmes of state building offices.

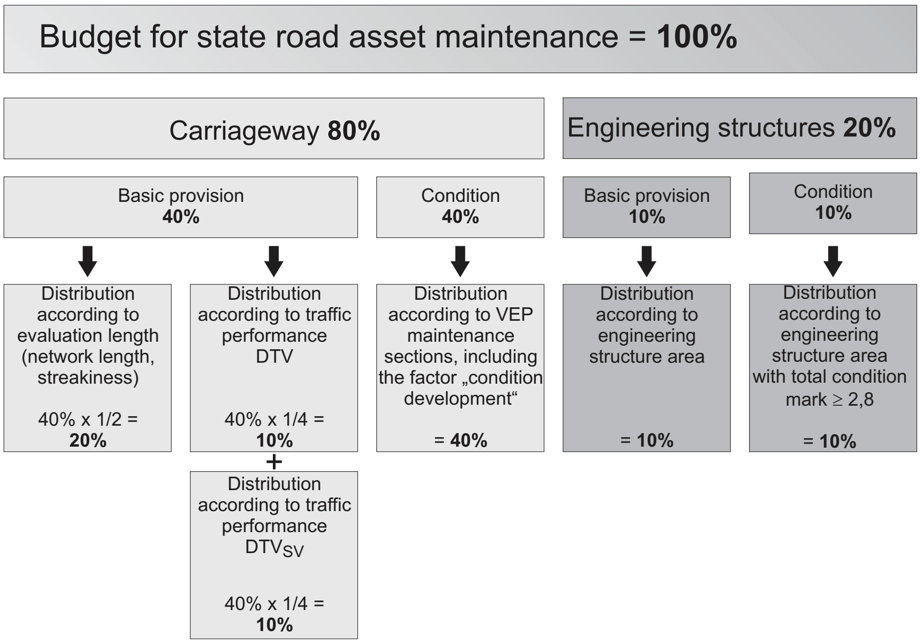

Figure 1: Summary view of the distribution of the asset maintenance funds for state roads

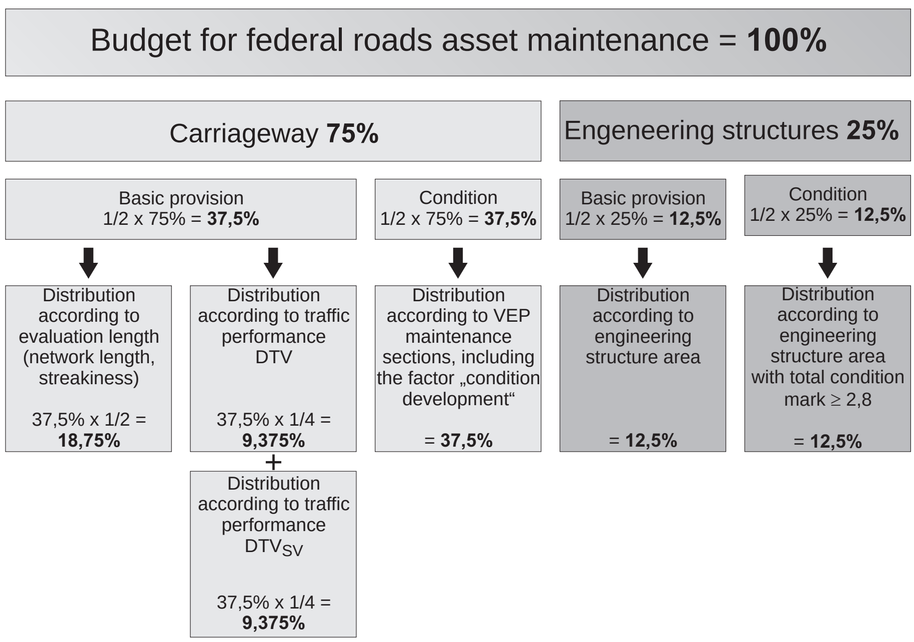

Figure 2: Summary view of the distribution of the asset maintenance funds for federal roads

Overall, half of the funds for the maintenance of pavements and engineering structures will in future be distributed according to the volume of assets and the other half according to their condition. The split of the funds between pavements and engineering structures is 80% to 20% and is based on experiences in road maintenance in the past.

