GEOGRAPHIC MODELING FOR EVALUATION OF THE LINES OF TORRES VEDRAS WHILE DEFENSIVE SYSTEM

Ricardo Abreu Figueiredo
Academia Militar and Instituto Superior Técnico, Lisbon, Portugal
ricardoabreufigueiredo@gmail.com

Abstract

With the use of a Geographical Information System (GIS), which allows much more than the simple maintenance and reproduction of spatial information, it is possible to simultaneously integrate and analyse several layers of information, and value useful items for the characterization of the territory. As an archaeological record is deeply linked with time and space, it is possible to use a GIS to establish spatial relations, combine environmental data of the described historical period and obtain useful characteristics for its comprehension.

The Lines of Torres Vedras, built to hold the early 19th century Napoleonic Invasions, were a highly effective defensive system taking advantages from the terrain and having an efficient communication system, aiming to adapt the defensive strategy to an offensive one. This study describes the geographic modeling of such defensive system, analyzing some of its main attributes, which may be used to characterize the systemic coherence and the efficacy of its intention.

Keywords: Spatial analysis; Geographic model; Defensive system; Lines of Torres Vedras; Archaeology.

1. Introduction

The analytical techniques used in Geographical Information Systems (GIS) enable the processing of large amounts of complex data. The knowledge offered to archaeological research through GIS-based analyses has benefited from their capabilities of exposing the spatial relations, incorporating temporal aspects, uncertainties and a large emphasis on the cognitive aspects of space. GIS have been widely used to develop theories and test alternative interpretations of space-related activities in ancient cultures (Fry *et al*. 2004). Given that most interpretations in archaeology depend or have geographical incidence, GIS show great potential in its adaptation to the study of the past, either in the management of the archaeological heritage, either in the study of archaeological sites, using archaeological data as the basis of work, for which GIS tools are useful (Martín 2007).

The case study applies to the Lines of Torres Vedras (LTV), a defensive system designed for the Portuguese and British troops (commanded by the Duke of Wellington) to cope with the Napoleonic forces during the 3rd French invasion in Portugal, in the early 19th century. This defensive system consisted of two lines in the North of Lisbon, at about 40 and 30 kilometers from the capital, respectively. There was also a third line around the Fort of São Julião da Barra, near the Tagus River. LTV works consisted in the construction and rehabilitation of a total of 152 fortifications, occupying defensive positions, taking strategical advantage of the terrain and covering the entire area from the Tagus River to the Atlantic coast. On the basis of such defensive functioning of LTV was a telegraphic communication system, consisting of 10 stations of signals, allowing the rapid transmission of messages.

Despite the large extension occupied by LTV and the thousands of people who have been involved in the planning, implementation and occupation of the defensive system, the secrecy in which it relied, needed to prevent its disclosure to the Napoleonic troops, causes a large information gap in the historical documentation of this construction, preventing a correct perception of the full functioning about the historical event. The iconographic and historical sources that exist for this subject are scarce and often ambiguous, giving some general ideas about the process, but without precise and concrete information about a particular subject (Luna *et al.* 2009).

The site choices for the structures are the result of a slow process of maturation and local topographic knowledge. As such, this project, understood as the decision of choosing the locations of the fortifications, constitutes a system geared towards the early detection of enemy approach, allowing to move troops and to adapt defensive strategies to the specificities of the attack. The analysis of the proper functioning of the LTV as a defensive system needs to assess the ability to communicate between forts and telegraphic stations, with the distribution of these over the terrain in order to isolate the entire peninsula of Lisbon, and with the location of the forts in topographic positions which enabled a defensive advantage.

The objective of this work is to draw up a model and a methodology allowing: the study of the LTV fortification distribution, using the parameters and values obtained by spatial analysis and the application of functions available in a GIS; contribute to the understanding of the history of the defensive system of Lisbon; evaluate the communication system used at the time for the proper functioning of the LTV; evaluate the deployment of forts individually and systemically, with regard to their coherence and effectiveness; lay the foundations for an archaeological predictive model, obtaining indices of characterization to explore the territory in the detection of sites to install defensive equipment as those at the analysed epoch. The resulting analysis of this defensive system has, as their main objective, the support and the assessment of the consistency of elements which characterized this historical event.

2. Methodology

For the construction of a workable model of the defensive system, LTV were characterized. The collected data was chosen by considering all of the known forts in the region, and a compilation of all the retrieved data was done. These data were also checked using the Google Earth service, where it was possible to observe many of the fortifications or traces of them over the displayed imagery.

