Dealing with uncertainty in spatial planning

Wies Vullings, Marian de Vries, Laurent de Borman
Alterra Centrum for Geo-information, OTB TU Delft, Nexpri BV
Wies.vullings@wur.nl , M.E.deVries@tudelft.nl, l.deborman@nexpri.nl

SUMMARY

The Dutch Ministry of Housing, Spatial Planning and the Environment aims to have digital, exchangeable and comparable spatial plans. The new spatial planning law compels the use and development of digital and exchangeable plans. However, first experiences show that the "comparable" part is not so easy to achieve. Uncertainty is an important factor that hinders the comparability of spatial plans. This paper describes a framework (under construction) that deals with uncertainty in spatial planning and that aims to improve transparency of spatial planning processes. Based on the taxonomy for uncertainty of Fisher (2005) a taxonomy of uncertainty for spatial planning is been developed. In this taxonomy the sources of uncertainty in plans, processes and procedures and their possible solutions are visualized. At the moment the solutions are subject of research. This paper describes the plans for research of two possible solutions: lineage and fuzzy set theory.
At the end of 2007 the framework of uncertainty in spatial planning with the taxonomy and the solutions as the core will be finalized. Before that the framework will be tested in two case studies.

INTRODUCTION

In the Netherlands space is a valuable asset. Spatial planning is complex and forms a dynamic process. Various parties make spatial plans from different spatial perspectives (local, regional, national). The Dutch Ministry of Housing, Spatial Planning and the Environment promotes digitizing of spatial plans into geographic datasets (DURP initiative). Aim is to have spatial plans that are "digital, exchangeable and comparable". This means that plans should be object-oriented and coded according to the national information model for spatial planning (IMRO). Many municipalities and provinces are working hard to achieve this. The general idea is that when plans are digitized and exchangeable, comparing of spatial plans will not be a problem. This would also give better possibilities for analysis, e.g. for monitoring the effectiveness of spatial planning policies by comparing the plans with real-world developments in land use.

First experiences however show that comparing and analyzing digital spatial plans is not as unproblematic as expected. This has to do with differences in scope and intention (some plans only give global indications of desired future land use, while e.g. municipal plans must be very detailed and precise), differences in scale (related to the reference datasets used for digitizing), and with other typical aspects of data quality and uncertainty: errors in the base datasets, semantic ambiguity, unknown lineage, unknown temporal accuracy, etc. In a case study in the province of Noord-Brabant also other sources of uncertainty came to light: the political process can lead to unclear definitions or last-minute changes that are not documented.

The objective of this project (GeO3) is to study various characteristics of uncertainty in spatial planning, to define them and to suggest solutions to deal with them. The GeO3 project aims to deliver a framework for dealing with uncertainty in spatial planning that will help to improve transparency of spatial planning processes. The GeO3 project started in 2005 and will run till the end of 2007. It is carried out by a consortium of the following parties: Alterra, TU Delft, Ministry of Housing, Spatial Planning and the Environment, Ministry of Agriculture, Nexpri, Nirov, Sense, Esri NL, TDKadaster and Geonovum. The project is part of the subsidy program Space for Geo-Information.

SPATIAL PLANNING IN THE NETHERLANDS

New Dutch spatial planning law

In the Netherlands a new spatial planning law will be enforced in 2007. The old one dates back to 1965 and a new law was very necessary. This new law aims to improve efficiency and effectiveness of evaluation and monitoring of spatial policy. The three main changing points are:

- Less rules: easier and shorter procedures in order to reduce administrative duties;
- Decentralize: position responsibility at the right governmental level;
- Focus on performance of policy: Less focus on development of new policies and more on the performance of existing policies (VROMa, 2006).

The new law also reorganizes the various types of plans. A few types of plans do not exist anymore and objectives of the still existing plans are made more clear. Also the procedures to carry over policies from the national government to the regional and local government are strongly simplified. Another change is that the new law compels the use and development of digital plans. Digital means in this context, object-oriented and coded according to the information model of spatial planning (IMRO). Digital plans are seen as a means to improve effectiveness and efficiency of spatial planning and to improve communication about spatial planning between government and civilians (VROMb, 2006). This new law is the main motive behind the research into uncertainty in spatial planning. Uncertainty will limit the use of digital plans if it is not dealt with in the right way.