New distribution key for asset maintenance funds for federal roads

The improved distribution key for federal roads mainly corresponds to that for the state roads. The main difference is the split of funds between pavements and engineering structures, which is at 75% to 25%. This reflects the higher share of bridges and bridge maintenance requirements on federal roads as compared to state roads. The allocations according to the distribution key are therefore shifted as shown in Fig. 2.

Effects of the new allocation of funds

The new distribution key provides state building offices with a worse road network, higher traffic loads and more engineering structures (in need of renovation) with more funds. In extreme cases, such state building offices might receive up to approx. 60% more maintenance funds than previously, when the funds for the whole of Bavaria are assumed to remain constant. However, that comes at the cost of state building offices with a comparably good road network, low traffic load and few engineering structures (requiring renovation). Such state building offices can expect reductions in their funding by up to half as compared to their previous allocation (Fig. 3). The new distribution of the funds assumes that all state building offices have worked with the same degree of economic efficiency and that the differences in the road and engineering structure conditions are only due to the external influences and necessities described above. This assumption is required to ensure the solidarity of the "donating" building offices.

The implementation of the new distribution key allows for minor adjustments of the maintenance funds in exceptional and justified cases. Building offices that are under extreme strain due to single, expensive projects, e.g. renovation of a large bridge, can thus be compensated. These adjustments are performed at district government level in agreement with the Bavarian Building Authority. It is essential that the funds are adjusted according to the distribution key during the following years.

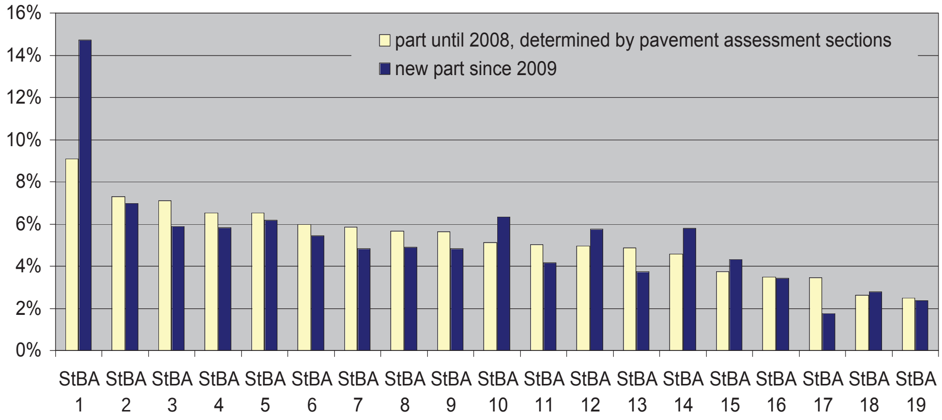

Fig. 3: Distribution key for asset maintenance funds for federal roads. Comparison of the shares of the 19 state building offices in the budget for the whole of Bavaria until 2008 and since 2009.

Outlook

The recently determined distribution keys for the asset maintenance funds were first applied in 2009 and are to be retained until the results of the next monitoring and evaluation of pavement conditions in 2011 are available. These results will then be used to evaluate the success of the current distribution key and to adjust it to the new framework conditions. This investigation will also include a detailed analysis of the type and extent of the asset maintenance measures performed.

It is already apparent today that the speed of the harmonisation of the road and bridge conditions in the whole of Bavaria will increase with the amount of maintenance funds available. A comprehensive improvement of the conditions will only take place when the funding for asset maintenance is sufficient. This requires, in particular, that the funds for state roads should be significantly increased as compared to previous years.

The need to allocate the available budget according to objective criteria in an effective and requirement-orientated manner will continue in future. However, different approaches can provide new findings and form the basis of new developments. Current work on the visualisation of combined condition and traffic data may be relevant in this context. The combined presentation of traffic and condition data can rapidly provide information about high traffic loads associated with bad road conditions. The finalisation of these investigations will provide the Bavarian Road Administration with an additional tool for strategic and operational maintenance planning and fast localisation of road sections with a high demand for action.

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Maintenance of engineering constructions

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Assets and condition

Our road assets include pavements as well as bridges and engineering structures. Bridges are of special importance, because they constitute critical points in the road network. Necessary closures or restrictions, e.g. during building work or due to building damage, usually require long detours to the next bridge crossing. Complex repair measures on bridge structures usually take much longer than comparable work in the normal road network.

