Networks for the Minoan Aegean

Tim Evans (Imperial), Carl Knappett (Exeter), Ray Rivers (Imperial)

See web site for publications
www.ic.ac.uk/people/t.evans
- e.g. see ISCOM project D.Lane et al. (ed.s) 2007 “Physical and Relational Networks in the Aegean Bronze Age”
`Minoa’
A reconstruction on show in Chania, Crete

See commentary on the modern context of this reconstruction
Approaches to Modelling

Several approaches when studying settlement patterns, many take *settlements* as the core unit.
- e.g. see EU ISCOM project D.Lane et al. (ed.s) 2007

**Agent Based Modelling**
- People/Goats as agents e.g. MASS group
- Cities as agents e.g. SIMPOP2 (Pumain et al.)

**Network Optimisation**
- *TSE, CJK, RJR ariadne*

**Equations**
- e.g. West et al.
Site-Site Interactions

• In archaeology relatively little attention has been given to the potential of interactions between sites being involved in the generation of those sites

⇒ Network models may prove to be useful

• Most models fixed site sizes, focused on local interactions, often just nearest neighbour interactions
  - Malta (*Renfrew & Level, 1979*);
  - Geometric Greece (*Rihll & Wilson, 1991*);
"The Small World of the Vikings", Sindbæk, Aarhus Univ.
Anskar’s Vita + data from finds, 9th c. AD

"Networks and religious innovation: an approach to understanding the transmission of pagan monotheism"
Collar, Exeter Univ.
Hypsistos cult inscriptions, 1-4 c. AD
Island Archipelagos as an Ideal Network

- **Vertices** = Major Population or Resource Sites
- **Edges** = Exchange between sites
  - physical trade of goods *or* transmission of culture
  - direct contact *or* island hopping links

- Sea isolates communities → **Natural Vertices**
- Interactions controlled by physical limitations of ancient sea travel → **Simple Links**
- Coastal Sites often isolated like islands due to geography and difficulty of ancient land travel
Earlier Island Network: - The Kula Ring

Malinowski (1922)

Hage and Harary (1991)

Hage and Harary formed a graph where edges are exchange relations and used random walkers to analyse the global properties of the system.

Also Terrell 1977; Irwin 1983; Broodbank 2000
Focus: Middle Bronze Age (MBA) Aegean

• Clear temporal delineation
  clear gaps (‘dark ages’) or shifts in record
  - c.2000BC distinct Minoan culture starts, and sail replaces oar
  - c.1500BC end of Minoan cultural dominance

• Physically largely self contained
  - questions regarding relationship to Egyptian culture
Some Questions

• **The Knossos Question**  
  What is the connection between macro-scale development of regional networks and the emergence of a primary centre?  
  The palace at Knossos does not have the best local environment.

• **Minoanisation**  
  What can explain the spread of and the variability in Minoan influence across the southern Aegean c.1700 BC?
Network Parameters

We want to find our optimal network given:

Inputs:
- Site sizes $S_i$
- Site separation $d_{ij}$

Outputs:
- Site occupation $v_i$
- Interaction levels $e_{ij}$
- Total population $\Sigma_j (S_i v_i)$
- Trade activity $\Sigma_j (S_i v_i e_{ij})$
Optimal Networks

- Adjust site and edge variables to optimise the ‘cost’ $H$ of the network:

$$H = -\lambda E - \kappa L + jP + \mu T$$

where

- $E$ – all exchange/trade
  Increase parameter $\lambda$ and interaction produces more benefits

- $L$ – all local production
  Increase parameter $\kappa$ and internal processes more profitable

- $P$ – total population
  Increase parameter $j$ and cost per person is increased

- $T$ – total strength of links
  Increase parameter $\mu$ and interaction links more expensive to maintain
Distance Scale $D$

We use: $D=100\text{km}$ for sail  $D=10\text{km}$ for rowing  
(after 2000BC)                           (pre 2000BC)

Interaction term for each pair of sites depends on distance $d_{ij}$ between sites such that for distances longer than a scale $D$ the benefit is zero i.e. no effective direct interaction.
Analysis

• Working with 34 sites

• Can not assign parameter values in model from physical data so make comparisons between different data sets
  e.g. vary one parameter, hold rest fixed. This represents slow evolution where system remains in effective equilibrium.

