# QUALITY ASSESSMENT OF ROAD DATABASES IN OPEN LANDSCAPE AREAS

M. Gerke and C. Heipke

Institute of Photogrammetry and GeoInformation, University of Hannover
Nienburger Str. 1, D-30167 Hannover, Germany - {gerke, heipke}@ipi.uni-hannover.de

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**ABSTRACT**

In this paper an approach to the automatic quality assessment of existing geo-spatial data is presented. The necessary reference information is derived automatically from up-to-date digital remotely sensed images using automatic image analysis. The focus is on the quality assessment of roads as these are amongst the most frequently changing objects in the landscape. In contrast to existing approaches for quality control of road data, common and consistent statistical modelling and processing of the road data to be assessed and the objects extracted from the images are carried out. A geometric-topologic relationship model for the roads and their surroundings is defined. The surrounding objects (context objects, such as rows of trees) support the quality assessment of road vector data as they may explain gaps in road extraction. The extraction and explicit incorporation of those context objects in the assessment of a given road database gives stronger support for or against its correctness.
During the assessment existing relations between road objects from the database and extracted objects are compared to the modelled relations. The certainty measures of the objects are integrated in this comparison. Normally more than one extracted object gives evidence for a road database object, therefore a reasoning algorithm which combines evidence given by the extracted objects is used. If the majority of the total evidence argues for the database object and if a certain amount of this database object is covered by extracted objects, the database object is assumed to be correct, i.e. it is accepted, otherwise it is rejected. The algorithms may be incorporated into a semi-automatic environment, where a human operator only checks the objects that have been rejected. The procedure is embedded into a two-stage graph-based approach which exploits the connectivity of roads and results in a reduction of false alarms.
The experimental results confirm the importance of advanced statistical modelling. The overall approach is able to reasonably assess the roads from the given database, using road and context objects which have been automatically extracted from remotely sensed imagery. Approximately 69% of the road objects have been accepted by the developed approach, 1% has been accepted though it is incorrect. Those false decisions are mainly related to a lacking assessment of road junction areas. However, further sensitivity analyses showed that in most cases the chosen two-stage graph-approach supports the reduction of false decisions.

## 1 INTRODUCTION

Geo-spatial data is the core and the most valuable part of any GIS. Information on its correctness is important for both, the data producer as well as for the user. The quality control of such data generally may comprise three steps: the check of logical consistency, the verification and the update. The logical consistency is checked by comparing the data with the defined data model, i.e. the existence of mandatory attributes and the consistency of geometry etc. is verified. During verification and update the existing data is assessed using reference information, e.g. from remotely sensed imagery. By verification the geometric accuracy as well as the correctness of attributes (if observable in the reference) are assessed. The completeness and temporal correctness is only partly considered, as only commission errors are identified. During a following update process, new or modified road objects not included in the database are extracted. By this means also completeness and temporal correctness are fully considered. In the present paper the verification using remotely sensed imagery is addressed. In practical applications the update of road databases from imagery plays a minor role, since update information is often derived from other source with a high update frequency. An example is the capture of roads using state-of-the-art navigation systems in vehicles or the direct import of planning data from the road construction administration. However, a quality control of this data, i.e. a verification, is necessary if up-to-date orthoimages, either airborne or spaceborne, are available.

The focus is on roads as these are amongst the most frequently changing objects in the landscape. Furthermore, only open landscape areas are considered, because these regions have two key advantages: a) sophisticated and also practically relevant road extraction algorithms are available, b) the modelling of relationships between roads and context objects, i.e. neighbouring objects, is of limited complexity.

In contrast to existing approaches for quality control of road data, a common and consistent modelling and processing of the road data to be assessed and the road objects extracted from the images is carried out. A geometric-topologic relationship model for the roads and their surrounding context objects is defined. If for instance aerial images are captured in summer, trees along roads hamper the road extraction as the road surface is not directly visible. The extraction and explicit incorporation of those context objects in the assessment of a given road database gives stronger support for or against its correctness.

The next section shortly introduces the related work, resulting in requirements for a new approach to road database assessment, which is described in the subsequent section. Details on its realisation, results obtained with the new approach, a summary and outlook are subject to the remaining sections.