The bridge and engineering structure assets on motorways, federal roads and state roads in Bavaria include more than 14,000 bridge constructions with more than 16,000 sub-structures that cover a total area of 6.1 million m^2, 58 tunnel constructions with a total pipe length of approx. 37 km as well as a multitude of support walls, noise protection walls, traffic sign bridges and other structures. In addition, nearly 1,000 bridges on regional roads are jointly administrated. The asset value of the bridge constructions is approx. 10.0 billion € (10,000,000,000 €) and that of the tunnels approx. 1.3 billion € (1,300,000,000 €). Concrete and pre-tensed-concrete brides have by far the largest share of the assets with regard to the bridge area covered.

A considerable part of these structures originates from the 1960s and 1970s, due to the economic development of Germany after the Second World War. Current experiences indicate that a part of these assets will require basic renewal during the next few years to satisfy current traffic requirements. Basic renewal is not only necessary due to age. New technical knowledge and updating of the technical regulations in connection with problems such as coupling joints, stress corrosion cracking of pre-stressed steel, not taking into account load case ΔT and too little shear reinforcement, also create the need for maintenance measures on bridges.

Effects on engineering structures

The life span of bridges and the maintenance effort required for them are mainly determined by the heavy-duty traffic load. The share of heavy-duty traffic (≥7.5 t) on motorways is currently already at approximately 19%. This implies that the right lane on highly stressed roads is almost continuously occupied by trucks. Steep increases are expected in future. Predictions indicate an increase in the goods traffic by 80% between 2005 and 2025. Increasing vehicle weights and axle loads will also have negative effects.

It can be expected that the introduction of a route-related traffic toll will lead to increased competition by the carriers. This effect, in combination with the currently available tracking and communication options, will clearly increase the capacity utilisation of trucks in future. This is desirable for traffic management, but leads to significantly higher loads on engineering structures.

Vehicles overloaded by up to 30% already cause serious concern, in particular in areas near the borders. This is due to the fact that the permitted total weight differs across Europe. In the Netherlands, for example, it is currently 50 t. The permitted axle loads and total weights have also increased in Germany during the last decades. The permitted total weight is currently 40 t or 44 t for combined traffic according to Directive 92/106/EEC. Further increases to 60 t are already being discussed, but they cannot be accepted due to the current state and condition of roads and engineering structures. The share of large-volume and heavy-duty transports requiring approval is continuously increasing as well. The example of the Northern Bavarian Motorway Office (Fig. 1) shows that this is an exponential increase. In 2010, the state building offices in Bavaria handled approximately 300,000 applications for heavy transport.

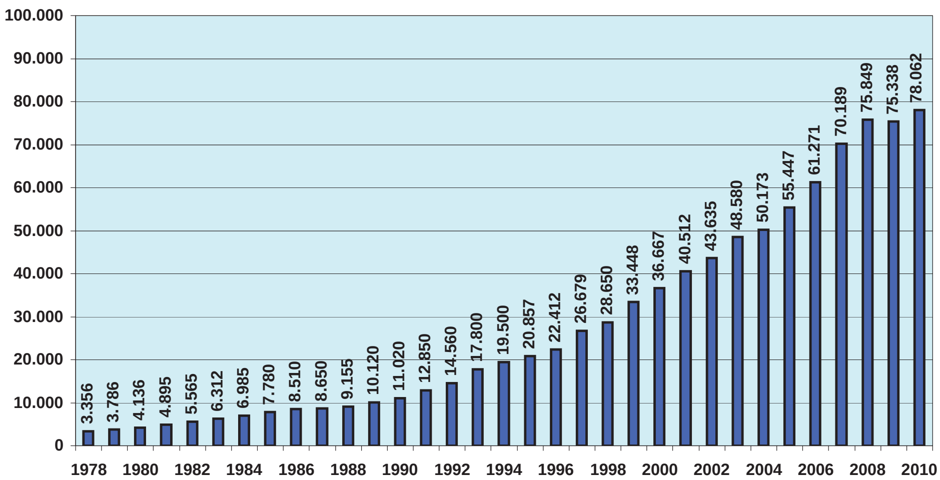

Fig. 1: Large-volume and heavy-duty traffic applications according to StVO (Road Traffic Ordinance) Section 29(3) at the Northern Bavarian Motorway Office

The dimensioning of the bridges and the legal limitations for vehicle weights and axle loads must be coordinated to ensure that the bridges withstand the stress during their planned life span. It must therefore be determined whether the load distributions that are currently allocated to specific road classes will be stable or whether different vehicle distributions are to be expected in future.

