GEOGRAPHIC MODELLING OF THE PERMEABILITY OF THE LINES OF TORRES VEDRAS DEFENSIVE SYSTEM

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Abstract

The use of Geographic Information Systems (GIS) as modelling tools allows far more than the collection and reproduction of spatial information, as the integration and simultaneous analysis of various layers of information generates valuable new data for territorial characterisation. As such, and being the largest part of military usage of the territory dependent on a thorough analysis of its morphology, spatial analyses in GIS reveal a great potential as a way for studying battlefields and/or other military buildings and scenarios from the past, while supporting interpretations of territorial occupation and related organisation of military forces through event simulation.
This work comprises a GIS-based analysis of the Lines of Torres Vedras (LTV) defensive system, a multi-line fortification complex which was operational during the Peninsular War in the beginning of the 19th century and located north of Lisbon, Portugal. The structures of the LTV, contemporary weaponry, communication infrastructure the local terrain were described, modelled and characterised using a set of proposed parameters that support territorial analysis. A methodical quantification and combination of these parameters enabled a better understanding of the systemic operation of the defensive lines in terms of its permeability, contributing to a discussion of the LTV particular military setting based on the interpretation of these indicators. Global and sectorial analyses of the permeability of the LTV defensive system were conducted.

Key words: Territorial Analysis, Geographic Information Systems, Defensive Systems, Torres Vedras Defensive Lines, Napoleonic Wars.

Introduction

In the last decades there have been countless studies sustained by spatial analysis based on Geographic Information Systems (GIS) in the archaeological and historical reenactment fields. Given that a great part of archeological studies depend on geographic incidence, GIS are of great utility both on patrimonial management and in fieldwork on archaeological sites, by allowing a simultaneous consideration of form, space and time, all of which are considered separately in traditional approaches. As such, it is possible to recreate ancient structures or simulate past events, quantifying a series of spatial parameters in order to create GIS-based indicators for territorial characterisation, allowing new ways to study of the past.

The focus of this work is the study of the Lines of Torres Vedras (LTV) defensive complex, built to defend the region of Lisbon from land invaders. Fletcher, the British chief engineer responsible for this military project, planned a defensive system divided in four different lines composed by a chain of fortifications, which, despite not forming a continuous closed line like Hadrian's Wall or the Great Wall of China, had a series of strongholds heavily armed and with the capability to hold a line of open fire (Norris & Bremner, 2001). Two of the lines were located 40 and 30 km north of the Portuguese capital, going from the Atlantic coast up to the right bank of the Tagus River, strategically taking advantage of the irregular terrain. Their purpose was to hold back any possible

attack from the Napoleon's *Grand Armée*. The third line surrounds the fort of S. Julião da Barra, and although this one had all the best firepower available at the time and was capable of launching long distance attacks, its sole purpose was to protect the English contingent in an eventual fall back, if the first two barriers were unable to stop the advances of the French army (Ferraz, 1909). The forth line was located near Almada and its purpose was to halt any French forces which may have arrived at that point from threatening the capital or the fleet docked in the river (Barata *et al.,* 2004). The smooth operation between these lines depended on a complex system of telegraphic communication that allowed a fast internal exchange of messages (Figueiredo, 2011; Norris & Bremner*,* 2001).

Using GIS, the LTV defensive system was modelled and characterised using parameters for territorial analysis. The methodical quantification of these is expected to provide better understanding of its systemic operation in terms of permeability, which is defined here as a measure of the probability of the defensive lines being crossed by attacking forces.

As such, the objectives of this work are:

- to build a GIS model for the distribution of the LTV fortifications, and expand it to include the communication lines used in the 19th century;
- to propose a model that expresses the defensive capabilities of each stronghold in the LTV lines, based on the characteristics of the contemporary firepower and weaponry;
- to propose and implement an analytical approach to evaluate the permeability of the LTV system, enabling the assessment of its efficiency in defending the communication lines against enemy attacks.

The proposed analyses refer to two historical periods: the state of the LTV will be identified for both the periods of 1810 (during the Third French Invasion) and 1812, when the improvements in the fortifications were concluded.

