Title

Estimating Llama Caravan Travel Speeds: Ethno-archaeological fieldwork with a Peruvian salt caravan

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Caravan

Estimating Llama Caravan Travel Speeds

Ethno-archaeological fieldwork with a Peruvian salt caravan

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Introduction

The distances between archaeological features, and understanding social and physical links across space, are fundamental to how anthropologists look at the past.
Spatial relationships may be conceived as discrete points along a route,

Moving phenomena, such as trade caravans, present special difficulties to archaeologists because the archaeological "sites" that remain are often ephemeral. Evidence of exchange relationships enduring through time often appear in the form of exotic goods and stylistic interaction over great distances. Examining the "mobile sector" of a past society, the activities of those people who engaged in long-distance exchange, demands that archaeologists bring together evidence from both regional trends and from the specific landscapes in which they moved. Generalized cost-distance models provide new ways to examine movement that are not based on representations of isotropy and Euclidean space.

This study uses ethnographic field data to derive an asymmetrical Cauchy (Gaussian) equation that describes the movement of a llama caravan along an ancient trail system as a function of topographic slope. This model is further refined by using ranked observations of changes in trail quality, the negotiation of obstacles such as stream-crossings, and the type and duration of rest periods during the daily travel. The resulting cost-distance function was then applied to the actual caravan route in order to evaluate the realism of the model.


Caravan above Santa Rosa

Llama caravans in the Andes

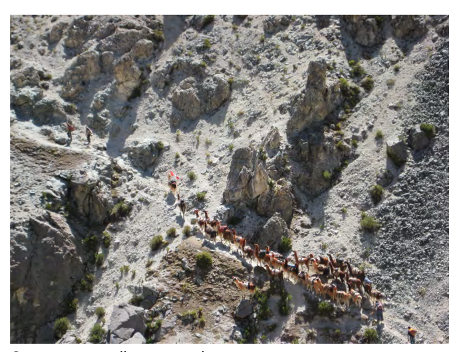
Background
Camelids were domesticated in South America at least 5000 years ago. In the mountainous interior llama caravans provided the only major source of cargo transport besides human labor. Exchange between people residing in different ecological zones in the mountains has always been vital, and llama caravans facilitated this kind of interaction.
Common features of long-distance caravans:
- consist of gelded male llamas, rarely alpacas.
- travel 15-20 km per day, and between 25 and 40 kg per animal.
- caravan drivers are typically men, and they serve a diplomatic role between communities.
- women were often seen with llamas doing shorter trips.
- equus have replaced llamas in much of the Andes, but the use of llamas continues in parts of southern Peru and Bolivia.

Archaeological significance
A general transport model contribute to addressing questions about the role or capacity of households in long-distance exchange, transport between ecological zones, interaction between state centers and colonies, and military provisioning by the expansionist states. In addition, geochemical studies provide one of the basic data sources for exchange studies, and provenance databases are increasing rapidly.
The Andes are a particular case because of the rich evidence of regional exchange and imperial spread. Consider the mountainous context for many Andean civilizations: they arose at high altitude far from the coast or major rivers and transport was largely overland.

Fieldwork in 2007
Observations of travel route:
- travel times calculated with GPS (both differential and non-corrected model)
- quality of trail (ranked)
- interviews with llameros concerning route finding and conceptions of space
- landscape perception: mountains and rivers, animism

Cargo:
- cargo weight
- size and estimated weight of llamas
- transfer of cargo from one animal to another during overnight stays

Travel strategies:
- grazing, scheduling
- negotiating trail obstacles (rivers, skree, wash-outs)
- interfacing with other herders and with agriculturalists


Caravan ascending steep slope.


Caravan fording stream.

