To see or not to see: Assessment of Probabilistic Visibility

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Abstract: Until present visibility has been assessed as a Boolean phenomenon in various kinds of Geographical Information Systems (GIS) and Computer Aided Design (CAD) systems: *either things can or cannot be seen*. Probabilistic Visibility (PV) is presented as an advanced alternative. PV represents the probability that one location of object can be seen from another. Results of PV analysis are stored in Probabilistic Visibility Graphs (PVG) which stores the probability of visual contact for all relevant pairs of locations (e.g. raster cells). A visibility graph will be calculated based on field experiments and literature visibility decay - as a function of terrain, distance, viewing-angle and vegetation type -. The presentation takes its point of departure from analysis of visibility in forested environments. It describes the field experiment, and how the graph is calculated and visualized. Furthermore, perspectives of the further development and application of probabilistic visibility graphs will be given.

INTRODUCTION

In Geographical Information Systems (GIS) and Computer Aided Design (CAD), visibility is normally treated as a Boolean phenomenon; either one location can be seen or it cannot be seen, from another. A location of origin is most often represented by a point. In some cases, the visibility from lines (e.g. roads) or areas (e.g. parks) can be assessed. An extension to this Boolean approach can be taken when the visibility of more than one object is in question; the number of objects, out of a set of target objects, which can be seen from a given location. The area which can be seen from a given object is termed its viewshed (Kim *et al.* 2004) or isovist (Benedict, 1979; Snizek, 2003). The term 'isovist' itself suggests an area that is evenly visible from a point location.

Often the outer boundary of viewsheds can be set as a maximum range of the analysis. But again, it is Boolean. Being outside the maximum range is interpreted as completely invisible. Being just slightly inside, is completely visible.

But is it so? Is it really so that visibility is a Boolean affair? Do you expect that it only takes a single step on the ground – across the top of a hill or beyond the maximum range of analysis - to make you invisible? As so often in Geography, the first thing that comes into mind is that it is a matter of scale. Analyzing visibility in large landscapes, the Boolean approach can make good sense. But working in more detail, objects like trees and other on-ground objects, that might interrupt visual contact, must be taken into account. In which case, more facets have to be dealt with. The ruggedness of the terrain plays a major role. In mountainous regions, the terrain itself will overrule possible effects of transparent on-ground objects; whereas in rather flat environments - like in Denmark – the terrain has less influence on visibility than in more rugged ones. Accordingly, assessment of probabilistic visibility will be more significant in such landscapes and environments than elsewhere.

A number of parameters can be taken into consideration, when considering visibility decay, including:

- *Increasing distance*. Even along an uninterrupted line of sight, the probability of paying attention to near things will be higher than to those at greater distances. This corresponds well to Toblers ‘First law of Geography’: "Everything is related to everything else, but near things are more related than distant things." (Tobler, 1970).

- *Transparency*. On-ground objects – or compounds of objects – provide different degrees of transparency. For instance different types of vegetation which will interrupt visual contact more or less. The same is true for weather and light conditions, such as mist and twilight. The transparency decay of vegetation is the main scope of the present paper.

- *Viewing angle.* The orientation of the viewer can influence the probability of visual contact. You are more likely to pay attention to things that happen right in front of you, than thing that are behind your back. The effect of viewing angle is of course affected by a range of additional things, including: other perceived information (e.g. noises and smells), is the viewer looking for something (scanning) or is he/she moving straight on towards the target, or is the viewer standing still or moving. Intuitively, it is expected that there will be a nonlinieary relation between viewing angle and probability of visual contact. The angle decay makes most sense, when applied to human or animal perception. If the visibility analysis is used for assessment of e.g. telemobile transmitter coverage, the probability of contact will be even all 360 degrees.

The formulation of visibility as graphs of mutual visibility of viewer and target locations or cells is introduced by O’Sullivan and Turner (2001). The work presented extents these Boolean visibility graphs to include probabilities – accordingly termed Probabilistic Visibility Graphs (PVG’s).

One application of PVG’s is in agent-base models (ABM’s) and computer games. When evaluating whether one agent can see another, the probability is revealed from the PVG. The probability is juxtaposed with a random number (Between 0 and 1), to determine if visual contact is ‘actually’ made. This suggests that two agents standing next to each other might not ‘see’ the same thing. Llobera (2003) provides a comprehensive review of the theory and concepts of isovists and viewscapes. A remark in given on the lack of attention given to the visual effect of detailed coverage objects (e.g. threes) and weather conditions, and other phenomena related to transparency, without further suggestions of further perspectives on assessment of the issue.