Plans, processes and procedures

To come to a better understanding of uncertainty within spatial planning it is important to know more about the development of plans. In principle the three main concepts plans, processes and procedures are important. For producing a plan spatial planning processes take place and these end in legal procedures. These three concepts can be defined as follows:

- A plan is an established visualization with a status that can vary. It is built up from concrete and global objects (polygons, text and characteristics).
- A process is the gathering of information in preparation of a (political) choice.
- A procedure entails the making of (political) choices. A procedure generates plans.

A plan consists of planning objects and with planning object we mean a policy object that is visualized on a map. It has a geographical location (dimension, shape, position) and descriptive characteristics (thematic attributes and policy measures and regulations). Uncertainty generally becomes visible when planning objects on different spatial plans are being compared. For that reason we concentrate on planning objects in this project. The project “Generalization of Base Maps” (another Space for Geo-Information project) investigates more in general how base maps of different scales can be made more consistent with each other (Poppe et al, 2006).

Different types of planning object

There is a broad range in scope and intention of spatial plans: from national, to provincial to local plans, and from legally binding to indicative (also see Navratil, 2006). There is also a whole spectrum of planning objects: from planning objects that are meant to coincide with parcels and buildings, to very global indications of future functions of complete regions.

For the time being we distinguish between two types of spatial plans, based on the intention (the purpose) of the plan: strategic and operational plans. At the same time we can group the planning objects according to the type of phenomenon (entity) they represent: ‘discrete’ versus ‘continuous’ phenomena. When we combine these two criteria this leads to the following subdivision:

- Strategic plans, where the content is not very detailed yet: with vague boundaries and maybe also vague classification. In our uncertainty taxonomy (see Figure 2) this leads to ‘Incompletely defined’ planning objects. Especially the location and probably also the classification is not established yet, and can therefore be not crisp.
- Operational plans that have effect for building and economic activity permits and that primarily deal with phenomena that are in principle 'discrete', with well-established (well-defined) boundaries: parcels, buildings, roads. The information has to be detailed and well defined, and the boundaries must be crisp.
- Operational plans that have to deal with continuous phenomena like noise, emission of pollution from chemical plants: here the information has to be detailed and well defined, but the boundaries cannot be crisp.

TAXONOMY OF UNCERTAINTY IN SPATIAL PLANNING

Uncertainty

For uncertainty related to geo-information many definitions exist. Leyk et al (2005) give a very useful overview of issues and definitions and point at the definition proposed by Fisher (2003) who describes uncertainty as: doubt about the information that is recorded at a location. Zhang and Goodchild (2002) define uncertainty as a measure of the difference between the data and the meaning attached to the data by the current user. According to Fisher (1999) and Atkinson and Foody (2002) it can be seen as a result of error, ambiguity, vagueness or lack of information and forms an umbrella term for these concepts.

In the GeO3 project we use the following definition: uncertainty is the acknowledgement that one does not know the situation of a system exactly because of imperfect or incomplete information. Hereby we assume that it is not the system or object that is uncertain, but we are uncertain about the system. Or, we do not know enough of the system to be able to deal with it properly. The way to deal with uncertainty is to gather more information about the system and about its context. The more is know about the context the more information is available implicitly about the system.

Taxonomies

A number of taxonomies exist that position various types of uncertainty in a unified framework. These taxonomies all assume that uncertainty results from the difference between objects in an information system and the real object. The taxonomy of Hong Shu et al. (2003) is based on a system containing three entities: Human, Computing Machine and Earth. The nature of the uncertainty in geo-information is related tot the uncertainty of the three entities and the interaction between those entities. The uncertainty decreases if the interaction and correlation between entities increases. Fisher et al. (2005) have proposed a taxonomy (based on Fisher (1999) and Klir and Yuan (1995)) where different types of uncertainty are related to how well the geographic objects are defined (Figure 1).