Inspection and condition

Engineering structures are subjected

Fig. 2: Large-volume and heavy-duty transport

to regular, specialised monitoring and inspection to ensure their continued functionality and traffic safety. The basis of the inspection of engineering structures is the DIN 1076 standard "Engineering structures along roads and paths; monitoring and inspection" (Version Nov. 1999). Monitoring and inspection of all engineering structures is classified into main inspections, simple inspections, inspections for special reasons (special inspections), visual inspections and on-going observations.

The first main inspection is performed before the acceptance of the building project and the second before the expiry of the warranty period. Thereafter, a main inspection by specially trained structural inspection engineers is performed every six years. Main inspections involve close-up visual inspection of all structural components, even of those that are difficult to access. Inspection devices and test devices are to be used where necessary. A simple inspection is performed three years after a main inspection. It involves an intense, extended visual inspection without the use of inspection devices, as far as this seems acceptable. A special inspection is performed after major events that affect the state of the engineering structure, e.g. a flood, accident, earthquake or when a visual inspection or observation seems appropriate. The extent of the inspection is determined by the reason for it.

The road and motorway maintenance offices inspect the structures in regular, annual visual inspections that are performed by expert personnel but without major equipment such as inspection vehicles. The visual inspection is omitted when a main or simple inspection is performed during the same year. All engineering structures are in principle inspected for traffic safety within the framework of the general route controls. In addition, all components of a structure are inspected at least twice a year for visible damage by the road control personnel.

All results of inspections, visual inspections and observations of each individual engineering structure are documented according to specific regulations. Modern IT systems based on the "Directives for standardised recording, assessment, documentation and evaluation of results of engineering structural inspections according to DIN 1076 (RI-EBW-PRÜF)" are used to record damage and to evaluate the condition. The individual faults are assessed by a building inspection engineer according to the criteria of stability, traffic safety and durability. Total condition marks from 1 (very good condition) to 4 (insufficient condition) are calculated. The total condition marks are then allocated to 6 condition ranges that are similar to the school mark system:

1.0-1.4 very good condition (condition range 1)
The stability, traffic safety and durability of the structure have been ensured. On-going maintenance is required.

1.5-1.9 good condition (condition range 2)

Fig. 3: Bridge inspection with underfloor device

Fig. 4: State road 2103, bridge damage at the Salzach bridge in Laufen

The stability and traffic safety of the structure have been ensured. The durability of at least one structural module may be compromised. The durability of the structure may be slightly compromised in the long term. On-going maintenance is required.

2.0-2.4 satisfactory condition (condition range 3)
The stability and traffic safety of the structure have been ensured. The stability and/or durability of at least one structural module may be compromised. The durability of the structure may be compromised in the long term. On-going maintenance is required. Repair may be required in the mid-term.

2.5-2.9 sufficient condition (condition range 4)
The stability of the structure is guaranteed. The traffic safety of the structure may be compromised. The stability and/or durability of at least one structural module may be compromised. The durability of the structure may be compromised. On-going maintenance is required. Repair is required in the short term.

3.0-3.4 insufficient condition (condition range 5)
The stability and/or traffic safety of the structure have been compromised. The durability of the structure can no longer be guaranteed. On-going maintenance is required. Immediate repair is required.

3.5-4.0 inappropriate condition (condition range 6)
The stability and/or traffic safety of the structure have been severely compromised or can no longer be guaranteed. The durability of the structure can no longer be guaranteed. On-going maintenance is required. Immediate repair or renovation is required.

The condition mark does not allow a direct conclusion regarding the extent of the damage or the costs of the repair measures required. However, it shows whether there is a pending need for renovation. The complete set of condition marks of all engineering structures provides an overview of the maintenance state of all structures under management.