• For any given set of (reasonable) values:
  a) can analyse intrinsic parameters
  b) can perform further `games’ to analyse properties e.g. simulate trade in physical objects, cultural transmission models.
Analysis Methods: Ranking

• The percentage of time spent at each node by an imaginary random walker on the network. The walker moves from site to site, choosing to follow a link with probability proportional to its strength. (Other choices possible).

⇒ Measure of GLOBAL network properties

As used by Hage & Harary 1991, and
The 34 Sites Used
Analysis of Single Network

• The new few slides show the analysis of one result of our model

• Look for sites which are off any general trends

\[ j=0, \ m=0.5, \ k=1.0, \ l=4.0 \]
Typical Output from ariadne

<table>
<thead>
<tr>
<th>Quantity/Value</th>
<th>Average</th>
<th>Sigma</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Weight</td>
<td>1.42</td>
<td>0.35</td>
<td>0.78</td>
<td>1.98</td>
</tr>
<tr>
<td>Site Out W. Strength</td>
<td>1.42</td>
<td>0.35</td>
<td>0.77</td>
<td>1.98</td>
</tr>
<tr>
<td>Edge Weight</td>
<td>0.04</td>
<td>0.08</td>
<td>0.00</td>
<td>0.45</td>
</tr>
<tr>
<td>Edge Value</td>
<td>0.03</td>
<td>0.06</td>
<td>0.00</td>
<td>0.34</td>
</tr>
</tbody>
</table>
Crete’s global network importance stands out. Dodecanese is slightly bigger but is not abnormally important in network.
Rank vs. Size shows Crete’s is more important to the global network that its size suggests, not so for Dodecanese.
Local properties often scale closely with site size (weight)

Incoming Edges/Weight

Site Size (weight)

Kasos

Amorgos

Petras

Rel.S.In

Linear (Rel.S.In)
Global network structure may be emphasised by non geographic displays.
Increasing Edge Cost ($\mu$)

Next 7 slides

- for large interaction benefits ($\lambda=4.0, j=0, \kappa=1.0$)

  • Increasing $\mu$ causes edges to concentrate on decreasing profitable routes.

  • The largest site size goes up while the smallest stays the same.

  • Total cost in edges the same (as vertex out strength) but
input file: aegean34
output files: output/aegean34_v1_3e-1.0m1.0j0.0k1.0b1.2s100.0Mcr0
Model: Standard Hamiltonian+Gravity (source and target site in trade term)

- model number 1_3
- Monte Carlo Update
- Limits on Out Strength 1.0
- max vertex value 5.0
- mu 1.0
- j 0.0
- kappa 1.0
- lambda 4.0
- distance scale 100.0
- short distance scale 5.0
- Zero Colour Frac 0.01
- metric number 5.0
- beta 524288.0
- Min. Colour Frac 0.2
- sites by Size
- Influence Range 1.0 (prob=0.5)

Quantitative Values:

<table>
<thead>
<tr>
<th>Quantity/Value</th>
<th>Average</th>
<th>Sigma</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Weight</td>
<td>1.72</td>
<td>0.54</td>
<td>0.77</td>
<td>2.66</td>
</tr>
<tr>
<td>Site Out W. Strength</td>
<td>1.72</td>
<td>0.54</td>
<td>0.77</td>
<td>2.66</td>
</tr>
<tr>
<td>Edge Weight</td>
<td>0.05</td>
<td>0.11</td>
<td>0.0</td>
<td>0.81</td>
</tr>
<tr>
<td>Edge Value</td>
<td>0.03</td>
<td>0.07</td>
<td>0.0</td>
<td>0.56</td>
</tr>
</tbody>
</table>
End of increasing $\mu$ sequence
Minoanisation Analysis Methods

• **Diffusion**
  Use random walkers doing variable short range walks to assess how ideas can percolate through system.