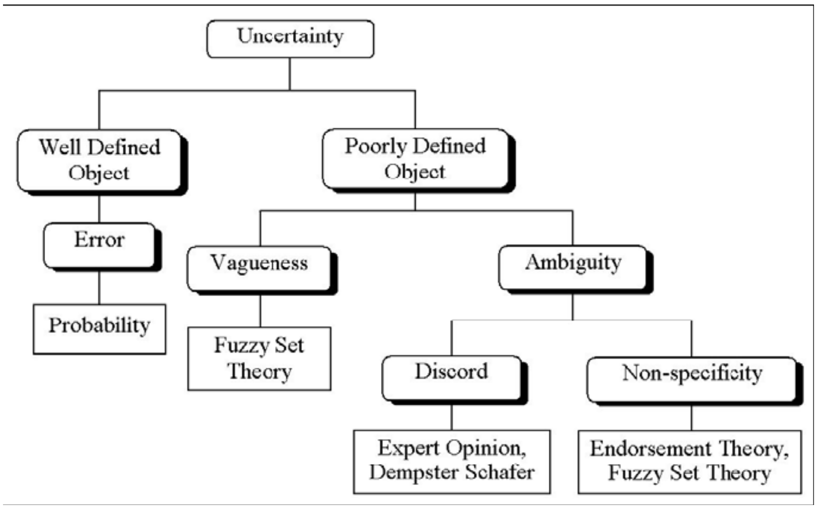

Figure 1: A conceptual model of uncertainty in spatial data (from Fisher et al., 2005).

We used the taxonomy of uncertainty of Fisher et al. as starting point, and extended it to fit the Dutch spatial planning domain. In our taxonomy of uncertainty (see Figure 2) we introduced the concepts ‘plan’, ‘process’ and ‘procedure’, but we maintained the vertical division into nature, sources of uncertainty and possible solutions that is also visible in the taxonomy of Fisher.

In the next section we will discuss two of these possible solutions to deal with uncertainty in spatial planning. The first is: having good quality metadata about the lineage of planning objects. With lineage metadata the sources of error, but also other kinds of uncertainty can be made explicit. The second approach we will shortly discuss is: using fuzzy set techniques to deal with two types of 'Incompletely defined objects': strategic planning objects that have not been given detailed boundaries yet, and, secondly, planning objects that are based on continuous phenomena like noise, emission of pollution from chemical plants, etc

DEALING WITH UNCERTAINTY IN SPATIAL PLANS

Lineage metadata

What is 'error' in the case of spatial planning? Errors in spatial plans can be introduced during the data collection and processing phase, either because the input data sets have errors or because not the right (in the sense of fitness-for-use) data sets have been used as reference layer, for example: the scale of the input data sets does not match the purpose of the spatial plan; there is temporal inaccuracy in the input datasets (outdated topographic or vegetation maps are used for the planning of a water overflow basin); or the classification schemas used in the input data sets are not known, and must be guessed at, or are ambiguous, with unclear definitions or not mutually exclusive categories.

The data collection and processing history of the spatial plan should therefore be recorded in enough detail, so that in case of court cases or other problems the quality of the spatial plan can be checked. Because of the error propagation aspect (from input data sets to spatial plan) and because the input data sets themselves also have their own lineage, this will be a 'chain' or 'network' of lineage information elements that link to each other.