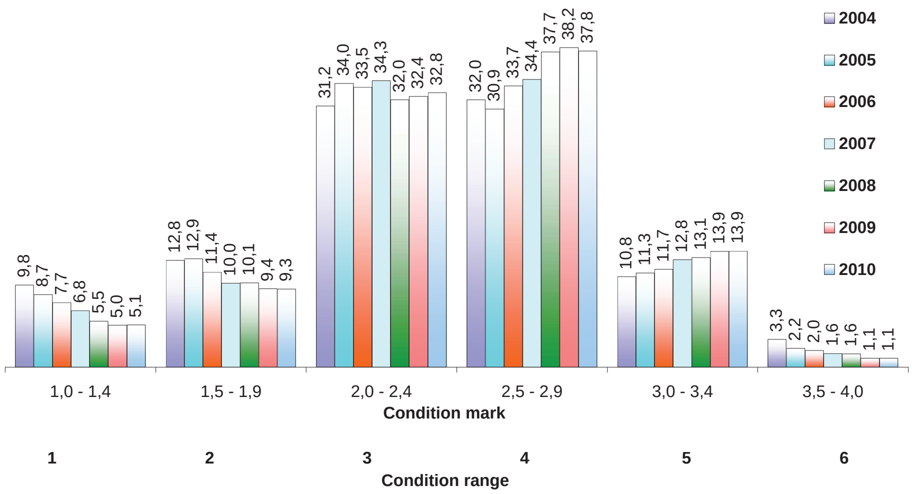

Fig. 5: Development of the condition marks of bridges on motorways and federal roads in Bavaria. Bridge area of the sub-structures by condition mark (%)

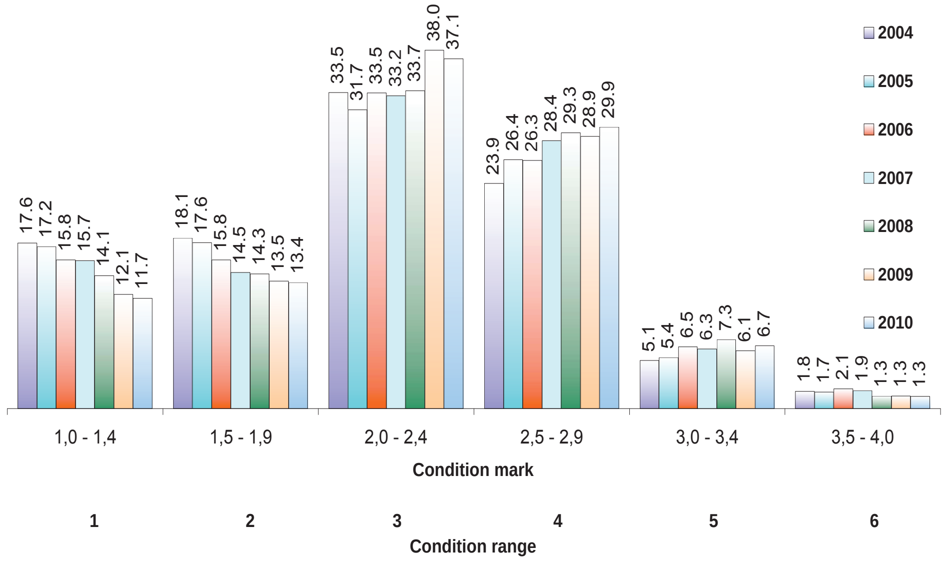

Fig. 6: Development of the condition marks of bridges on state roads in Bavaria. Bridge area of the sub-structures by condition mark (%)

Operation and maintenance of tunnels

Tunnels have a special position regarding the maintenance of structural assets. A distinction must be made between the maintenance of engineering structures and maintenance of the technical installations. The maintenance of engineering structures extends far beyond the actual tunnel structure, for example to drainage systems with retaining basins for approx. 100 m^3 or water tanks for fire fighting. However, intermediate ceilings and ventilation channels, stairwells for escape routes and rescue galleries also form part of some tunnel structures and must be inspected, kept safe for traffic and maintained in a usable condition. Inspection according to DIN 1076 applies. Regular inspection of the engineering structures of the tunnel must be performed to ensure stability and traffic safety during use.

The directives for the equipment and operation of road tunnels (RABT), Version 2006, indirectly define the safety level of a tunnel by its equipment. This safety concept implies that all safety devices must always be operational, which requires continuous monitoring or at least continuous support on-call. In addition, a "rapid intervention group" in the form of a knowledgeable tunnel team or a specialised company must be available. This is relatively easy to arrange for motorway tunnels, but may cause considerable organisational effort when remote tunnels in the subordinate networks are concerned. The planned bundling of tunnel monitoring in traffic centres

Fig. 7: A99 federal motorway, Aubing tunnel portal

at Freimann and Fischbach will be an important step towards fulfilling these requirements. Ensuring safe and problem-free operation of all tunnels will still require considerable efforts in the fields of tunnel operation and tunnel maintenance during the years to come.

