QUALITY ASSESSMENT OF ROAD DATABASES USING AERIAL IMAGERY

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ABSTRACT

Digital road databases are widely used in many facets of our daily life. Most of these databases come with a nominal quality indication, but often more detailed quality descriptions regarding possible errors, the positional accuracy, and information on the completeness of the vector data are desirable. In this paper an approach for the quality description of road data from the Authoritative Topographic Cartographic Information System (ATKIS) of Germany is introduced. The work is embedded in a project initiated by the German Federal Agency for Cartography and Geodesy (BKG), which is interested in an automation of the road data verification process.

How existing road vectors from ATKIS can be assessed by combining the information coming from several object extraction algorithms is investigated. These objects are modeled in the so called relationship model where the topologic and geometric relation between roads and other objects are given. For example a row of trees is often parallel to roads and has a minimum and a maximum distance from the carriageway. Every extracted object - such as rows of trees extracted from aerial imagery - may then support a given ATKIS road. If it does not coincide with the model it gives evidence against the ATKIS road. The Hint-Theory is used which is derived from the Dempster-Shafer Theory of evidence to combine all information related to an ATKIS road segment. Example results show that the introduced procedure is able to yield reliable information on the quality of ATKIS objects.

1 INTRODUCTION

Nowadays, large scale road vector data is available in many countries as part of the national geo-spatial core data. Questions are starting to arise from the user's side: is the data accurate enough for a particular application, is it up-to-date and are the attributes correct? In this paper a method for an automatic quality assessment for given road vector data using information automatically extracted from digital aerial images is developed. Quality comprises completeness, positional accuracy, attribute correctness and temporal correctness for each object. The presented method is not designed to check the completeness as only objects contained in the database are considered (verification of existing data). However, a potential extension regarding the detection of new roads will be sketched in the outlook.

In (Gerke et al., 2004) road objects from the Authoritative Topographic Cartographic Information System (ATKIS) of Germany are verified using automatic road extraction algorithms. The road extraction algorithm used in that work exploits knowledge on the appearance of roads in aerial or satellite imagery, but does not consider so called local context objects. These objects (such as rows of trees) may hamper the extraction of roads, as these may not be directly visible due to occlusion. The explicit modeling of the topologic and geometric relation which do exist in reality between such context objects and road objects helps to interprete gaps in road extraction and thus supports road extraction, e.g. see (Hinz and Baumgartner, 2000) and (Hinz, 2003).

In this work the topologic and geometric relations between local context objects, extracted roads and ATKIS road objects are modeled in a so called relationship model. The goal is to assess given ATKIS objects by means of extracted objects (either local context objects or road objects). Every extracted object gives a certain portion of evidence regarding the hypothesis that a certain object from the ATKIS database maintains the modeled relations. In order to balance the given evidences the Hint-Theory being an approach to the Dempster-Shafer-Theory is applied.

2 THE HINT-THEORY: AN APPROACH TO EVIDENCE-THEORY

The background of the Evidence-Theory (E-T) is the assessment of incomplete knowledge by means of degrees of belief (lower probability) and degrees of plausibility (upper probability). The roots of E-T can be found in (Dempster, 1967), whereas the actual origin of E-T is known to be set by Shafer in his monograph (Shafer, 1976). The degree of belief (often called credibility) expresses to what extent information can be trusted. The degree of plausibility specifies to what extent there is no disagreement regarding an information. Further information regarding E-T can be found in (Shafer and Pearl, 1990), an introduction to the Dempster-Shafer-Theory is given in (Gordon and Shortliffe, 1990).

The Hint-Theory (H-T) is an approach to the E-T, its fundamentals can be found in (Kohlas and Monney, 1995). The measure to what extent a hypothesis is proved by the Hint $\mathcal{H}$ is called support (degree of certitude). The extent to what there is no disagreement to a hypothesis is called plausibility. The interpretations of support and plausibility are very close to Dempster's theory of upper and lower probability. Hints are combined applying Dempster's Rule.

In (Kohlas and Monney, 1995) it is shown that the Bayesian approach can be represented by E-T, whereas a representation of E-T by Bayes Theory is not feasible. One interesting difference to the Bayesian approach is the possibility to formulate ignorance: in the Bayesian framework the evidence must be allocated completely to the possible hypotheses, thus a priori probabilities are selected in order to calculate conditional probabilities from found evidence. In E-T it is allowed to expliciteIy formulate ignorance and therefore a specification of a priori knowledge is not required.

In this work the Hint-Theory is preferred to a Bayesian approach because assumptions about a priori probability distributions concerning the quality of an individual ATKIS object can not be made. One could take into account to obtain this information from experience but this could lead to a distortion of results. The main reason for this is that the influences to the data quality of ATKIS are manifold and can not be modeled a priori.