Fisher (1991) addresses visibility probabilities in terms of the effect of the inaccuracy of the involved DEM on the uncertainty of the visibility derived from it.

The remainder of the abstract will first provide some background, on how probabilistic visibility has been assessed in an Australian case. Following is a description of the field experiment applied. Then the applied analytical method will be described, accompanied by examples of results. Finally, remarks on the future application and further development will be given.

SETTING TRANSPARENCY PARAMETERS

Very few documented attempts have been made to set actual decay parameters for different land cover types. A rare example is provided by Ipswich Council (2002). In Ipswich Council situated in Queensland (Australia) the visual exposure of the landscape was assessed by a combination of locations, where people would go (roads, viewing points etc.), and the transparency of different land cover types. For each land cover type, a set of decay parameters was suggested. Decay parameters for a selection of land cover types are shown in table 1 below. The parameters were not tested empirically in field (Preston, Pers. com. 2005).

Table 1: Selected transparency distance decay factors in different land cover types (Source: Ipswich Council, 2002). The decay parameter for the class 'open' has been adjusted to 0.975. In the original table the class was termed 'water' and was set to 1.0, indicating that objects would be evenly seen no matter the distance.

		Distance from viewer (m)					
Land cover type	***Decay factor, per 25 m***	***0***	***25***	***50***	***75***	***100***	***500***
1: Open	***0.975***	***100%***	***98%***	***95%***	***93%***	***90%***	***60%***
3: Pasture	***0.975***	***100%***	***98%***	***95%***	***93%***	***90%***	***60%***
6: Low density trees	***0.900***	***100%***	***90%***	***81%***	***73%***	***66%***	***12%***
7: Dense trees	***0.750***	***100%***	***75%***	***56%***	***42%***	***32%***	***0%***
8: Very dense trees	***0.500***	***100%***	***50%***	***25%***	***13%***	***6%***	***0%***

FIELDWORK

To empirically justify the parameters found in table 1 (Ipswich Council. 2002) a pilot field experiment was set up in a fairly open old (approximately 150 years), fairly homogeneous beech forest. The aim was to investigate to what extent a person could see another person, given different distances and angles away from a central line of sight.

Three persons were involved:

- A controller, taking care of time and records.
- A respondent, seeing or not seeing the target.
- A target, roaming the forest.

At five different locations in the beech stand, five sessions were conducted. Before each session, the location of a base station was recorded. Likewise, the angle of a central line of sight was decided and recorded. During a session, the controller and the respondent were standing at the base station. The outlook of the respondent was blocked in the direction of the central line. The target was moving around in the forest stand. At uneven intervals the target would stand still, and the respondent was given either 1 or 5 seconds to realize, whether the target could or could not be seen. Every time the target would record its location by GPS. At each session, 10 recordings based on 1 seconds exposure and 10 based on 5 seconds exposure were obtained. In this way a total of 100 recordings was made. Figure 1 shows the location of the controller/respondent and the target of such one session.