## 2 RELATED WORK

This section gives a brief overview on work aiming at the verification of a given highly detailed road vector dataset. Such vector data are available for example in Germany (ATKIS DLM-Basis), in France (BDTopo), or in Great Britain (OS Mastermap). In (Gerke, 2006) a review on existing approaches to road network extraction and road database assessement is given. Most of the existing approaches on road database verification, such as

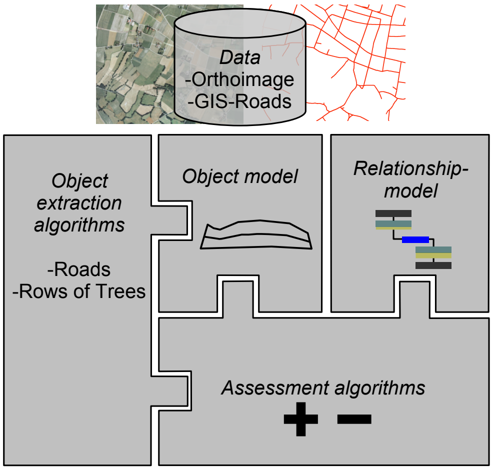


Figure 1: Components of the approach

(de Gunst, 1996, Gerke et al., 2004), lack an adequate modelling of the relations between road and context objects, although it has been shown that the incorporation of context objects can give valuable evidence for road objects (Ruskoné, 1996, Straub et al., 2000). Moreover it was found that the statistical properties of the input data are not sufficiently modelled and considered: the common and consistent modelling of the uncertainties and fuzziness during data capture is essential for a successful quality assessment of a given road database. Whereas in most approaches the uncertainty is not considered at all, in (Gerke et al., 2004) the uncertainty is represented using a constant buffer (Wiedemann et al., 1998). To buffer the objects implicitly assumes a uniform distribution for the objects. This assumption is not realistic: the normal distribution is more appropriate if only random errors affect the object capture. Road network topology is incorporated in some approaches, e.g. (Plietker, 1997, Gerke et al., 2004) and was found to be a valuable means for enhancing the overall results.

The three aspects, namely the incorporation of context objects, a statistical modelling and the exploitation of network functionality constitute requirements for a new approach to road database assessment in open landscape areas. Algorithms for the automatic extraction of road objects and rows of trees, representing the most salient context objects, from remotely sensed imagery in open landscape areas exist. Therefore, adequate input information for the quality assessment of road objects from geo-spatial databases is available.

## 3 APPROACH

The requirements which resulted from the discussion in the preceding section have been taken into account for the development of a new approach to road database assessment using remotely sensed imagery. This new approach consists mainly of four components (cf. Fig. 1). The *assessment algorithms* assess the GIS data through a quantitative comparison of the modelled relations (*relationship model*) and the existing relations between *extracted objects* and the given GIS road data. The *object model* provides a common geometric and statistical modelling of objects.

In the following, first the modelling is described in detail. Then, the object extraction is presented, subsequently the overall workflow, which implements the overall strategy for road database assessment is outlined. The final section gives details for the developed algorithms for the object and network assessment. A detailed account of the whole approach can be found in (Gerke, 2006).

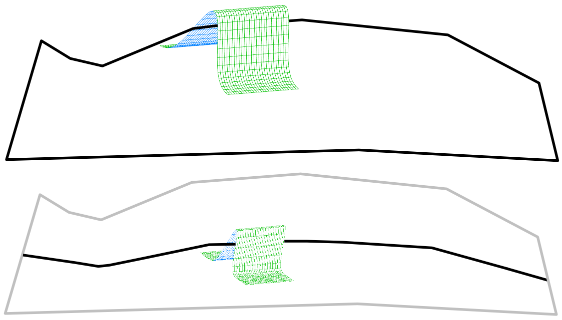

Figure 2: Object model. Upper: border representation and assigned density function, lower: medial axis representation and assigned density function.

