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Assessing the spatial data quality of farmer’s field geometry for use in the BGT key register for large scale topography

Robbert-Jan Geldhof

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Author: Robbert-Jan Geldhof, BSc.
Supervisor: Dr. Ir. Sytze de Bruin
Reviewer: Ir. Edward Verbree
Professor: Prof. Dr. Ir. Arnold Bregt

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ABSTRACT

In the Hoeksche Waard, the Netherlands, farmers capture geometry of crop fields in order to optimize vehicle paths for farming operations. It is investigated to what extent these farmers' data can be used as source data in the Key Register for Large Scale Topography (BGT), a component of the Dutch national spatial data infrastructure (SDI). The use of farmers' data for this purpose can be seen as an example of volunteered geographic information (VGI). There is an ongoing debate as to the quality of VGI, particularly in relation to SDI.

There are different elements of spatial data quality, which were combined to come to an integrated assessment of the fitness of the farmers' data for use in the BGT using a weighted sum model. The elementary scores and weights used in this model were obtained by empirical research. The empirical research consisted of two types of field work and an interview of two experts who are employed by an SDI stakeholder that is responsible for assembling the BGT for agricultural areas. The first field work involved the observation of a positional data acquisition process by farmers and the second fieldwork concerned the acquisition of positional reference data. The aim of the interview was to obtain the weights in the weighted sum model.

It was found that farmers' data meet the BGT requirements for currency and positional accuracy, but not for semantic quality. Furthermore it was found that farmers' data are too incomplete to be used as source data in the BGT assembly, but that they can be used to report back topographic changes. To improve the fitness for use, the semantic quality of farmers' data should be improved.

PREFACE

In this preface I would like to take the opportunity to share some personal motivations and experiences. First of all, the topic of this thesis is quality of geographic data. My interest in this topic was first sparked during the work I did for the municipality of Nederlek. I noticed how data quality was often ignored – also by myself – and how this affected policy. First I was surprised, but later shocked by the fact that erroneous data could lead (and, unfortunately, have led) to wasteful spending of public means.

It was, however, not until a lecture by Pepijn van Oort in Utrecht that I realized that geographic data quality is a field of study in its own right within geo-information sciences. It was then that I realized I would like to somehow incorporate data quality into my thesis. When an opportunity for a thesis about data quality in the BGT presented itself, I made the decision. The BGT was not new to me, as it was also the subject of my Bachelors' thesis. Data quality, however, provided a whole new dimension to an already familiar research subject.

I can honestly say that it has been very challenging. I had to familiarize myself with new concepts and methods and the learning curve has been steep. Data quality plays no prominent role in the GIMA curriculum, and I could not rely on experience either. However, my personal interest and the conviction that the topic is of great importance to professional practice have maintained my motivation throughout the project.

Lastly, I would like to take this opportunity to express my thanks to people whose contribution and support have been invaluable. First I want to thank all members of the GAOS community who have supported me throughout the project. Most notably I want to thank Peter Lerink and Aad Klompe for their inspiring enthusiasm and valuable feedback and support. I also express my thanks to Mark Gooskens and Marc Middendorp of RVO for the interview, and to Viana Asha Achthoven of WSHD. I am particularly grateful to Philip Wenting for accompanying me on the very instructive fieldwork. Lastly, I wish to express my thanks to Arnold Bregt and Edward Verbree for reviewing the thesis. But I am most grateful to Sytze de Bruin, my supervisor, who I wish to thank for his patience with my learning curve, and for his invaluable insights and contributions throughout the project.

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1 INTRODUCTION

Geographic information is becoming increasingly important in broad sections of society – in the Netherlands and elsewhere. Agriculture is no exception to this development. The use of geographic information and associated technologies for adjustment of farming practices to local circumstances is known as precision farming, and encompasses the use of observation, measurement and imaging technology to improve crop performance and environmental quality (Pierce & Nowak, 1999; Oliver, 2010). Example applications of precision farming are GNSS tracking of farm vehicles, crop monitoring and path optimization (Stafford, 2013). An example of precision farming in the Netherlands can be found in the Hoeksche Waard, south of Rotterdam (Figure 1). The Hoeksche Waard is part of the Rhine-Scheldt delta and is surrounded on all sides by water. The area is a rural area where crop farming is the dominant land use. It is in this area where farmers have enthusiastically embraced geographic information as a means to preserve the land-based agriculture and economic vitality. They do so under the umbrella of the *H-Wodka* foundation, an organization founded by farmers in the Hoeksche Waard to promote the use of geographic information technology.

From the aforementioned examples of precision farming, path optimization, among others, is applied in the Hoeksche Waard. In cooperation with Wageningen University and Research (WUR) *H-Wodka* has developed GAOS for vehicle path optimization. GAOS is a GIS and stands for Geo-Field Optimization Service (translated from Dutch). By using GAOS, farmers optimize the paths their vehicles use on the field and thus minimize the costs associated with using the vehicles and at the same time maximize the use the arable land (De Bruin et al., 2009). GAOS requires accurate geometry of farmers' fields. Prior research in the Hoeksche Waard has shown that field geometry requires cm-level accuracy to be of use for vehicle path optimization (De Bruin, Heuvelink, & Brown, 2008). As data of this quality is not available (freely or commercially), farmers use RTK-GNSS to capture the data themselves. The costs of capturing these data do not outweigh the benefits of the path optimization (De Bruin, Heuvelink, & Brown, 2008). As of September 2013, the database of farmers' fields contained 385 objects, covering 4.035 out of the roughly 20.000 hectares of cropland in the Hoeksche Waard. The question soon arose if farmers' data could be used for other purposes than path optimization in GAOS.

Figure 1: The Hoeksche Waard in the Netherlands

Although one can think of various purposes for accurate field geometry – especially in the sphere of precision farming – this research focuses on a different application. The question arose if the farmers' data could be used in the Key Register for Large

Scale Topography, or BGT[1] in Dutch. The BGT is part of the Dutch national spatial data infrastructure (SDI). This SDI contains "core" data sets of geographic information including large scale topography: the BGT. The BGT is currently being assembled and is planned to be finished by 2016. It is essentially a detailed topographic map of the whole of the Netherlands, which is of uniform quality and which will be the default large scale basemap for visualization and spatial analysis for all government organizations.

"Using" farmers' data in the BGT is easier said than done. There are obstacles in a wide range of research domains. Therefore it is necessary to define the research scope. To do this, the research context is explored and some key themes that underpin the research are introduced.

1.1 Spatial data infrastructure

To understand the potential of farmers' data in the BGT it has to be understood what constitutes a key register. This introduces the concept of spatial data infrastructure, or SDI. SDI has received much attention in both research and practice the past decade and is therefore a pervasive research topic in geo-information science. One often used definition of SDI is the definition by Rajabifard and colleagues (2002). They define SDI as an enabling platform by means of which people connect to data in the broadest sense of the word. This "enabling platform" is a dynamic environment which, in addition to people and data, consists of three components: an access network, policies and standards (Figure 2). The "enabling platform" is in fact an institutional framework which facilitates the distribution of large quantities of data to a large number of users, in an organized manner (Van Loenen & Van Rij, 2008). An access network, like a geo-portal, facilitates physical data-exchange between data users and producers. Standards ensure that this exchange process is streamlined and unhindered by incompatibility of systems and services. Policies, finally, are of conditional importance for political, organizational, legal and financial matters, as well as technical matters.

The component of SDI which is most interesting in this research however is not the institutional framework but rather the data themselves. Large scale topography is one of the "building blocks" of the Dutch national SDI. It constitutes the system of key registers along with five other geographical key registers. The government considers these data sets to be of national importance and are vital to many government operations. The data sets are linked to each other and to other, non-geographical data sets like the trade register, vehicle register and register of natural persons.

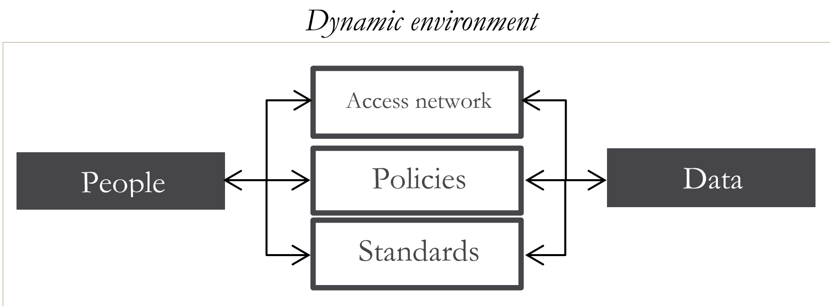

Figure 2: SDI as an enabling platform between people and data (Rajabifard, Feeney, & Williamson, 2002)

[1] Dutch: *Basisregistratie Grootschalige Topografie*

1.2 Custodianship and Volunteered Geographic Information

The building blocks of data that constitute the Dutch national SDI, be they geographic in nature or not, are captured, stored, processed and used by one or more bodies of government. The Chamber of Commerce for example is responsible for the trade register, and the Dutch Cadastre for the small scale topography and cadastral key registers. "Responsible" in this sense means that the respective organization is obliged to capture the data of the key register and make sure it conforms to the quality requirements set by the legislator. This responsibility is legally defined in the role of custodian (e-Overheid, 2014). Other roles are the registration keeper, provider and client (Table 1).

Table 1: Roles in the System of Key Registers and in the present case the BGT (e-Overheid, 2014)

Role	Description	BGT
Registration keeper	The final, political responsibility lies with the registration keeper.	Ministry of Infrastructure and the Environment (I&M).
Provider	The executive organization tasked with collecting, storing and disseminating the data in the key register.	Dutch Cadastre
Custodian	Responsible for capturing and supplying data to the key register and keeping it up to date and conforming to quality requirements.	Municipalities, provinces, water boards, the Rail Authority and the three Ministries of I&M, Defence and Economic Affairs.
Client	Clients are public and private organizations that are principal users of the key register. All public organizations are legally obliged to do so.	All private and public organizations with an interest in large scale topography

1.2.1 Custodianship in the BGT

In the case of the BGT key register the custodianship is complex as there are many different custodians. Custodianship in the case of the BGT generally corresponds with the responsibility of the custodian as manager of infrastructure and public space. The Ministry of I&M, for example, is responsible for the BGT pertaining to national infrastructure, the Rail Authority to railways and the municipalities to built-up space in general. The BGT, therefore, is in fact a patchwork of partitions of different custodians patched together to form a nationwide coverage. The most extensive "patch", comprising 45% of the nation's surface, is that of *Rijksdienst voor Ondernemend Nederland* (RVO), an executive branch of the Ministry of Economic Affairs (Huis & Van der Wal, 2013). RVO is the organization which handles the distribution of agro-subsidies under the EU's Common Agricultural Policy (CAP) in the Netherlands. For this purpose RVO keeps two spatial databases pertaining to agricultural areas (RVO, 2014):

- The Key Register Crop Parcels (BRP): This database contains crop parcels. Crop parcels are fields owned by one farmer, that have one ownership status (ownership, rent, etc.), and are used for the cultivation of a single crop. Every year, farmers declare their crop parcels by drawing them in a web interface, thereby applying for agro-subsidies. Also farmers may submit GNSS-data instead of drawing the parcels in the interface.

- The Agricultural Area Netherlands (AAN): This database is a topographic database, containing so called topographic parcels. Topographic parcels are the topographic reference for crop parcels. A topographic parcel is an uninterrupted plot of land used for the purpose of agriculture, and is typically limited by hard topographic boundaries like roads or ditches. A topographic parcel may contain multiple crop parcels, but a crop parcel may not exist outside a topographic parcel. The reference layer for topographic parcels comprises orthophotos with a resolution of 25cm. One-third of AAN is updated yearly (Huis & Van der Wal, 2013).

The legislator tasked RVO with the custodianship of the agricultural areas, with the aim of eventually replacing the AAN register with the BGT as the topographic reference layer for crop parcels. Therefore RVO's obligations and work processes under the CAP policy provide an important context for the BGT.

The legal obligations of RVO under the CAP are typical for the institutional role of the custodian as data-provider. It fits the "traditional" concept of SDI-data being produced and provided by expert organizations, to be used by other expert organizations (Budhathoki, Bruce, & Nedovic-Budic, 2008). According to Budhathoki and colleagues this model of user-producer relations underutilizes SDI potential. They argue that many potential users and producers of SDI data are excluded because they are not expert organizations. This is problematic because non-experts can also contribute geographic information, which is called volunteered geographic information (VGI).