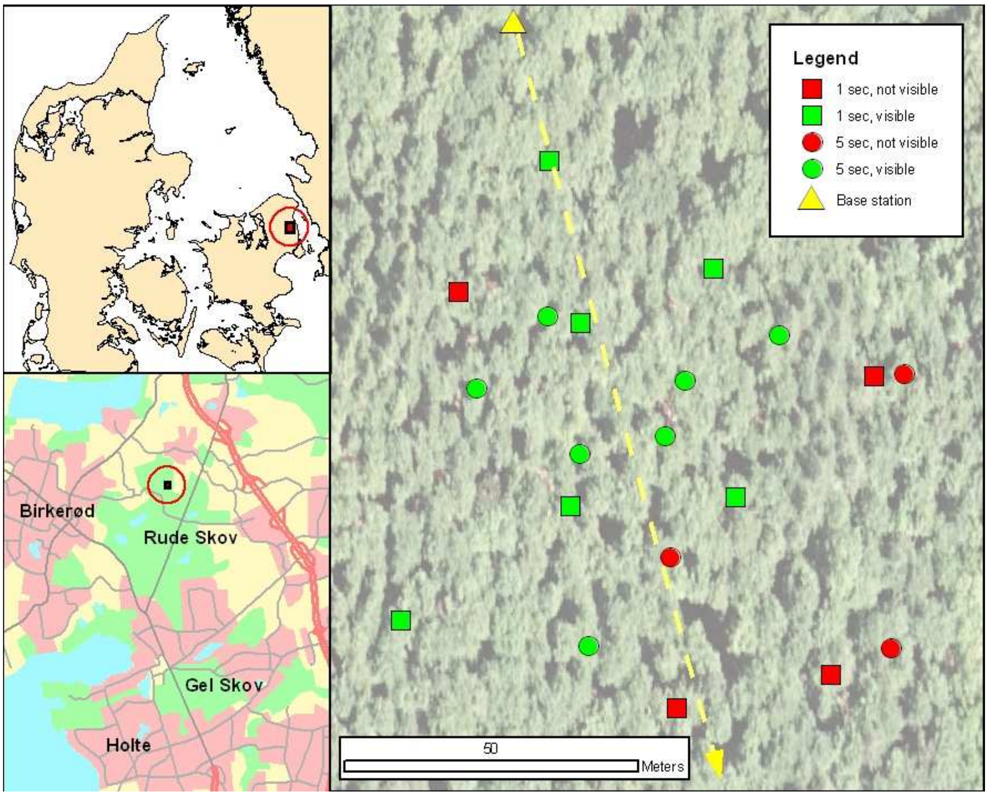

Figure 1. Location of fieldwork site and one out of five sessions. The controller and the respondent were located at the basestation. The targets location and the respondent's ability to see the target is indicated according to the legend. The 'central viewing angle' is indicated by the yellow dashed arrow.

STATISTICAL TREATEMENT

Based on the GPS recordings the distances and angles between base stations and target locations could be calculated and assessed as explaining variables for the probability of being seen. Logistic regression analysis was carried out in SAS™, using the LOGREC procedure.

Table 2: Parameter estimates and P values revealed from the logistic regression for the full model.

Parameter	**Standard Estimate**	**Pr > ChiSq**
Intercept	2.8644	0.0051
Angle	-0.0136	0.3611
Distance	-0.0236	0.0112
Session	-0.0287	0.9022
Exposure time	-0.0433	0.8724

As appears from table 2 only the distance and the intercept are significant for the explanation of visibility. The estimate for the effect of deviating angle from the central viewing line, has the expected sign (the further away from the central line, the less probability of visual contact). The P value for angle indicates that a larger number of observation could be expected to reveal higher significans.

The relation between visibility, angle and distances is shown in 3D in figure 2.

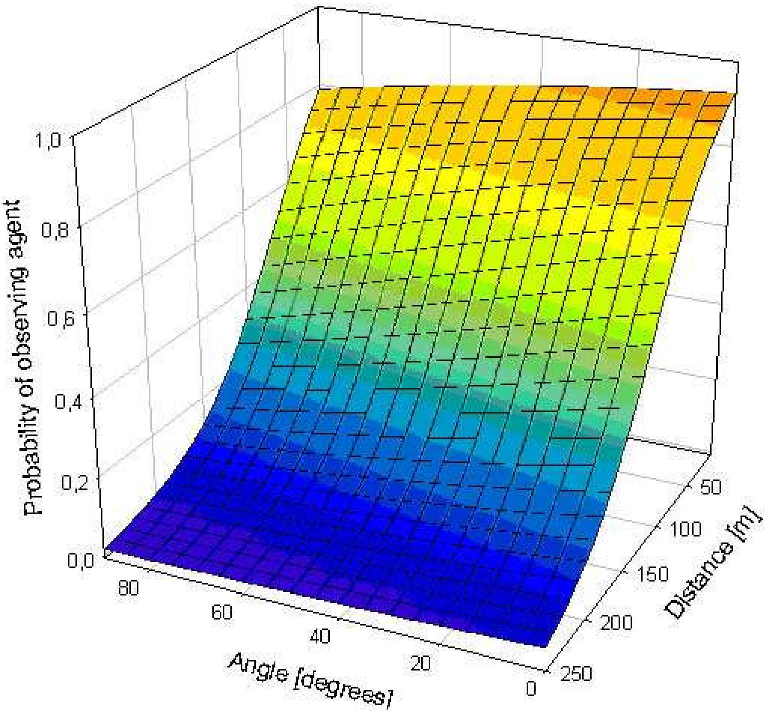

Figure 2: Illustration of the transparency decay as a function of distance and angle, based on logistic regression. Please bear in mind that the angle was shown not to have a significant effect and cannot be taken as authoritative. Illustration and statistical treatment by Associate Professor Henrik Meilby, Danish Forest & Landscape.