3 RELATIONSHIP MODEL

The assessment of ATKIS objects by means of extracted objects or by means of objects of a higher quality requires a model describing the properties of all involved object classes and their relations. The model used here has two major properties: a) the attributes and the attributive and positional certainties can be assigned in an uniform manner and b) a separation between objects to be assessed, objects which directly give evidence and context objects is given. These properties are important because a) assures that the model is extensible with new object classes and b) allows to apply this approach even without having information about context objects.

The relationship model (ref. to Fig. 1) contains three major classes: ATKIS objects, context objects and extracted road objects. Additionally the topologic and geometric relations are described. Such models are called relationship models, because the main intention is to illustrate the relations between the objects of interest. It can also be understood as an extension to so called local context models as introduced in (Mayer, 1998). The main extension consists in the insertion of the GIS objects which have to be assessed. Moreover the geometric subelements of a line object (segments) are explicitely contained.

Objects are geometrically described by a concatenation of segments consisting of two points (thus resulting in a line-string). The decision to choose this representation (e.g. in contrast to a polynomial one) is based mainly on computational considerations. If necessary the conversion from any representation to a line-string representation is done by a quantization (accepting a certain amount of loss of accuracy). In the assessment phase each segment of an object is analysed separately. By means of combining the assessment results of all object's segments it is possible to obtain an assessment result for the whole object.

The relationship model is independent of global context, i.e. the appearance of objects in different environments. This knowledge must be considered by the respective object extraction algorithm.

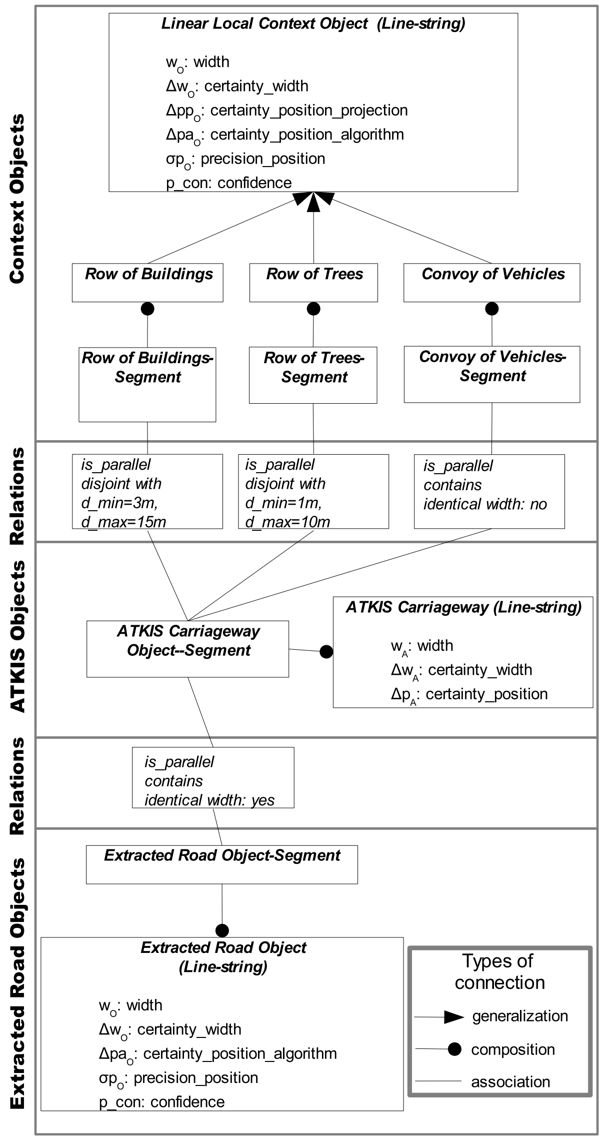


Figure 1: Relationship Model

3.1 Object Classes

Three groups of attributes for the specification of the quality are used (refer to Fig. 1):

1. *certainty* Δ: The certainty represents the range in which a variable is defined. *Certainty* can be understood as an equipartition. For example if an attribute *width* is 5m and the certainty of this value is 2m than it is assumed that *width*=$[3 \ldots 7\text{m}]$.

2. *precision* σ: The precision is a measure in the sense of a standard deviation (Gaussian). If in the above example the *precision* is 2m then the probability that *width*=$[1 \ldots 9\text{m}]$ would be about 95% (2σ).

3. *confidence* p_{con}: Many object extraction algorithms apply an internal evaluation of the results. This measure should be used in the assessment phase and is therefore also part of the attributes. The confidence is defined in $[0, 1]$.