The topographic maps used for terrain modeling were the M888 Series from the Portuguese mainland (scale 1/25 000) and “Arredores de Lisboa” series (scale 1/20 000), provided by the Geographical Institute of the Portuguese Army. The software used to build the model and analyse the defensive system was ArcGIS 9.3.1 (ESRI®, ArcInfo version, 3D Analyst and Spatial Analyst extensions), with a license provided by Instituto Superior Técnico. Obtaining the region’s digital elevation model (DEM) resulted from a process that used the basic information of the 1/25 000 maps, analyzing contours, height points and streams. A TIN

(Triangular Irregular Network) model was built, later converted to a regular square grid with 25 meters of spatial resolution.

To carry out various studies of the LTV defensive system the following spatial data sets were also included in the project: structures from the first and second lines of fortifications; location of telegraphic stations; macadam roads from 1/20 000 maps of the series of "*Mapas dos Arredores de Lisboa*"; and additional points of interest needed to evaluate the communication with Lisbon (Castle of St. Jorge, Alto de Monsanto, etc.). Figure 1 illustrates some of these datasets.

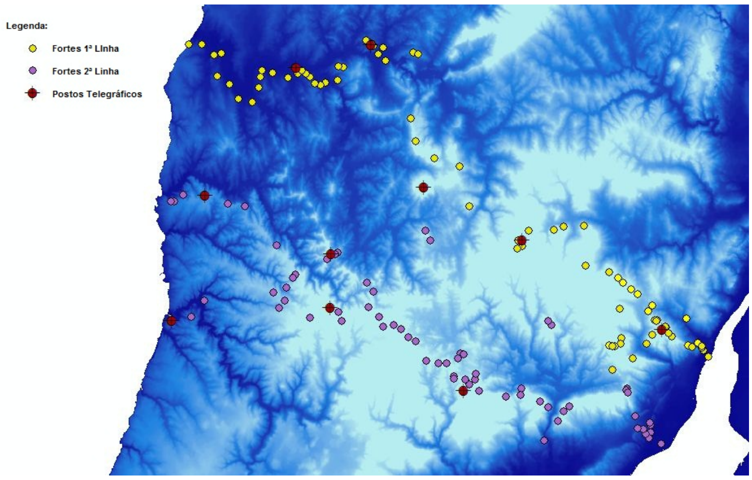

Figure 1 – Model for analysis of the defensive system.

To analyse the functionality of the communication network, visibility analyses were carried out (using the line-of-sight operation, an existing function in the GIS software). This function allows, by entering the height that the observation point is above a point designated as an observer, to test the visibility to a target point, for which height can also be defined.

The methodology consisted in an individual analysis of each telegraphic station as an observer of all others, adopting an height of 2 meters above the terrain for the observer, considering that he could locate himself in the best observation position, and a height of 6 meters, considered as the average height of telegraphs.

It was also devised an analysis of communication with the telegraphic station of Monsanto, similarly to the previous analysis, to sustain a communication axis with Lisbon. From this station, communications with all telegraphic stations were tested, and also with Fort of S. Julião da Barra and the St. Jorge's Castle. This telegraphic station, for the purposes of analysis, was positioned where it is now the Monsanto prison, since, as other telegraphic stations, its exact location is unknown.

In the designation of a distance limit of observation/perception of telegraphic messages, a visual boundary of approximately 13 kilometers was adopted, has it was described in Luna *et al*. (2009), referring to the memoirs of Captain John Jones describing the placing of telegraphs, to allow good visibility among them (with distances between 10 and 13 kilometers).

In order to enable analyses on the correct positioning of the fortifications, determine its importance in the context of the defensive system and to characterize them individually, the following parameters were studied: individual parameters (i) dimension; (ii) height; locational parameters (iii) landform classification; (iv) proximity to terrain obstacles; and (v) proximity to roads; and integration parameters: (vi) visual dominance; (vii) index of intervisibility.

The classification of the forts as their dimension (i) was part of a survey of archaeological data, after which the forts were classified as small, medium or large, taking into consideration the perimeter and area. The heights of the forts (ii) were obtained by running a GIS function (extract values to points) which consists in the extraction of the DTM raster values for the points scattered in the analysed space.