Methodology

The methodology of this work includes three stages: (i) construction of a GIS project, (ii) modelling the weaponry, and (iii) analysis and interpretation. All GIS operations were conducted in ArcGIS software, a desktop GIS with spatial data analytical capabilities.

Construction of a GIS project

Firstly, to make a representative model it was necessary to acquire, process and integrate in a GIS all the information available that might be useful to characterise the LTV system and the surrounding terrain. It was necessary to confirm the precise location of the strongholds that composed the lines. For that an analysis of two distinct sources (Figueiredo, 2011), (DIEP, n/d) was performed; in cases where both sources were not coincident, satellite images available at the Google Earth software and the local terrain were used to scrutinise the possible location of the structures. A digital elevation model (DEM) made for this essay was based on topographic maps at a 1:25 000 scale (M888 series from the Portuguese Army Geographic Institute), using contours,

height points, and stream lines to generate a TIN (triangulated irregular network) which was later converted into a RSG (regular grid) with 25 meters of spatial resolution.

In order to figure out the layout of the contemporary roads in the area, the maps *Esboço da Carta Itinerária Militar*[1] and *Roteiro das Linhas de Torres Vedras*[2] were used. After georeferencing these datasets, it was possible to digitize roads and paths in the region of the fortifications (Figure 1). Still, there were gaps between some of the sections of roads that were impossible to identify. To overcome this situation, a series of local cost surface analysis was done to suggest the most probable path connecting each pair of endpoints of missing sections of roads that were mapped in the sources.

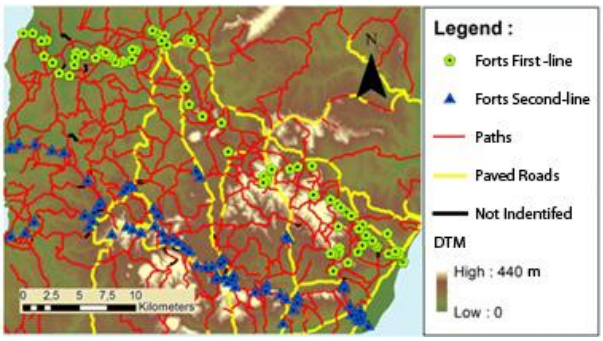

Figure 1 – Layers used in the analysis: terrain, roads and fortifications

Modelling the weaponry

In the Peninsular War period, the Portuguese Army used the same doctrine as their British allies, resulting in the artillery made by the Portuguese having the same characteristics as the English weaponries. So, in order to overcome the lack of data on weaponry manufactured by the Portuguese (6 lbr, 9 lbr and 12 lbr artillery), English data was used. These were acquired through studies conducted in 1835, with the objective of documenting the effectiveness of the cannons from the beginning of the 19th century (Wise, 2004). A quadratic function was obtained by regression analysis to identify and quantify the probability of a target being effectively hit by a cannon shot, based on weapon to target distance: areas near fortifications were normally hit by fire from different redoubts, this crossfire being more effective and having a more traumatic effect for the attacking troops. However, for this particular case study, this possibility was not considered because a quantification of this effect in shooting success was not found. Figure 2 displays the obtained function for the 6 lbr case.

To create a model of the firepower of the artillery it was necessary to determine the attack perimeter of each fortification. An analysis of visibility was made using viewshed tools in the GIS software to obtain the areas around each fortification that are visible from it (Figure 3). This analysis is merely approximate as, unlike current artillery, the cannons back then performed a kind of tense shot, failing to hit effectively blind spots. For this analysis, it was considered that the location of strongholds allowed their garrisons to see and open fire in every direction, based on the fact that the strongholds possessed openings or embrasures covering all shooting directions. In the viewshed calculations, observers were considered to be in the position of the weapon

[1] Topographic map *Esboço da Carta Itinerária Militar* by Majors Neves Costa and Frederico de Caula (1809), at the 1: 110 000 scale

[2] Topographic map *Roteiro das Linhas de Torres Vedras*, 1956, at the 1:50 000 scale

nozzle, 2 m above the terrain level, as on average the cradle part of the weapon would normally be placed at approximately 1.2 m above the battlement of the redoubt, also being above the normal level of the terrain.