3.1.1 *Linear Local Context Object*

In order to fulfill the requirement of a general framework for describing context objects a generic class *Linear Local Context Object* has been defined. All local context objects are defined based on a common model; they just differ in the relation to the ATKIS object. The attributive description for any object defined in *Linear Local Context Object* is explained in the following:

- *width* w_O and *certainty_width* Δ_{wO}: The local context objects are represented by means of the center axis. In order to be able to describe and assess topologic relations knowledge about the width and its certainty is necessary.
- *certainty_position_projection* Δ_{ppO}: In this value the certainty regarding the position inherited by orthoprojection is considered: normally orthoimages are used which have been rectified using a terrain model, not considering objects above the ground (like trees and buildings). This leads to a position offset of those objects in the orthoimage, which has to be taken into account when topologic relations are assessed. The precise value of this offset is mostly unknown due to missing height information, but a range can be specified.
- *certainty_position_algorithm* Δ_{paO}: This value is similar to the previous attribute, but it emanates from the algorithm extracting the object (or more general: from the source of information): Often it is unclear how to fix the position of an object. For example the object *Row of Trees* is situated beside the road, i.e. the stems stand outside the carriageway. But in an aerial imagery one can just observe the crowns and is therefore just able to make assumptions about the position of the stem. This assumption needs to be reflected in *certainty_position_algorithm*.
- *precision_position* and *confidence*: Refer to the general description of the quality attributes. In practice these measures are obtained for every algorithm individually, for example incorporating the pixel size and sub pixel accuracy for *precision_position*. The *confidence* is obtained by applying an interior assessment of the results.

One could also consider defining a Gaussian distribution for some measures defined as *certainty* above. If such a representation suits the requirements better has to be investigated in the future.

3.1.2 *ATKIS Carriageway Object*

Regarding the ATKIS objects the carriageway object is considered. In ATKIS the carriageway is implicitly contained in roads and in objects of higher complexity such as highways. It can be easily derived from the standardized ATKIS road classes. The geometric description of carriageways in ATKIS consists of the center axis and the width, given as attribute (assuming a constant width). The width w_A of an ATKIS object, its certainty Δ_{wA} as well as the nominal certainty of the position (Δ_{pA})[1] are given in the attributes of the base class *ATKIS Carriageway Object*.

[1] Normally this value is $\Delta_{pA} = 3m$

3.1.3 *Extracted Road Object*

In the relationship model a general class for extracted road objects is also present: *Extracted Road Object*. Its attributes are similar to the ones defined for the *Linear Local Context Object*, except for *certainty_position_projection*, this certainty is normally not of interest for roads as they are situated on the ground[2].

3.2 Relations

In the relationship model the geometric and topologic relations between an ATKIS object and the local context objects as well as the extracted road objects are also given. It is important to note that the given relations are independent of any quality values: it is a general description of the reality.
The geometric relation *is_parallel* expresses the fact that in reality context objects are often parallel to road objects: For example in open landscapes elongated rows or trees are situated parallel to roads; in settlement areas the same holds for building rows.
The topologic relation is important for this work as it must be taken into account that for example rows of trees must be situated outside the carriageway given in ATKIS whereas an extracted road (the surface of the road) must be contained in the ATKIS carriageway and the width of both objects must be identical. The topologic relations considered so far are *disjoint* and *contains*. The latter one is defined relative to the ATKIS 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), which defines on the one hand an empty space between the road and the respective context object (d_min) and on the other side some sort of influence border (d_max). For example a row of trees must have a minimum distance to the carriageway (due to security reasons) and also it is expected that trees having a distance to the carriageway larger than a certain value have no relation to the road.
The topologic relation *contains* is for objects being situated on the carriageway. The possible side condition for this relation is the indication that the width of both objects needs to be identical. This is important for extracted road objects. In Fig. 1 some object classes are derived from *Linear Local Context Object*, but an extension to other objects is possible thanks to the common framework. The given side conditions for the topologic relations are chosen from experience, but the incorporation of prior knowledge from road planning instructions is also possible.

4 STRATEGY FOR ATKIS ROAD ASSESSMENT AND IMPLEMENTATION

In the framework of road assessment it is sufficient to define a region of interest (ROI) for each *ATKIS Carriageway Object*-Segment including all extracted objects and to assess the given segment using these objects. The size of the ROI depends on the modeled relations as well as on the given quality measures: the worse the extracted data, the larger the ROI. As will be shown later the degree of support an extracted object gives for the assessment also depends on its quality. The strategy for road assessment is as follows:

[2] Special cases such as road bridges not being present in the height model are for the moment not of interest.

1. Extraction of *Linear Local Context Objects* and assignment to *ATKIS Carriageway Object*-Segments (depending on the quality of extracted *Linear Local Context Objects* and its modeled topologic relation to ATKIS).

2. Definition of ROI for each *ATKIS Carriageway Object*-Segment, depending on the assumed quality of *Extracted Road Objects*. Subsequent extraction of road objects in the ROI.

3. Assessment of the ATKIS segment using Hint-Theory: To what degree do the extracted objects support the existence/nonexistence of the ATKIS segment? The given certainties and precisions assigned to the objects are considered and are reflected in the degree of support.

4. Linkage of the assessment results of all segments from one ATKIS object in order to achieve an object-wise assessment.

The sequence concerning the assignment of *Extracted Road Objects* to the ATKIS segment (step 2) depends on the road extraction strategy. If the road extraction algorithm uses input information from AKTIS (as done e.g. in (Gerke et al., 2004)) the definition of a ROI before road extraction is reasonable, whereas if it does not use such information the road extraction is independant from the ROI (similar to the procedure for *Linear Local Context Objects*).

