Calm Before the Storm? Modelling Military Supply and Movement

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Abstract—Food production and transport infrastructure play a large role in the outcome of a military campaign and the results of failure can have a profound effect on the whole state. Yet these are areas often poorly covered by contemporary sources. The Medieval Warfare on the Grid project is using agent-based modelling to produce quantitative data to examine the mechanisms required to move armies across a pre-industrial landscape. Though focused on the march of the Byzantine army to the Battle of Manzikert in AD1071, the results can improve our understanding of the logistical challenges faced by armies in other periods and places. The use of quantitative data from later sources provides valuable assistance to both design and validation of the models.

I. INTRODUCTION

Although simulation studies have been applied within historical studies for some considerable time there has been a noted increased level of interest in agent-based modelling in recent years [1], In part this may be a simple reaction to the availability of appropriate technology for such work although these developments have taken place in the context of an increasing awareness of the potential of simulations to answer novel questions that traditional studies are not well placed to resolve and, perhaps, within areas of study where there is an absence of traditional data for concrete analysis and where the presumption of the action of unseen agents may make such studies essential if we are to make sense of past behavioural data.

The choice to undertake such studies should, therefore, be based upon a number of questions including whether such techniques are appropriate for simulation and also whether data (direct or proxy) is available to support simulations of events which are poorly recorded or where there is is no direct parallel or proxy data to provide basic behavioural rules for simulation. This lack of data is particularly noticeable during the validation of models. For that reason it is essential that simulation studies are explicit about why studies are undertaken and what their significance is to the chosen subjects but also how behavioural rules are developed for modelling purposes.

This paper provides an account of the Medieval Warfare on the Grid project (MWGrid) project and outlines how some of the data used by the project were developed during the period of research. Although the full project will be published during 2015 the need to promote debate on the nature of such projects is of value to identify areas of best practice and also to avoid those situations in which modelling appears to be an aim in itself and, consequently, where disciplinary goals are not well developed and the content of the simulations is not well suited to providing substantive historical research outputs.

Contemporary accounts of historical military campaigns traditionally focus on battles and personalities. If we are to believe the accounts of the participants, it is on the battlefield that heroic deeds are performed, commanders show their genius and questions of power are decided. It is this bias within the historical record that gives the impression that the operations which precede the battle are simple, mundane and unimportant. Yet it is the raising, moving and feeding of armies that occupies the resources of a state and provides a large drain on incoming taxes. Food production and transport infrastructure play a large role in the outcome of a military campaign and the results of failure can have a profound effect on the whole state. Gaps in the historical record regarding these systems are therefore both important and noticeable. The lack of historical detail regarding military support infrastructure means that other sources of data must be used in order to examine the ways in which premodern states moved and fed their armies. Quantitative data, so often ignored in favour of qualitative details, is required in order to establish the limits of what is possible under certain circumstances.

The MWGrid project [2], [3] has been simulating the march of the Byzantine army across Anatolia to the Battle of Manzikert in AD1071. It uses agent-based modelling (ABM) to simulate the movement and supply of an army with varying sizes, compositions, types of organisation and distances covered. This paper describes the organisation and aims of one set of these models, those simulating a single day's march of an army. The initial project design called for a single model to simulate the whole march across Anatolia in one single run. This was to explore the interrelation between settlement, transport infrastructure, army size and composition and the provision and transport of equipment and food. A single day's march became the main focus of the MWGrid modelling effort when it was realised that the number of variables needed to be drastically reduced in order to properly explore the parameter space. The models detailed here focus on the way that small details in organisation affect the army's overall speed, noting how this would affect the supply situation. Further models will build on this work to expand the scope of the project.

The results of these models show a more complex situation regarding the organisation of the army's march than that depicted in contemporary accounts. Using the details of eyewitnesses combined with other Byzantine military writing and more modern data, the MWGrid models seek to create quantitative data that can be combined with the qualitative data in the written sources in order to provide parameters in which the campaign can be framed.