To extract values of the locational parameters, the application of a landform classification (iii) was useful, as it is related with the assumption of a correct positioning for all the forts, which would have taken advantage of the terrain, and allows the characterization of the favored terrain morphologies for the location of fortifications. To execute this analysis an additional toolbox ("Topography Tools", Jenness n/d) was used. The function which sorts the field in 10 classes is the Landform Classification, which takes as input the raster DTM, creating a new raster with the values of the landform classification of the terrain. To assess the proximity of forts to obstacles (iv) an analysis through the existing slope-function, considering terrain slopes greater than 25 degrees correspond to steep climbs, was executed. For the proximity analysis of forts to communication roads, which allowed the movement of troops and materials, the macadam road map was used.

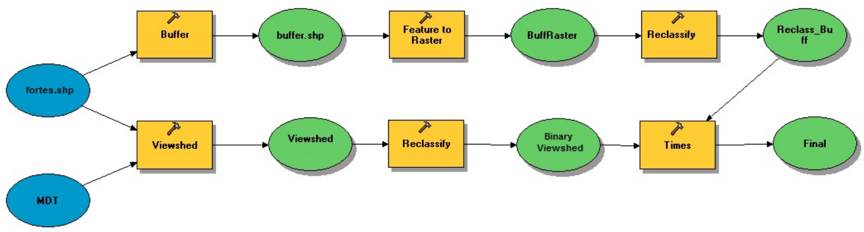

Figure 2 – ModelBuilder diagram of the sequence of operations for the calculation of visual dominance.

The integration parameters are assessed through a visual dominance evaluation (vi), within a certain area of influence. The calculation is carried out through the analysis of *viewshed* visibility, creating a binary viewshed in which the value 1 is identified as visible areas (cells) of the resulting raster, while zero-valued areas (cells) are not visible (either from a specific fortification, or from a set of fortifications). In this context, it is intended to quantify the percentage amount of visible terrain by one fort in an area covering a circle for which the radius is related to a limitative distance of visibility. It was adopted the radius of 6600 meters, considered by Higuchi as a threshold of the average visibility, defined as being the visual limit up to which it can be distinguished a forest, a path or shape of the terrain (Wheatley & Gillings 2000). For the calculation of this index, an algorithm was produced in ModelBuilder, the diagrammatic specification of spatial analysis operations of the used software (Figure 2). Assigning an intervisibility index (vii) to the forts of LTV provides an interpretation of visual integration of these in their respective lines, determining how many fortifications can be seen from a particular fort. This analysis is to perform the viewshed function for a group of fortifications at the same time, assigning each DTM raster cell the number of positive visibilities, forming an intervisibility raster. Questioning the functioning of the defensive system, it is also needed a collective functioning analysis, concerning the timely detection of enemy troops and their intervisibility, enabling the communication system installed in the defensive lines to quickly adapt the strategy to deal with the presence of enemy troops.

3. Results

3.1 Analysis of the communications system

The visual connections between telegraphic stations were assessed as **visible**, **not visible** or **conditioned**. Results considered *positive*, i.e., that verify the visibility between the telegraphic stations, were those which, for a distance less than the 13000 m limit, there is no possibility of existence of any visual obstructions. The *negative* results were those that did not conform to the adequate communication conditions, where analyses presented obvious obstructions or the possibility of the existence of these. Results were considered to be *conditioned* if there are no visual obstructions but the distance between telegraphic stations is greater than the limit, or if there is the possibility of existence of visual obstructions at a smaller distance. The analyses have enabled a qualification of the visibilities between the stations, (Table 1 and Figure 3).

14	Forte do Alqueidão, Forte Grande	14									
21	Forte de São Vicente	15928	21								
30	Reduto do Grilo, Ponte do Rol	18521	5265	30							
118	Forte dos Sinais, Forte do Moinho Branco	10795	26316	29289	118						
A	Serra do Socorro	7290	9756	11377	18075	A					
76	Forte do Sonível	13214	17263	15763	21644	9901	76				
80	Forte da Quinta da Boa Viagem (Chipre)	12440	13784	12294	22095	7383	3527	80			
91	Forte da Alagoa	20830	14641	10159	30999	14214	10958	9045	91		
97	Forte de São Julião	23380	22190	18326	31921	18537	10353	11265	8465	97	
B	Cabeço de Montachique	10480	23174	23659	13547	13478	10198	12387	21075	19508	B
C	Prisão de Monsanto	28262	41133	40793	25669	31612	25250	28563	35329	29772	18266

Legenda:
Vísivel
Não visivel
Condicionado

Table 1 - Table of visibilities between telegraphic stations.

