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# Modeling Global Historic Maritime Trade Using A Least-cost Surface Analysis

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We present a workflow for creating a global set of shipping routes that flexibly accounts for ship, spatial, and projection constraints; validate our estimated data against historic records; and have sharable scripts to implement the workflow available. This work expands on previous methodologies for creating a global set of trade routes using a least-cost path surface raster analysis. While previous researchers have endeavoured to model historic shipping, their focus was on one local area (Alberti 2018) or at the country-level using one primary port per country with limited details available explaining the implementation (Pascali 2017). This presentation will walk through our workflow for modeling port-level historic shipping routes on a global scale and our process for validating the model against known historic records.

Modeling how shipping technology has changed is helpful because shipping plays an important role in facilitating international trade and economic activity over time. Recent researchers have endeavored to use geospatial methodologies to represent ancient and historic maritime shipping (Alberti 2018, Pascali 2017). Previously, historians and archaeologists have used a least-cost path raster analysis to estimate the terrestrial travel of ancient peoples (Scherjon 2014). In 2018, Gianmarco Alberti expanded on that research with his toolbox, TRANSIT, which automated the process of generating a cost surface for from a single origin, at a regional scale. We introduce TRANSIT-global, which extends TRANSIT to create cost surfaces for multiple locations and models multiple origin-destination (OD) route-pairs globally. We maintain the ability to accommodate ship characteristics and add the ability to run TRANSIT-global within a larger workflow to account for projection constraints and to support spatial constraints (such as the opening of international waterways) as inputs. These inputs can be adjusted to evaluate their overall impact on global maritime shipping patterns.

Factors that can influence maritime transit include ship characteristics, wind/ocean-current conditions, sea-state, and human factors (Alberti 2018). Ship characteristics, specifically hull and sail type, can be approximated by the selection of a maximum ship speed and the frictional challenge for it to turn against the wind (termed horizontal factor). We directly observe wind speeds and direction which largely drive superficial ocean-current conditions (Alberti 2018, Fitzgerald & Callaghan 2008). Since sea-state and human factors occur on a shorter time scale and can be anticipated by sea navigators, they are not factored into this analysis.

A least-cost path raster analysis is a geospatial analysis which consists of two parts. First, a raster surface known as a cost surface is calculated where each cell in the raster represents the challenge of moving to another cell. Second, a least-cost path is generated which represents the route that uses the fewest cumulative resources to travel from a specified origin point to a destination point (Conolly and Lake 2006). Alberti's TRANSIT toolbox automates calculating the raster cost surface for a single origin using a wind speed raster layer, a wind direction raster layer, and the horizontal factor. Alberti leaves the second part of the least-cost raster analysis — generating a route from one origin to another destination — to the individual researcher. This limits the user of his toolbox to generating one route at a time, which makes it difficult to scale up the route generation process for global analysis.

In our workflow (Figure 1), we begin with wind speed and wind direction raster layers derived from the World Oceanic Circulation Experiment's (WOCE) surface wind velocity data. WOCE is the largest publicly-available survey of ocean circulation, which includes standardized measurements of oceanic climactic data. To adjust for spatial constraints, such as the opening and closing of canals and global waterways, we manually edit the wind raster layers to make chokepoints traversable or not, according to what is historically appropriate. These data are input into our arcPy-based tool, TRANSIT-global, where we expand on Alberti's work by automating the process of calculating least-cost paths between a large list of OD pairs, alongside generating a cost raster. We run TRANSIT-global on two projections — one centered on the Prime Meridian, the other rotated 180 degrees — to allow for modelled routes to "wrap" around the earth in either direction. Our implementation uses approximately 250 cities, which produces over 64,000 OD pairs per run.

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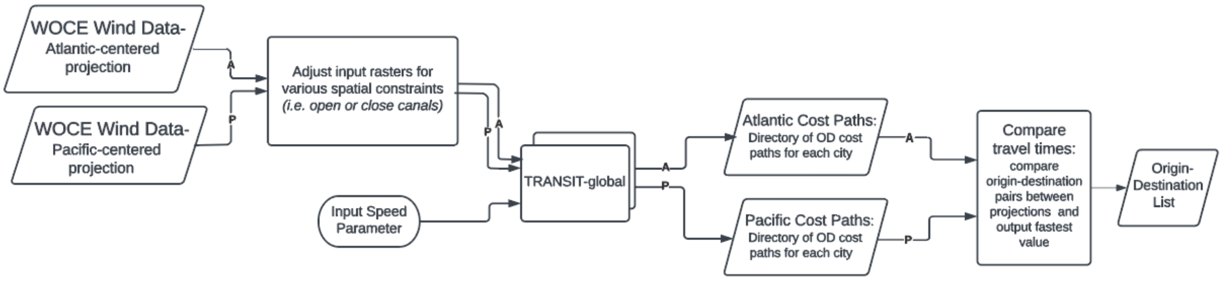


*Figure 1.* A diagram showing the workflow for generating travel times between a global list of cities.

To validate our model, we compared our modelled routes and travel times against the Climatological Database for the World's Oceans (CLIWOC) data. The CLIWOC database is a compilation of 280,000 logbook entries from French, Dutch, Spanish, and British ships from 1750-1850 (Kelly and Ó Gráda 2017). One challenge for our validation process was that CLIWOC data represented historic shipping travel times, but we could not extrapolate from the data which routes those vessels took in order to compare them against our modeled routes. These routes likely included stops for refuelling or trade which impacted the overall travel time but were not identified in the data. To remedy this challenge, we compiled our own list of publicly available, non-stop historic shipping records at the port-level globally. Notably, most records of non-stop routes were speed records, published by shipping companies for publicity. Finally, we compared our data against published modeled data such as Pascali (2017). Among comparable OD pairs, we found a high correlation between our modelled transit times with the assembled list of historic shipping records, as well as consistency between our modelled times and Pascali's data.

In our workflow, which uses the TRANSIT-global toolbox, we provide a publicly available method for researchers to investigate how shifts in shipping technology and geographic constraints impact global trade. Economists, for example, have been researching how changes in shipping technology have altered maritime transit routes and have important implications for international trade and economic activity (Pascali 2017, Kelly and Ó Gráda 2017). The creation of a global set of probable OD routes can allow economists to visualize spatial patterns in the shifting dynamics of global maritime trade – the mapping of the routes allows changes in route density to be visually apparent between different constraints such as the opening of canals or potential new trans-Arctic routes related to climate change. While our model does not address uncertainty or outside economic forces, running the model with varying input parameters allows comparison across scenarios that reflect the relative accessibility of trade ports over time. We present a workflow for creating a global set of shipping routes that accounts for ship characteristics, spatial and projection constraints, and validate our estimated data against historic time records and routes.

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