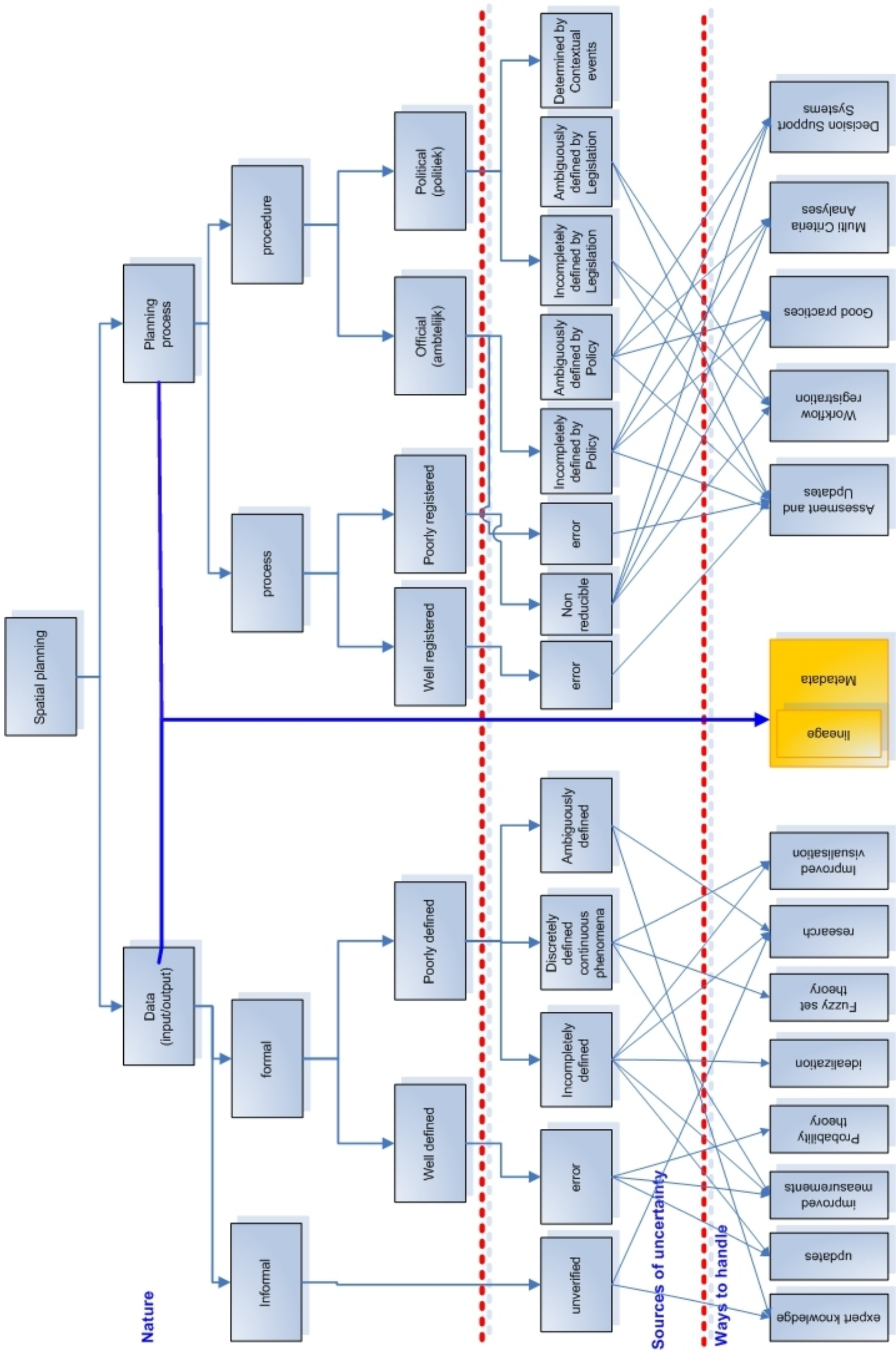

Figure 2: A taxonomy of uncertainty in spatial planning.

In the international standards (e.g. ISO 19113 and 19115) lineage is part of the metadata. Unfortunately this is always seen as a 'free text description', which makes it difficult to automate the process of building the lineage metadata 'stack'. Questions here are:

- How can we automate the collection of lineage metadata? And how can we build the lineage ‘stack’ during the complete process from input data sets to spatial plan (c.f. Bose (2005) for an overview of issues and possibilities).