Not only do the historical sources not tell us how the army moved or was fed, they give no indication of what was possible within the medieval period. However there are fixed points from which we may anchor any model that seeks to investigate these problems. Terrain, human and animal movements speed, calorie consumption and the physical size of the army's participants and equipment can be plausibly modelled based on modern or historical data. Simulation can then test unknowns such as organisation and army size and composition in order to provide minimum and maximum values to some of the many variables associated with an army on the march. This gives us a range of possibility within which to reframe the historical debate regarding how the Byzantine army moved and fed itself. This also allows us to attempt to assess the effects of the army on the communities through which it travelled.

II. Problems

In AD1071, the Byzantine Emperor, Romanos IV Diogenes, led an army from Constantinople towards the southeastern corner of what is now the modern state of Turkey. It formed an attempt to engage and decisively beat the Seljuk Turk nomads who had been raiding Byzantine Anatolia since the middle of the 11th century. Romanos was confronted by the Seljuk Sultan Alp Arslan at the fortress of Manzikert, just north of Lake Van. The defeat of the Byzantine army at the Battle of Manzikert and the subsequent period of civil war that followed has been described as "the most decisive disaster in Byzantine history"[4]. From this point on the Byzantines never exerted control over the whole of Anatolia and the Turkic people were never driven out.

Considering the importance of the event and the number of historians, both contemporary and subsequent, who have described and commented on the events of the battle, the lack of reliable quantitative data is profound. Byzantine sources give no numbers for the size of the army at all. Arabic and Armenian sources give figures which are considered by modern historians to be exaggerated to emphasise the scale of the Seljuk victory. More broadly, the logistical mechanisms by which the Byzantine Empire could move an army "more numerous than the sands of the sea"[5] across a landscape with limited transport infrastructure and occasionally scarce food resources are barely described at all. This lack of supporting data poses problems not just for the design of an ABM but also for the validation of any ABM produced. There are, however, some starting points that can be plausibly assumed. The terrain of Anatolia is largely the same now as in the 11th century, in elevation although possibly not in the type of transport infrastructure and vegetative cover. Humans and horses take up roughly the same amount of space and move at roughly the same speed now as they did then so there is a solid base on which to build a crowding model. It can be assumed that the human body burns calories as a result of work done in much the same way.

III. The Day's March Models

There are many factors involved with moving an army, including availability of resources, number of participants, proportion of cavalry and infantry, number of baggage animals etc. Some of these factors are interdependent, for instance the number of baggage animals required depends on the size and composition of the army and the distance between resupply locations[6]. Computer simulation can be used to model some of these factors and provide parameters within which the historical debate can be framed. ABM's architecture of autonomous agents moving and interacting within an environment of resources seems an appropriate method of simulating the actions taken by an army on the march.

A series of scenarios have been run, each set focussing on a single aspect of the march. This is an attempt to explore the parameter space as fully as possible. The problems of using models to extract the maximum useful data while being able to perform the modelling in a useful time are well known. As a point of comparison, a day's march for 100 agents takes around 90 seconds to run. The same scenario for 10,000 agents takes around 90 minutes and for 40,000 agents it takes around 90 hours.

A. Size and distance

An army consisting of homogeneous agents is marched from one day's camp to the next. These camps are at a variety of distances between 10km – 30km. Three sizes of army are used: 101 agents, 10,001 agents and 40,001 agents. The extra agent represents the structure in the model in which 1 main route planning agent heads the column and squads featuring regular numbers of soldiers follow in order of march.

B. Composition

Cavalry are added to the army in varying percentages in order to assess the effect this has on overall army speed and arrival time. Cavalry agents differ from infantry agents in that they move faster (4mph as opposed to the 3mph of infantry agents) and occupy more space in an environment cell.

C. Variable cavalry speed

Furse [7] suggests that cavalry spend part of the march on the trot, part walking and part being led by their riders. This ensures the horses are well exercised but don't become fatigued. This is implemented in the model in order to assess its effect on arrival time.

D. Resting

Periodic resting on the march is recommended in the 19th century literature. This not only gives soldiers the opportunity to drink or release water but also operates as a mechan-

ism to close up an army column that has a tendency to elongate over time. A certain part of the rest period can be used to close up the gap on the unit in front if it has moved too far ahead. The effect this has on arrival time and column length is assessed.