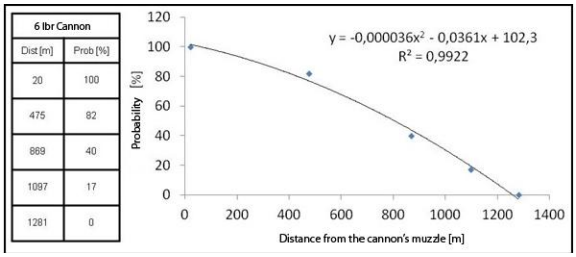

Figure 2 – Regression analysis: equation and graph used for modelling 6 lbr cannon.

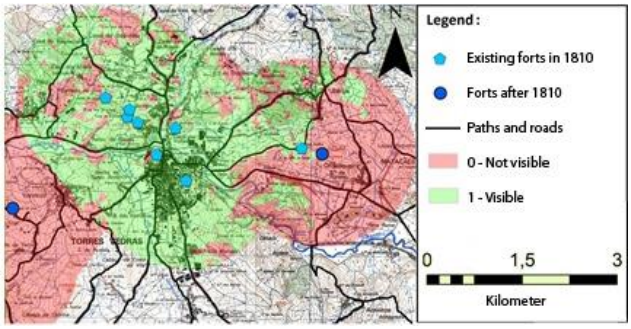

Figure 3 – Area visible from the strongholds with the purpose of defending Torres Vedras. This area also corresponds to the area with most potention for being under fire.

It was necessary to integrate the probability of fire success, because not only the accuracy of the weapons depended on the distance to target but also the artillerymen, deprived from a good logistical system, were forced to shoot only when success was granted, to save ammunitions, gunpowder, the pieces of artillery (which had limited usability time) and other resources, such as the rations for the animals. As such, shooting success from the distinct fortifications was calculated with the proposed modelling functions, enabling the evaluation of the region in terms of the overall permeability. Probability values also considered that cells that could be hit by projectiles from several forts, with different probabilities of success, assumed the highest of the corresponding probability values.

Analysis and interpretation

Between late 1810, at the time of the arrival of the André Masséna's army, and 1812, when all the strongholds were finished, the first line was reinforced by the construction of 20 new forts. As such, both historical periods were analysed. To aid the interpretation of these results, the lines were divided into sections. This division considered the consistency of the obtained results, the different defensive purposes, and even some historical events[3].

To determine objectively the permeability degree of the LTV, while taking into account the ability for bombing in the early 19th century, he following indexes were proposed and calculated:

- ***Virtually bombed area*** (VBA) – is the percentage of the surrounding area around a group of redoubts that, in 1812, is possible to hit, i.e., where the probability of hitting the target is larger than zero. If the terrain within the shooting range of a fortification was

[3] The used sections follow the LTV zoning defined in "*Memoria sobre as Linhas de Torres Vedras*", 1909, by Lieutenant Ivens Ferraz, and in the work "Invasões Francesas" by Victorino César

flat, that percentage would be maximum (100%); normally, VBA is affected by the irregularity of the terrain, and the occurence of blind spots.

- ***Virtually bombed sections*** (VBS) – is the percentage of the total length of the roads and paths that a number of redoubts had the ability to hit with their weaponry within their VBA in 1812. If the surroundings were flat, such percentage would be 100%, proportionally decreasing with increasing unevenness of the ground.
- ***Average hit probability*** (AHP) – is the average probability of a direct hit from a weapon in a stronghold against invading forces in the VBA or the VBS. The closer the enemy to the stronghold is, the greater the likelihood of being hit.