- At what granularity level do we want to store this lineage metadata: sometimes it is enough to do this at data set level (if only one reference layer is used for digitizing the spatial plan). But as we found out in the Noord-Brabant case study: when 3 or more data sets are used as input, data set level metadata does not suffice: ideally then each planning object instance should contain lineage info: the object-id, timestamp and feature name and origin of the objects it is based on.

At the moment we are looking at ways to integrate the collection and maintenance of the lineage metadata with the actual GIS processing steps from input data to spatial plan, in combination with ModelBuilder (ESRI) or another process workflow tool.

Fuzzify vague planning objects

In a Boolean set an object or location either belongs to a class or it does not belong to that class. In a fuzzy set the degree of belonging can very between 0 (no member) and 1 (completely in that set) and is expressed by a real number in the range [0,1] (Zadeh, 1965). Fuzzy-set techniques are used in GIS and remote sensing in cases where the boundaries between classes are not sharp (crisp) but vague, e.g. the boundary between woodland and pasture, or between 'dense' forest and 'more open' forest. The question is whether fuzzy-set techniques can also be useful for dealing with vagueness in spatial planning. We will give two examples.

Compared to uncertainty in other kinds of geo-information there is in spatial planning a high incidence of 'Incompletely defined’ objects, especially in the case of strategic plans, where the details (the exact location and boundaries and/or the precise land-use classification and policy) is not yet known or not yet relevant. Of course cartographic symbols can be used to denote the indicative nature of these planning objects. An example is in Figure 3, where arrows are used to very roughly indicate spatial policy.

Figure 3: Incompletely defined planning objects.

We could create fuzzy polygons in a case like this. And although it appears contra-intuitive, we could even fuzzify the arrows and treat them as polygons: we give the area on the edge of the arrows a lower membership (in the planning object that is represented by the arrow), than the center-part of the arrows.

Also for another category of planning objects a fuzzy-set approach can be very useful: planning objects that are linked to continuous (natural) phenomena, like noise pollution, see Figure 4. The bold (red) curve shows the noise intensity. The lighter (blue) curves are different functions for noise pollution (hinder). Instead of one or two zones with sharp boundaries, a fuzzy set approach would be more realistic. Depending on the calculated membership of locations in the noise zone around the wind turbine (also depending on predominant wind direction etc.), the subsidy to be paid to house owners to make their house "noise-proof" could be calculated in a more adequate way. In this case 'continuous' plan objects can lead to more fine-tuned, 'continuous' policy.

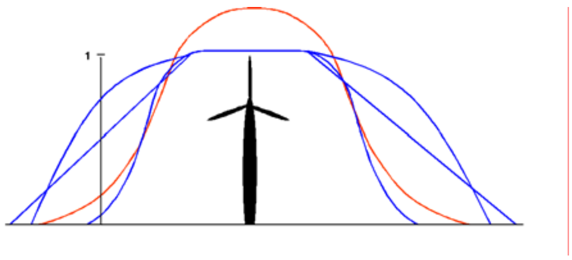

Figure 4: Fuzzy membership of locations in noise zone around wind turbine.

These two examples show how a fuzzy set approach can help to deal with uncertainty in spatial planning. ‘Incompletely defined’ and ‘continuous’ vague objects can now still be used in GIS analysis, where locations with a low membership in the planning zone are treated differently from locations in the core.

Finding the best fitting membership function for each type of planning object is a challenge, also involving expert knowledge. The form of the membership function differs from case to case (gradual diminishing membership or more abrupt, skewed or symmetrical) and depends on the type of phenomenon and planning object. This will be part of the further research carried out this year.