Maintenance planning

The first, major maintenance steps are usually required after operating periods of 20 to 30 years. They are usually apparent from the corresponding damage. Regular engineering structural inspections according to DIN 1076 provide the building administrators with a good overview of the current damage patterns and their development. The condition marks form the basis for further maintenance planning.

During or after the inspection of the structure, the smaller tasks concerning operational or structural maintenance are listed by structure or route and handed to a bridge team for implementation. Minor faults can thus be eliminated in the early stages and major consequential damage can be avoided. This ensures fast, efficient and direct implementation of the findings of structural inspections. Remaining faults are addressed by the decentralised maintenance planning in the individual offices. For this purpose, the Bavarian Road Administration has developed the coordinated maintenance and building programme (KEB) for federal roads and state roads. The Bavarian Building Authority provides the offices with Excel-based KEB lists that contain suggestions for measures on pavements and suggestions for measures on engineering structures by listing all structures with a total condition mark of ≥ 2.8 (condition range 4, sufficient). These structures are investigated by the building maintenance staff in the offices to determine whether measures are to be provided as part of the medium-term maintenance planning or the annual building programmes and whether these measures could be coordinated with possible work on the pavement (see article "Coordinated maintenance and building programme (KEB) for federal roads and state roads" in this special journal).

In 2010, a total of 38.7 million € was spent on the maintenance of engineering structures on motorways and federal roads (Fig. 8). In 2009, the economic stimulus package led to a spending peak of 85.08 million €. Expenditure for engineering structures on state roads reached a peak of 19.02 million € in 2008 and subsequently dropped to 14.8 million € in 2010 (Fig. 9). The economic stimulus package did not lead to an increase in expenditure for the maintenance of engineering structures on state roads, in contrast with expenditure on federal roads. The funds spent on the maintenance of engineering structures are insufficient overall.

Figures 8 and 9 show the actual distribution of expenditure on maintenance in general and on maintenance of engineering structures in particular for the years 1996 to 2010. The share of the engineering structures declined relative to the increased total expenditure.

This is also reflected by the condition marks for the road bridges on Bavarian federal roads and state roads, which have continuously deteriorated in recent years (Fig. 5 and 6). These marks indicate that more than half of the engineering structures would require short-term repairs.

The economic stimulus package provided additional funding and thus short-term improvements on motorways and federal roads. However, future maintenance will require a sustained flow of additional funding.

Bridge management system (BMS)

The difficult financial conditions and

continuously increasing traffic load on the engineering structures as well as their deteriorating age distribution require further optimisation and systematic planning of the bridge maintenance process. Since 1998, considerable efforts have therefore been made to develop a Bridge management system (BMS).

The Federal Ministry of Transport, Building and Urban Development (BMVBS) is mainly interested in the provision of information to create an overview of the conditions of engineering structures and to control the use of funds. The states are more interested in practical support for planning and implementation of maintenance programmes

The BMS consists of four main modules that are divided into a large number of sub-modules.

The central unit of the BMS is the Measure Variant Module (BMS-MV). It uses structural, damage and condition data to develop maintenance measures based on the engineering structure inspection according to DIN 1076. Each specific fault is linked to several possible measure variants that are associated with costs, including the set-up of the building site, scaffolding and traffic routing. Each measure is associated with a reset value, depending on its effectiveness. The reset value reflects the expected improvement of the condition evaluation once the measure has been performed.

When the damage mechanisms are not clear, an object-related damage analysis (OSA) must be performed. The process described above is then suspended.

The Measure Evaluation Module (BMS-MB) is used to evaluate the measure versions created in the BMS-MV at object level, i.e. for each engineering structure. Two types of evaluation are possible. One is purely based on the condition and the other purely on the user costs and environmental costs. It is furthermore possible to create a mixed system that uses both methods with a selectable weighting. The current state of development allows for all three options.

The BMVBS has always insisted on a BMS version that performs evaluations purely based on user and environmental costs. This model is very complex. Even the development of the much simpler Pavement Management System (PMS) was therefore changed to purely condition-orientated evaluation. The output of the module is an orderly sequence of measure variants for specific structures (object evaluation). This evaluation at object level is performed without budget restrictions.