4.1 Assignment of Extracted *Linear Local Context Objects* to ATKIS Segments

The decision if a *Linear Local Context Object* is assigned to a certain ATKIS segment depends on a) the width of the extracted object, b) the quality measures of both objects and c) the modeled topologic relation. The ROI in which an extracted local context object must be situated is a buffer with the radius $r\_ROI = \Delta + w_O + d\_max$ around the respective segment of the ATKIS Carriageway. The value Δ is the sum of all certainty values given for the ATKIS-Segment and the extracted *Linear Local Context Object*: $\Delta = \Delta_A + \Delta_O$, with $\Delta_A = \Delta_{wA} + \Delta_{pA}$ and $\Delta_O = \Delta_{wO} + \Delta_{ppO} + \Delta_{paO} + 2\sigma_{pO}$. Note that the precision σ is here converted to a certainty measure by means of the 2σ calculus as the ROI can be interpreted as a 95%-confidence area of the two segments.

4.2 ROI-Definition and Extraction of Road Objects

The calculation of r_ROI for the subsequent extraction of road objects is similar to the definition above: $r\_ROI = \Delta = \Delta_A + w_O + \Delta_O$ with $\Delta_O = \Delta_{wO} + \Delta_{paO} + 2\sigma_{pO}$. As the width of the extracted objects is unknown a priori a predefined value can be used, keeping in mind its impact to the assessment result. If however a road extraction was performed independently of ATKIS data no assumptions have to be made.

4.3 Assessment of ATKIS Segments Using Hint-Theory

In the relationship model the topologic and geometric relationship between an ATKIS segment and the segments of *Linear Local Context Objects* (resp. the *Extracted Road Objects*) are defined. It is now desirable to exploit this knowledge in the assessment phase. This means two frames of discernment can be defined: a) $\Theta_G = \{G, \neg G\}$ which includes the hypothesis G expressing that the segment of the extracted object and the ATKIS segment coincide with respect to geometric relations, respectively its negation $\neg G$ and b) $\Theta_T = \{T\}$ including hypothesis T which refers to the topologic relations. Note that the complementary hypothesis regarding topology $\{\neg T\}$ is not included. This is motivated by the fact that it is already assured in the assignment phase that a considered extracted road or context object has an impact to the respective ATKIS object. Thus it is clear that it supports T. The question is to what degree it does support this hypothesis.

The focal sets are not completely disjoint: any object just gives as much evidence for the hypotheses that an ATKIS segment and this object coincide regarding the modeled relation as justified by the respective measures and quality values. Here the advantage over traditional probability theory or a Baysian approach is exploited: the formulation of ignorance is possible.

4.3.1 Hints Regarding Topologic Relations For the examination of the topologic relations between two objects the approach presented in (Winter, 1996, Winter, 1998) is applied. In that work the topologic relations between imprecise and uncertain regions are assessed. Winter shows that all eight topologic relations two objects may undergo (divided in two relation clusters C_1 and C_2, refer to Tab. 1) can be derived from the minimum and maximum distance between so called certain zones. Winter proves that if two objects undergo the relation *touch* (considering their uncertainty) it is impossible that they undergo relations beyond overlap (C_2) and vice versa. The decision whether C_1 or C_2 applies is made based on an overlapping factor. Certain zones are then defined depending on the relation cluster: in C_1 the area not being covered by the two objects is certain, in C_2 this area is uncertain. The signed distance function between the certain zones is introduced as ϑ and derived from the morphologic distance transform along the zonal skeleton of the uncertain zone. Winter introduces the sign of ϑ being dependant on the object the zonal skeleton intersects. The definition of range classes $\Psi_\vartheta = \{\psi_-, \psi_0, \psi_+\}$ allows to represent the topologic relations by means of the min. and max. value of ϑ[3]. For this work the definition of the range classes have to be extended in order to consider the side conditions d_{min} and d_{max} for the relation *disjoint*:

$$\Psi_\vartheta = \{\psi_-, \psi_0, \psi_+\} \text{ with } \begin{cases} \vartheta \in \psi_-, \text{if } \vartheta < d_{min} \\ \vartheta \in \psi_0, \text{if } d_{min} \leq \vartheta \leq d_{max} \\ \vartheta \in \psi_+, \text{if } \vartheta > d_{max}. \end{cases}$$

The assignment of ϑ_{min} and ϑ_{max} to these classes leads to ψ_{min} and ψ_{max} which can be transferred to the topologic relations (ref. to Tab. 1). Note that the modeled relation *contains* is supported by the original relations *contains, covers, equal* as it is allowed that the boundaries of the respective objects are identical. Special attention has to be paid if the side condition *identical width* is given for *contains*. This side condition can not be checked by means

[3] Winter uses the term Ω for the range classes. In order to avoid confusion with the terms used for the Hint-Theory here the expression Ψ is introduced.