For the interpretation of results, the first line of defence was divided in five sections, listed from west (Atlantic Ocean shoreline) to east (Tagus River bank):

- Polygon 1: lines the area occupied by the forts with the purpose of defending the area from the mouth of the Sizandro River to the outskirts of Torres Vedras;
- Polygon 2: area occupied by the redoubts defending the town of Torres Vedras;
- Polygon 3: delimits the occupied forts that were intended to defend the surrounding area southeast of the town of Torres Vedras up to the area of Sobral de Monte Agraço;
- Polygon 4: area occupied by forts with the purpose to defend a possible attack coming from Sobral de Monte Agraço;
- Polygon 5: area occupied by a set of strongholds aiming to defend the eastern area, from Sobral de Monte Agraço to the bank of the Tagus River.

Table 1 summarizes the results of the proposed indices for the 1810 scenario Assessing the results for the two historical periods some considerations are possible to extract:

- In 1810 the first line displayed excessive defensive weaknesses from the Atlantic coast to the region of Sobral. This may justify the claims of Norris (2001), stating that Wellington, and, in particular, Fletcher, believed that both the dams at the mouth of the Lizandro River as well as the difficult access to the roads in this region due to heavy rains, were sufficient to delay an eventual attack from the French, preventing them from launching a surprise assault in this place without Wellington having the opportunity to readjust his army for defence.

Table 1 – Table summary of indexes obtained for the First Line in 1810

1810 scenario						
Section	Fraction of 1812 VBA		Paved roads		Paths, footpaths	
	% VAB	%AHP	% VBS	% AHP	% VBS	% AHP
1	63%[4]	52%	n.a.	n.a.	64%	53%
2	52%	56%	53%	64%	50%	58%
3	20%	40%	21%	29%	21%	47%
4	57%	44%	53%	52%	86%	47%
5	76%	57%	95%	56%	75%	58%

[4] 63% means that in 1810 the BVA is only 63% of the BVA in 1812. This way it is possible to compare and determine the evolutions in terms of permeability of the lines in the two different historical moments. The same case is applied for the VBS.

- The weakness of the first line also proves that it was originally conceived as an advanced and secondary defense line, while the second line was the principal; therefore, the first line was not fully prepared to hold off an attack when Masséna's army arrived. Thus, according to the results, it is possible to conclude that, most probably, the main goal of this line was to wear out the troops, saving the rest of the army for battle; defenders would later fight against exhausted and perhaps a demoralized enemy.
- Results from the 1810 scenario for the first line also indicated a concern in defending the area between Sobral and the Tagus River. According to several authors, it was precisely in this area that Fletcher and other officers believed that the French would attack on towards Lisbon. Regarding this, it should be noted that the weakness of the area mentioned previously may also had been caused by the deviation of men and resources to this region, consequently neglecting the work in the western sections of the line (Figure 4).
- Another interesting result was the verification that the Forte de S. Vicente (one of the most powerful strongholds of the first line) was at a key location in the defensive system of Torres Vedras and was built on a hill with a complete and clear view over the town, a position of clear advantage to the French, if they occupied that hill.

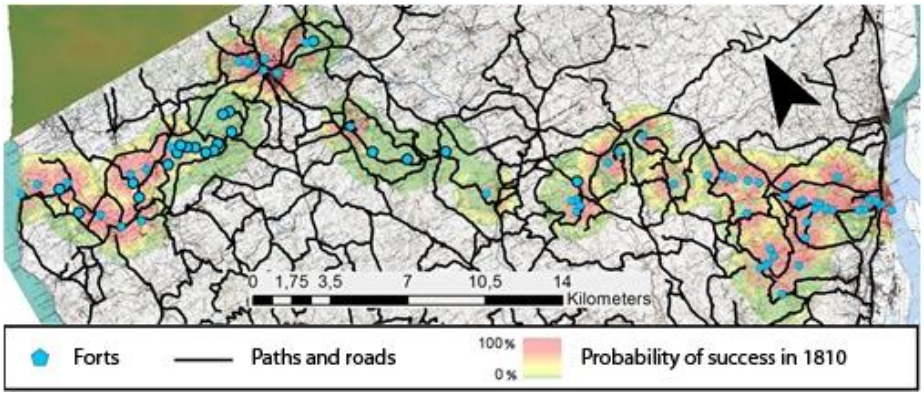

Figure 4 – Probability of hit success in the First Line in 1810; the green areas correspond to areas of low probability of success and therefore permeable, red areas correspond to less permeable areas.