Thereafter, the object evaluation is transferred to the Maintenance Planning Module (BMS-EP) for evaluation at network level. Two goal functions are possible: The “quality scenario“, which calculates the minimum budget required to achieve a specific structure condition, and the “finance scenario“, which calculates the optimal structural conditions in the network achievable on a given budget.

The BMS-EP first uses the quality scenario to determine the budget required to prevent a drop below the minimum standard in the network during an activity period of six years. This results in the budget for the compulsory programme. When the actual budget is only slightly larger, little optimisation will be possible, i.e. only strictly necessary measures are planned for the maintenance programme. The recommendations are restricted to the compulsory programme. When more funds are available, the finance scenario can be used for optimisation purposes. This may concern a specific structure (bundling of individual measures for one object) or a selected route

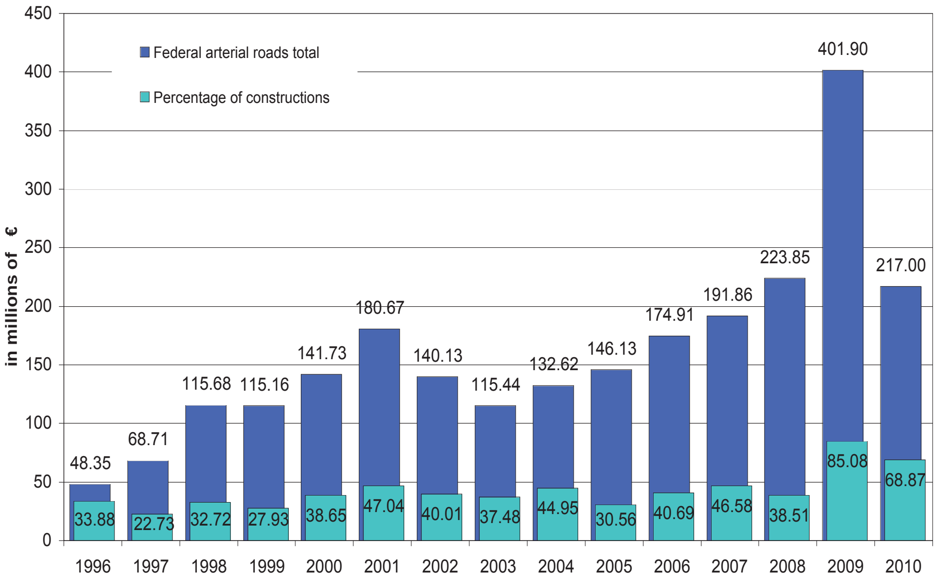

Fig. 8: Expenditure on the maintenance of motorways and federal roads in million €

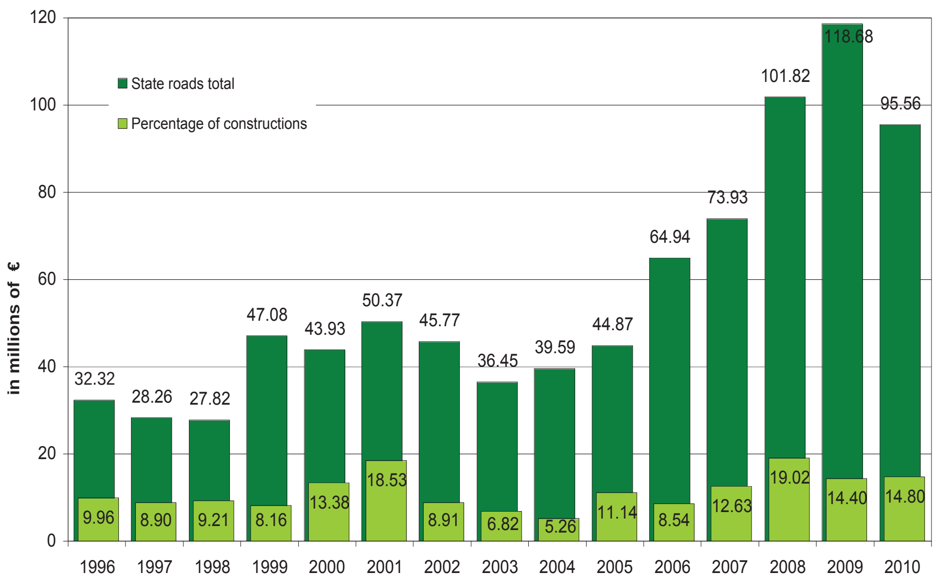

Fig. 9: Expenditure on the maintenance of state roads in million €

(minimisation of traffic obstructions). The result of the BMS-EP module is a suggestion for the maintenance programme.