### 3.1 Models

**Object model** In the present approach only elongated objects are considered. Any object is represented by its borders and medial axis. The medial axis representation can be derived from the borders if necessary. For this task at first a skeletonisation is conducted. Undesired small branches of the skeleton are removed and the remaining medial axis is elongated towards the border, compare the upper and the lower plot in Fig. 2. The object's uncertainty and imprecision is modelled through uniform and normal distributions. The uncertainty is related to the abstraction of the real world during object extraction, for instance the decisions of an operator concerning the question which points on the road surface belong to the road's medial axis. The imprecision is related to the measuring process, i.e. it is the deviation of a (unknown true) variable from its mean (measured) value. The individual parameters for the density functions (i.e. standard deviation for the normal case, and radius for the uniform case) need to be chosen according to the used input data for object extraction, and according to specific object properties. The final density function of the object is obtained by a convolution of those two input functions.

**Relationship model** In the relationship model the geometric and topologic relations between a GIS road object, the local context objects and the extracted road objects are given (cf. Fig. 3).

In contrast to many other definitions our geometric description does not comprise the position of an object, but the shape and orientation. The relative position of objects is modelled by the topologic relation. The geometric relations *same shape* and *same orientation* express the fact that the course of a GIS road object and the respective extracted object needs to be identical (shape) and that both objects must point towards the same direction. The topologic relation is important for this work due to the fact that for example rows of trees (the stems of the trees) must be located outside the road given in the GIS whereas an extracted road (the surface of the road) must be contained inside the GIS road surface. The topologic relations considered are *disjoint* and *contains*. The latter one is defined relative to the GIS object.

Besides this qualitative topologic relation one may define side conditions. For *disjoint* it is often desirable to give a minimum and a maximum distance ($d\_\min$, $d\_\max$). For example a row of trees must have a minimum distance to the road (due to security reasons) and it is also expected that trees having a distance to the road larger than a certain value are not suitable to explain gaps in the road extraction, i.e. they do not cover the road in aerial imagery. For *contains* additionally an *identical width* of objects may be required. The relations between the *GIS Road Object* and the *Local Context Object* and the respective values given in

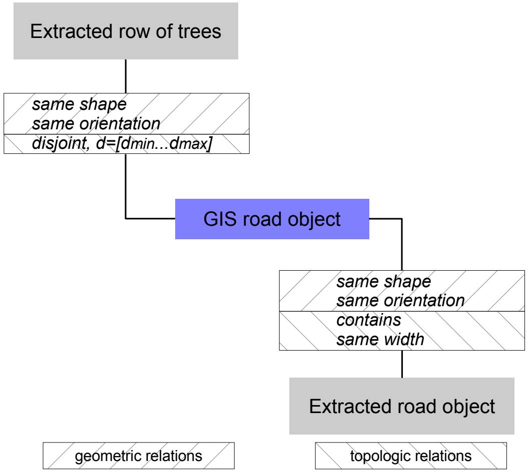


Figure 3: Relationship model

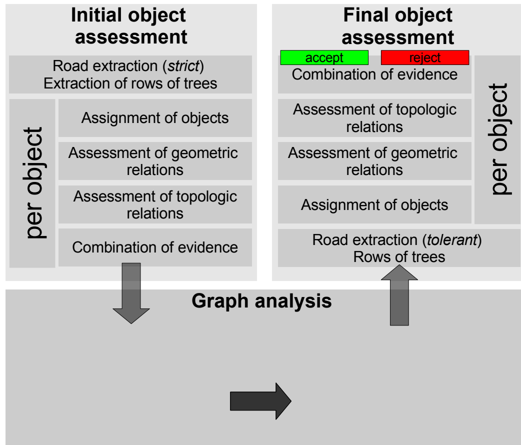


Figure 5: Workflow

the depicted relationship model are defined by experience and common knowledge. An alternative way to find the measures would be to incorporate official specifications, for instance from road construction.

### 3.2 Object extraction

Road objects and local context objects are extracted from the given sensor data. The extraction results in a geometric description of road objects, including statistical measures using the approach described in (Wiedemann, 2002). Roads are modelled as linear objects in aerial or satellite imagery with a resolution of about 1 to 2 m. The underlying line extractor is the one introduced in (Steger, 1998). The initially extracted lines are evaluated by fuzzy values according to attributes, such as length, straightness, constancy in width and in grey value. The final step is the grouping of the individual lines in order to derive topologically connected and geometrically optimal paths between seed points. The decision of whether extracted and evaluated lines are grouped into one road object is made corresponding to a collinearity criterion, allowing for a maximum gap length and a maximum direction difference. The rows of trees have been digitised manually from the image. In Figure 4 an example is given, showing the extracted objects.