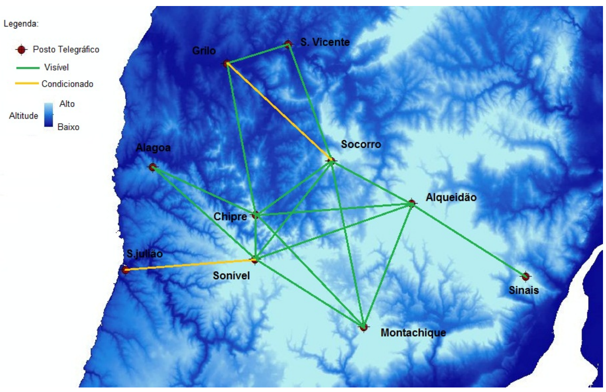

Figure 2 – Communications' scheme between telegraphic stations.

This scheme of communications between telegraphic stations represents the communications considered *positive* and *conditioned*, and leads to the following conclusions:

São Julião's telegraphic station depended solely on visual contact with the Sonível station, being the communications between these stations considered conditioned; Sinais telegraphic station, despite being in line of sight with Montachique and Sonivel stations, depended on the communication with Alqueidão station; the stations of Alqueidão, Socorro, Chipre, Sonivel and Montachique, altogether, established a strong circle of communications as they all could see each other; the communication between the three forts on the Atlantic coast, Grilo, Alagoa and São Julião, was null and void; communications with the Navy, on the Atlantic coast, had to be done through Alagoa telegraphic station, and on the Tagus River through Sinais station. Although the analyses show that the stations of Montachique, Sinais and Alqueidão are in line of sight with Monsanto station, the telegraphic communications are considered null due to the large distance between stations.

This analysis allowed the identification of an efficient communication system between the central telegraphic stations, which ensured the communication between both lines, demonstrating that the communications with the outermost stations were guaranteed by the central telegraphic stations, with little or no communication between the peripherical stations.

3.2 Evaluation of the defensive system

For the systemic behavior appraisal, interpretable parameters which were considered to express the functioning of the defensive system were the *intervisibility* and the *visual dominance*. These analyses are applied to a set of forts.

Visual dominance was examined for the two lines in separate, allowing the assignment of an index to each. From the analysis of dominance for the first Line (Figure 4), an index of 55.68% it was obtained. It is possible to note the following aspects: the existence of a full coverage of the front line, allowing the detection of attacking forces in all the directions of possible approaches; there is a visual dominance to the rear of the line, indicating a possible visual contact between lines; there is a strong visual domain of the Valley of the Sizandro River.

The visual dominance analysis of the second Line (Figure 5) resulted in an index of 33.92% and allowed the following considerations: a predominant factor for the front of the line is observed; there is positive visual contact with many of the forts of the first line, with the exception of those in the Sizandro River Valley.

Interpreting the results for both lines, it can be seen that, based on agglomeration of the forts in Sizandro's Valley area and given the visual dominance over this (Figure 4), the Sizandro's zone was, in the military tactical plan of Wellington, structured to stop the enemy, taking advantage of the natural barrier offered by the river, establishing an effective defense of the area but the fortification of the following areas was neglected to this axis approach (West zone of LTV), particularly in the Sarafujo and Lisandro River, where if they observe the construction of some forts on the second Line but outnumbered and with low visual dominance (Figure 5). It is also noticeable that there are four forts belonging to the second Line (Figure 5), (Forte Grande da Ajuda, Forte Pequeno da Ajuda, Forte Pequeno da Enxara and Forte Grande da Enxara), which are detached from this line, allowing the visibility of the 2nd to the 1st Line and vice versa. The defensive device in LTV's central zone foreshadows, through these forts and the larger fortification of the 2nd Line, the probability of the existence, in the tactical plan of Wellington, of a mobile defensive system, using the sharp features of relief to install such facilities. These four forts could also be associated with the fulfillment of that tactical plan, and constitute intermediate defensive positions to slow the enemy, while the forces arranged in the 1st Line regroup in the 2nd Line and then stop the enemy.