• **Cultural Transmission**
  Use the networks produced here as substrate for well known models of cultural transmission (Bentley & Shennan 2003) and language transmission (Stauffer et al. 2006)
  - based on copying (drift) and innovation (mutation) processes
Summary

• Starting to extract basic results systematically
• Some behaviour looks interesting to an archaeologist
  – Crete and Dodecanese usually form strongest clusters
• Some types of behaviour do not appear to be possible
  - Greek mainland rarely gives significant sized sites
• Some factors seem to be playing a key role
  – small differences in physical distance from Crete may be significant
• Many options remain to be explored
  – improve distance data, more analysis tools, more what if scenarios, EBA vs MBA, general time evolution, other data sets
Additional Material

More stuff …
PPA - Proximal Point Analysis

Most models focused on local interactions, often just nearest neighbour interactions

- Malta (Renfrew & Level, 1979)
- Geometric Greece (Rihll & Wilson, 1991)
- Proximal Point Analysis
  Connect each vertex to 3 (or whatever) nearest neighbours
  - EBA Aegean (Broodbank 2000)
  - Vikings (Sindbæk, in prep.)
  - Hypsistos Cult (Collar, in prep.)
Increasing Interaction Benefits (\(\lambda\))

Next 5 slides …
Model: Standard Hamiltonian+Gravity

- Monte Carlo Update
- Limits on Out Strength 1.0
- Max vertex value 5.0

- Distance Scale 100.0
- Short Distance Scale 5.0
- Metric Number 5.0

Absolute Edge Display, Max 1.0
Influence Range 1.0 (prob=0.5)
End of increasing $\lambda$ sequence
Statistical Variation Constant Values

• The variables are held constant so simple statistical variations are evident
• These are reasonable, strengths of individual components vary by reasonable amounts, the details remain similar.
Range of Distance Scales ($d$)

- Next 4 slides
Network Description

- $d_{ij}$: Fixed distance between sites identified from the archaeological record. This may be physical but may include penalties for prevailing winds, currents, land travel, ...
- $S_i$: Fixed site size = maximum local resources
- $v_i$: Variable site occupation fraction. So if $v_i > 1$ then the site needs external resources.
  - Site Weight $(S_i \cdot v_i)$ = Site `population`
- $e_{ij}$: Fractional Edge values $0 \leq \Sigma_j e_{ij} \leq 1$
  - Edge Weights $(S_i \cdot v_i \cdot e_{ij})$ = ‘Trade’ (interaction) going from site i to site j
Robustness

- Are we finding a model that gives us the results we want?
  - Select on the basis of some pre-determined notion of reasonable results.
  - Do comparisons, do not use absolute results
- Do results depend on fine details of model?
  - Topological Congruence, Universality Classes
- Do results depend on how we encode the input data?
  - Scaling behaviour - when is an archaeological site a vertex?
Middle Bronze Age Aegean (2000-1500 BC)

- Palaces on Crete
- ‘Minoanisation’ begins
- Theran eruption 1600 BC
- ‘Collapse’ – 1500 BC

DIFFERENT TO EBA of Broodbank (2000)
- Ø Scale of networks
- Ø Uneven site size
- Ø Length of links
- Ø Directionality

Mycenae
Thera
Knossos
### Brief Chronology of the Aegean

<table>
<thead>
<tr>
<th>Era</th>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neolithic</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7000 BC</td>
<td>• Initial colonisation – introduction of farming</td>
<td></td>
</tr>
<tr>
<td>4000 BC</td>
<td>• Secondary colonisation of small islands</td>
<td></td>
</tr>
<tr>
<td><strong>EB I</strong></td>
<td>2500 BC</td>
<td>• Nucleation and hierarchy in 3rd millennium BC</td>
</tr>
<tr>
<td><strong>EB II</strong></td>
<td>2200 BC</td>
<td>• Partial collapse?</td>
</tr>
<tr>
<td><strong>EM I</strong></td>
<td>1900 BC</td>
<td>• Emergence of Minoan civilisation in 2nd mill BC on Crete, sail technology appears</td>
</tr>
<tr>
<td><strong>EM II</strong></td>
<td>1500 BC</td>
<td>• Collapse</td>
</tr>
<tr>
<td><strong>LB I</strong></td>
<td>1450 BC</td>
<td>• Mycenaean mainlanders emerging power</td>
</tr>
<tr>
<td><strong>LB II</strong></td>
<td>1200 BC</td>
<td>• Bronze Age collapse</td>
</tr>
<tr>
<td><strong>LB III</strong></td>
<td>1100 BC</td>
<td>• ‘Dark Ages’</td>
</tr>
</tbody>
</table>
Efficiency?

• Need not be space filling in any sense.
• Need not be lowest number of links needed to connect all sites (Minimal Spanning Tree).
• ‘Deliberate Waste’ - may well favour redundancy to reduce path lengths, to increase possible interactions, to increase resilience to change.