1.2.2 Volunteered Geographic Information

VGI is a source of citizen-generated geographic information. The phenomenon has led to initiatives such as Wikimapia and OpenStreetMap, where large numbers of amateur enthusiast contribute spatial data. Developments like Web 2.0 and mobile devices have made capturing and disseminating spatial data much more accessible, and turn every person into a potential "citizen-sensor" (Mooney & Corcoran, 2011).

Elwood and colleagues (2012) state that VGI can have a profound impact on SDI because it can overcome constraints that are traditionally associated with SDI: the reliance on remote sensing and the inflexibility in keeping data sets up to date. Essentially VGI breaks with the hegemony surveyors and cartographers had before the rise of "*neogeography*" (Goodchild, 2009; Goodchild, 2008). Based on this Elwood and colleagues suggest that VGI can complement or provide an alternative to "traditionally authoritative forms of geographic information and extend earlier modes of information production in novel ways" (Elwood, Goodchild, & Sui, 2012, p. 578). To fully accommodate VGI in SDI it is however necessary to reconceptualise the nature of the user. As was observed earlier, the traditional model of user-producer relations in SDI is based on professional organizations where one organization delivers to another organization. Budhathoki and colleagues (2008) therefore suggest to include individual, amateur users and producers of VGI into the SDI model. They also argue that, in the VGI paradigm, there is no real distinction between users and producers anymore because the environment has become much more dynamic and the lines between users and producers of spatial data have become blurred (Budhathoki, Bruce, & Nedovic-Budic, 2008). However, despite the profound impact VGI could potentially have on SDI, it is unlikely that VGI can satisfy the needs of professional, organizational users of SDI data in terms of spatial data quality. The quality of VGI is disputed because it is not usually subjected to procedures for data acquisition and quality assessment (Elwood, Goodchild, & Sui, 2012). Furthermore, research suggests that VGI data have very inconsistent quality patterns (Haklay, 2010). Additionally, the quality is often simply not known because systems of quality assurance and metadata are generally absent in VGI (Goodchild & Li, 2012). In the context of SDI spatial data quality is a particularly important topic because SDI data sets are often "core" data sets that comprise an organization's, or even nation's "digital geographic infrastructure", as is the case of the BGT (Van Loenen & Van Rij, 2008). SDI data sets often form the basis on which many other data sets or applications are built. It is therefore necessary that a certain level of quality is maintained, monitored and assured. Not only from a functional perspective, but from a legal perspective as well, because often a certain degree of liability is associated with organizations that are actors in the SDI (Janssen, 2008). Custodians of the BGT for example are legally obliged to provide data to the BGT, in conformance to the legislator's quality requirements.

Thus it is now established that the roles of producers and users of data in SDI are on the one hand fixed in an institutional framework, like the custodians of the BGT, but on the other hand there is an ongoing trend of citizen-based geographic information that SDIs cannot permit to ignore. An important obstacle however lies with spatial data quality, a topic which requires further exploration.

1.3 Fundamentals of spatial data quality

1.3.1 Error and quality in spatial data

Spatial data are a model of reality, which, in principle, means a generalized representation of the real world. Generalization means that information is consciously simplified, eliminated or in another way manipulated (Devillers & Jeansoulin, 2010). There are many factors that influence this generalization process, human, technical or environmental, which can cause error in spatial data (Devillers & Jeansoulin, 2010). Errors can arise from different sources, in different stages of capturing, processing and using data, as listed in Table 2.

Table 2: Types of error originating from different stages in data handling (Devillers & Jeansoulin, 2010)

Stage of data handling	Examples of errors
Data collection	Faulty equipment, inaccurate measurements, incorrect recording procedures
Data input	Digitizing error, interpretation of fuzzy objects
Data storage	Numerical precision, redundant data
Data manipulation	Wrong class intervals, error propagation in overlay analysis
Data output	Scaling, inaccurate output device
Data usage	Misuse or misunderstanding of the data

It is evident that errors in spatial data are undesirable because it affects usability. Error is addressed by describing spatial data quality using different quality indicators. However, spatial data quality also addresses issues that do not specifically relate to error, like the credibility of the data provider (Devillers & Jeansoulin, 2010).

1.3.2 Internal and external quality of spatial data

It is generally agreed that there are two approaches to determining the quality of spatial data. The first approach is to compare the "ideal" data specifications, as intended by the producer, to the data actually produced. This is the so called internal spatial data quality. Internal quality is often defined in data specifications, a set of requirements formulated by the data producers to which the data must conform. If data conform to all these specifications they are called "nominal ground" (Devillers & Jeansoulin, 2010). What is essential in the definition of internal quality is that the requirements are set by the producers. In the second approach the requirements are set by the users. The second approach is about assessing the fitness for use of the data for a given purpose. This is called the external spatial data quality, also called fitness for use (Devillers & Jeansoulin, 2010).

Given a certain use, the external quality of spatial data might be better for one user and less for another. With the rise of VGI, and the increasing availability of spatial data to a larger group of users, fitness for use assessments are becoming more important (Ivánová et al., 2013). Indeed, this research also comprises a fitness for use assessment. Specifically an assessment of the fitness of farmers' data to be used in the BGT key register, taking into account the aspects of SDI and VGI that were identified in this chapter.

1.4 Research questions and report structure

Now that the scope and context of the research have been described, research questions can be formulated. The main research question is: **To what extent are farmers' data fit for use in the BGT key register from a spatial data quality point of view?**

Four sub-questions support the main question:

- Q1. What is the acquisition process of farmer's data?
- Q2. What is the data quality of farmer's data?
- Q3. To what extent does farmer's data meet requirements to be used in the BGT?
- Q4. How can farmers align the data acquisition process to better meet BGT quality requirements, taking into account incentives for farmers to do so?

This chapter has introduced the key concepts that underpin the research. It was established that a fitness for use assessment is required to evaluate the possibilities of farmers' data being used in the BGT. In the next chapter the theoretic framework of quality indicators for this assessment is presented. In chapter 3 the methodology of the research is explained, followed by an overview and explanation of the results in chapter 4. These results are discussed in chapter 5, after which in chapter 6 the research is concluded by answering the research questions.

2 THEORETICAL FRAMEWORK

To assess the fitness for use of farmers' data in the BGT a set of quality indicators is required. The starting point in establishing this set should be the internal quality requirements of the BGT, as laid down by the legislator, because these requirements would eventually apply to farmers' data if they are used in the BGT.

2.1 SPATIAL DATA QUALITY IN THE BGT

2.1.1 THE NORM QUALITY

Spatial data quality in the BGT is described by the Ministry of I&M, the registration keeper, in the information catalogue. In addition to quality requirements, the catalogue describes the purpose of the BGT, the design principles, information model, and more. The indicators of spatial data quality in the BGT are summarized in Table 3. The quality as defined in the catalogue is the standard, or norm, to which all BGT data must eventually conform. The legislator anticipated, however, that there should be a period of transition during which the BGT is assembled. It is relevant to review how spatial data quality is applied during this assembly phase, as it entails the selection of source data sets that will constitute the BGT.

Table 3: Description of the indicators for the internal norm quality in the BGT (Ministry of Infrastructure and the Environment, 2013)

Quality indicator	Description
Currency	Currency describes how up-to-date the data are. It is defined as "the extent to which data are consistent with reality within a defined time internal" (Ministry of Infrastructure and the Environment, 2013, p. 23). In the BGT, the currency is defined at the object class level. So different object classes have different currency requirements.
Positional accuracy	Positional accuracy is the accuracy of coordinates. In the BGT, accuracy is the precision of coordinates expressed in the relative, or internal positional accuracy. The positional accuracy is defined at the object class level. A value for accuracy is stored in the attributes of some BGT objects.
Completeness	The BGT defines completeness as the extent to which objects that are to be represented in the data are also actually in the data.
Logical consistency	Logical consistency refers to the topology of data in the BGT. The BGT must conform to one topological rule and that is that the map universe is a spatial partition. This means that there can be no gaps and no overlap of objects.
Time	Time refers to the registration of temporal parameters of objects, like the date of capture, registration and termination.
Thematic accuracy	Thematic accuracy is the accuracy of related thematic information. Most thematic attributes which do not refer to position or time are either ordinal or nominal values, like land use type.

2.1.2 Quality in the assembly phase

The assembly phase, which lasts from mid-2012 to the 1 January 2016, comprises the process of building and assembling the BGT by the custodians from their source data. "Building" means transforming existing source data to conform to the BGT specifications, or capturing data if no suitable source data exist. "Assembling" means technically aligning source data between custodians. This means, among other things, that contested areas are assigned a custodian, and that the physical boundaries between custodians are established at the object level.

The SVB-BGT[2] sets guidelines for custodians for assembling the BGT (SVB-BGT, 2014). These guidelines state that the AAN register is the primary source data for agricultural areas. They also state that spatial data quality is used as a criterion for deciding on boundaries between source data with different quality. Simply put, a source data set with a higher known quality takes precedence over another data set with lower known quality. This also applies to the AAN register of RVO (Huis & Van der Wal, 2013).

2.1.3 After the assembly: realized quality and quality improvement

When the assembly phase ends on 1 January 2016, all custodians must have assembled their source data sets and formed a nationwide coverage. This "proto-BGT" has a realized quality that is likely not conforming to the norm quality, which does not take effect until another four years, on 1 January 2020. The legislator anticipated that an operation of this magnitude and complexity would require considerable time on part of the custodians and planned an additional period of four years for improving the BGT to eventually conform to the norm in 2020. Not much yet can be said of this period because there is no (official) documentation yet covering this period other than the highly abstract catalogue, which itself is still under revision because of experiences in the assembly phase.

This section has addressed the internal aspects of spatial data quality in the BGT. It has been observed that there is a set of quality indicators which constitutes an internal norm for quality. It has also been observed that this norm quality is only achieved after a phase-wise transition during which the emphasis is on the assembly of the BGT. The next section addresses external spatial data quality and proposes a set of indicators for assessing the fitness for use of farmers' data in the BGT.

2.2 The set of spatial data quality indicators

External data quality follows the principle that the fitness for use of data varies from one application to another (Figure 3). It is argued that the internal quality requirements of the BGT are in fact the external quality requirements of farmers' data in the fitness for use assessment. So farmers' data are compared with the BGT quality requirements. In addition to the BGT quality requirements there are several other requirements necessary for the fitness for use assessment that are explained in the following sections.

[2] The coordinating project bureau for the assembly and transition of the BGT

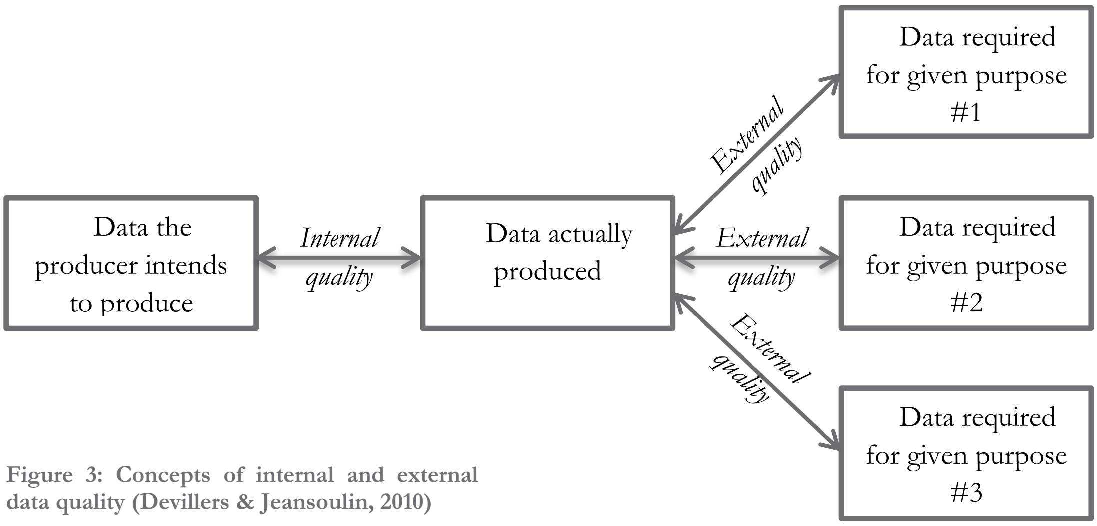

Figure 3: Concepts of internal and external data quality (Devillers & Jeansoulin, 2010)

2.2.1 Currency

Currency, also known as temporal validity, is a subtype of temporal quality (i.e. quality relating to aspects of time) (Harding, 2010; Van Oort, 2005). To define currency, the definition given in the BGT catalogue is revisited: "Currency is the extent to which data are consistent with reality within a defined time interval" (Ministry of Infrastructure and the Environment, 2013, p. 23). The catalogue explains that this is related to update policy: the currency for agricultural fields is 18 months because these objects rely mostly on orthophotography to signal changes. Orthophotos are generally captured yearly and they require 6 months to be processed. The processing of an update in an agricultural field may thus not take longer than 18 months after the change took place in reality. The example offered by the catalogue is consistent with perspectives on currency in literature. Harding (2010) suggests that currency is a parameter for update policy, which is a policy or a system that data producers require in order to organize their data capture and meet the currency requirements.