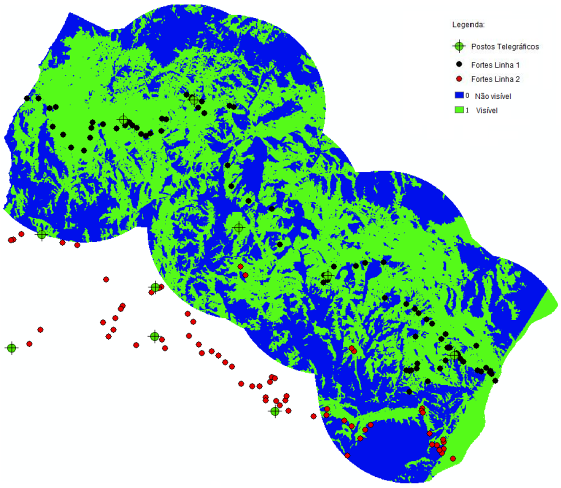

Figure 3 – Visual dominance map of the first Line.

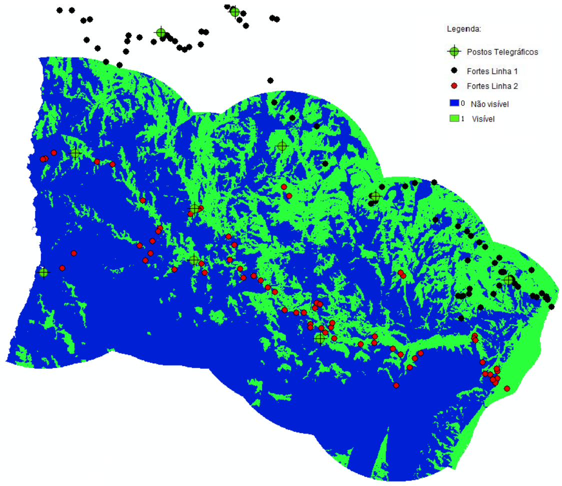

Figure 4 – Visual dominance map of the second Line.

The intervisibility analysis was designed in separate for the two lines, giving rise to two maps. The first map corresponds to the intervisibilities of the first Line (Figure 6) and allows observing: a great visual impact on the North side of the Sizandro River; a high level of intervisibility in Serra do Socorro and Serra de Montejunto; a line with higher intervisibility index, on which are the most part of the 2nd Line forts. The second map corresponds to the intervisibilities of the 2nd Line (Figure 7) and allows to observe: a heightened visibility to the North of the Line, especially in the East area of LTV; good visibility of the northern slope of the Serra de Sintra, of the Serra Chã area, of the Castle slope area and Monsanto; a limit of visibilities coincident with the first Line is also noticed.

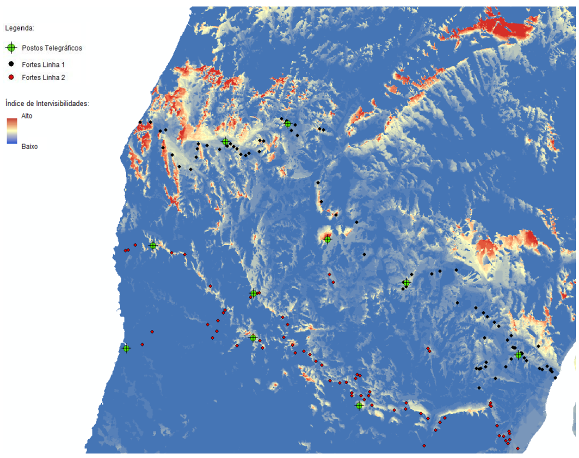

Figure 6 – Intervisibilities map of the First Line.

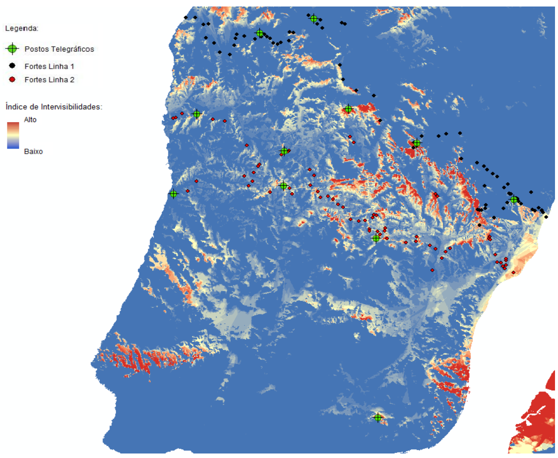

Figure 7 – Intervisibilities map of the Second Line.