Table 3: Parameter estimates and P values revealed from the logistic regression for a model, including only the distance and intercept.

Parameter	**Standard Estimate**	**Pr > ChiSq**
Intercept	2.3235	0.0013
Distance	-0.0223	0.0100

The interpretation of the parameter estimate for distance (table 3) is a reduction of probability of 0.0223 per meter can be expected $(1 - 0.0223)^n$. Where n is the distance in meters). In table 4 below, the estimate applied to the distances used in table 1, is shown.

Table 4: Distance decay based on regression estimates of decay parameter.

		Distance from viewer (m)					
	Decay factor, per 25 m	0	25	50	75	100	500
Based on estimate	0.57	100%	57%	32%	18%	10%	0%

As it can be seen in tables 1 and 4, the decay parameters revealed from the field experiment are in the magnitude of those in table 1, somewhere between ‘Dense trees’ and ‘Very dense trees’. Optimally it would be expected that the measures should apply to ‘Low density trees’, but many things can influence the magnitude of the measures, including:

- Moving targets will be more visual (in the present experiment, the target was immobile)
- Different color outfits will be more or less visible (in the present case all targets were wearing back jackets).
- Definition of what is seen as ‘Low density forest’ or ‘Very dense forest’ obviously differ in different environmental settings.

The results of the field experiment cannot be used as a formal inductive proof of the figures found in table 1, but it points in the right direction. In the present context, the parameters of figure 1 will be used in the methodological development of the remainder of the presentation. The angular deviation from the central line will not be taken into further account.

CALCULATION METHOD

A prototype application was developed in JAVA. The terrain was represented by a 25x25 m Digital Elevation Model (DEM) provided by the Danish Survey and Cadastre. The DEM was resampled to 5x5 m and imported as an ASCII raster file. Data representing the vegetation was provided by the Danish Forest and Nature Agency. Land cover type, tree specie and –age was reclassified to correspond to the classes of table 1. Finally, visibility classes was converted to a 5x5 m raster and imported as ASCII.

A simple line of sight algorithm was applied on every possible combination of cells of the grid. The algorithm has two components: a) assessment of 'normal' line-of-sight and b) application of vegetation transparency.

Regarding a) The first step is to calculate the slope between vantage point (the viewer's position) and target point. Along the line towards the target point traversed cells are sampled, based on the slope between any of the sampled points and the vantage point, Boolean visibility can be assessed: As long as the slope for one cell is lesser than for the previous cell, it is visible. When this angle again gets steeper, the cells are invisible. The slope of the last visible cells is recorded as intermediate minimum slope. Still moving on along the line, the terrain continues to be invisible, until the slope raises above intermediate minimum slope, where the terrain again becomes visible. And so on….

Regarding b) Every time a new cell is sampled along the line, the transparency probability of the represent vegetation class is added to a list. Starting with 1 (absolute visibility) the decay value of every cell is multiplied. In the present version, invisible areas (e.g. in valleys) are treated as 'open'; even tough vegetation canopies could be interrupting the view.

The result is then stored as a PVG in a geo-enabled PostgreSQL database. The calculation of a 624 x 519 (in principle approximately $105*10^9$ iterations) grid took about 24 hours on a MacBook Pro 2Ghz Intel Core Duo with 2GB RAM.

A module was designed to query the PVG to return the probabilistic visibility, given two points or cells. Spatial indexes and caching enhances the performance of the query. Further, the PVG facilitates generation of ASCII raster grids depicting probabilistic viewsheds from given points - or even linear and areal objects.

RESULTS

Based on the parameters of table 1 and the application described above, resulting probabilistic viewsheds and PVG's will be shown. All examples are based on a viewing height of 2 m, whereas the height of the target object is assumed to be 1 m.