Figure 4: Object extraction. Upper: image, lower: extracted roads (blue) and extracted rows of trees (yellow).

### 3.3 Workflow

The process of road database assessment consists of three main parts: *Initial object assessment, Graph analysis* and *Final object assessment*. This partitioning makes the network exploitation aspect explicit: the *Initial* and the *Final object assessment* are related to single road objects of the GIS database, whereas in the Graph analysis the transition to network edges is performed. To shorten the following text, the term *Phase 1* is used for the *Initial object assessment*, while *Phase 2* is employed for the *Final object assessment*. Phase 1 aims at a very reliable assessment. This means, the number of falsely accepted road objects (false positives) should be very small. As a consequence, the total number of accepted road objects will be quite low. In the Graph analysis part the network function of the road net is exploited, and local context objects are also incorporated. The idea is to identify those roads which have been rejected in Phase 1 but which perform important network functions, i.e. connect reliably extracted road network components. If local context objects give hints regarding the correctness of those important road objects, they will be accepted, otherwise they are subject to a second assessment in Phase 2. In that phase road extraction is applied a second time, but the algorithm is modified to extract objects in a more tolerant way. The workflow is sketched in Figure 5. The respective algorithms are described in the next section.

## 4 ASSESSMENT ALGORITHMS

The following assessment algorithms are applied to single GIS road objects. In Phase 1 every road object stored in the database is assessed, whereas in Phase 2 only those objects are regarded which turned out to fulfil an important network function, but which have been rejected in Phase 1. This decision is made according to the results of the Graph analysis.

### 4.1 Assignment of objects

The task here is to find those $N$ extracted road objects and local context objects (or parts of them), which may give evidence whether the currently processed GIS road object maintains the relations modelled in the relationship model. Additionally, the respective amount of coverage $qcov_i$ is calculated. This value becomes important when the evidence given by the extracted objects is combined. It is used as a weighting factor indicating the influence an extracted object has on the overall assessment of the GIS object.

### 4.2 Assessment of geometric relations

In this component the probability $P_{g_i}, i = 1 \dots N$, is calculated. It expresses to what extent one extracted object and the GIS road object maintain the modelled geometric relations *same shape* and *same orientation*. The probability $P_{g_i}$ consists of two components: the extent to what the shapes of both objects are identical is expressed by $P_{g-shape_i}$ and $P_{g-ori_i}$ concerns the identity of the orientation. The final probability is the product of both measures:

$$P_{g_i} = P_{g-shape_i} \cdot P_{g-ori_i}. \tag{1}$$

The medial axis representation is used for the calculation of both components.

**Assessment of identity of shape:** The basic idea of comparing the shape of two objects is that if the shapes of these objects are identical, the translation and rotation invariant line moments up to a certain order need to be identical, too. This choice is based on the moment uniqueness theorem (Hu, 1962) which states that an object can be represented by an (infinite) set of moments. Details on line moments are given in (Lambert and Gao, 1995). When the uncertainties of the objects are considered, the comparison of the moments can be expressed in terms of a statistical test. The probability $P_{pq}$ that the translation and rotation invariant moments (order=$p + q$) of two objects are equal is expressed by the probability that the difference of both moments is zero:

$$P_{pq} = F(y_{1-\alpha/2} - \tilde{D}_{pq}) - F(y_{\alpha/2} - \tilde{D}_{pq}), \tag{2}$$

with $y_{1-\alpha/2}$ and $y_{\alpha/2}$: boundaries of the confidence interval (quantiles of the standard normal distribution). Here the probability of error $\alpha = 0.01$ is chosen. $D_{pq}$ is the test statistic, i.e. the difference of moments divided by its standard deviation. $F$ is the normal distribution function.