Rel. Cluster	Modeled Relation	Side Cond.?	$\psi_{min}[d_{min}, d_{max}]$	$\psi_{max}[d_{min}, d_{max}]$	Original Relation
C_1	disjoint	no	$\psi_+[0,0]$	$\psi_+[0,0]$	disjoint
C_1	disjoint	yes	$\psi_0[d_{min}, d_{max}]$	$\psi_0[d_{min}, d_{max}]$	–
C_1	–	–	$\psi_0[0,0]$	$\psi_+[0,0]$	touch
C_1	–	–	$\psi_-[0,0]$	$\psi_+[0,0]$	weak overlap
C_2	–	–	$\psi_-[0,0]$	$\psi_+[0,0]$	strong overlap
C_2	contains	no/yes	$\psi_-[0,0]$	$\psi_-[0,0]$	contains
C_2	contains	no/yes	$\psi_-[0,0]$	$\psi_0[0,0]$	covers
C_2	contains	no/yes	$\psi_0[0,0]$	$\psi_0[0,0]$	equal
C_2	–	–	$\psi_0[0,0]$	$\psi_+[0,0]$	covered by
C_2	–	–	$\psi_+[0,0]$	$\psi_+[0,0]$	contained by

Table 1: Equivalence between $\{C, \psi_{min}, \psi_{max}\}$ and topologic relations

of the distance function, this problem will be addressed later on.

It is interesting, to what extent (probability) two segments maintain the modeled topologic relation, considering their certainties. The probability $P(\vartheta|\psi_i)$ that a distance ϑ belongs to a certain class ψ_i is derived from an equipartition which depends on the sum of all certainties, assigned to the objects (Δ in sections 4.1 and 4.2) and the relation cluster, refer to Fig. 2. As all possible values for ϑ have to be considered, the boundaries $\vartheta_{min.possible}$ and $\vartheta_{max.possible}$ have to be chosen carefully. Up to now this simple statistical model with equipartitioned variables is used, but an extension to arbitrary density functions is feasible. For example the value Δ reflecting the certainties of the objects also contains the precision in the position of the extracted object σ_{pO} (ref. to section 4.1), but inserted as a 95% confidence value. Another density function will result from a convolution of the certainties and the precisions (i.e. a convolution of a equipartitioned density function with a Gaussian). This combination has not been realized here because in practice the impact of σ_{pO} compared to the equipartitioned certainties is relatively low.

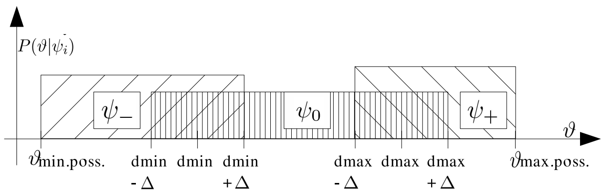


Figure 2: Density Functions for Distance Classes

From the figure the a-priori probabilities $P(\psi_i)$ can be also derived, i.e. the probability for each class compared to the whole range of possible values. Together with $P(\vartheta|\psi_i)$ conditional probabilities $P(\psi_i|\vartheta)$ can be derived:

$$P(\psi_i|\vartheta) = \frac{P(\vartheta|\psi_i)\, P(\psi_i)}{\sum_{\psi_j \in \Psi_\vartheta} P(\vartheta|\psi_j)\, P(\psi_j)}$$

By multiplying the respective $P(\psi_i|\vartheta_{min})$ and $P(\psi_i|\vartheta_{max})$ according to the equivalences given in Tab. 1 the probability p_t that a given pair of segments maintains the modeled topologic relation can be achieved. This probability value can be used for a Hint which contains the hypothesis that the current segments coincide with the model. The focal sets and the assigned probabilities for a Hint $\mathcal{H}'_T$ concerning the topologic relation are shown in Tab. 2. Here two more parameters are involved in the confidence measure:

Ω	Γ	P
ω'_{T1}	$\{T\}$	$p_t \cdot q_{cov} \cdot p_{con}$
ω'_{T2}	Θ_T	$1 - p(\omega'_{T1})$

Table 2: Hint $\mathcal{H}'_T$

p_{con} is the confidence assigned to the extracted object. The evidence given by an object is the more credible the more confident it is. The parameter q_{cov} expresses to what degree the segment of the extracted object covers the ATKIS segment which is to be assessed. This factor is important in order to limit the impact of a Hint given from an object to the proportion it influences the ATKIS segment. The focal set Θ_T represents ignorance.

The final Hint $\mathcal{H}_T$ regarding the topologic relation is also influenced by the width of the two objects in case the side condition *identical width* is given for the relation *contains* (if it is not required then $\mathcal{H}_T = \mathcal{H}'_T$). The difference of widths must be zero, but the certainty of the widths measure must also be considered. Therefore $\mathcal{H}_W$ is introduced which supports T depending on the difference of width and the given certainties. From the combination of $\mathcal{H}'_T$ and $\mathcal{H}_W$ applying Dempster's Rule follows $\mathcal{H}_T$.