Field Setting


Ethnographer Félix Palacios Ríos attached heart rate monitor

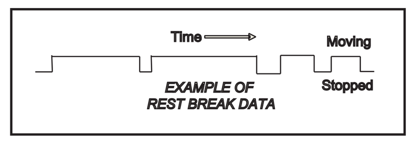
In July 2007 Fidel Cruz and his cousin Tadeo Ancco repeated a traditional journey with 28 llamas, their two younger male relatives. They allowed us four investigators to travel with them as they bought salt from villagers who manage an ancient salt quarry, and then they transported it to their home base at Chancara. From there, they prepared for a journey of approximately 90 km to the north to a river valley area that lacks local salt deposits. In the northern valley they traded salt for maize, tubers, and other goods and return to their home at Chancara.


Virginia Gutierrez readies cargo

Spatial Data Gathering Methods

Each morning prior to departure a GPS datalogger was secured to the back of the focal llama, Cantu, set to a 2 second logging interval, together with a Trimble GPS to permit post-processing. An equine heart rate monitor was also attached to Cantu in the morning. A third GPS running ESRI Arcpad 7 was used to take spatially referenced notes into along the journey.
- steady travel all day until arriving at the destination corral, though this travel was interrupted by some short breaks and a lunch break.
- llamas graze in the afternoons but not at night, so early departures ensured that we would arrive mid-afternoon to allow the animals to graze.

Sources of Spatial Data
GPS: iTrek data logger (2 second interval)
GPS: Trimble Juno
GPS: Dell Axim with Trimble XC GPS (CF card)



Topographic surface: 30m DEM from ASTER (Courtesy of NASA and JPL)

Further considerations
Rest breaks:
- Refastening of cargo
- Human / Animal rests, meals
- Coca chewing

Assumptions
- Specific ancient routes
- Comparability with modern circumstances
- Accuracy of travel times
- Limits of data resolution & method of PathDistance calculation


Community of Chancara

Data Analysis

GPS iTrek data logger provides relatively clean data for a non-differential unit. WAAS is not available in South America. In analysis, all positional data are included where slope < 50 º and speed is < 30 Km/hr. Datalogger results are examined in ArcGIS 9 and descriptive statistics are produced with SAS JMP 7. A test run from a stationary position was analyzed for positional accuracy error (see Figure).
The data consisted of a unique ID number, latitude and longitude, and altitude positions with time and date stamps. These were projected to the metric coordinate system, UTM Zone 18 south, so that distance measurements would occur in projected space. Next, Hawth's Tools (Hawthorne Beyer) was used to calculate Movement Parameters including "StepLength". For each position, the StepLength from the previous location and the clock were used to calculate speed in ArcGIS, and Slope º = ATAN (Δ Z / StepLength).


Rómulo Cruz and Fidel Cruz rest against stacked cargo

A Cauchy (Lorentzian) function based on Slope in degrees against Km/hr is fit to the data in JMP using the Non-linear, Gaussian models. This function is used to generate a "Vertical Factor table" of custom values that is provided to the ArcGIS Path Distance function. This function can be used to generate similar cost-distance curves for llama caravans in other regions.

Evaluation
The resulting function was tested against the caravan route itself to evaluate the accuracy of the model. The path distance function was confined to buffer 60m wide along the actual caravan route by using a DEM that was clipped to this buffer. A Euclidean distance calculation of the travel time based on a constant of 4 km/hr along the GPS route (disregarding slope) is also computed for comparison.