2.2.2 Positional accuracy

Positional accuracy has always been the best established and sometimes only measure of quality in spatial data (Chrisman, 1991). Simply put, positional accuracy is the accuracy of coordinate values of data. In the BGT, positional accuracy is understood as the relative, or internal, positional accuracy. This is the positional accuracy of data relative to other data in the same data set, as opposed to absolute positional accuracy, which is the accuracy of data compared with matching coordinates on the same reference system (Van Oort, 2005). The latter is relevant in this research, as the aim is to assess the external data quality. So in order to assess the absolute positional accuracy, the coordinates of farmers' data should be compared with matching coordinates on the same reference system.

2.2.3 Completeness

Completeness is the extent to which objects that exist in reality are also present in the data. A less abstract definition is offered by Van Oort (2005): completeness is a measure of the absence of data and the presence of excess data, resulting in errors of omission and errors of commission respectively. The completeness in the BGT requirements is the so called "data completeness". Data completeness refers to the standards as intended by the data producer, in other words, internal quality. Opposite data completeness is "model completeness", which refers to the completeness of data as an indicator for fitness for use in a certain use or application (Brassel et al., 1995), which corresponds to external quality. The reason behind this distinction is that data may be complete for internal data specifications, but not sufficiently complete for external uses, or the other way around.

2.2.4 Logical consistency

Although logical consistency commonly refers to the "fidelity of relationships in the data structure" (Van Oort, 2005), including attribute values, temporal values, and the consistency of geometry, it only refers to the latter in the BGT (Ministry of Infrastructure and the Environment, 2013). As was mentioned previously in Table 3, the topology in the BGT is defined by the rule that the map universe forms a perfect spatial partition. Again there is a difference between internal and external quality. To test the external logical consistency of farmers' data they would have to be "fitted" in a BGT map and checked for topological conflicts with adjoining BGT objects. Due to the absence of the BGT map this is not yet possible, so farmers' data cannot be tested to the BGT requirements for logical consistency. So instead farmers' data are tested for the internal logical consistency.

2.2.5 Thematic accuracy

Thematic accuracy, also known as thematic quality, describes the accuracy and correctness of all attributes other than geographic attributes (Van Oort, 2005; Goodchild, 1995). It refers to the information in the attribute tables related to geographic objects. An example of thematic accuracy is that an object classified as a building is also a building in reality and not, say, a crop field. Thematic accuracy is assessed by determining to what extent attribute information required in the BGT is also present in farmers' data. In this sense thematic accuracy overlaps with completeness. Completeness as described in section 2.2.3 refers to the absence or presence of geographic features. A different kind of completeness is attribute completeness, which refers to the absence or presence of attribute information (Veregin, 1999). It is decided to assess this completeness as part of thematic accuracy so that all quality aspects that relate to non-geographic information are grouped in one quality indicator.

2.2.6 Semantic quality

Although the internal quality indicators of the BGT have been redefined as external quality indicators in the fitness for use assessment, still not all aspects of quality are covered. None of the above indicators is concerned with the question whether farmers' data actually describe the same spatial phenomena as the BGT. This kind of quality relates to how the real world is modelled, and what decisions are taken in the simplification process regarding the definition of objects. This aspect of quality is called semantic quality and is added as an indicator to the set of indicators.

Salgé (1995) argues that semantic quality is inherent to a fitness for use assessment of spatial data, because the semantic quality of a data set, by definition, is different for producers and users, if the data set is used for another purpose than its intended purpose. However, the indicator is also disputed. Van Oort (2005) suggests that the question of semantic quality is the very first step in a fitness for use assessment and actually precedes the quality assessment and is therefore not a real quality indicator. In either case the semantic quality should be evaluated and is therefore added to the set of indicators.

2.2.7 META-QUALITY

Another quality indicator that is specifically important in an external quality context is the quality of the metadata, or meta-quality. Metadata inform the user about the fitness for use of data by providing information pertaining to many of the aspects of quality that were discussed in previous sections. Various authors stress the importance of the availability and quality of metadata in a fitness for use assessment (Ivánová et al., 2013; Lush et al., 2012). Meta-quality is determined by assessing the presence and absence of important metadata, and to what extent these metadata provide information about confidence, homogeneity and reliability (Servigne et al., 2010):

- Confidence: An element of meta-quality that describes the accuracy of quality information. Confidence is concerned with the accuracy and appropriateness of the method used to obtain the reported quality information.
- Reliability: This element of meta-quality applies when a sample based quality test is reported in the metadata. Reliability requires that the sample size and sampling method are explained in the metadata.
- Homogeneity: This element of meta-quality describes variation in quality. It is a description of the expected or tested variation of quality in the data set.

Confidence and reliability both refer to information about the quality of data, i.e. they refer to metadata. Homogeneity on the other hand refers to the data themselves, because data can be homogeneous even if it is not reported in the metadata. Perhaps for this reason some authors treat homogeneity as a separate quality indicator (Van Oort, 2005).

Lineage is added as a fourth element of meta-quality to this indicator. Lineage provides an overview of the history of the data: how and when it was captured, transformed and disseminated and by whom. Although some authors treat lineage as a separate quality indicator (Clarke & Clark, 1995; Van Oort, 2005) it is decided to group it here under meta-quality, as the presence or absence of lineage in itself is a measure if meta-quality.

These sections have defined indicators for spatial data quality. Together they comprise the set of indicators for the fitness for use assessment of farmers' data in the BGT.

3 METHODOLOGY

As a means of structuring the methodology it is explained in three steps. These steps are:

1. Quality assessment of farmers' data acquisition
2. Multi-criteria analysis of quality indicators
3. Quality assessment of farmers' data

3.1 QUALITY ASSESSMENT OF FARMERS' DATA ACQUISITION

Spatial data quality originates to a considerable extent from decisions and actions taken in the capture process (Harding, 2010). To describe and analyse the data acquisition process, Harding's model (2010) was used as a reference (Figure 4). Harding's model is based on the data acquisition process of the Ordnance Survey, Great Britain's national mapping agency, incorporating different stages of data acquisition. For each model component a comparison was made to farmers' data acquisition process.

3.1.1 CAPTURE SPECIFICATIONS

Based on Harding's (2010) definition of capture specifications, the following questions were addressed:

1. Are the objects to be captured clearly defined?
2. Are the responsibilities of the stakeholders (e.g. surveyor, farmer) clear?
3. Are data quality standards defined?
4. How many objects were captured in accordance with the measurement protocol?

The information sources for answering questions 1 to 3 were the GAOS measurement protocol (H-Wodka, 2010a), a supplement to this document (H-Wodka, 2010b) and a field work where data acquisition of three fields was observed in the presence of a farmer, a surveyor and the author of the measurement protocol, which took place on 8 November 2013. The aforementioned questions were asked to these participants. Afterwards there was e-mail

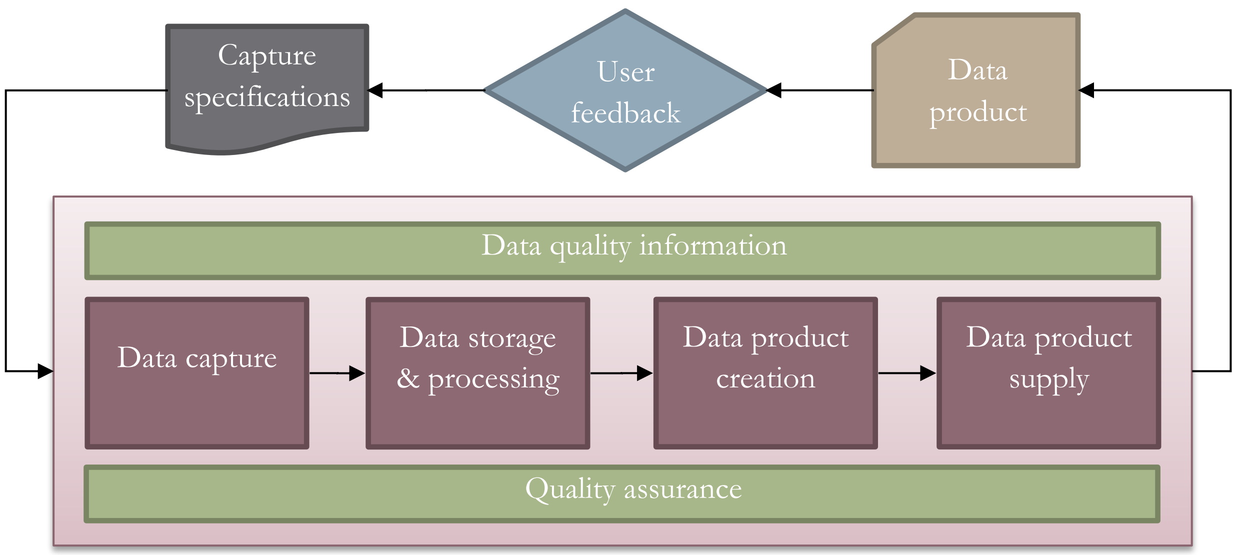

Figure 4: The capture process of spatial data, adopted from (Harding, 2010)

correspondence with the author of the measurement protocol to clarify some of the findings (Lerink, 2014). Question 4 for was tested by a visual inspection of the geometry of the farmers' data. In this inspection it was observed if objects are constituted by many vertices with regular space in between them or if they are constituted by vertices placed at identifiable corners with few vertices in between. Due to the relatively small size of the farmers' database (385 objects) it was possible to do this inspection manually. The evidence that supports this question and method is explained in the next chapter.

3.1.2 The acquisition process: from data capture to product supply

The model then identifies four stages of data acquisition. For these stages, questions were formulated as well as outlined below:

1. What is the survey method and what equipment is used?
2. How is the data stored and managed?
3. How is the data processed before delivery?
4. What is the final data product and how is it delivered?
5. How is user feedback processed?

Again the measurement protocol and the field work are sources of information for these questions. In addition, research by De Bruin and colleagues (2014) provides further information about the workflow of the data acquisition process.

3.1.3 Quality control and quality assurance

Finally the model encompasses quality control (QC) and quality assurance (QA). Definitions for QC and QA are provided in Table 4.

Table 4: Definitions of quality control and quality assurance (Harding, 2010, p. 152)

Quality measure	Definition
Quality control	Quality control encompasses checks applied to data at all stages of the data capture, editing, storage, and manipulation process, to ensure that data integrity is maintained.
Quality assurance	Quality assurance is an independent check for data quality that is applied to a sample of data which is the product of a process.

The following questions were addressed to assess to what extent QC and QA are present in the data acquisition process:

1. To what extent are there quality checks in all stages of the acquisition process? (QC)
2. To what extent are there independent checks on the data quality? (QA)

These questions were also answered using aforementioned sources. As with the previous questions, there was correspondence afterwards to clarify some of the findings (Lerink, 2014).

3.2 Multi-criteria analysis of quality indicators

It is argued that a multi-criteria analysis (MCA) is a useful tool in this research because it enables an overall assessment of the set of quality indicators in a single composite score, taking into account all the indicators and differences in importance that exists between them.

For scoring the indicators, a scale of 1 to 5 was used where 1 denotes that the indicator does not meet the BGT requirements and 5 denotes it fully meets or exceeds requirements. The requirements for these scores per quality indicator were assigned to a rubrics matrix (Appendix A: Rubrics matrix). The criteria for assessing the quality indicators are explained in section 3.3. In addition to scores, weights were assigned to express the relative importance of individual criteria. Furthermore, a scenario was formulated which describes in what way farmers' data can be used in the BGT. The basis for the scenario and the weights was an interview with two experts at RVO, the BGT custodian for agricultural areas. This interview is explained in more detail in the following section.