4.3.2 Hints Regarding Geometric Relations

Similar to the judgment of topologic relations a measure is needed describing to what extent the modeled geometric relation is maintained by two objects.

The calculation of the Hint $\mathcal{H}_G$ concerning the question whether two segments are parallel is done in the following manner. If the direction of those two segments is given by t_A and t_O the angle enclosed is $\alpha = |t_A - t_O|$. In the given problem it is sufficient to define α on $[0, \frac{\pi}{2}]$. Parallelism means that α may not exceed a certain value. This fixed threshold is α_p and set to $\alpha_p = 15^\circ$.

The probability p($\alpha < \alpha_p$) depends on the precision given for the objects (it is presumed that quality measures assigned to the single segments are the same as assigned to the object). Further it is assumed that the certainty of the segments has no significant effect on the computation of the direction, because a certainty in the given context is understood as an unknown displacement of the whole object, and such a displacement has no impact on the direction. As a standard deviation for the position of an ATKIS segment is not given in the model the standard deviation σ_α just depends on σ_{pO}, the precision given for the extracted segment:

$$\sigma_\alpha = \sigma_{tO} = \frac{\sigma_{pO}}{L_O}.$$

with L_O: Length of the respective segment. The probability $p(\alpha < \alpha_p)$ can now be calculated using the Gaussian probability density function for α:

$$p(\alpha < \alpha_p) = F(\alpha_p) = \int_{-\infty}^{\alpha_p} f(\alpha) d\alpha$$

The Hint $\mathcal{H}_G$ allows three interpretations as shown in Tab. 3. In contrast to $\mathcal{H}_T$ this Hint also supports $\neg G$. As the objects are assigned to the respective ATKIS segment without considering the geometric relation it is reasonable to support $\neg G$ here.

Ω	Γ	P
ω_{G1}	$\{G\}$	$p(\alpha < \alpha_p) \cdot q_{cov} \cdot p_{con}$
ω_{G2}	$\{\neg G\}$	(1-$p(\alpha < \alpha_p)) \cdot q_{cov} \cdot p_{con}$
ω_{G3}	Θ_G	$1 - p(\omega_{G1}) - p(\omega_{G2})$

Table 3: Hint $\mathcal{H}_G$

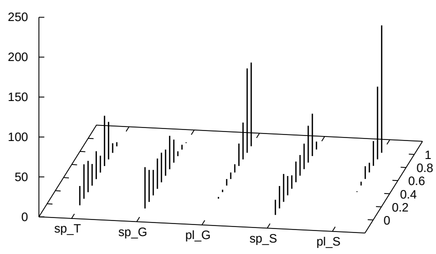
4.3.3 Combining Hints for one ATKIS Segment The Hints defined in the last two sections refer to the relation between an ATKIS segment and a segment of the extracted objects. Applying Dempster's Rule all Hints referring to one ATKIS segment can be combined. The Hints $\mathcal{H}_T^S$ and $\mathcal{H}_G^S$ are thereby computed, representing the overall coincidence of the ATKIS-Segment to the model with respect to both relations. The frame of discernment $\Theta = \Theta_T \times \Theta_G$ containing hypotheses whether the ATKIS segment fits to the model (H^S) or not ($\neg H^S$).

5 RESULTS

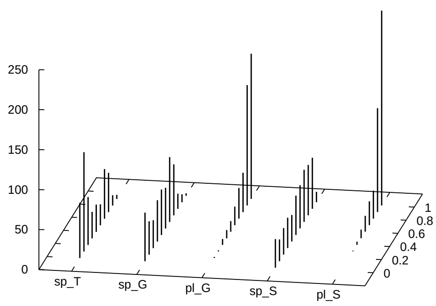
In this section preliminary results of the introduced approach are given. In order to investigate whether the quality of ATKIS objects is reflected by means of *Extracted Road Objects* and *Linear Local Context Objects* some experiments were carried out. Two sets of ATKIS road data have been prepared: set A) just contains objects with a correct geometry. For set B) the correct objects have been rotated in order to obtain incorrect geometries. Each sets contains 1851 ATKIS segments.

The *Extracted Road Objects* are obtained by the approach presented in (Gerke et al., 2004). The parameters are trimmed for a very strict road extraction, because the influence from artifically inserted road segments (due to automatic gap bridging) should be very low. Those gaps are often caused by vegetation and the intention of the following experiments is to test if explicitely inserted context objects give adequate evidence. As the road extraction algorithm is not able to reliably extract roads in built-up areas the examples are restricted to open landscape areas. The rows of trees representing a class of *Linear Local Context Objects* are captured manually and the parameters for the rows of trees are uniformly set to $w_O = 1m$, $\Delta_{wO} = 0.2m$, $\Delta_{ppO} = 2m$, $\Delta_{paO} = 3m$, $\sigma_{pO} = 0.6m$, $p_{con} = 1$.