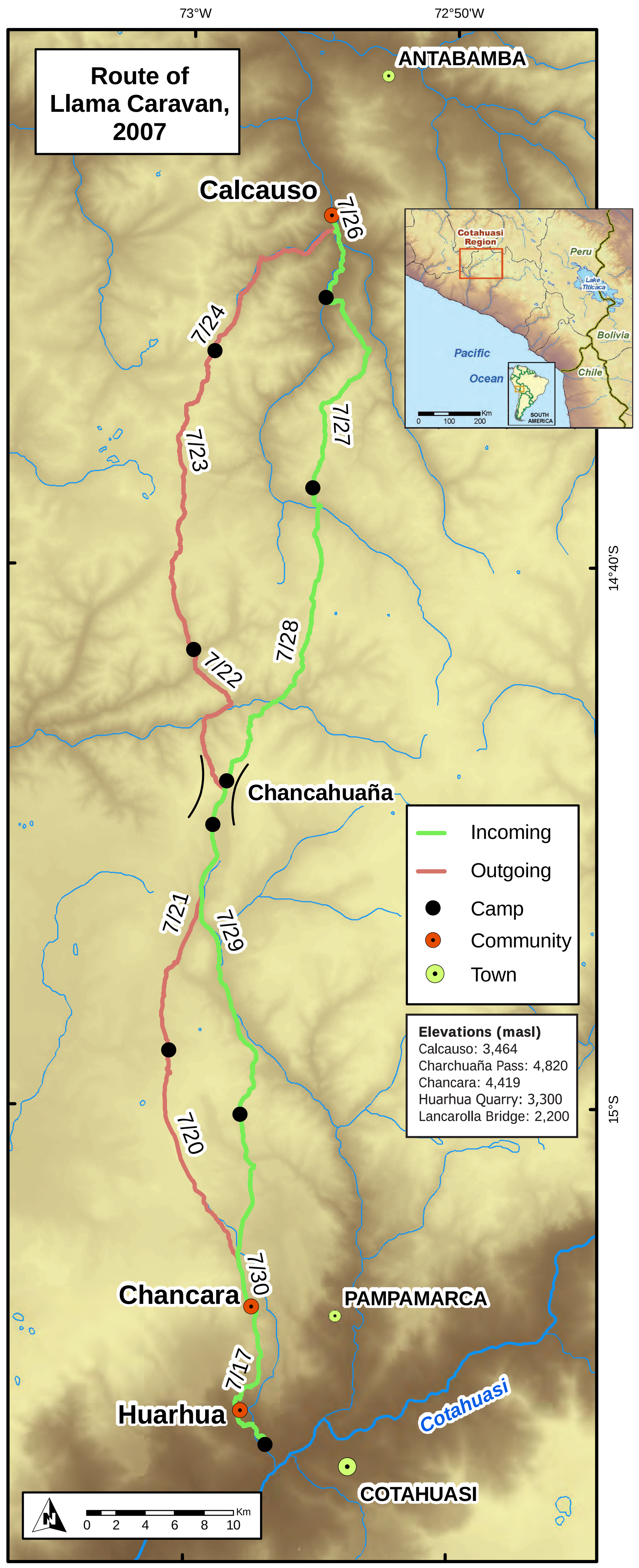
Results

The entire journey resulted in over 100,000 GPS positions along trails ranked in quality between 1 and 5. The effects of the differences in trail quality were subtle, so a single llama caravan function will be presented here.

Using the Cauchy function in the form:

$$\frac{h * W^2}{((Slope - x0)^2 + w^2)}$$

h = 4.028, x0 = -4.127, w = 46.0



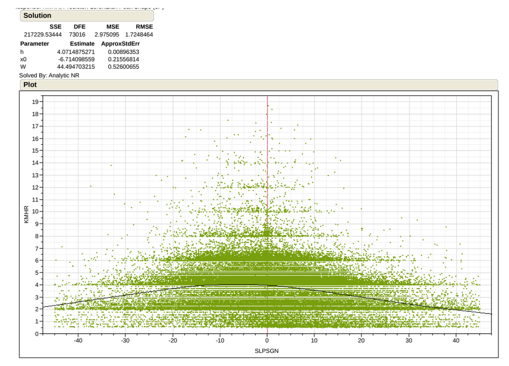
Map showing caravan route

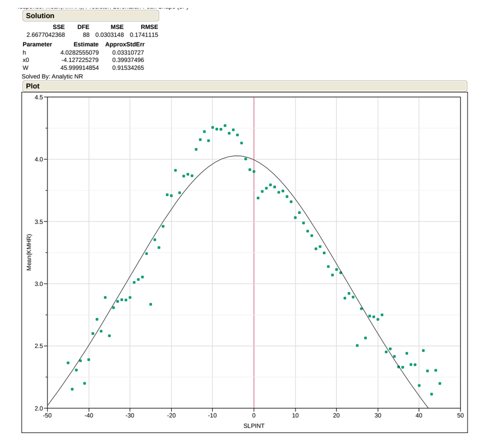
	July 14	July 15	July 16	July 17	July 18	July 19	July 20	July 21	July 22	July 23	July 24	July 26	July 27	July 28	July 29	July 30	Totals
Events	Encounter llameros at bridge and initial studies	Climb to Huarhua salt quarry	Acquire salt from Huarhua mine	Climb from Huarhua to Chancara	Organize caravan food, measure llamas	Rituals prior to departure	Depart Chancara, Anillo, Yanacocha	Yanacocha to Jalcachi	Abra Chancahuaña, Santa Rosa	Santa Rosa to Trapiche	Descend from Trapiche to Calcauso	Depart Calcauso, camp by stream	Ascend to puna through Malpaso	Camp on Chancahuaña Pass	Stay in Hapja valley, camp under outcrop	Arrive in Chancara	
(1) # Observations (2 sec)	Stopped	3913	Stopped	6945	Stopped	Stopped	1006	irregular	11748	16957	9641	4356	14796	15813	15752	7633	108560
Departure (Time)		7:04 AM		8:52 AM			8:39 AM	6:50 AM	7:16 AM	5:52 AM	11:37 AM	12:27 PM	6:53 AM	6:40 AM	7:02 AM	7:06 AM	
Arrival (Time)		10:20 AM		2:39 PM			1:13 PM	10:13 AM	1:48 PM	3:17 PM	4:59 PM	2:52 PM	3:06 PM	3:27 PM	3:47 PM	11:21 AM	
Daily Distance (Km)		6.92		10.70			19.31	17.58	17.15	24.56	16.69	7.15	19.46	26.08	26.81	14.94	207.33
Actual Total Time (Min)		195.75		347.20			273.50	202.72	391.82	565.20	322.65	145.00	493.00	527.07	525.17	254.40	4243.47
(2) Rest Breaks (Min)		19.45		156.35			0.73	3.47	137.80	174.13	68.80	37.47	147.13	104.43	126.30	37.37	16.89
Other Slow Times (Min)		31.35		44.95			2.60	3.17	26.83	17.17	7.37	5.20	22.83	21.50	13.90	9.83	3.45
Total Slow Times (Min)		50.80		201.30			3.33	6.63	164.63	191.30	76.17	42.67	169.97	125.93	140.20	47.20	20.34
(3) Predicted Moving Time (Min)		76.92		148.68			312.85	264.46	258.26	372.20	234.90	117.30	286.22	385.92	402.26	220.20	3080.17
Predicted Moving + Slow (Min)		127.72		349.98			316.18	271.09	422.89	563.50	311.07	159.97	456.18	511.85	542.46	267.40	4300.31
Actual Time - Tot. Predicted (Min)		68.03		-2.78			-42.68	-68.38	-31.08	1.70	11.58	-14.97	36.82	15.21	-17.29	-13.00	**323.52**
(4) Euclidian Moving (4kmhr)(Min)		103.73		160.45			289.59	263.73	257.21	368.37	250.28	107.30	291.96	391.20	402.14	224.09	2845.85
Euclidean + Rest Times (Min)		154.53		361.75			292.92	270.36	421.84	559.67	326.44	149.96	461.93	517.13	542.34	271.29	3813.88
l Time - Tot. Euclidean (Min)		41.23		-14.55			-19.42	-67.65	-30.02	5.53	-3.79	-4.96	31.07	9.93	-17.17	-16.89	**262.21**