3.2.1 Setup of the expert interview

The interview was conducted as a double interview with two experts. One expert is a geo-information advisor who was involved in the farmers' practices in the Hoeksche Waard in the past and the other expert is tasked with organizing the BGT custodianship at RVO. A double interview setting was chosen over two separate interviews because in this setting the experts could complement each other. Both experts indicated they received a presentation about GAOS in the past. The participants agreed to a recording of the interview (audio). The interview took place on 9 January 2014.

The interview was organized as a semi-structured interview where certain topics were fixed but with sufficient opportunity for open discussion as well. Beforehand, a document was sent to the participants in preparation for the interview. The two-page document outlined the background of the study, the aim of the interview and the structure of the interview (Appendix B: Interview preparation document). Also it was asked to the participants if the aims of the research and the interview were clear. The role of the author in the interview was to steer the conversation but also to participate when certain topics were not deliberated enough. In such cases the author prompted the participants with new ideas or alternative viewpoints to stimulate the discussion. After the interview there ensued some correspondence with the participants for additional information and clarification.

Two main topics were discussed in the interview: the importance of the quality indicators and the scenario. The scenario describes a use case of how farmers' data can be used in the BGT from the viewpoint of RVO. It was assumed that such a scenario would be required because there are different ways RVO might use farmers' data in the BGT. The participants were asked to keep an open mind in thinking about possible scenarios, and were asked to treat the interview as a brainstorm session. For the weights it was attempted to make sure that all indicators were discussed in equal amount. In this discussion the merits and demerits of different quality indicators were discussed. It was asked of participants to agree on a hierarchy of the indicators and indicate why certain indicators are more important than others.

Afterwards, based on notes and the audio recording, weights were assigned to the hierarchy the experts agreed on by using Analytical Hierarchy Process (AHP) pairwise comparisons, using an Excel spreadsheet by Goepel (2013). The weights are normalized between [0..1] with their sum being 1.

3.2.2 Weighted sum model

Once scores and weights were established, they were entered into a weighted sum model. The weighted sum model, also known as the simple additive weighting method, is a simple and often applied MCA-methodology that is used to calculate a best alternative based on weighted scores. Formally, the weighted sum model can be described as (Tzeng & Huang, 2011):

$$CS_i(x) = \sum_{j=1}^{n} w_j s_{ij}\,(x)$$

Where $CS_i\,(x)$ denotes the overall or composite score of the model for alternative i, w_j denotes the weights of the jth criterion on the interval [0..1], and $s_{ij}\,(x)$ is the score of the ith alternative with respect to the jth criterion. The model assumes that all criteria are independent, which means that the scores of the criteria are not influenced by one another. Alternative i suggests that the model is used to compare different alternatives. This is typically true, but in this research the model was used to compute a composite score for only one alternative. Like the individual scores, the composite score is a value on the interval [1..5]. With 1 being the worst score and 5 being the optimal score. The CS classified according to the rubrics matrix. So a score of 4,2 would be between "almost fit for use" and "fit for use", but more inclined to the former.

3.2.3 Sensitivity analysis

The final step in the methodology was a sensitivity analysis on the weight factors in the weighted sum model. The purpose of the sensitivity analysis is to evaluate the sensitivity of the composite score to alternative weight sets. This is necessary in order to evaluate to what extent a different judgement over the weights affects the composite score. For the sensitivity analysis the method of Memariani and colleagues (2009) was used, which is designed to proportionally change all weights if one weight is manually changed. This method assumes the weights are normalized between [0..1] with their sum being 1. Then, if the weight of indicator P changes from w_p to w'_p as:

$$w'_p = w_p + \Delta_p$$

Then the new weights of the other criteria, denoted as w' for the j^{th} criterion, change as:

$$w'_j = \frac{1 - w'_p}{1 - w_p} \cdot w_j$$

$$w_p \neq w_j$$

The sensitivity analysis was applied by adding 0,1 and 0,2 to each weight. This way it could be assessed if the composite score improves or worsens if a quality indicator is changed in weight, and by how much.

3.3 Quality assessment of farmers' data

In this section the criteria and methods for the quality indicators are explained.

3.3.1 Currency

In order to assess whether or not farmers' data conform to the BGT currency requirements the update policy was examined. The update policy would give an indication of how often fields change and how long it takes to update the data (if these are updated at all). A formal update policy, like a document, was not present, so the field work of observing data acquisition was used to ask the participants about the "informal" update policy instead. The following questions were asked:

1. How often do fields change?
2. How long does it take for the data to be updated?

If fields are updated within 18 months of a field change (the BGT norm) then a score of 5 was awarded. If data are never updated a score of 1 was assigned. An "in-between category" was used for a 24 month currency.

3.3.2 Positional accuracy

To assess whether or not farmers' data are accurate enough to be used in the BGT there are two options: compare the farmers' data to independent reference data from a field survey and to compare them to another, existing data set deemed to be of higher accuracy. Both options were used in this research.

3.3.2.1 Independent data from field survey

Reference data were acquired from a field survey. The population for this survey comprises all the fields that are also represented in farmers' data. The sample was drawn only from those fields that were estimated to be captured in accordance with the capture specifications. This decision was made because only these data represent the nominal quality of farmers' data, as laid down in the capture specifications. As the data acquisition process for these data is known, it is possible to trace inaccuracies in the data back to the data acquisition process.

A survey was conducted to estimate how many fields could be captured given the constraints imposed by the availability of equipment and support. It was estimated that five fields could be captured in the sample. Along these fields points were captured. A distinction was made between corner and edge points because they have to be treated differently. Corner points were deemed to be identifiable in the field so they can be compared with identical points in the reference data, and this way allow for the assessment of errors in X and Y directions. For edge points this is not the case and only the shortest distance between edge and survey points can be directly measured (Van Niel & McVicar, 2002). All corner points in the sample were captured, as well as four random points per edge. A general guide has been approximately one random point for each 100m of edge length. So on a 400m edge, 4 points were sampled along the entire length of the edge. For particularly short edges (less than approximately 100m in length) only two random points were captured. The *Create Random Point* feature in ArcGIS was used to sample the locations of the edge points. The data were acquired using RTK-GNSS equipment. A base station was used in combination with a rover. The measurements were taken on the field boundary: on the onset of the slope of the ditch or on the boundary of a "hard" physical boundary, like a concrete path.

3.3.2.2 ACCURACY STATISTICS

In the BGT, positional accuracy is expressed using standard ellipses. Standard ellipses can be considered the two dimensional variant of the standard deviation (Veraghtert, 2005) (Figure 5). The length of the semi-major axis is the accuracy criterion. Farmers' fields have to conform to an accuracy of 60cm. This means that for a given point *i* the length of the semi-major axis may not exceed 60cm. Standard ellipses may be calculated using the standard deviations of X and Y coordinates. The orientation of the ellipse is determined by the correlation between X and Y. A greater spread in the distribution for X or Y results in a different shape of the ellipse. In the event the standard deviations are equal, the standard ellipse is in fact a circle.

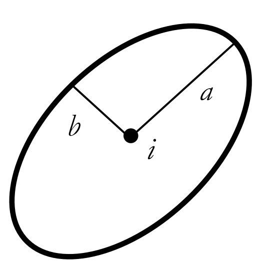

Figure 5: A standard ellipse of point *i* illustrating the semi-minor (*b*) and semi-major (*a*) axes

As positional accuracy is expressed by the standard deviation, differences between the accuracies of X and Y were assessed using a test for equality of variance. In case of normally distributed data, Bartlett's test was used, otherwise Levene's test was used which is robust to the assumption of normality. The hypotheses are:

H_0: *Variance of X = Variance of Y*
H_A: *Variance of X ≠ Variance of Y*

To determine whether the samples come from normal distributions the Anderson-Darling test for normality was used. The hypotheses are:

H_0: *The samples for X/Y are drawn from normal distributions*
H_A: *The samples for X/Y are not drawn from normal distributions*

If the equality of variances could not be assumed, the semi-major axis of the standard ellipse was calculated and compared to the BGT criterion of 60cm. The orientation of the ellipse was calculated using Pearson's R correlation coefficient. If it could be assumed that the variances are equal, and the spread in the distribution is the same in both X and Y, the standard circle was considered rather than the standard ellipse, in which case the radius of the standard circle was compared to the BGT criterion of 60cm. The radius of the standard circle is the standard deviation of the Euclidean distances between corner points in farmers' data and the corner points in the reference data.

This is not possible for edge points because they do not have known corresponding points. So in this case another approach was needed to find the standard deviation. This approach is visualized in Figure 6 and assumes that the standard deviation is a standard circle (i.e. the variances of X and Y errors are assumed equal). The shortest distance between a test point and the edge of the field is a best case, where the unknown reference point is closest to the test point. However, as the reference point is unknown the worst case was assumed. In the worst case the distance between the test point and the unknown reference point is equal to the shortest distance (a) multiplied by √2, which results in (c). This is known because the error is expressed as a standard circle, and so (a) and (b) are equal. So, in the case of edge points, the distances between test points and edges were multiplied by √2, after which the standard deviation was compared to the BGT criterion of 60cm.

If the positional accuracy of farmers' data was 60cm or less, a score of 5 was assigned. A lower score was assigned for every 10cm of increased inaccuracy.

3.3.2.3 Reference data from a water board

The Hoeksche Waard falls under the jurisdiction of Water Board Holland Delta (WSHD) and this water board uses large scale geometry of water ways and ditches for water management and other tasks. Therefore WSHD has derived a data set of rivers, pools, ditches and other water bodies from from AHN2, the current digital elevation model (DEM) of the Netherlands. AHN2 is a collection of point clouds covering the whole of the Netherlands, which has been captured using laser-altimetry. AHN2 has an elevation (Z) as well as a planimetric (X, Y) accuracy (Wittwer, 2012). The planimetric accuracy of AHN2 is of interest in this study. A research was done by the water boards and concludes that AHN2 conforms to BGT standards for positional accuracy (Wittwer, 2012). Therefore, WSHD's data were used as a reference data set.

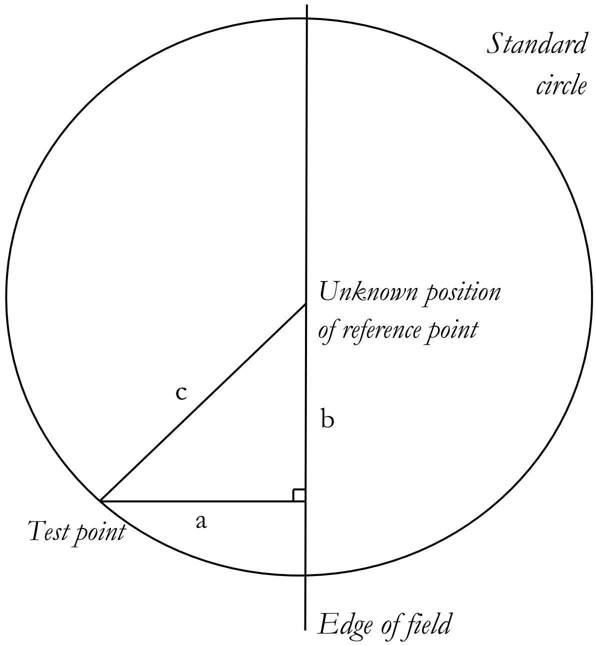

Figure 6: Schematic for calculation of the radius of the standard circle (c) for edge points

First, the geoprocessing model used to generate the data was examined. Then WSHD's data were compared with the field survey data in order to measure the positional accuracy. This way it was possible to see which of the data are more accurate: WSHD's data or farmers' data. If WSHD's data are indeed more accurate than farmers' data, then these data can be used as a reference for farmer's data. To measure the positional accuracy of WSHD's data the same method was applied as for farmers' data. However, WSHD's data do not have corner points. As a consequence only the edge point approach could be used for measuring positional accuracy, which means that the distances between test points and edges were multiplied by √2 after which the standard deviation was compared to that of farmers' data.

3.3.3 Completeness

It was explained in the theory that there is "data completeness" and "model completeness". Data completeness requirements of the BGT state that farmers' data should provide a complete coverage of agricultural fields in the Netherlands. If this was the case then this yields a score of 5. If the RVO experts agreed that the data are sufficiently complete to be used as source data in the assembly phase a score of 3 was assigned. In the worst case RVO experts think that farmers' data are not sufficiently complete to be of use in the BGT (Appendix A: Rubrics matrix). To assess this, completeness was discussed in the interview with the RVO experts, not only for the weight but also for the score. The experts were informed about the size of the GAOS-database to base their judgement on. Model completeness was considered as well. In model completeness requirements are dependent on the use case, rather than the internal (BGT) requirements. So it was assured that the RVO experts took the completeness of farmers' data into consideration when discussing scenarios for the potential use of farmers' data.