In 1812, the first line shows better results (Table 2, Figure 5), which shows that Fletcher was aware of the aforementioned weaknesses. Only at this point it can be considered as a true defensive line, due to the results showing that only in that year it had potential to endure a French attack (the second line had this capability since 1810).

Table 2 - Table summary of indexes obtained for the First Line in 1812

1812 scenario						
Section	Fraction of 1812 VBA		Paved Roads		Paths, footpaths	
	% VBA	%AHP	% VBS	%AHP	% VBS	%AHP
1	91%	59%	n.a.	n.a.	93%	63%
2	80%	54%	57%	65%	85%	55%
3	45%	45%	21%	29%	45%	47%
4	75%	48%	97%	52%	69%	48%
5	76%	57%	95%	56%	75%	58%

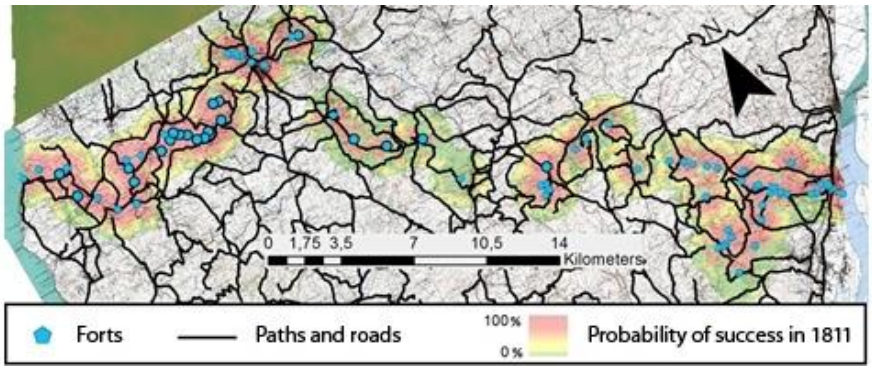

Figure 5 - Probability of hit in the First Line in 1812; the green areas correspond to areas of low probability of success and therefore permeable, red areas correspond to impermeable areas.

- Curiously, results suggest that in the defenses at Serra da Archeira (section 3, first line), the purpose of the three forts built after 1810 was not to defend the road network, but to repel an attack on that slope. Its position enabled construction teams to initiate defensive works safely and in relative secrecy, even after the arrival of the enemy forces. The forts are out of line of sight and also out of the line of enemy fire.

The second line of defense, unlike the previously analysed first line, was not reinforced after the arrival of the Masséna's army (end of 1810), and it had the same outline as when the redoubts of the first line were considered to be ready (in 1812).

Like the first line, and in order to aid the interpretation of results, this line was divided into eight sections, numbered from west to east:

- Section 1: defines the area occupied by the strongholds with the goal of defending the area from the Atlantic Ocean to the north of the Sobral River;
- Section 2: delimits the area occupied by the forts that aimed to defend the area from the Atlantic Ocean to Carvoeira, seven kilometers south of the polygon 1;
- Section 3: delimits the area occupied by the redoubts aiming to defend the area from the Sobreiro delta to the Jerumelo delta;
- Section 4: delimits the area occupied by the redoubts which goal was to slow down the French forces coming from the road that linked Torres Vedras to Loures;
- Section 5: delimits the area occupied by the forts that aimed to defend the area stretching from the Jerumelo delta to the village of Freixal;
- Section 6: delimits the area occupied by the redoubts with the purpose of delaying the French forces moving from Sobral de Monte Agraço to Loures;
- Section 7: delimits the area occupied by the strongholds intended to defend the area extending from Cabeço of Montachique to Bucelas;
- Section 8: delimits the area occupied by the forts intended to defend the area east of Bucelas up to the bank of the Tagus River.