Through the analysis of the relief, it is shown that Serra de Montejunto was a natural obstacle to the movement of the troops of the invader general Masséna, splitting Wellington's defensive planning in the two areas mentioned above.

Results from the intervisibility analysis confirm the existence of two terrestrial defensive tactical systems: Sizandro River, detaining the French invasion west of Serra de Montejunto and a central one, which could hold the French invasion on its eastern side.

The largest agglomeration areas of forts can then be easily interpreted as crucial engagement areas of the British and Portuguese troops.

The defense of a possible entrance next to the Tagus River was also studied, demonstrated in the previous analysis by the total visual coverage of this area and the high rates of intervisibility.

There are two areas of the intervisibilities analysis that stand out from the others, for which the interpretation allows to unravel a major role in the defensive system: the northernmost area of Serra de Montejunto, which features a high index from the first Line, raising the possibility of the existence of a communication outpost, being possible to identify the direction and position of approximating enemy troops, with the characteristic of allowing timely preparation of the defensive system; and the zone of Serra Chã, which features a high index from the second Line, raising the possibility of the existence of a telegraphic station to effectively communicate between Montachique and Monsanto.

3.3 Integration of the Fortifications in the Defensive System

The integration of the forts in the defensive system seeks an interpretation to the individual assessment of all fortified positions, highlighting its usefulness in the defensive system.

The evaluation parameter about the morphology of the terrain (Landform Classification) has not demonstrated significant variations, serving only to evaluate the deployment of most of the forts in classes 7 (plateaus and slopes of gentle slope) and 10 (steep ridges and ridges), demonstrating the adequate use of land position for the deployment of forts (advantageous defensive positions).

In both lines forts were found without visual communication with the respective line (Table 2), having obtained an average value of visual dominance of 10.08%.

In conclusion, Fort of São Julião presents very low values for the spatial parameters analysed here (Visual Dominance: 6,87%; Intervisibility: 4), so the existence of a telegraphic station in this fort, turns out to be a weak feature, which is accentuated when it overlaps with the analysis results for the communication with other telegraphic stations. The Fort of Alagoa also revealed low spatial parameters (Visual Dominance: 3,92%; Intervisibility: 6), however, in the communication analysis, it establishes communication with two telegraphic stations, being the only exterior telegraphic station in line of sight with more than one central station. Finally, the Fort of Archeira, due to its size and the spatial parameters obtained (Dimension: large; Visual Dominance: 13,41%; Intervisibility: 23), may have had an important role in the defensive plans of the Duke of Wellington.

Numeração		Identificação		Avaliação dos Fortes				
Linha	N.º Forte	Nome	Concelho	Sinal	Cota	Dim	LF	DV
1	5-C	Bateria 2ª de Alfarge	Vila Franca de Xira	0	182,75	S	4	1,98%
1	4	Bateria de S. Fernando	Vila Franca de Xira	0	56,63	S	4	7,41%
1	5-B	Bateria 1ª de Alfarge	Vila Franca de Xira	0	265,88	S	1	7,44%
1	120	Forte Novo do Formoso	Vila Franca de Xira	0	296,65	S	7	8,16%
1	5-F	Bateria 1ª da Serra do Pinheiro	Arruda dos Vinhos	0	259,77	S	1	14,63%
2	43	Bateria do Vizo	Loures	0	243,25	S	7	2,00%
2	127	Forte do Moinho, Forte da Boca da Lapa	Vila Franca de Xira	0	110,00	S	7	11,41%
2	45	Bateria do Penedo	Loures	0	243,28	S	7	19,35%
2	48	Forte do Tojal, Bateria da Espadarinha	Loures	0	100,21	S	7	11,41%
2	78	Forte do Telhadouro, Forte do Picoto	Mafra	0	223,17	S	10	5,96%
2	42	Reduto da Portela Pequeno	Vila Franca de Xira	0	262,51	S	7	7,52%
2	47	Bateria dos Galvões	Loures	0	194,42	S	10	11,27%

Dim – Dimension; S – Small; LF – Landform Classification; DV – Visual Dominance.

Table 2 – Forts without intervisibility on the Line.