3.3.4 Logical consistency

The logical consistency of farmers' data was tested by validating the topology. The only rule that could be tested was that objects may not overlap. Farmers' data were imported into an ESRI File Geodatabase. For this database a topology was created based on the rule that objects must not overlap. Then this topology was validated using the Validate Topology toolset in ArcGIS. Where objects overlapped, polygons were generated that represent the areas of topological error. Then a selection of farmers' data was made based on an intersection with these error polygons. The percentage of farmers' data that was topologically inconsistent determined the score (Appendix A: Rubrics matrix).

3.3.5 Thematic quality

For thematic quality, the aim was to evaluate to what extent attribute information, including temporal attributes, can be derived from farmers' data. This was done by comparing the attributes of farmers' data and the BGT. First, all information that is present in farmers' data attributes was identified (for example: registration date of object, owner of field). Then it was determined if this information is also present in the BGT data model (Ministry of Infrastructure and the Environment, 2013). This way it was established to what extent attribute information in farmers' data matches with the data model of the BGT. If all BGT attribute information could be derived from farmers' data, a score of 5 was assigned. If almost none or no information could be derived, a score of 1 was assigned.

3.3.6 Semantic quality

For semantic quality, the aim was to define the objects in farmers' data and investigate ambiguity in these objects. Two sources of information were used: the measurement protocol (H-Wodka, 2010a) and the field work where the data acquisition of three fields was observed. The participants were asked how they deal with defining the boundary of the fields. In particular it was observed how the surveyor was able to follow the identification of the fields. The findings of the observation were then compared to the definitions provided in the measurement protocol, to see if these are consistent. Then the definition in the measurement protocol was compared to the definition of crop fields in the BGT. The interview with the RVO experts was used to clarify the BGT definitions.

Also it was assessed to what extent there is agreement between RVO and farmers about the definition of field boundaries. This is relevant because farmers declare the geometry of their crop parcels every year to RVO to apply for CAP subsidies. RVO's perspective on this was discussed in the interview. To obtain the farmers' perspective, a farmer was consulted who has experience using data from GAOS in declaring crop parcels (Klompe, 2014a). If there is disagreement, or ambiguity, in the field boundaries of fields this was also reflected in the score for semantic quality (Appendix A: Rubrics matrix).

3.3.7 Meta-quality

It was assessed to what extent the four meta-quality elements are present in the metadata. In addition it was assessed to what extent the BGT requires that metadata are stored in the data. The sources of metadata are the measurement protocol (H-Wodka, 2010a) and the data themselves. Also the BGT data model was examined (Ministry of Infrastructure and the Environment, 2013). One of the meta-quality elements, homogeneity, requires a separate explanation, because variation in quality can be present in different quality indicators. If indications were found for any quality indicator that the data quality varies from object to object this was also reflected in the score for meta-quality. A high score is associated with present meta-quality elements and little variation in quality, whereas a low score is associated with no present meta-quality elements and greater variation in quality (Appendix A: Rubrics matrix).

4 RESULTS

First the results for the quality in the data acquisition are presented. Then the results per indicator are presented including the assigned score. The order in which the indicators are discussed is different from the previous chapter in order to accommodate a more logical structure of the results. After the score results, the scenario and weights are explained. Finally the composite score is calculated using the weighted sum model.

4.1 THE DATA ACQUISITION PROCESS

4.1.1 CAPTURE SPECIFICATIONS

The capture specifications are laid down in the measurement protocol (H-Wodka, 2010a). This document provides information on several topics:

- Description of objects to be captured and boundary definitions (semantics)
- Instructions for the surveyor concerning where to capture points and how to store the lineage information
- Responsibilities of the farmer (client), surveyor (contractor), and the geo-information service point (GISP) with respect to payment, delivery and control.

Farmers capture the geometry of crop fields. These objects are called gross parcels. A gross parcel is a crop field defined by a hard topographic boundary like a ditch or a path or by a neighbouring parcel. In the latter case there isn't necessarily a hard topographic boundary. The farmer and surveyor indicated that the semantics of gross parcels are sufficiently clear to them.

The three actors in the data acquisition process are the farmer, the surveyor and the geo-information service point (GISP). The surveyor is a contractor or a farmer who happens to have data capture equipment. Most of the data was captured by two surveyors, one of whom was

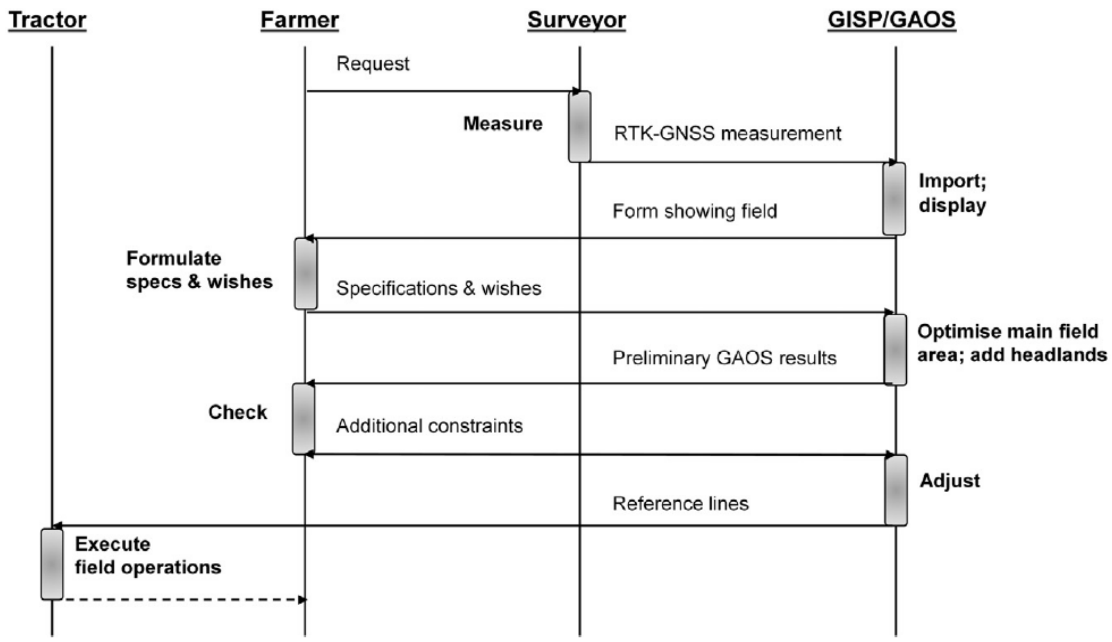

Figure 7: Sequence diagram of actors, their responsibilities and the data flow within the GAOS program (adopted from De Bruin et al., 2014)

present at the field work. GISP is comprised of three farmers who act as agents for the other farmer-users. They were also the first users of GAOS and are therefore the most experienced in using GAOS and handling the data (Lerink, 2014; De Bruin et al., 2014). The responsibilities of each of these actors can be visually expressed in the sequence diagram of work and data flow (Figure 7). Note that this diagram visualizes the entire GAOS work flow and that the actual data acquisition ends with importing and displaying the data by GISP.

Except for the object specifications (semantic quality), the measurement protocol does not provide standards for other data quality indicators. (H-Wodka, 2010a). Neither does it entail procedures for quality control and quality assurance.

The data acquisition process described until now is the "blueprint" process, as laid down in the measurement protocol and described by De Bruin and colleagues (2014). However, it became clear that many farmers do not or only partly adhere to the protocol because some geometries in farmers' data are very distinct from others. This was confirmed by the author of the measurement protocol (Lerink, 2014). Farmers who choose not to follow the protocol don't capture identifiable points with some points in between but employ continuous tracking. With this technique the identification is followed with a moving vehicle and points are captured at discrete time intervals. This technique is supposedly faster and more convenient for the farmer but less accurate because well identifiable points are not captured separately. On the basis of the visual inspection of the geometry it was estimated that 240 out of 378 gross parcels[3] (63%) in the GAOS database are captured according to protocol. As the metadata do not provide information about which objects were captured in accordance with the measurement protocol, this estimate cannot be supported by metadata.

4.1.2 The acquisition process

Farmers' data are captured using RTK-GNSS equipment mounted on a quad (Figure 8). Earlier research has verified that this approach is the best approach to obtain the positional accuracy required in GAOS (De Bruin et al., 2008). In the survey method, points are captured on corners. As a minimum, there should be one point in the corner, two points on either side at most 3m from the corner, and an additional two points on either side, 15m from the corner. In addition, points are captured on edges with 50m intervals, at most, in between. The protocol describes several field situations and how many points with what intervals should be captured in those situations.

Data are sent to GISP which imports the data in the GAOS database, or farmers import data directly using a web interface (Lerink, 2014). The data are stored in a relational database and communicate with the interface using web services (De Bruin et al., 2014). The final responsibility for the data lies with the farmer, as he is the owner of the data. This responsibility includes management of the data after they have been imported into GAOS (Lerink, 2014). There is no central database management authority.

Figure 8: Farmers use RTK-GNSS equipment mounted on a quad (H-Wodka, 2010)

In the acquisition process some processing takes place.

[3] 7 objects that were not gross parcels were first removed from the selection.

Notably the splitting of objects. When fields are captured based on hard topographic boundaries like ditches or roads, farmers may wish to split the field in two gross parcels because one part belongs to a different farmer. In this case the splitting results in two separate objects in the farmers' data (Klompe, 2014b).

The final data product is one or more objects representing farmers' fields in the GAOS-database which the farmer can then access and use in GAOS. It was not found that there is regular feedback between the farmer and the surveyor after the data acquisition. Rather, participants of the field work indicated that the farmer is usually present at the data acquisition to instruct the surveyor directly.

4.1.3 Quality control and quality assurance

In the field work of the data acquisition it was observed that the surveyor applies the measurement protocol. The surveyor explained that the protocol is adhered to, but that in some circumstances this is not possible, for example if the identification is blocked by a tree or other obstacle. This wasn't perceived as a problem by all the participants.

GISP checks the geometric consistency of the data in order to prevent topological errors in GAOS. This was found necessary because in the early stages of GAOS farmers would occasionally submit inconsistent data with loops and self-intersections (Lerink, 2014). There are no other procedures for quality control. Also there is no independent check on the data quality (quality assurance). For example, the farmers and contractors who own and operate the RTK-quads are not certified as surveyors.

4.2 Currency

The participants of the field work indicated that fields do not change often and that as a result of that it is not necessary to acquire new data for a field very often. Changes that require a data update are significant changes like the dredging of a ditch or a reallotment of parcels. However, the farmer indicated that when a field does change it is in his interest to update the data as soon as possible in order to be able to optimize the field in GAOS. The farmer indicated that it is "a matter of weeks" to organize a data capture with the surveyor and arrange for a survey. It is argued that with this update policy of farmers the currency requirement of 18 months is amply met, and therefore a score of 5 was assigned to currency.

4.3 Positional accuracy

4.3.1 Survey result

In the survey 25 corner points and 67 edge points were captured (Table 5). Due to local conditions not all points could eventually be captured. Sometimes a point was obstructed and in the case of field 1 there was not sufficient daylight left to finish the survey. The identification of field boundaries was found to be clear on the edges but less so in the corners. Unlike field edges, field corners were very irregularly and gently sloped, and weeds and

Figure 9: A dam located in a field's corner, making pinpointing the exact corner difficult

grasses in the corners were sometimes poorly kept at the moment of capture, making it very difficult to pinpoint a corner. In addition, a dam was sometimes located in a field corner so that there was no clear topographical corner of the field (Figure 9).

Table 5: Captured points per field. Between brackets the sampled number of points.

Field	Corner points	Edge points
0	6 (6)	14 (17)
1	0 (14)	3 (29)
2	4 (4)	15 (15)
3	8 (10)	21 (22)
4	7 (10)	14 (22)
Total	**25 (44)**	**67 (105)**

4.3.2 Positional accuracy of farmers' data

Table 6 reports the results for X and Y errors. The Anderson-Darling test for normality yielded a p-value of less than 0,05 for both errors. The null hypothesis that the samples are drawn from normally distributed populations was therefore rejected. To test the equality of variances Levene's test was then used. The p-value was greater than 0,05 (0,78), therefore it was assumed that the variances of X and Y errors are equal. Since the variations were considered equal and the standard circle was assumed, there was no need to determine the orientation of the standard ellipse using correlation.