The second line shows far better results of permeability than the first line, in 1810 (Table 3, Figure 6). This line has not undergone improvements (relatively to the number of forts), which probably indicates that in the year of the invasion the military engineers considered it already impermeable to the advances of the Masséna's army.

Table 3 - Table summary of indices obtained for the Second Line in 1810 and 1812

1810 and 1812 scenario						
Section	Fraction of 1812 VBA		Paved roads		Paths, footpaths	
	% VBA	%AHP	% VBS	%AHP	% VBS	%AHP
1	55%	47%	n.a.	n.a.	70%	50%
2	51%	48%	n.a.	n.a.	58%	50%
3	60%	55%	64%	65%	67%	58%
4	56%	43%	28%	48%	77%	51%
5	78%	59%	86%	78%	76%	57%
6	69%	41%	82%	55%	99%	78%
7	65%	52%	66%	40%	76%	61%
8	82%	55%	86%	60%	81%	55%

Some conclusions may be extracted from the presented map and tables:

- Unlike what was noticed for the first line, where it is possible to identify a regular alignment of the strongholds despite these being located closer along the roads, the redoubts of the second line are scattered, following the roads' design, so as to create maximum distress for the invaders.

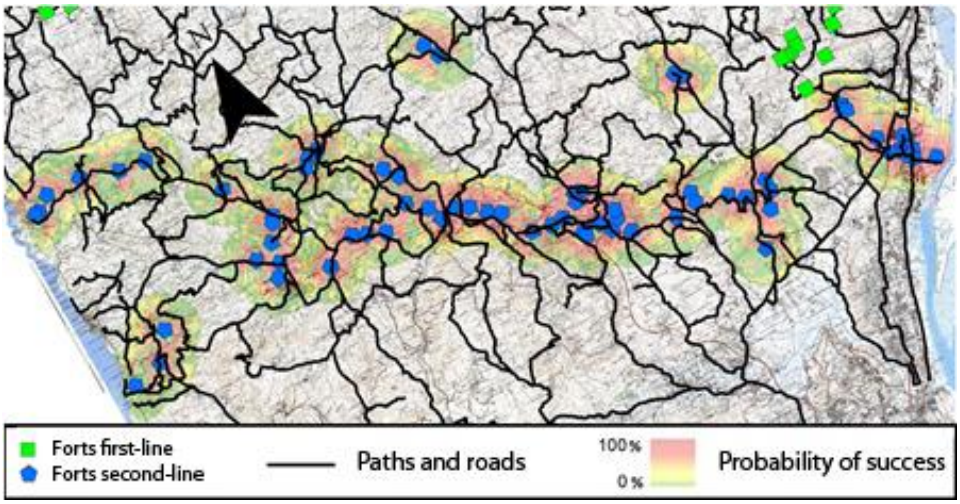

Figure 6 - Probability of hit success in the Second Line; green areas correspond to areas of low probability of success and therefore permeable, red areas correspond to less permeable areas.

- With help from the obtained data, it was interesting to verify that probably some of the forts in this line were placed to create traps for the invading army. Some areas, such as the defenses south of Ericeira or around the Tapada de Mafra (a hunting reserve near Mafra), seem to have the purpose of cornering or dividing the enemy army. If these strategies were not overtly intentional, it would be difficult to understand why Fletcher did not to take care of the defensive weaknesses in Vale da Mangancha, or allocate the defenses around the Tapada de Mafra, instead of creating a straight line, in which the strongholds would be closer to each other (increasing the ability to run crossfire), certainly obtaining better results in terms of the impermeability of the area (Figure 7).