3.4 Predictive Modeling

With the purpose of building a predictive model, that allows to explore the territory in the detection of the sites conducive to defense equipment installation, such as those at the analysed epoch, in the course of this work there the following spatial characterization indices were obtained: the morphological classification of terrain features a predominant index of value 7 (plateaus and slopes of gentle slope) and 10 (steep ridges and ridges), values that occur in 41% and 49% of the forts of LTV, respectively, constituting an index of high reliability; the distance to the communication roads (in this case to macadam roads represented in contemporary maps), also constitutes an index, in that it allows to determine an area of influence over these (430 meters as an average value); the distance to high slope areas (more than 25 degrees), allows to further refine the study area, eliminating the areas with a slope greater than this value and creating an area of influence around these of approximately 110 meters (average value).

When the observed tendencies are expressed, these parameters can be applied to other areas to reveal patterns of probable sites, or, in contrast, to explain patterns of the establishment of terrain occupancy (Whitley 2006).

4. Conclusions and Future Developments

Despite all the approximations made, the model built in this work and analyses enabled by it allowed to obtain some interesting results. Better results where obtained in the evaluation of the forts while these were considered as units of a defensive system (Visual Dominance of 55,68% for the first Line and 33,92% for the second), than when individually considered (Mean Visual Dominance 10,08%). This expresses that the facilities took advantage of their position on the terrain, both in defense and in communication. This fact proves the qualitative perception of Berger (2009), who stated: "More than simple lines of fortified defensive positions, the Lisbon Defense Lines were a masterpiece of the use of the terrain through its cartographic knowledge, the speed of construction, the secrecy of the same and even more, the idealization of a tactical system based on the defender army's mobility and in the speed of communications".

Through this work it is observed that the possibility of integration of relevant defense data, logistical planning and communications turns GIS into a fundamental tool for the proposed analytical tasks.

This study can serve as the basis for future projects related to the management and analysis of heritage resources, taking especially into account the enormous potential of these tools. The presented predictive model is an example of an extension, and can serve as a useful tool for the archaeological field work and historical reconstruction analyses.

As future developments, the presented work may act as a basis for, among other possibilities: improve the rigor of the visibility analyses, incorporating parameters considering the guidelines of the preferred visual fields; use probabilistic vision basins, to test the dominance of each fort in relation to its immediate, intermediate or more distant areas, enabling to inspect on its ability in the early detection of enemy armies, or in the reinforcement of intermediate positions; test *in situ* the plausibility of the communications system, suggesting appropriate values for a later parameterization of visibility, adapted to each fortification; and use the predictive model for the location of any smaller forts or mobile communication devices, strategically placed to an additional coverage of the terrain, or to enable the efficient communication with points out of the defensive lines.

References

Berger, J. P. (2009) "A Engenharia Militar na Salvaguarda do Património Nacional". *Ingenium* Nov./Dez. pp. 76-77. ISSN0870-5968.

Fry, G. L. A.; Skar, B.; Jerpasen, G.; Bakkestuen V.; Erikstad, L. (2004) "Locating archaeological sites in the landscape: a hierarchical approach based on landscape indicators". *Landscape and Urban Planning*. 67: pp. 97-107.

Jenness, J. (n/d) *ArcView 3.x Extensions by Jenness Enterprises.* (available on the Web at:http://www.jennessent.com/downloads/TPI_jen.zip. Acessed July 2011).

Luna, I.; Sousa, A. C.; Leal, R. S. (2009) "Telegrafia Visual na Guerra Peninsular. 1807-1814". *in Boletim Cultural 2008*. Câmara Municipal de Mafra. pp. 67-142.

Martín, A. M. (2007) *Using GIS to Deconstruct Iberian Iron Age Landscapes: The Territory of Kelin Between 6th – 5th Centuries BC (La Plana d'Utiel, Valencia)*. Layers of Perception – CAA. pp. 1-7. (available on the Web at: http://archiv.ub.uni-heidelberg.de/propylaeumdok/ volltexte/2010/519/pdf/ 08_08_martin_kelin.pdf. Acessed August 2011).

Wheatley, D. W.; Gillings, M. (2000) "Visual Perception and GIS: developing enriched approaches to the study of archaeological visibility". *in* Lock, G. (ed.) *Beyond the Map: Archaeology and Spatial Technologies.* IOS Press. Amsterdam. 29 p.

Whitley, T. G. (2006) "Predictive Modeling in a Homogeneous Environment: An Example from the Charleston Naval Weapons Station, South Carolina". *in* Meher, M. W.; Wescott, K. L. (eds.) *GIS and Archaeological Site Location Modeling*. First Edition. Taylor & Francis. pp. 355-391.