Table 6: Statistics for X and Y errors in farmers' data

Statistic	X error (m)	Y error (m)
n	25	25
Mean	0,2	0,1
Variance	1,218	0,886
Standard deviation	1,104	0,941
Anderson-Darling test	X error	Y error
Anderson-Darling A^2	1,31	1,552
p-value	0,002	0,004
Levene's test		
Levene's W		0,079
p-value		0,78

After the equality of variances was assumed, the Euclidean distance between test and reference points was calculated to determine the radius of the standard circle. This was done for both corner and edge points (Table 7). As can be observed, the standard deviation for corner points was found to be greater than for edge points. Based on the corner points a score of 1 would be assigned, and based on the edge points a score of 5 would be assigned. However, due to the fact that there were problems with the identification with the corner points and the fact that a sample of 25 points is relatively small, it was decided to base the score on the edge point accuracy. This yielded a score of 5 for positional accuracy.

Table 7: Statistics for the accuracy of edge points of farmers' data

Corner points statistic	Result (m)	Edge point statistic	Result (m)
n	25	**n**	65
Variance	1,168	**Variance**	0,172
Standard deviation	1,081	**Standard deviation**	0,414

4.3.3 Positional accuracy of WSHD's data

In the geoprocessing model of WSHD's data it was found that geometry is derived from AHN2 using slope as a parameter. The onset of the slope is determined with a parameter in the model. The user can change this parameter. A vector boundary is then created on this slope onset. This boundary forms the geometry of water ways. So it was found that WSHD's data and gross parcels both share the onset of the slope of water ways (like ditches) as boundaries. The geometry, once it has been derived from the AHN2 raster, is generalized in three steps in order to eliminate the rough and crenelated edges caused by the raster to vector-conversion process. Finally the positional accuracy of WSHD's data was assessed. With a standard deviation of 0,511m it was found that the positional accuracy of farmers' data is greater than for WSHD's data (Table 8).

Table 8: Statistics for the accuracy of edge points for WSHD's data

Statistic	Result (m)
n	65
Variance	0,261
Standard deviation	0,511

4.4 Completeness

Based on the size of the GAOS-database the RVO experts indicated that farmers' data are too incomplete to be used as source data for the BGT. This refers to the "data completeness" of farmers' data. The explanation that the experts give is the magnitude of the BGT assembly. They describe the assembly as a "macro-process" and argue that such a process cannot accommodate small data sets as source data for the BGT, even if these data have better currency and positional accuracy. The experts explain that this is because the data quality of custodians is aggregated and then labelled with a "quality level", which denotes the "average" quality of all the custodian's data in a predefined administrative area. Based on this aggregated quality level the BGT is assembled and technical alignment takes place between adjacent source data from different custodians. The consequence is that superior quality of some objects may be negated by the "inferior" quality of the data at the aggregated level. Considering these facts a score of 1 is assigned to completeness.

4.5 Semantic quality

4.5.1 Object definition

First the object definitions were examined. In the BGT a crop field is a "vegetated terrain element", defined as "a functionally independent, uninterrupted terrain with compact vegetation" (Ministry of Infrastructure and the Environment, 2013, p. 38). The RVO experts clarified that the BGT's definition of a vegetated terrain element is the same as the definition of a topographic parcel in AAN. The boundary definition of a topographic parcel is a ditch, or any other hard physical boundary, like a concrete path or a road. In case of a ditch the onset of the slope is the exact boundary.

Gross parcels also have hard topographic boundaries. At the field work, the surveyor explained that when he captures fields he aims to follow the onset of the slope of the ditch as the identification, or another hard topographic boundary like a concrete path. However, also an important difference was found, namely that a neighbouring parcel can also be a valid boundary. Although farmers are advised to capture fields based on hard boundaries it is possible that after optimization in GAOS the gross parcel is split in two objects because, for example, one part belongs to another farmer (Klompe, 2014b). This way the field is constituted by two gross parcels whereas in AAN the field would exist as one topographic parcel.

4.5.2 Boundary ambiguity

In addition to object definitions it was assessed to what extent there is agreement between farmers and RVO about object boundaries. It was found that there is considerable discussion between farmers and RVO about the exact boundaries of crop fields, especially where a field is defined by ditches, which is very common in the Hoeksche Waard (Figure 10). The onset of the slope is often difficult to identify and is prone to change as a result of farming operations. Farmers may issue requests to correct the topographic boundary of fields but RVO is prudent in accepting geometry submitted by farmers. This prudence is manifest in a stringent policy of tolerance buffers around topographic parcels. Change requests within these buffers are rejected by default. The RVO experts explained that only in the case of new topographic situations, captured using GNSS, these are taken into consideration. RVO subjects these farmers' data to three subsequent and independent quality checks. First by comparison with orthophotos and then by two subsequent surveys performed by two different surveyors. The RVO experts explained that this strict policy should be seen in the context of the CAP. They argued that farmers have an interest in changing the topographic boundary because they receive subsidies based on the amount of land they own. The experts also suggested that this policy would have to be less stringent if the surveyors of farmers' data were certified, and as such could be trusted to be independent.

It was found that farmers also acknowledge that field boundaries are ambiguous, and that discussion with RVO over these boundaries is prevalent. Sometimes farmers do not want to bother submitting their data, knowing that RVO will likely reject them, even if the farmer knows that the data describe the topographic reality better than AAN. A farmer who regularly submits GAOS-data to declare crop parcels said that RVO's version of the topographic reality – the AAN register – is a "mix of

Figure 10: A typical field boundary in the Hoeksche Waard with a potato field on the left, a ditch in de centre and a dyke on the right

the real situation and an accepted situation [by farmers], to be rid of the hassles" (Klompe, 2014a).

To summarize, it was found that the BGT's definition of a crop parcel is different from farmers' data because a soft field boundary is possible in farmers' data due to splitting. Also it was found that discussions between farmers and RVO over field boundaries are prevalent and so that field boundaries are ambiguous. To reflect these results a score of 3 was assigned to semantic quality.

4.6 Logical consistency

When the topology of farmers' data was validated it was found that a significant portion of the error area is caused by more or less identical objects in the data (Figure 11). These objects were presumed to be redundancies and were removed (28 objects). Then the topology was validated again. Out of 357 objects 60 were found to be inconsistent with the rule that objects may not overlap, which is 16,8%. This result was assigned a score of 5.

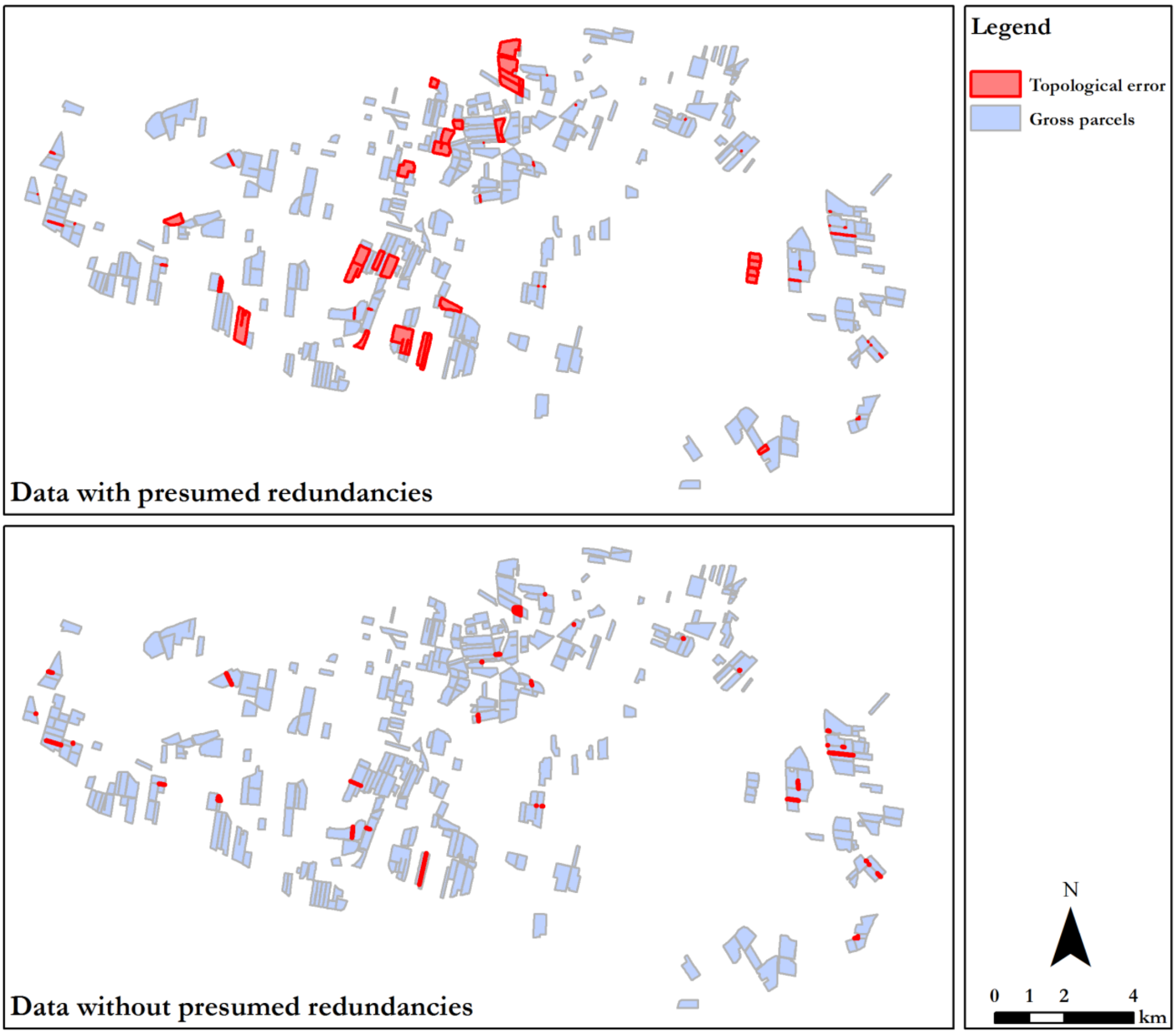

Figure 11: Maps representing topological errors in farmers' data

4.7 Thematic quality and meta-quality

The geometry of farmers' data is associated with one attribute that contains lineage information. As lineage is one of the elements of meta-quality the results for thematic quality and meta-quality are combined in one section. Other elements of meta-quality were confidence and reliability. Both refer to metadata that reports tested data quality. It was found that such metadata are not available, so no statements could be made regarding these elements. However there were results for homogeneity, but first the results for lineage are examined.

In the BGT, metadata are to be stored in a point object class called "location point" (*plaatsbepalingspunt*). A location point is a point that is geographically related to every coordinate pair, or vertex, in the BGT and contains metadata about the data acquisition of that point. In farmers' data, thematic information is stored in the GAOS database and in the lineage attribute of the geometry. The lineage attribute is a text string with the following format: `<JKY_BP_090331_HBE_Achterstee>`. In this example `JKY` are the initials of the farmer, `BP` refers to gross parcel, `090331` is the capture date, `HBE` are the initials of the surveyor, and `Achterstee` is the name of the crop field. With the exception of the date of capture and the initials of the surveyor this information is stored separately in the GAOS database. The metadata requirements of BGT location points were compared to the lineage attribute of farmers' data (Table 9). The capture date, capture method and capture entities are present, but accuracy is not.

Table 9: Comparison of BGT location point attributes and farmers' data lineage attribute

Location point attribute	Description	Present in farmer's data?
accuracy	Reported positional point accuracy in cm	No, positional point accuracy is absent in farmers' data
captureDate	Date of data capture	Yes, the capture date is stored in the lineage attribute
captureMethod	Method used for data capture, for example orthophotos or GNSS.	Yes, it is known that both surveyors use GNSS for data acquisition.
captureEntity	The entity that captured the point. This could be the custodian or a delegated entity (surveyor).	Yes, both the data owner (farmer) and the delegated entity (surveyor) are stored in the lineage attribute.

However, it was found that there is a discrepancy between farmers' data specifications and the observed data. Of the 384 objects in the farmers' data set only 15 objects (4%) contained all the lineage elements in accordance with the format. The remainder only reported a few of the lineage elements and most of which in a nondescript format. This is a manifestation of heterogeneity in the data quality. For other indicators it was also found that there is heterogeneity in the data quality:

- As surveyors are not certified, quality is not independently assured, which leads to uncertainty about positional accuracy (notwithstanding the skill and expertise of these surveyors).
- Not all farmers adhere to the measurement protocol when it comes to the data acquisition method. This leads to uncertainty about positional accuracy.
- If a farmer does not adhere to the protocol, and uses an alternative method instead, it is not known to what extent this method is able to pinpoint the identification (e.g. field boundaries or corners), which leads to uncertainty about semantic quality.