E. Day length

Night marching is to be avoided where possible. For this reason the models are set up to only simulate the length of time corresponding to the amount of daylight. The Manzikert campaign ran from early March to August and so would have seen a variety of lengths of daylight in each day. The effects of this are modelled.

F. Splitting into columns

One method of increasing the 'bandwidth' of the army is to split the force into separate columns who travel to the same destination via different routes. This is especially prevalent with the increased army sizes of the Napoleonic era but can provide benefits for armies of the proposed size of the Byzantine army at Manzikert. The benefits include having more soldiers on the march at the same time. However, there can only be one optimal route, soldiers sent via alternative routes will either have a longer or harder march. Splitting the army into 2 or 3 columns is compared to single column marching.

G. Baggage

It is clear from both Byzantine and more modern sources that the organisation of baggage was rarely simple. A tripartite division of the baggage animals is often suggested where each squad has its own baggage animal for frequently used items with a unit baggage train for less frequently used items and an army baggage train for reserves of supplies and siege equipment. The MWGrid ABM has the ability to add baggage animals in a variety of organisational schemes and compare the effects on both equipment carrying ability and overall army speed.

H. Terrain

Terrain affects route planning, resulting in longer travelling time and more calories burned. The movement of the army would have depended on existing routes which themselves would have depended on a variety of factors. Unfortunately there is not enough reliable data on Byzantine road systems to produce a plausible transport infrastructure. We also lack data such as land use and the location of water courses in order to factor in the effects that these undoubtedly had on route planning. The best we can do is take into account the factors we can simulate plausibly, namely terrain and its effects on calorie consumption. For this reason, the route planner tries to take the shortest route while avoiding steep inclines. The degree to which it tries to avoid steep climbs varies based on the ABMs parameters and the effects of these parameters is explored in these scenarios.

I. Cumulative effects

Although it is not yet practical to model every days march of the Manzikert campaign consecutively as the campaign took around 6 months and some models take longer to simulate than the corresponding march took to complete. Nevertheless, by

J.

K. The Manzikert campaign

The only real method of validating the model via direct comparison to contemporary accounts is to see if the army as modelled would be able to travel over 700 miles across Anatolia from Constantinople to Manzikert within the time provided. Representative samples of days marches using plausible historical army sizes at various points along a hypothetical route are used to determine whether the 6 months of the actual campaign are possible for the army as modelled. The army itself would have been subject to various delays for a variety of reasons, unmodelled within the ABM and so we would expect the model to outperform reality. If that is not the case, if the modelled army would have been unlikely to be able to reach Manzikert within the time recorded by historical accounts then it is a sign that the model may be wrong enough to not be useful. If the model does outperform the actual army that does not of course prove that the army moved itself as modelled.

The scenarios described above represent over 100 different runs of the simulation requiring a processing time of over 1,000 hours. Even so there are combinations of ABM parameters that have not been modelled. The parameter space is just too large to sensibly explore all of it. This presents a problem within historical ABMs in general where there are few known points with which to anchor a model and too many variables with too great a range to completely explore the possible combinations.

IV. VALIDATION

Validation can be problematic when dealing with historical ABMs. This is certainly the case with the MWGrid models, where comparative data is scarce. The length of the campaign as a whole is known but the behaviour of the army on a day's march and the way in which the various factors interrelate are almost complete unknowns. Historical records can produce bits of information that can be used to calibrate the models, however contemporary accounts of the Manzikert campaign are unhelpful. Byzantine military treatises exist from the 10th century but these are often light on the actual quantitative data required to compare to the output of an ABM. Quantitative data from similar situations can be found from other sources. However, the 19th century saw the publication of a number of military manuals and memoirs, some of which contain detailed descriptions of military manoeuvres under similar circumstances and of the same scale as the Manzikert campaign.