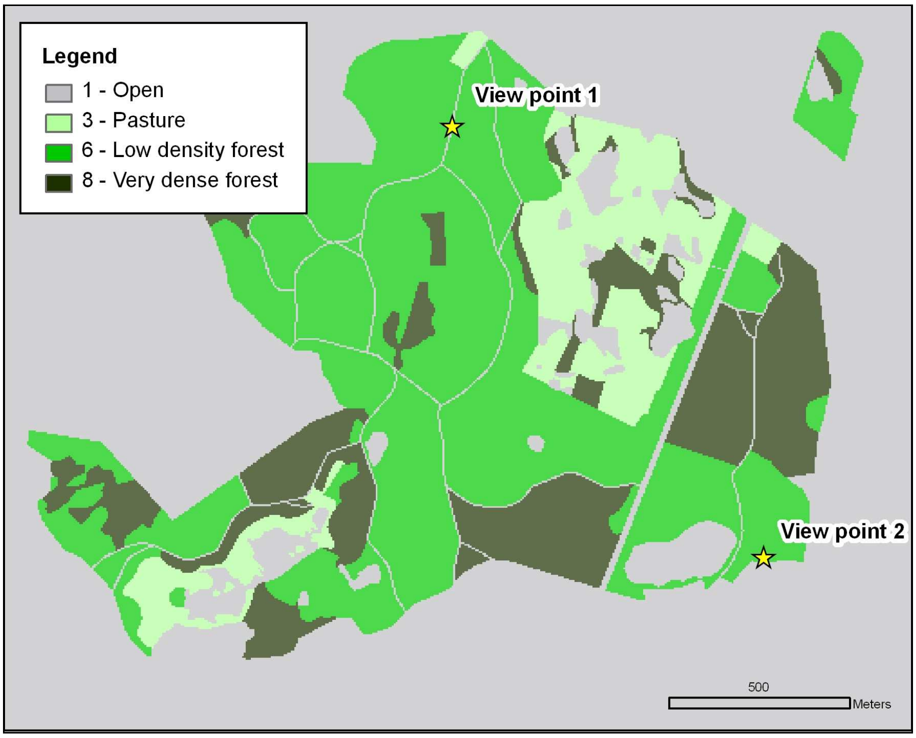

Figure 3: Northern part of Rude Skov, Zealand (Denmark). Land cover/Transparency classes applied (according to table 1). Viewpoints 1 and 2 are used in the examples in figure 4 and 5 below.

In figure 3 relevant land cover classes of the northern part of Rude Skov (Denmark) is shown.

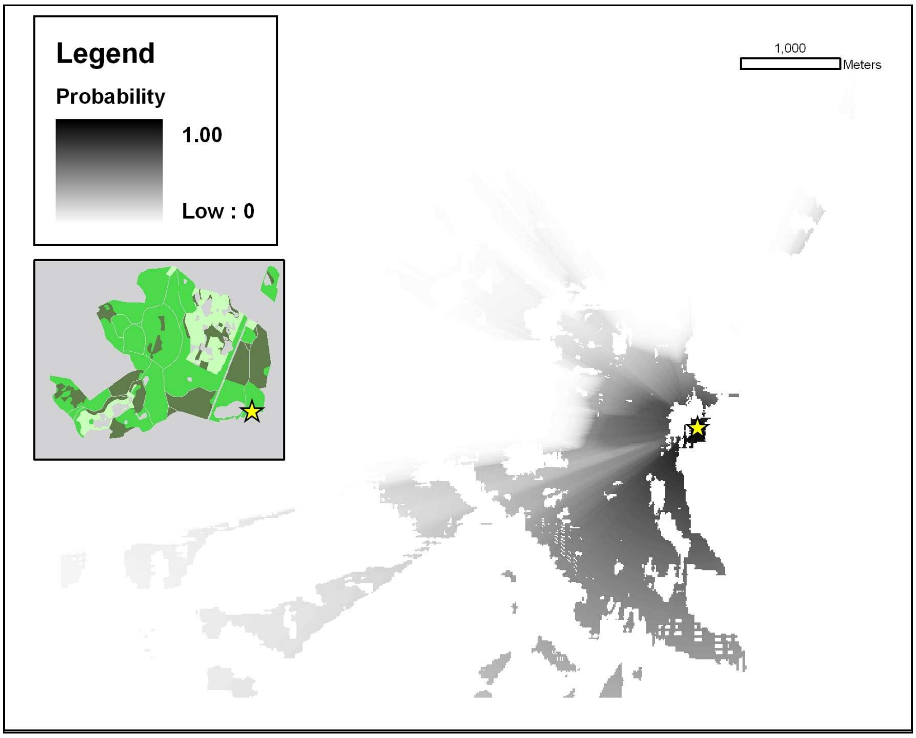

Figure 4: Example of probabilistic viewshed. Based on viewpoint 2 in the figure 3 above.

In figure 4 a probabilistic viewshed can be seen. From the point of departure, probabilities of seeing locations in the landscape – given the terrain and the vegetation – is seen. The shadowing effect of dense vegetation can be seen as rays.