- It was found that parcels may be split on soft boundaries, and so deviate from hard topographic boundaries, which also results in uncertainty about semantic quality.
- And finally, as said before, it was found that most of the objects have incomplete lineage information reported in the attribute of the geometry.

It was found that farmers' data are not sufficient in several respects regarding thematic quality and meta-quality. Thematic quality is assigned a score of 1 because the amount of attribute information that can be derived from farmers' data is limited. In this sense the attribute completeness of farmers' data is not sufficient. Meta-quality is assigned a score of 2 because the required meta-information is scarcely present in the data, but moreover because evidence suggests considerable variation in data quality.

4.8 Scenario for using farmers' data in the BGT

Most of the discussion about how farmers' data could be used in the BGT was about the assembly phase. The RVO experts explained that the assembly is very complex. They indicated that there is still discussion between custodians on how to exactly align adjacent data and that these discussions may still result in different data specifications for the BGT. They indicated that as long as the assembly process is not completed, the BGT data and quality specifications are not yet final. However, they agreed that currently the issue with using farmers' data in the BGT would be the incompleteness of the data. The problems with completeness resulted in a score of 1 and were explained in detail in section 4.4. The experts argued that, however farmers' data may score on other quality indicators, they cannot be used in the assembly due to their incompleteness.

The experts indicated farmers' data would become more interesting in the maintenance phase of the BGT. Then farmers' data could be used to improve an existing BGT map by reporting back errors in the topographic parcels. The experts indicated this is currently already the case because of the crop parcel declaration system. It was explained that farmers may declare their crop parcels using their own data (see section 1.2.1). This system is already used to monitor changes in topographic parcels, and is one of RVO's most important change monitors for the AAN register (Huis & Van der Wal, 2013). In this scenario the incompleteness of farmers' data would no longer be relevant, because even if a farmer declares a single crop parcel it could be compared to the BGT and used to correct a topographic boundary.

In this scenario logical consistency is also not maintained as a quality indicator in the weighted sum model. If data submitted by farmers is evaluated separately by RVO, then the internal inconsistencies of the farmers' data set are no longer relevant.

4.9 Determining the hierarchy in quality indicators

Completeness was found to be important, but as a condition: farmers' data are not sufficiently complete to be used as source data in the assembly. Therefore the alternative scenario was chosen which uses farmers' data as a means for updating the BGT via the crop parcel declaration system. In this scenario completeness is no longer relevant and as such receives no weight. For the other indicators the RVO experts agreed on a hierarchy:

1. Semantic quality
2. Currency
3. Positional accuracy

4. Meta-quality/thematic quality

The RVO experts indicated that semantic quality is the most important quality indicator. They argued that there can be no ambiguity in the definition of objects. The reason they gave for this is the CAP. Topographic parcels must be well defined in order to allocate CAP subsidies properly. RVO is inspected by the European Commission regularly and has been fined in the past for having too inaccurate data that also had considerable semantic issues (e.g. ditches were subsidized because they were part of topographic parcels) (Huis & Van der Wal, 2013). The importance of semantic quality can further be illustrated by the fact that the experts indicated that they still consider it a possibility that the AAN register will be maintained parallel to the BGT if it turns out that the boundaries of topographic parcels change as a result of the assembly with other custodians' data.

Currency was second in the hierarchy. The experts indicated that for them the importance of currency stems from the fact that RVO is the only custodian that is not also "manager" of the BGT area to which it has been assigned. As was explained in the introduction, all custodians are in some way responsible for land management or infrastructure maintenance in the BGT-partitions they are assigned to. For RVO however this is not the case because RVO is typically not aware of changes in the physical properties of individual fields. If, for example, a ditch is dredged and RVO is not notified, then RVO would only be aware after new orthophotos become available. In order to be better able in allocating CAP subsidies the experts indicated RVO always pursues more current data.

Third in the hierarchy is positional accuracy. The RVO experts argued that positional accuracy is important but that highly accurate data may also give rise to new semantic discussions over field boundaries. They questioned to what extent it is possible to capture highly accurate data of field boundaries, which are often vague. In section 4.5.2 it was explained that discussions over exact boundaries are already prevalent and both RVO and farmers tend to avoid them. In addition, the experts noted that RVO intends to move from 25cm resolution to 10cm resolution orthophotos. They expect that the added value of highly accurate farmers' data will then be less.

Then meta-quality and thematic quality were discussed. The experts argued that the presence and quality of metadata would be important if farmers' data were a source data set for the BGT assembly. But in the scenario of correcting topographic parcels using the crop parcel declaration system metadata are not at all important. The experts indicated that RVO may request metadata from farmers who declared crop parcels using their own data, but that this is rarely the case. Thematic quality was also not important, because RVO extracts thematic properties of fields from the BRP and orthophotos, and this was deemed sufficient by the experts.

4.9.1 Assigning weights using AHP

Weights were assigned to the quality indicators using AHP. The relative importance of each indicator was expressed in the AHP matrix (Table 10). The consistency ratio of the AHP matrix was 7%, which is below the generally accepted maximum of 10% (Goepel, 2013).

Table 10: AHP matrix for quality indicator weights

	Sem.	Cur.	Posit.	Meta	Them.	Normalized weight
Sem.	-	2	5	7	9	0,47
Cur.	1/2	-	3	5	9	0,29
Posit.	1/5	1/3	-	3	7	0,14
Meta	1/7	1/5	1/3	-	5	0,07
Them.	1/9	1/9	1/7	1/5	-	0,03

4.10 Composite score and sensitivity analysis

The weights and scores yielded a composite score of 3,7 on a scale of 5 (Table 11). The sensitivity of the model was determined using two alternative weight sets: one where each indicator was increased by 0,1 and one where each indicator was increased by 0,2 (Table 12).

Table 11: Composite score of farmers' data

Quality indicator	Weight	Score	CS
Semantic quality	0,47	3	1,41
Currency	0,29	5	1,45
Positional accuracy	0,14	5	0,7
Meta-quality	0,07	2	0,14
Thematic quality	0,03	1	0,03
Composite score (CS) on scale [1..5]			3,73

Table 12: Alternative CS based on alternative weight sets (+0,1 and +0,2)

Indicator	Baseline	+0,1		+0,2	
		Δ (%)	Alt. CS	Δ (%)	Alt. CS
Semantic quality	3,73	-0,03	3,59	-0,07	3,45
Currency	3,73	0,06	3,92	0,1	4,09
Positional accuracy	3,73	0,05	3,88	0,09	4,03
Meta-quality	3,73	-0,04	3,54	-0,09	3,36
Thematic quality	3,73	-0,07	3,45	-0,14	3,17

5 Discussion and evaluation

In this chapter the fitness for use of farmers' data in the BGT is discussed. Also some aspects of the research are evaluated.

5.1 The fitness for use of farmers' data in the BGT

5.1.1 The composite score

With a CS of 3,7, farmers' data are inclined to be more "almost fit for use" than "somewhat fit for use" in the BGT. The CS is sensitive to changes in weights that are associated with high scores. Given the scores, the CS only improves if currency and positional accuracy are assigned more weight. For the other indicators the CS worsens. Major contributors to the CS are semantic quality and currency. Semantic quality was found to be only somewhat fit for use, but received a high weight. Currency was less important but received the maximum score. These indicators are also the most interesting because they illustrate the relation between the CAP and the BGT, which is explained in the next section.

5.1.2 Relation between CAP and BGT

In the interview it became clear that the fitness for use of farmers' data in the BGT cannot be seen separately from the CAP, and the role that both farmers and RVO play in that. The reason for this is that the BGT becomes a part of the CAP because it aims to replace the topographic reference upon which agro-subsidies are based. So the semantic discussions that farmers and RVO have over field boundaries are eventually transferred from AAN to the BGT. Therefore RVO would treat farmers' data contributions to the BGT just as prudently as it would treat their contributions to AAN.

At the same time farmers' data are welcomed because of their superior currency, which RVO assigned a high weight to. The update policy of AAN is based on time intervals. Currently one-third of AAN is updated yearly using orthophotos while the BGT requires a currency of 18 months. So RVO requires more current data. The update policy of farmers on the other hand is change-driven. A topographic change in a field requires that the farmer recaptures the data in order to keep the benefits from GAOS for that field. Already farmers are considered the most important change monitor for AAN, perhaps this will also be the case for the BGT, especially if the update cycle of orthophotos remains insufficient to meet the 18 month criterion.

It is argued that there is tension between these facts: on the one hand RVO and farmers tend to avoid discussions over field boundaries, and it was found that farmers accept "RVO's topographic reality" even if they have data of which they know it describes the real situation better. On the other hand RVO needs farmers' data, or at least farmers' notifications, in order to monitor topographic changes.

Also there may be tension between the data quality requirements of the BGT and the data quality requirements of the CAP topographic reference. This was not investigated in this research, but in the interview it was clear that RVO's responsibilities to the CAP play a major role in accepting farmers' data in the BGT. This was particularly clear with semantic quality and currency. In this way it can be argued that RVO's responsibilities as a BGT custodian are entwined with their responsibilities as a CAP executive organization. The implication of this is that VGI contributions, by farmers or others, must not conflict with the data quality requirements of the CAP, or RVO will not accept them. And as farmers have a special (financial) interest in the CAP, it is difficult for them to contribute VGI to the BGT.

5.1.3 Improving semantic quality?

The fitness for use of farmers' data in the BGT could be improved most by improving semantic quality, as this indicator carries the highest weight. This would mean that the semantic discussions between farmers and RVO should be resolved. The RVO experts argued that certifying surveyors would help because quality controls would not have to be so stringent. However, it is questionable how this would benefit farmers. They capture data for GAOS and GAOS does not require certified surveyors. Also, for new topographic situations RVO already accepts farmers' data of new topographic situations when these are submitted in the crop parcel declaration, albeit after thorough quality checks as described in section 4.5.2. And this remains so in the counterfactual scenario when AAN is replaced by BGT.

5.2 Farmers' data acquisition

For studying farmers' data acquisition the capture specifications were taken as a starting point, using Harding's (2010) model as a reference. The decision was made to investigate the positional accuracy and semantic quality of only those data that were estimated to be captured in accordance with the data specifications, i.e. the measurement protocol. During the course of the research it was found that only 63% of the gross parcels are estimated to have been captured in accordance with this protocol, and other indications of heterogeneity in data quality were found as well. Farmers are given the freedom to decide on how to capture the data for GAOS, and the measurement protocol is therefore only a guideline in that respect. This finding is consistent with other VGI research: if there are data quality specifications for a VGI dataset, these are often not mandatory and this leads to variation in data quality (Haklay, 2010; Girres & Touya, 2010).

This also means that the positional accuracy and semantic quality of a considerable part of farmers' data were not tested, while the interview with RVO experts revealed that these are two of the most important quality indicators. It is argued that in situations like these, where the data acquisition is very decentralized, a formal approach centred around data specifications is not the best approach for investigating the data quality, because it cannot be assumed that all data were captured in accordance with the specifications. An alternative approach, as Hacklay (2010) suggests, would be to test all the data, regardless of their reported or expected conformity to specifications, and then investigate if deviations from the specifications can be associated with particular contributors, geographical areas or other properties.

Another consequence of the decentralized data acquisition was that there is no database management authority. Every farmer is the owner of the data he captures and is also responsible for managing these data after they have been captured. It is therefore not known to what extent objects in farmers' data are redundant or not. It may well be possible that a farmer no longer uses a field in GAOS and disregards the data without having them removed from the database. For GAOS this may not be a problem but if farmers' data are to be used for other purposes this could be a quality issue.

The variation in data quality is also a reason to evaluate the meta-quality indicator. Homogeneity was one of the elements of meta-quality, as identified in the literature (Servigne et al., 2010). Seeing the significance of variation in quality in VGI, it is argued that homogeneity should be a separate quality indicator. Consequently, meta-quality is only concerned with the data about the data, like Van Oort (2005) suggested, and is argued to be a more logical ordering of quality indicators.

5.3 Evaluation of the field survey and positional accuracy

A set of reference data was captured in a field survey to test both farmers' data and WSHD's data. It was found that farmers' data are more accurate than WSHD's data comparing only accuracy of the edge points. Therefore WSHD's data cannot be used as a reference for measuring the positional accuracy of farmers' data. As it was found that WSHD's data are cartographically generalized this could be a reason for the greater inaccuracy in these data, because generalization manipulates the geometry.