The late 18th century and early 19th century was a period in which military writing flourished along with the accessibility of written publications. The early 18th century saw the hugely influential writings of Clausewitz [8] and Jomini [9] but higher standards of literacy and lower publishing costs subsequently ensured an audience for the writings of veterans of the wars of the mid to late 18th century. There were not only personal memoirs written of wars in Europe

and the Americas e.g. [10], [11] but also military manuals, produced for the consumption of both the military themselves and an interested public. Virtually unknown today, some of these military manuals were written by highly decorated and experienced officers. George Armand Furse was a Colonel in the Black Watch and wrote a series of books on such subjects as 'The Art of Marching' [7] and 'Provisioning Armies in the Field' [12]. He had served in the Boer War and had also been Quartermaster General of the Nile Expedition to relieve Khartoum in 1884-1885. Colmar Freiherr von der Goltz was a Prussian Field Marshal who served in the Franco-Prussian War and later spent twelve years helping to reorganise the Ottoman army after the Russo-Turkish War of 1877-1878. He also wrote a series of books based on his experiences e.g. [13], [14].

These books often contain a wealth of information regarding 18th century military organisation, much of it applicable to pre-modern examples. Although the invention of the railroad and canned food had altered military logistics, there were still plenty of campaigns away from a railway network and plenty of food consumed that did not come in a tin. The mechanisms were still there to promote war in the same way that it had been done since the time of Alexander the Great. People, animals and goods still needed to be transported across unpaved roads, mules were still much in demand, wagons still carried heavier weights but were less tolerant of poor road conditions than pack animals. The basic elements were all there in the British campaigns in 18th century India that had been used by Alexander a little further West, some 2,200 years before.

The extent to which army movement can be compared between the two periods is of course debatable. Nevertheless, where similar circumstances are mentioned in both Byzantine and 19th century military writing, the advice given is usually strikingly similar. Examples of advice common to both Byzantine and 19th century military manuals include:

•Baggage trains should be kept as small as possible.
•Civilian populations should be respected.
•A combination of supply and foraging is required.
•Soldiers should be well-fed.
•March order should be rotated.
•The route needs marking with signs or people.
•Leaders who share in the soldiers' lives are more respected.
•There is a tripartite division of baggage: Army, unit and personal level.
•Parties should be sent ahead to clear the road.
•Some space should be left on one side of column for local traffic or army cavalry/messengers.
•Wagons are standard but pack animals are quicker and should be used if speed is a factor.
•Care should be taken over camp locations, the criteria for which stays the same over time.
•In case of the column lengthening, the front should slow rather than the rear speed up.
•Local knowledge is very important.

This overlap between the advice of experienced military officers of the 19th century and that of the Medieval period allows large amounts of new data to be included in the design phase of any models. This increases the number of behaviours within the model that can be supported by historical data. This then reduces the parameter space that needs to be explored during the simulation process. In addition, the presence of quantitative data within the 19th century manuals allows them to be used to validate the results of the models. Within the 19th century manuals can be found speeds of units and columns, weights of equipment, capacity of baggage animals and the degree to which an army column lengthens on the march, all data absent from Medieval sources. The substantial overlap between the areas that are covered by sources from both periods gives confidence that the 19th century sources may be used as plausible supporting data in areas which are ignored by Medieval accounts.

V. RESULTS

The MWGrid ABM outputs 2 text files, a dayfile and a tickfile. The dayfile contains one line for each agent which provides aggregated data for the day's march. These include:

- Distance travelled
- Calories expended
- Amount of time on the march spent resting
- Arrival time at camp

The tickfile records the location of each agent for each tick of the simulation and can be very large, over 11Gb for 40,000 agents over 12,000 ticks. This tickfile can be processed by a Python script to create 2D and 3D images and animations via Blender, the open-source 3D modelling package [15]. The data contained in both dayfile and tickfile can also be visualised via graphs and tables.

In addition, data can be derived from the dayfile and tickfile in order to produce data such as maximum and minimum length of an army column and the actual travel time of each individual agent. This data should not be taken as a direct statement of historical fact but is often more useful as a comparison between other runs of the simulation. For instance, calories expended on the march can give an indication of any extra food that would be needed based on different types of march but it should be remembered that this does not include activity before and after the march and so can only be used for comparative purposes.