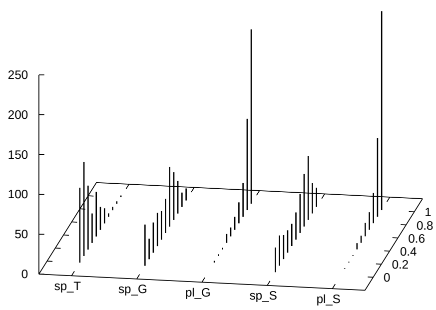
The diagrams in Fig. 3 and 5 show the results in the form of absolute histograms, keeping in account all assessed segments. The five histograms per diagram show from left to right: 1) the support for the ATKIS segments regarding the topologic relation, 2) and 3) the support and the plausibility for the ATKIS segments regarding the geometric



ATKIS: $\Delta_{pA} = 3m, \Delta_{wA} = 3m$, just extracted road objects. 316 ATKIS segments assessed.



ATKIS: $\Delta_{pA} = 3m, \Delta_{wA} = 3m$, extracted road objects and rows of trees. 475 ATKIS segments assessed.



ATKIS: $\Delta_{pA} = 0m, \Delta_{wA} = 0m$, extracted road objects and rows of trees. 446 ATKIS segments assessed.

Figure 3: Results for Correct ATKIS Data

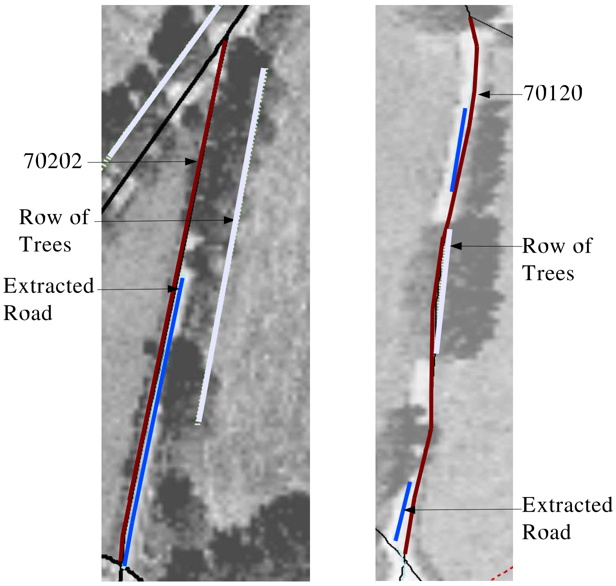


Figure 4: Objects 70202 (left) and 70120 (right), Orthoimage and ATKIS ©Landesvermessungsamt Nordrhein-Westfalen

Exp.	#Seg.	sp_T	sp_G	pl_G	sp_S	pl_S
a)	1	0.52	0.75	0.99	0.88	1.00
	2	0.66	0.71	0.97	0.90	0.99
	3	0.40	0.39	0.99	0.63	1.00
b)	1	0.52	0.75	0.99	0.88	1.00
	2	0.66	0.74	0.98	0.91	0.99
	3	0.48	0.68	0.88	0.82	0.93
c)	1	0.18	0.92	0.99	0.94	0.99
	2	0.07	0.82	0.97	0.83	0.97
	3	0.34	0.73	0.92	0.82	0.95

Table 4: Results for 70202 (consists of 3 Segments)

Exp.	#Seg.	sp_T	sp_G	pl_G	sp_S	pl_S
a)	1	0.57	0.20	0.70	0.59	0.85
	2	—	—	—	—	—
	3	0.52	0.25	0.79	0.60	0.89
	4	0.14	0.17	0.83	0.27	0.85
b)	1	0.58	0.28	0.73	0.64	0.86
	2	0.00	0.39	1.00	0.39	1.00
	3	0.54	0.35	0.81	0.67	0.90
	4	0.17	0.13	0.65	0.24	0.70
c)	1	0.25	0.36	0.79	0.49	0.83
	2	0.00	0.44	1.00	0.44	1.00
	3	0.45	0.35	0.78	0.60	0.86
	4	0.04	0.12	0.74	0.14	0.75

Table 5: Results for 70120 (consists of 4 Segments)

relation and 4) and 5) the outcome from the combination. The plausibility regarding the topologic relation is not defined as $\neg T$ is not supported. On the z-axis the particular number of segments which have reached a certain support or plausibility value (10 bins on y-axis) is displayed. The histogram-based analysis was chosen in order to obtain a first overview on the quality representation. As all observed ATKIS segments are supposed to be correct or incorrect respectively, the histograms represent how good the approach reflects the quality.

Three experiments have been accomplished with the correct data (Fig. 3): a) assessment of ATKIS segments using extracted road objects, b) additional incorporation of rows of trees and c) like b) but with decreased certainty and precision for ATKIS (set to zero). At first glance one might be confused at the low support rates for the segments. This can be explained by the relatively low number of extracted objects: if at all, most ATKIS segments are not completely covered by the extracted objects.