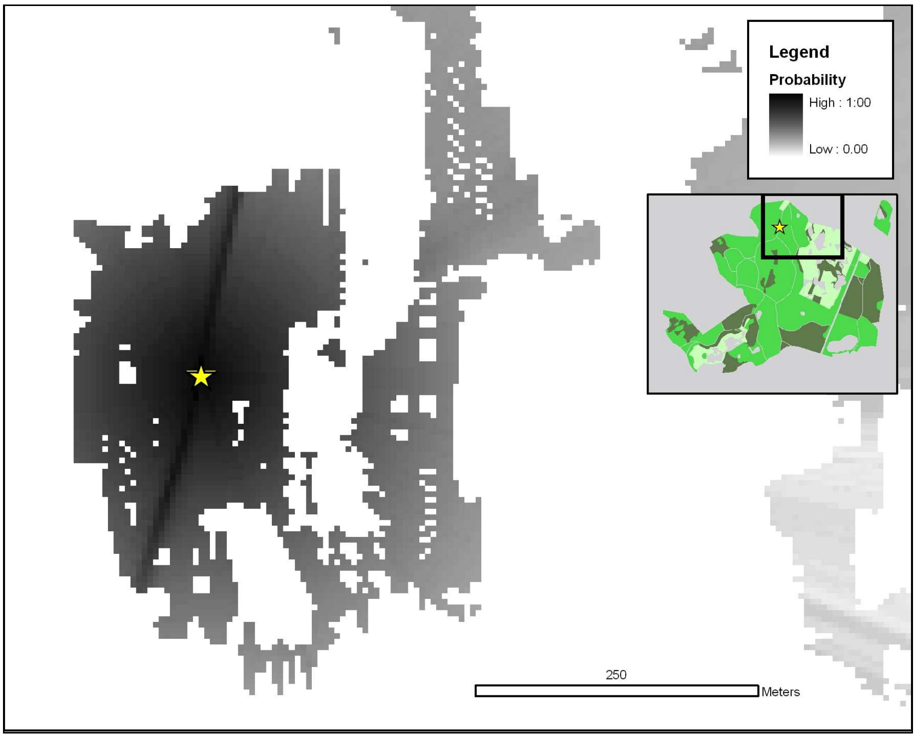

Figure 5: Details from probabilistic viewshed. Based on viewpoint 1 in the figure 3 above.

In figure 5 a detail of a probabilistic viewshed is shown. The viewer is located on a forest road. As expected the visibility is relative good along the road, when compared to the surrounding forest. This example shows quite clearly, how the spatial structure of visibility can be influenced by the vegetation type.

Col_1	Row_1	Col_2	Row_2	Probability
1	1	1	2	0.9852
1	2	1	3	0.9912
…				
1	1	389	256	0.0012
1	2	389	257	0.0000
…				
624	519	624	517	0.8898
624	519	614	518	0.8791

Figure 6: Selected records from the resulting PVG based on a 389x257 cell grid. E.g. is cell 389, 257 invisible from cell 1, 2, whereas the probability of visual contact between cell 624x519 and cell 624x517 is 0.8898.

If multiple lookups are required for a given application, storage of PVG in a database can be beneficial. Figure 6 provides an example of selected records of the developed database. In the present version of the application querying the database can be based on both cell references of geographical coordinates.

CONCLUSION AND PERSPECTIVES

This is only the beginning. No doubt probabilistic visibility enhances our ability to analyze – and may be understand – our surrounding environment. But there is still far more to investigate, develop and apply. Both in terms of field monitoring techniques and quantitative analytical methods can be developed.

Topics that can be further assessed include:

- Application of viewing angles. More empirical data is needed. E.g. the relation between movement speed and impact of viewing angle is of interest.
- Dynamic probability. Visibility analysis taking into account obstacles that might changes during the time span of a model run. E.g. smoke, weather- and light conditions and the number and type of other agents between the viewer and the target.
- Bidirectional decay functions. In the present case, visibility is treated evenly, no matter the direction of viewing. But e.g. looking in and out of a bush is not the same. Along the notions of the general graph theory, bidirectional visibility graphs can be developed.
- Objects ‘rising above’ valleys – e.g. the application of reduced visibility through canopies of trees being higher than the valley they are located in.

- Monitoring and application of different effects of stabile (as applied in the present case) vs. moving objects. This calls for further development of the present approach.

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