Finally, the probability $P_{g-shape_i}$, considering all moments with order $o$ from $o_{min}$ to $o_{max}$ is

$$P_{g-shape_i} = \prod_{o=o_{min}}^{o_{max}} \prod_{q=0}^{o} P_{pq} \text{ with } p = o - q. \tag{3}$$

The moments of the first and second order are used for the calculation of the centre of gravity and the orientation, and are thus implicitly considered in the moments of higher orders. For this reason, the minimum order used for the comparison of translation and rotation invariant moments is $o_{min} = 3$. In empirical studies it was found that moments of a order larger than 8 are not significantly different from zero in real data, therefore $o_{max} = 8$.

**Assessment of identity of orientation:** $P_{g-ori_i}$, the probability that both orientations are identical, is computed applying a similar approach as developed for the determination of $P_{pq}$. Here, the test statistic is derived from the difference of the orientation of both objects. The object's orientation and the respective variance is obtained from line moments, see (Gerke, 2006) for more details.

### 4.3 Assessment of topologic relations

The task of this algorithm is to find a reasonable value for the probability $P_{t_i}$ that the given GIS road object and an extracted object keep the modelled topologic relation. For the examination of the topologic relations the approach presented in (Winter, 1998) is applied. In that work the topologic relations between imprecise and uncertain regions are assessed, considering any density function for the respective object's borders. Winter shows that all eight topologic relations two objects may undergo can be derived from the minimum and maximum distance between so-called certain zones of both objects. All relations modelled above can be assessed by this approach. Three distance classes (minus, zero, plus) are defined and based on the given density functions for the object's borders the probability for the class membership of the minimum and maximum distances are derived. All topologic relations can be mapped to a concrete class membership of both distances. Its probability can be calculated using the derived class membership probabilities. Hence, the probability $P_{t_i}$ that a given pair of objects maintains the modelled topologic relation is obtained.

The value of $P_{t_i}$ is also influenced by the width of the two objects in the case that the side condition *identical width* is given for the relation *contains*. The difference of widths must be zero, but the certainty of the widths measure must also be considered. The probability that this difference is zero is derived, and finally leads to a refined value for $P_{t_i}$.

### 4.4 Combination of evidence

The objective of the combination of evidence is to find a quality indication for the GIS road object depending on the present Phase incorporating the results from the assessment algorithms just described. Every extracted object being assigned to a GIS road object allows a conclusion $\xi_i = 1$, i=$1 \dots N$, which states that the GIS object and the respective extracted object keep the modelled geometric and topologic relations. The probability of whether $\xi_i = 1$ is true ($P_i^+$) or false ($P_i^-$) is assumed to depend on the collected measures.

The probability $P_{g_i}$ that the modelled geometric relation holds gives the main evidence: if it is likely that the shape and the orientation of both objects comply with the model, $P_i^+$ will be correspondingly large, and vice versa: the smaller $P_{g_i}$, the larger $P_i^-$ will be.

The measures $P_{t_i}$ and $qcov_i$ describe the impact an extracted object has on the assessment of the respective GIS road object: the larger these values are, the larger the evidence given by $P_{g_i}$ should be. Thus, these two measures are interpreted as weighting factors $\alpha_i$. Under the additional assumption that no other influences exist these considerations lead to:

$$\begin{aligned} \alpha_i &= P_{t_i} \cdot qcov_i, \\ P_i^+ &= P_{g_i} \cdot \alpha_i, \\ P_i^- &= (1 - P_{g_i}) \cdot \alpha_i. \end{aligned} \tag{4}$$

The incorporation of $P_{g_i}$ and $(1 - P_{g_i})$ in both, $P_i^+$ and $P_i^-$ implies a threshold of $0.5$: if $P_{g_i} > 0.5$, the evidence given by the object $E_i'$ is in favour of $P^+$, otherwise $P^-$ is larger than $P^+$.

In order to be able to assess the whole GIS road object, the evidence delivered by all extracted objects assigned to the GIS road object need to be combined. Two hypotheses are defined for this purpose:

$H^+$: the whole GIS road object is correct given the observed data, i.e., the modelled relations hold for the extracted objects and the GIS road object, and
$H^-$: the whole GIS road object is not correct given the observed data, i.e., the modelled relations do not hold for the extracted objects and the GIS road object.

An approach combining all conclusions $\xi_1 \ldots \xi_N$ related to, i.e. giving evidence for, a GIS road object must consider all the individual probabilities and finally infer the quality, permitting an overall assessment conclusion, i.e. confirm $H^+$ or $H^-$.