However, remarks about the accuracy of farmers' data should be made as well. It was found that the error in corner points is much greater than for edge points. A reason for this might be the fact that the corner points are difficult to identify in the field. This was a surprising result because it was expected that corner points would be well identifiable as opposed to edges, but it turned out to be the other way around. If the surveyors of farmers' data encounter the same difficulties in identifying corners it might be an important source of errors in corner point data. On the other hand, the error found in corner point data is not very reliable because the sample contained only 25 measurements. Unfortunately, it was underestimated how many fields could be captured within the time and resource constraints, and the field with the most corner points was planned last in the survey.

5.4 Evaluation of the weights

The weights are an important part of the weighted sum model. In this research the weights were not directly chosen by experts. Rather the experts determined a hierarchy and provided an explanation for that hierarchy, after which the author used AHP to determine the numerical weights. AHP was only introduced in a later stage of the research, and it would have been better to let the experts directly determine the weights using this method. This would have contributed to the validity of the research.

6 CONCLUSIONS

To conclude the research questions are answered after which recommendations are made.

6.1 RESEARCH QUESTIONS

Q1. What is the acquisition process of farmer's data?

This research has found three characteristics of farmers' data acquisition process. First, the data acquisition process is a decentralized process where farmers hold full responsibility over the data and where there is no central database management. Second, the surveying rests with farmers and contractors who have the proper RTK-GNSS equipment but who aren't certified for surveying. Lastly, although the data specifications are laid down in a measurement protocol, farmers are not obliged to adhere to these specifications and it was found that not all data do conform to these specifications. Considering these arguments it is not possible to speak of "the" farmers' data acquisition process as if it were a universal process. Rather, the process is a decentralized, "light-weight" process where much depends on choices of the individual farmer, and where the effects of these choices can also spill over into the data quality.

Q2. What is the data quality of farmer's data?

Q3. To what extent does farmer's data meet requirements to be used in the BGT?

It was found that farmers' data are too incomplete to be fit for use in the BGT. Therefore another scenario was portrayed wherein farmers submit data via the crop parcel declaration system and thereby contribute to the topographic reference, which is now AAN but will eventually become the BGT. In this scenario farmers' data are inclined to be almost fit for use, which was reflected in a CS of 3,7. Semantic quality and currency contribute most and almost equally to this score. Semantic quality is considered the most important indicator but is only somewhat fit for use. This is because object definitions are not entirely the same and there is ambiguity in the exact location of field boundaries. Currency on the other hand meets the BGT requirements but is less important. The positional accuracy of farmers' data also meets the BGT requirements, but was found to be less important. Meta-quality and thematic quality farmers' both scored badly but this did not influence the CS much because these indicators were not considered important for fitness for use in the BGT.

Q4. How can farmers align the data acquisition process to better meet BGT quality requirements, taking into account incentives for farmers to do so?

In order to better meet BGT requirements farmers have to improve the semantic quality of their data, as this contributes most to the CS. This would mean resolving semantic discussions over field boundaries with RVO. A possible solution is to certify surveyors but it is unsure how this would benefit farmers as they capture data for GAOS and not for RVO or for the BGT.

To conclude the main research question is answered: **To what extent are farmers' data fit for use in the BGT key register from a spatial data quality point of view?** The BGT can benefit from farmers' data because they meet the requirements for positional accuracy and are more current than the source data of RVO, the BGT custodian. However, the data quality requirements for the BGT are entwined with the data quality requirements of the CAP. And as the BGT custodian and farmers have conflicting interests in the CAP this causes discussion in semantic quality, which compromises the fitness for use. Therefore farmers' data are inclined to be almost fit for use in the BGT key register, which was reflected in a CS of 3,7.

6.2 Recommendations

6.2.1 Recommendations to farmers and RVO

It is recommended that farmers make minor changes to their data acquisition process in order to facilitate a broader use of their data. It is recommended that an attribute is added to the data that specifies if data were captured using the procedure in the measurement protocol or using a different technique. Also it is recommended that periodically farmers declare what data they still use and what data is redundant, for example by making GISP responsible for database management. This would not only help future researchers but also farmers if they would want to use their data for other purposes than GAOS. Also, as a means of quality assurance, GISP could be certified for this task so that formal organizations like RVO can more readily access farmers' data. Another recommendation that pertains to certification of GAOS actors is the certification of surveyors. RVO stated that certification of surveyors would improve the semantic quality of the data, which in turn would increase the fitness for use of farmers' data in the BGT. However, it is unclear how certification of surveyors would benefits farmers as GAOS does not require it. Therefore it is recommended that farmers' organizations like H-Wodka and RVO together perform a cost-benefit analysis for certification of GAOS actors. This cost-benefit analysis should weigh the benefits of RVO using farmers' data against the costs of certification.

6.2.2 Recommendations for future research

It is recommended that the exact relationship between the BGT and the CAP is further investigated, for example by comparing the data quality requirements of the CAP and the BGT. This way it can perhaps be better understood how RVO could accept VGI as input for the BGT. A more general recommendation is that it is investigated how precision farming data could be used in the CAP. As precision farming becomes more common and the amount of data increases, it may become interesting for CAP executive organizations to use these data.

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APPENDIX A: RUBRICS MATRIX

	Indicators						
Scores	**Currency**	**Posit. accuracy**	**Completeness**	**Logical consistency**	**Thematic quality**	**Semantic quality**	**Meta-quality**
5. Fit for use	Farmers' data are updated within 18 months of a change in the field	Accuracy criterion[4] equals 60cm or less	Farmers' data provide a complete coverage of agricultural fields in the Netherlands	Number of inconsistent objects is between 0% and 20%	All attributes from the BGT data model can be derived from farmers' data	Object definitions are the same and objects are not ambiguous.	All meta-quality elements are present; there is no variation in quality
4. Almost fit for use	-	Accuracy criterion is between 60-70cm	-	Number of inconsistent objects is between 20% and 40%	-	-	All meta-quality elements are present; there is little variation in quality
3. Somewhat fit for use	Farmers' data are updated within 24 months of a change in the field	Accuracy criterion is between 70-80cm	Farmers' data are incomplete but can still be used as source data	Number of inconsistent objects is between 40% and 60%	Approximately 50% of the BGT attributes can be derived from farmers' data	There are some differences in object definitions; objects are ambiguous.	-
2. Marginally fit for use	-	Accuracy criterion is between 80-90cm	-	Number of inconsistent objects is between 60% and 80%	-	-	Not all meta-quality elements are present; there is variation in quality
1. Not fit for use	Farmers' data are never updated	Accuracy criterion is greater than 90cm	Farmers' data are insufficiently complete to be used as source data.	Number of inconsistent objects is between 100% and 80%	Almost no attributes can be derived from farmers' data	There are fundamental differences in object definition.	No metadata are present; there is much variation in quality

[4] Accuracy criterion: the semi-major axis of the standard ellipse or the radius of the standard circle

APPENDIX B: INTERVIEW PREPARATION DOCUMENT

The following text was sent to the interview participants in advance so they could prepare for the interview. In addition, the measurement protocol (H-Wodka, 2010a) and some further background information was sent to the participants.

Boerendata in de BGT?

Voorbereiding voor interview 9-1-2014, 11:00-12:30

Inleiding

Boeren in de Hoeksche Waard winnen geometrie van hun percelen in met behulp van RTK-GPS. Deze geometrie hebben zij nodig voor GAOS, een GIS-programma ontwikkeld door de stichting H-Wodka en de Universiteit Wageningen. Met GAOS kunnen zij efficiënter hun land bewerken. De geometrie die zij inmeten is die van zogenaamde brutopercelen, semantisch gezien identiek aan DR's topografische percelen. Daarnaast wordt apart geometrie ingewonnen van objecten op het veld zoals hoogspanningsmasten en betonpaden. Voor een gedetailleerdere beschrijving van wat de boeren precies inmeten het meetprotocol dat is bijgevoegd. Voor meer achtergrond over GAOS zie het document "Akkerbouw in Groen en Blauw fase3a" hoofdstuk 4. Dit document is iets verouderd maar de essentie is actueel.

De data die ingewonnen wordt met de RTK-quad is dusdanig grootschalig dat de vraag gerezen is of de data misschien gebruikt kan worden in de BGT. Het doel van het onderzoek is om dan ook om vast te stellen in hoeverre data die door boeren in de Hoeksche Waard wordt verzameld geschikt is om te gebruiken in de BGT. Het onderzoek bestaat uit twee belangrijke delen:

1. Het onderzoeken van de datakwaliteit van de boerendata en het inwinningsproces
2. Het beoordelen van deze kwaliteit met behulp van een multicriteria-analyse (MCA)

Kwaliteitsonderzoek

Het onderzoeken van de datakwaliteit bestaat uit het meten of beoordelen van een aantal kwaliteitsindicatoren. Op deze kwaliteitsindicatoren geef ik een score van 1 tot 5 punten, waarbij 1 punt betekent dat een indicator niet voldoet aan de BGT-eisen en 5 punten betekent dat het wel voldoet of zelfs beter is dan de BGT-eisen. Echter, niet ieder kwaliteitscriterium is even belangrijk en daarom voer ik een MCA uit (deel 2 van het onderzoek).

Actualiteit	Hoe actueel is de boerendata, wat is de updatefrequentie?
Nauwkeurigheid	Wat is de positionele nauwkeurigheid van de boerendata?
Compleetheid	Bevat de boerendata omissies of commissies ten opzichte van het gebruiksdoel?
Logische consistentie	Hoe is de topologische kwaliteit van de boerendata?
Attribuutkwaliteit	Welke attribuutinformatie bevat de boerendata en wat is de kwaliteit

	daarvan?
Metakwaliteit	Wat is de kwaliteit en beschikbaarheid van de metadata?
Semantische kwaliteit	Stemmen de definities van objecten in boerendata overeen met de BGT?

Multicriteria-analyse

In de MCA worden de scores vermenigvuldigd met een gewicht (tussen 0 en 1). Dit maakt een kwaliteitsindicator belangrijker of niet. Deze gewichten zijn afhankelijk van het scenario, ofwel de case. De case van het onderzoek is dat BGT-bronhouder boerendata gebruikt om haar eigen brondata aan te vullen, te verifiëren of te verbeteren. De BGT-bronhouder is Dienst Regelingen, aangezien het agrarische percelen betreft. De brondata van DR zal primair het AAN zijn, naast luchtfoto's e.d. De vraag is dus in hoeverre DR de boerendata kan gebruiken om haar eigen brondata aan te vullen, te verifiëren of te verbeteren. Wat daarbij in het interview centraal staat is de kwaliteitsindicatoren: welke zijn belangrijk en welke minder belangrijk? En waarom dan? Het resultaat van het interview moet zijn dat ik gewichten kan hangen aan de scores die ik bepaal in de MCA.

Normaliter wordt een MCA gebruikt om verschillende alternatieven te vergelijken, bijvoorbeeld door verschillende auto's te scoren op brandstofverbruik, aanschafprijs en comfort. Ik heb echter nu nog maar één alternatief namelijk de case. Een secundair doel van het interview is dus om te kijken of we differentiatie kunnen aanbrengen in de case. Zijn er verschillende manier waarop DR de boerendata zou kunnen gebruiken? Zo ja, hebben die dan verschillende gewichten voor de kwaliteitsindicatoren?

Wat een aanname is in dit hele verhaal is dat DR de boerendata wel wil c.q. kan gebruiken. Dit is natuurlijk geen vanzelfsprekendheid. Er zijn veel institutionele, organisatorische, juridische en financiële belemmeringen. Mijn onderzoek gaat daar echter niet over, het beperkt zich tot de data.

Opzet van het interview

Het interview zal een discussie zijn tussen ons drie. Ik leid het gesprek, maar laat jullie zo veel mogelijk aan het woord. Zie het als een brainstormsessie waarbij jullie de opdracht krijgen om te onderzoeken of de boerendata gebruikt kan worden in het DR-deel van de BGT: welke kwaliteitsindicatoren zijn dan van belang en waarom? De reden dat het een "groepsinterview" is is dat een brainstormsessie altijd effectiever is met meerdere mensen. Op het eind van het interview zal ik jullie vragen om zelf een voorstel te doen voor de gewichten.

Laat je inspireren door de case: de boerendata zal niet geschikt zijn om één op één geknipt en in de BGT geplakt te worden. Maar kan het misschien gebruikt worden om de brondata van DR te verifiëren of aan te vullen?