VI. BROADER APPLICABILITY

The similarity between Byzantine and 19th century military writing supports the hypothesis that while battlefield tactics can change quickly over time as commanders respond to changing opponents, weapons and battlefields, the twin enemies of the logistician are distance and hunger and these have more stable characteristics over time. This results in a greater commonality in problems occurring over a larger range of time and space and consequently more stability in the systems used to overcome those problems. therefore the results of the MWGrid project should not only

interest Byzantine military historians but those interested in the logistics of all pre-industrial eras and even some more recent campaigns in circumstances that mirror those of the Medieval period.

The Manzikert campaign was conducted as though the enemy were too far away to be a threat to the marching army and this, as mentioned in Byzantine military treatises, results in a different order of march. It presumably also alters the attitudes of the campaign's participants. A rethink of the agent behaviours will be necessary if the march of an army near an enemy is to be modelled.

VII. Conclusions

This paper began with a statement that appealed for explicit and critical assessments of simulation models and their capacity to answer the questions posed by historical researchers. It should be clear from the body of the paper that the MWGrid project required significant input from sources that had not been identified at the onset of the research. Whilst there is no doubt that the project was able to incorporate these new data it is apparent that the final output was not a holistic solution. For instance, the focus of these models on distance moved and calories consumed may lead to a deterministic view of an army on the march. Significant elements are unmodelled however and any conclusions drawn from the project must take this into account. Although the number of calories consumed during marching can be plausibly calculated, the number consumed before setting off on the march and upon arrival at camp are unknown and likely to vary greatly depending on circumstances. This will in turn affect the supply situation of the army which will in turn affect movement. However the results of this project are not our conclusions but a baseline against which we can measure our conclusions and the conclusions of others. They can be an arbiter of how practical the previously untestable hypotheses regarding the march of the Byzantine army to Manzikert are. The infrastructure created in the MWGrid project deals with problems fundamental to army movement and supply in many pre-industrial and some post-industrial settings and can therefore be used to model military logistics in other times and places.

References

[1] M. W. Lake, "Trends in Archaeological Simulation," *J. Archaeol. Method Theory*, pp. 1–30, 2013.

[2] B. Craenen, G. Theodoropoulos, V. Suryanarayanan, V. Gaffney, P. Murgatroyd, and J. Haldon, "Medieval military logistics: a case for distributed agent-based simulation," in *Proceedings of the 3rd International ICST Conference on Simulation Tools and Techniques*, 2010, p. 6.

[3] P. Murgatroyd, B. Craenen, G. Theodoropoulos, V. Gaffney, and J. Haldon, "Modelling medieval military logistics: an agent-based simulation of a Byzantine army on the march," *Comput. Math. Organ. Theory*, pp. 1–19, 2011.

[4] S. Runciman, *History of the crusades, volume 1: the first crusade*. Cambridge University Press, 1951.

[5] A. E. Dostourian, "The Chronicle of Matthew of Edessa: translated from the original Armenian, with a commentary and introduction," Rutgers University, 1972.

[6] D. W. Engels, *Alexander the Great and the Logistics of the Macedonian Army*. Univ of California Pr, 1978.

[7] G. A. Furse, *The Art of Marching*. 1901.

[8] C. von Clausewitz, *On War, translated and edited by Michael Howard and Peter Paret*. Princeton, NJ: Princeton University Press, 1976.

[9] A. H. Jomini, *The Art of War, translated by GH Mendell and WP Craighill*. Greenwood Press, Westport, Connecticut, 1971.

[10] H. C. Symonds, *Report of a Commissary of Subsistence, 1861-1865*. The author, 1888.

[11] F. J. Lippitt, *Reminiscences of Francis J. Lippitt: Written for His Family, His Near Relatives and Intimate Friends*. Preston & Rounds Company, 1902.

[12] G. A. Furse, *Provisioning armies in the field*. W. Clowes & sons, Limited, 1899.

[13] C. von der Goltz, *The Conduct of War: A Brief Study of Its Most Important Principales and Forms*. Hudson Kimberley, 1896.

[14] C. von der Goltz, *The Nation in Arms: A Treatise on Modern Military Systems and the Conduct of War*. H. Rees, 1906.

[15] P. Murgatroyd, "Visualising Large-Scale Behaviours: Presenting 4D Data in Archaeology," in *Visual Heritage in the Digital Age*, Springer, 2013, pp. 259–274.