What is more interesting are changes from a) to c). Compared to experiment a) the rows of trees (b) give a lot of support and regarding geometry relations, the plausibility also increases for most segments. The support regarding topology increases mostly in the lower part (0.1 to 0.4) as due to the relatively low certainties of the rows of trees the support for this relation may not be very good in principle. It also corresponds to the model that in most cases the support regarding topology in c) decreases as the quality measures for ATKIS are set very strict[4]. In contrast the support and plausibility regarding geometry just changes marginally compared to b).

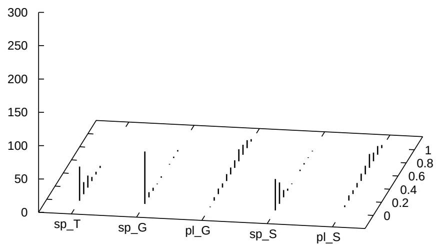
Two examples are chosen to clarify the sketched behavior of the approach. The left image in Fig. 4 shows ATKIS object 70202 being covered to approx. 50% by an extracted road object and another 70% by a row of trees. The right image show ATKIS object 70120 being covered to approx. 20% by extracted road and to another 20% by a row of trees. The detailed assessment results for 70202 are given in Tab. 4, Tab. 5 shows details for 70120. The first example demonstrates very good support for the segments as these are fully covered (compare experiment a) to b)). The support for the geometric relation in experiment c) increases for some segments as the ROI decreases and therefore the rows of trees in the northern part (which are not parallel to the ATKIS segment) are not taken into account. In the second example the support is not very good as the coverage is not sufficient. But the relatively high plausibilities allow the conclusion that the existing extracted objects give not much evidence against the hypothesis that the ATKIS segments coincide well with the model.

The experiments with incorrect ATKIS data (Fig. 5) were conducted to investigate if the approach is able to detect bad quality. Here two experiments have been carried out: a) the extracted correct road objects are used to assess the incorrect data and b) additionally the correct rows of trees are incorporated. An outstanding property of both histograms is that there is nearly no support beyond 0.3 for both relations as well as for the combination. In some cases in experiment (b) the plausibilities are relatively high. Such situations may occur as similar to the support for the hypothesis the support against it is not very high due to the poor coverage.

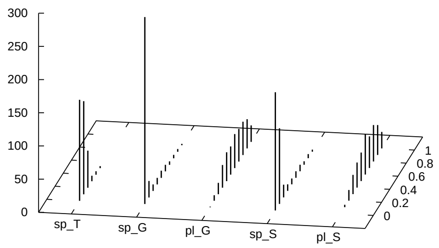
6 CONCLUSIONS AND OUTLOOK

In this paper an approach for quality assessment of ATKIS road vector data is introduced. A relationship model contains the object class to be assessed and the object classes in topologic and geometric relation to it. Besides the relations quality measures are defined having an impact on the subsequent assessment phase. Here extracted objects are assigned to the ATKIS segments according to the modeled topologic relation and the respective given quality measures. Afterwards the existing topologic and geometric

[4] If however the given geometry of an ATKIS segment coincides well with the extracted object, the support from topology increases.



ATKIS: $\Delta_{pA} = 3m, \Delta_{wA} = 3m$, just extracted road objects. 100 ATKIS segments assessed.



ATKIS: $\Delta_{pA} = 3m, \Delta_{wA} = 3m$, extracted road objects and rows of trees. 364 ATKIS segments assessed.

Figure 5: Results for Incorrect ATKIS Data

relations between any ATKIS segment and the assigned objects are assessed. The given evidence is collected and combined using Hint-Theory which is an approach to the Dempster-Shafer Theory of evidence. By this means any ATKIS segment obtains a certain portion of support and plausibility expressing its compliance to the model.

First results show that the quality of ATKIS road vector data is reflected by means of this approach. In further work it will be investigated how a final verification decision (whether an ATKIS object will be accepted or rejected) can be derived from the support and plausibility measures for the segments. It was shown with the examples that for an acceptance both values must exceed a certain threshold, the definition of this threshold is a matter of further research.

Moreover it has to be investigated whether a substitution of the simple equipartitioned statistical model for the analysis of topologic relations by a more individual density function does improve the analysis.

Another potential improvement concerns the global network aspect: the road network is designed to connect important places by an optimal path and every road object gives a certain contribution to this network. In the presented evidential framework this contribution can be judged and considered for the assessment.

Concerning the update of the road network, i.e. the detection of roads not currently contained in the database, it is to investigate to what extent the given approach can be used. For example, it will be possible to formulate hypotheses for new roads based on the accepted network and additional information from other sources or from road extraction algorithms. Such hypotheses may then be judged in a similar way the given road network is assessed.

Last but not least the evaluation of object extraction algorithms is very important. In this paper a formal framework for the assessment of road vector data is given, but the overall result still depends on the quality of input information.

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