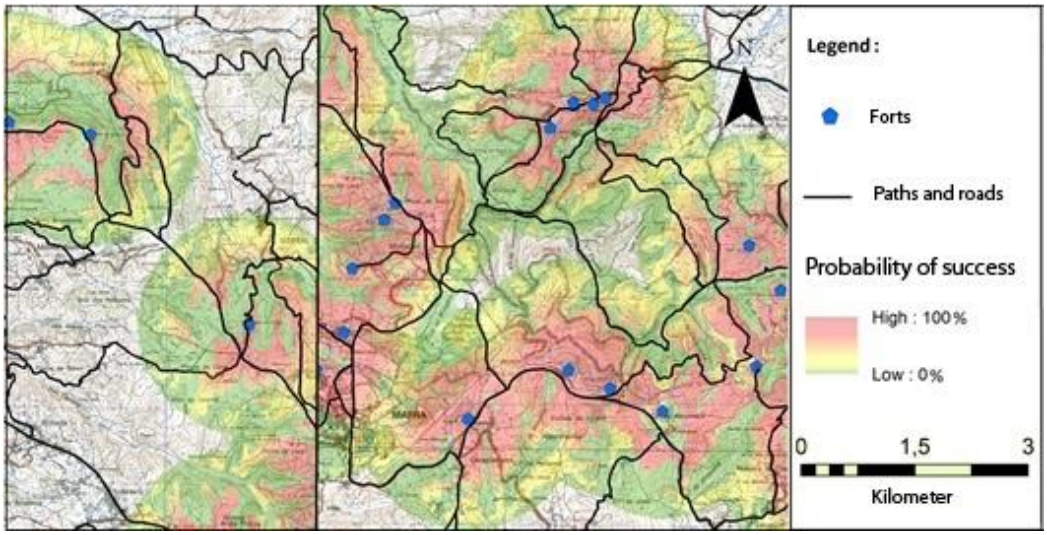

Figure 7 – Left: defense weakness in the valley of Mangancha, Right: stronghold distribution around Tapada de Mafra

Final Considerations

Following the presented methodology, specifically developed for this work, using a GIS-based LTV model and analysing the results obtained with the geographic modelling of this defensive system, it was possible to quantify the permeability of LTV using original indices.

From this assessment it is possible to conclude that, at a global level, this system was prepared to hold a French attack in 1812, a period in which the possibility of a new invasion was still a source of deep concern for military leaders.

In relation to the year of the invasion (1810), the first line still had some weaknesses, that somehow could have compromised the success of its goals, if the invading force had gone on the offensive immediately, contrary to what really happened. In any case, the results of the analysis conducted on the geographical model show that, from 1810, the second line would have already had sufficient tactical and strategic ability to stop the advances of attackers, in case of an eventual collapse of the first line of defense. Incidentally, through the information obtained by the intelligence service of the French army, Masséna's army would know that passing this first hurdle would be far from being, by itself, a guarantee of success in their march to Lisbon, since the high morale levels of the troops after their success of that hypothetical first strike, would surely be shaken as soon as they got to a stronger defensive line.

Future Developments

In this work models for the weaponry shooting success and for the assessment of the permeability of fortification lines were proposed, which were applied to the case of the Lines of Torres Vedras, enabling a comprehensive study of these particular aspects of the historical episode.

The developped work could be extended to include further characteristics of these military construction or its setting. One suggestion is to model the dams on the Sisandro River, therefore evaluating the effect of this type of construction in the system southwest of Torres Vedras.

Through this analysis a more clearer notion of how this area was defended might be studied, as in the current analysis it appears to be a flaw of considerable importance in their defence.

A distinct GIS-based analysis that might be followed concerns the study of the distribution of strongholds based on the occurrence of the projectile rebound effect, based on a technique to increase the destructive power of a shot, known to have been used. As the terrain of the LTV region is quite irregular, probably this effect was limited; however, it would be interesting to disclose if, in areas that concentrated the invading forces (routes through valleys and crossroads) there is a favourable positioning of the forts in order to allow this effect.

A third suggestion to extend the work is the modelling of other contemporary defensive systems in order to compare their results with the LTV case. Examples are the second line of the Nivelle River (defensive system of the Atlantic Pyrenees in France) and the Borodino entrenched camp, in Russia. It is interesting to note the relative ease with which Wellington beat the French lines, taking into account that, according to several authors, the design of these defences was inspired by the Portuguese lines, while in the Russian defence system only six fortifications are known to have caused a remarkable number of casualties to the French army.

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