The last module, the BMS-SB, can be used to evaluate maintenance strategies. The module can, for example, calculate the development of the condition mark as a function of the budget used for a large number of structures over several decades. The time required for such calculations is relatively short. The results can be used to compare long-term maintenance strategies.

The module allows for comparison of maintenance strategies based on a detailed engineering structure database for long periods and can provide information concerning the efficiency and consequences of possible strategies. It can be used to get specific information on the development of a set of engineering structures over the next few decades.

Several prejudices in connection with the BMS have persisted since its early days. It must therefore be emphasized that the BMS only provides the engineer with a suggestion that can be used as a starting point for a maintenance programme. This suggestion does not take into account the wide range of peripheral conditions beyond the scope of the computer-based BMS. The final decision on maintenance measures will therefore always rest with the engineer responsible.

We have had the use of the first prototype for approximately one year. It is being intensively checked in a test phase before it will be used in practical applications.

Future maintenance requirements / outlook

The allocation of funds for alterations and extensions as well as for asset maintenance is gaining in political importance. Neglect of asset maintenance would lead to considerable problems with the existing road network. The funding requirements for asset management must therefore be given more weight. This will be problematic, due to the multitude of pending new constructions and extensions. However, it is already obvious that not giving more weight to asset maintenance will lead to a considerable backlog within a few years. This backlog will be hard to work off, even in the long term, given the financing, staff and building capacity resources available and the fact that building operations interfere with traffic.

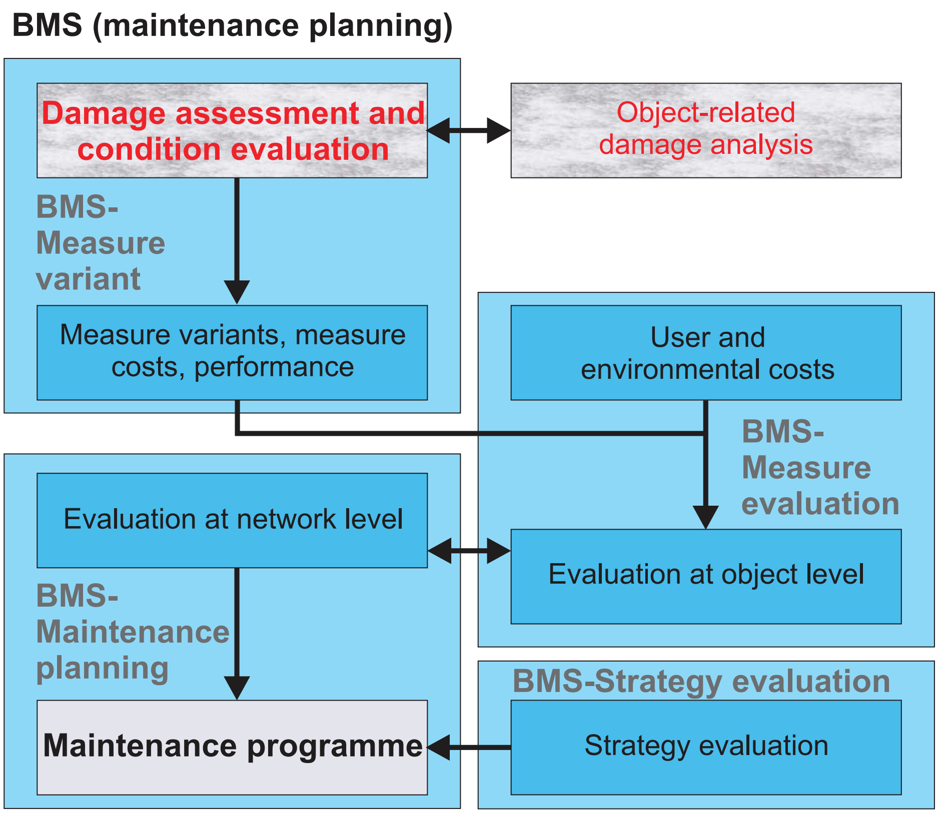

Fig. 10: Diagram of the BMS modules

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