The conditional probabilities for the correctness of the statement $\xi_i = 1$ are assumed to be given by $P_i^+$ and $P_i^-$ and the weighting factor $\alpha$:

$$\begin{aligned} P(\xi_i = 1|\theta_1 = H^+) &= P_i^+ = P_{g_i} \cdot \alpha_i, \\ P(\xi_i = 1|\theta_2 = H^-) &= P_i^- = (1 - P_{g_i}) \cdot \alpha_i. \end{aligned} \quad (5)$$

The $\xi_i$ are assumed to be independent:

$$P(\xi_i, \xi_k|\theta_j) = 0 \qquad \forall i \neq k, \quad (6)$$

therefore, the combined probability for the correctness of $\theta_1$ and $\theta_2$ can be derived through the addition of the individual probabilities:

$$P(\xi_1 + \cdots + \xi_N|\theta_j) = \sum_{i=1}^{N} P(\xi_i|\theta_j). \quad (7)$$

Whether the road database object is accepted depends on a maximum probability decision. Additionally, a required minimum total coverage cov_req needs to be reached for the road database object to be confirmed. This is important to assure that a major part of the GIS object was assessed.

In the overall strategy, the separation of evidence from extracted road objects and local context objects is a key issue. In Phase 1 an object is *fully accepted* if solely the extracted road objects confirm its correctness, it is *preliminary accepted* if only the fusion of evidence from extracted road objects and local context objects lead to a confirmation of the hypothesis $H^+$. This decision implies that the local context objects are necessary to explain gaps in the road extraction. Finally, if none of the extracted objects give enough evidence to confirm $H^+$, the respective object from the database is *preliminary rejected*. If the extracted objects, regardless of the class, confirm the hypothesis, an object is *finally accepted* in Phase 2, otherwise it is *finally rejected*.

### 4.5 Graph analysis

The steps to road object assessment described in the preceding sections are related to individual road objects; the road network has not been incorporated so far. The exploitation of road network topology is based on the requirement that road objects having been accepted in Phase 1 need to be connected to each other. To restrict the number of possible connections and according to the assumption that road objects link places on short paths, the criterion to be fulfilled is that the distance between objects is minimised. The further treatment of objects not having been accepted in Phase 1 depends on whether they are part of the shortest distance between accepted objects and on the amount of evidence given by local context objects in Phase 1.

The assessment result per GIS road object is transfered to edges of the road network. This is important to be able to reasonably analyse the network function of the assessed roads. Afterwards, the assessment result is transfered to the network edges, and shortest paths between the *finally accepted* edges are searched, applying the A*-Algorithm (Duda and Hart, 1973). The edges are then labelled according to the following rules: if a preliminarily accepted edge is part of a shortest path, it is labelled as *finally accept*. This rule is motivated by the assumption that the local context objects are able to explain existing gaps in the road extraction. This assumption is additionally supported by the network analysis and thus the correctness of the edge – respectively of the assigned GIS objects – may be expected. If a preliminarily rejected edge is part of a shortest path, it is labelled as *check again*. The network function of those edges is assumed to give enough evidence to check them again, applying a road extraction with more tolerant parameters. All remaining preliminarily rejected or accepted edges are labelled as *finally reject* as it is assumed that they do not fulfil an important network function. The labels from the edges are then transfered to the GIS road objects. The objects being labelled as *check again* are prepared to be processed again in Phase 2, the remaining objects, i.e. objects being labelled *finally accept* and *finally reject*, are not checked again.

## 5 TEST OF THE APPROACH

An exhaustive test of the proposed approach to road database assessment in open landscape areas is presented in (Gerke, 2006). In the following the focus is on the question whether the incorporation of local context objects – here: rows of trees – into the assessment increases the overall result. The chosen test site is located in the German state North Rhine-Westphalia. It has a size of $2 \times 8\text{km}^2$. The employed RGB ortho images have a ground sampling distance of about 30cm. The ATKIS DLMBasis[1] contains about 530 road objects. A reference verification of the dataset showed that about 98% of the objects are correct, and about 25% of them are significantly occluded by rows of trees. The object extraction from the given imagery was conducted by the algorithms described above in section 3.2.