FURTHER RESEARCH

In the previous chapter two solutions, fuzzy set theory and lineage were briefly discussed. These two solutions are an example of dealing with uncertainty, because they generate more information on the object or the context. They will be subject of further research in 2007. The other 12 possible solutions can be divided into two groups. A group that requires more research: probability theory, idealization, improved visualization, workflow registration, Multi-criteria analysis; and a group for which a brief exploration suffices: expert knowledge, updates, improved measurements, research, assessment & updates, good practices, decision support systems. In the first category the solution ‘workflow registration’ has already been tested during a case study. In this study ModelBuilder (ArcGIS) was used to model a complex spatial planning process (in Dutch: “Integrale zonering” of rural areas in the province of Noord-Brabant). This model simplifies reruns with alternative sources and settings, and for that reason it will also be used to try out analysis based on probability theory (Monte Carlo simulation) and Multi-criteria analysis. With the solution ‘improved visualization’ we like to deal with the visualization of fuzzy objects and cartographic objects like arrows, area hatching and point symbols. As input for several of these solutions we will provide a list of the various kinds of planning objects that exist and establish their default values for membership function and (maybe) their semantic distance to other planning objects and base map objects (idealization).

The GeO3 project aims to deliver a framework for dealing with uncertainty in spatial planning at the end of 2007 and the taxonomy with its solutions will form the core of this framework. During 2007 the framework will be tested in two case studies.

BIBLIOGRAPHY

Atkinson, P.M. and Foody, G.M. (2002). Uncertainty in remote sensing and GIS: fundamentals. In Foody G M and Atkinson P M (eds) Uncertainty in Remote Sensing and GIS. New York, John Wiley and Sons: 287–302

Bose, R. and J. Frew (2005). "Lineage retrieval for scientific data processing: a survey." ACM Computing Surveys 37 (1): 1-28.

Fisher, P.F. (1999). Models of Uncertainty in Spatial Data. In Geographical Information Systems: Principles, Techniques, Management and applications, edited by P.Longley, M.Goodchild, D.Maguire, and D.Rhind (Wiley and Sons, New York) vol 1, pp 191-205.

Fisher, P. (2003). Data quality and uncertainty: Ships passing in the night! In Shi W, Goodchild M F, and Fisher P (eds) Proceedings of the Second International Symposium on Spatial Data Quality. Hong Kong, Hong Kong Polytechnic University: 17–22

Fisher, P., A. Comber and R. Wadsworth (2005). Approaches to Uncertainty in Spatial Data. Pp. 9-64 in Qualité de l'information géographique, (eds. Rodolphe Devillers and Robert Jeansoulin), IGAT, Hermes, France

ISO (2002). ISO 19113 - Quality Principles, TC211-Geographic Information.

ISO (2006). ISO 19115 - Metadata, TC211-Geographic Information.

Klir, G.J. and B.Yuan (1995). *Fuzzy Sets and Fuzzy Logic: Theory and Applications.* Prentice Hall, Englewood Cliffs

Leyk, Stefan, Ruedi Boesch and Robert Weibel (2005). A Conceptual Framework for Uncertainty Investigation in Map-based Land Cover Change Modelling Transactions in GIS 9 (3), 291–322.

Navratil, G. (2006). Data Quality for Spatial Planning - An Ontological View. CORP 2006 - 11th International Conference on Urban Planning and Spatial Development for the Information Society, Vienna, Austria.

Poppe, E. L., C. P. J. M. van Elzakker & J. E. Stoter (2006), Towards a method for automated task-driven generalization of base maps. In: E. Fendel en M. Rumor (eds.), Proceedings of the 25th Urban Data Management Symposium (UDMS 2006), Ålborg, Denemarken, 15 - 17 mei 2006, pp. 3.51 - 3.64.

Shu, H., S. Spaccapietra, et al. (2003). Uncertainty of Geographic Information and Its Support in MADS. Proceedings of the 2nd International Symposium on Spatial Data Quality, Hong Kong, China.

VROMa. 2006. De nieuwe wet ruimtelijke ordening: Ruimte geven voor ontwikkeling. Leaflet Ministry of Housing, Spatial Planning and the Environment.

VROMb. 2006. Digitale plannen verplicht met nieuwe wet ruimtelijke ordening. Leaflet. Ministry of Housing, Spatial Planning and the Environment.

Zadeh, L. A. (1965). "Fuzzy sets." Information and Control 8(3): 338-353

Zhang, J. and M.F. Goodchild (2002). Uncertainty in Geographical Information. London, Taylor and Francis.