(1) Number of observations with the iTrek Z1 GPS data logger . Departure and arrival reflect first and last moving GPS positions of the day. Daily Distance calculated from logger points as linear feature. Actual Total Time is the Arrival - Departure times. (2) Slow Times are any GPS displacement < 0.5 km/hr, and Rest Breaks are two contiguous slow readings in a row. Total Slow Times summed with daily measures of Moving Times should add up to Actual Total Time. (3) Predicted Moving Time is calculated using the Cauchy distribution to derive an asymmetriical cost distance function, which is then then applied as a custom Vertical Factor table to the Path Distance function in ArcGIS 9.2. Predicted summed with Slow Times for each day is subtracted from Actual clock time. (4) Euclidean Moving assumes a constant moving velocity of 4 km/hr.

Discussion
Preliminary results indicate that the asymmetry of the cost-distance function provided greater realism in areas with higher topographic relief. Travel speeds in the more level areas of the caravan journey can be effectively estimated by simply using 4 km/hr along the caravan route. Considering the effect of rest breaks, including the duration and qualitative aspects of the rest, are an important component of these models. Based on observations in 2007, the causes of rest breaks can be physiological (exhertion), for social visits and information gathering, and for ritual activities.

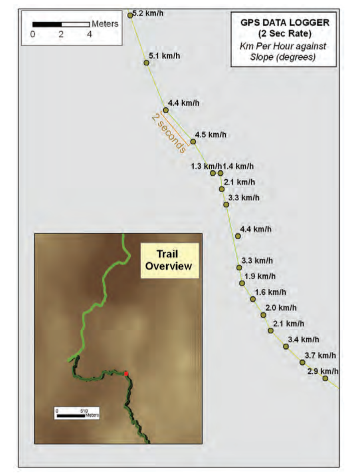
Further results from this fieldwork beyond the scope of this poster include ethnographic and ethno-archaeological observations about the llama caravan traditions and transport strategies. Observations concerning the types of archaeological features used by llamas, such as corrals, as well as the changing flocking patterns of the animals, and the effects of trail quality were also possible. Data that includes heart rate data from humans and from llamas will contribute to possible behavioral ecology studies in the future.

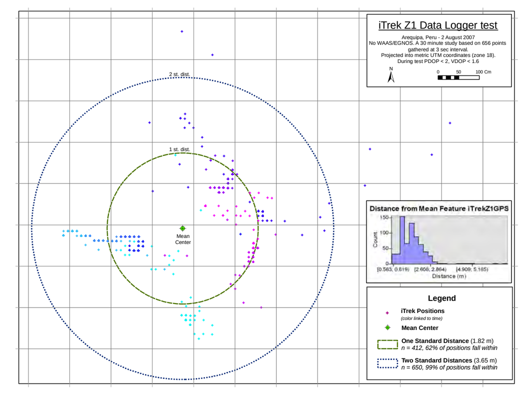

Function calculated on raw values.


Function calculated on means for each Slope Integer group.

Conclusions

Improvements in geospatial technology, such as GPS data loggers and accessible cost-distance functions in GIS software, has simplified the task of developing asymmetrical models for various moving phenomena. The utility of this function is particularly apparent in high relief areas. This transport model calibrated to llama caravans can be applied to archaeological phenomena that were likely disseminated using llama caravans. For example, the speed of diffusion of obsidian from the Chivay source in southern Peru to consumption areas throughout the region can be modeled as a function of topography using this cost-distance model.


Example of trail with 2 sec interval positions.


Positional error in the iTrek GPS unit while stationary for 30 minutes.

Participants

Llameros
- Fidel Cruz Anco, Virginia Gutierrez, Romulo Cruz
- Tadeo Ancco, Raul Ancco

Investigators
- Nicholas Tripcevich, Felix Palacios, Edison Mendoza, Cheyla Samuelson, Willy Yepez

Photo credits
E. Mendoza, C. Samuelson, and N. Tripcevich

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The group on the last night