A means to evaluate the assessment results is to define an error matrix, where the reference and the assessment result are compared. The types of error and their impact on the practical semi-automatic workflow are given in Fig. 6. The operator who is inspecting the road verification results just concentrates on the objects which have been rejected. Therefore the number of true positives should be relatively high since it indicates efficiency. The false positive errors are undetected errors and thus should be minimised.

| | | **Assessment decision** | |
|---|---|---|---|
| | | *accept* | *reject* |
| **Reference** | *correct* | True Positive (efficiency) | False Negative (manual postprocessing) |
| | *incorrect* | False Positive (undetected error) | True Negative (manual postprocessing) |

Figure 6: Error-matrix for the evaluation of results

In Figure 7 the assessment results obtained with the approach are compared to the reference decisions. The left error-matrix shows results where no rows of trees have been incorporated into the assessment, whereas the right matrix shows the results obtained by the additional consideration of the rows of trees. It is obvious that the rows of trees help to increase the efficiency: the number of true positives increases from about 60% to 68%. However, the number of false positive decisions also increases: one additional object has been accepted though incorrect in the second case. The false positive decisions are mainly related to the lacking modelling of junction areas. The medial axis does not adequately represent the road object and thus often errors are not detected. The

[1] ATKIS: Authoritative Topographic Cartographic Information System, it represents the official topographic reference dataset for Germany. The DLMBasis is the dataset with the highest resolution. Its content approximately equals a topographic map of a scale of 1:25,000 and is not generalised.

| | | Assessment decision | |
|---|---|---|---|
| | | *accept* | *reject* |
| **Reference** | *correct* | 59,8% | 38,1% |
| | *incorrect* | 1,0% | 1,1% |

| | | Assessment decision | |
|---|---|---|---|
| | | *accept* | *reject* |
| **Reference** | *correct* | 68,0% | 29,9% |
| | *incorrect* | 1,2% | 0,9% |

Figure 7: Error-matrices. Left: without incorporation of rows of trees, right: with incorporation of rows of trees

false negative decisions, i.e. correct road objects which have been rejected, can be explained by an unsuccessful road extraction, for instance due to weak contrast. A certain amount of false negative errors is related to the graph-approach: if roads constitute dead-ends or if they are situated at image borders and if they have been rejected in Phase 1, they are currently not assessed again in Phase 2, because they are connected at only one end to the road network and therefore may not be part of a shortest connection between two adjacent objects.

## 6 CONCLUSIONS AND OUTLOOK

The presented approach to road database assessment using remotely sensed imagery shows that a modelling of objects and their relations, including a consistent statistical processing is essential for the comparison of vector datasets from different origins. The evaluation of the algorithms for geometric and topologic relation assessment demonstrates that it is worth incorporating error propagation methods to obtain reasonable results. The effectiveness of the assessment also depends on the performance of the used road extraction operator. If correct road objects are not extracted or if non-road objects which appear as roads in the imagery lead to false extractions, errors in assessment decisions cannot be avoided. However, by means of the chosen graph-based strategy which also uses context objects to explain gaps in road extraction, the number of this kind of errors is reduced considerably.

The incorporation of further objects into the assessment seems to be an interesting and promising means of improvement. The relationship model can easily be extended towards new object classes. For instance, the edges of forests are not considered up to now. Similar to rows of trees they may occlude roads and therefore hamper the automatic extraction of roads. The geometric and topologic relations can be modelled similar to those for rows of trees. To integrate additional object classes is also interesting for the graph-based optimisation. In the current approach only reliably extracted roads are considered for the definition of start-nodes. Especially for dead end roads other object classes may give rise to imply that a road object is important in the sense of connection functionality. Additional significant improvements concern the extension of the approach regarding quality assessment in settlement areas, which requires an enhancement of the relationship model and further investigations on the incorporation of the existing data into automatic road extraction. Object classes to be included into the relationship model are for instance buildings, or rows of buildings, respectively, and objects on the road like vehicles.

The approach to road database assessment presented in this paper is integrated in the workflow at the German Federal Agency for Geodesy and Cartography (BKG) where a system for the automated verification and quality control of the ATKIS DLMBasis is installed.

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