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Spatial Analysis of Logistics Indicator Data for Health Commodities

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Data collectors use a GPS device to record waypoint data during a logistics assessment in Nigeria. This enabled a spatial analysis of indicators.

All of the spatial analysis methods presented in this paper excel in providing insights into the logistics system.

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Introduction

The application of cartographic and spatial analysis methods in the context of public health and disease surveillance has a lengthy history going back centuries, and perhaps made most famous by the mapping of cholera epidemics in the 1850's. The central figure in the evolution of this emerging field, Dr. John Snow, shed light on the inherent spatial relationships of public health outcomes with factors as diverse as environmental conditions, socioeconomic class, and human-built infrastructure. Indeed, the now mythic story of London's 1854 cholera epidemic and the infamous Broad Street pump is obligatory learning for public health and epidemiologic professionals, and set the stage for countless studies of geographic disease distribution for the plagues of our time—influenza, malaria, HIV and AIDS, and others.[1]

With advancing technology and the advent of computerized geographic information systems (GIS), public health professionals are now able to perform complex spatial analysis on health outcome data and develop statistical models that help to explain the incidence and spread of disease. When coupled with global positioning system (GPS) data, GIS analyses are even more capable of pinpointing specific occurrences of a given variable, in order to more effectively measure their geographic distribution or even to track disease spread over time. Yet a focus only on the spatial variation of disease occurrence solves only one half of the public health problem, the demand for health services. A complete view of the problem will account for both the demand and also the supply of health services, manifested in health facilities, health personnel and systems, and health commodities.

This last piece of the supply of health services—health commodities—and the spatial analysis methods needed to effectively monitor and locate them in a health system, is the focus of this paper.

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[1] Koch, Tom. 2005. Cartographies of Disease: Maps, Mapping, and Medicine. ESRI Press: Redlands, California.

Purpose

The USAID | DELIVER PROJECT has developed robust monitoring and evaluation tools to quantitatively and qualitatively assess the performance of logistics systems for essential health commodities.

The purpose of this paper is to explore how analysis of stock indicators by location provides added value to these data sets, through a relatively minor investment in GPS devices and GIS software.

Methodology

During 2008, the project conducted initial pilot activities in Zambia and Paraguay to collect GPS data for health facilities visited during implementation of the Logistics Indicator Assessment Tool (LIAT). In order to provide a smooth integration of this new technology into the data collection process, the project chose to rely on commercially available GPS devices that provided accurate location data and also were easy to learn how to use for the data collection teams. Training on how to use the GPS devices to record waypoint (i.e. location) data was incorporated during LIAT data collector training. During the training data collectors practiced using the devices and demonstrated their competency. Each team was able to master the steps for obtaining and recording the GPS data. Data collection teams also received handouts with review information and extra batteries to take with them, just in case.

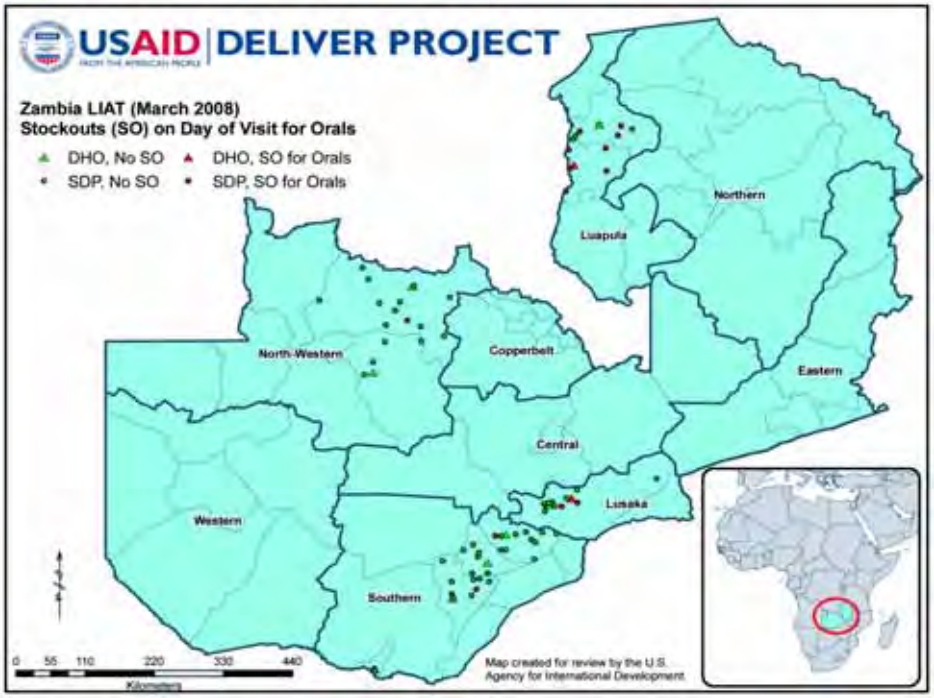
Once the logistics indicators and the GPS coordinates were collected and compiled into a single database, this information was exported to the GIS for the spatial analysis of some select indicators.

Overview of Analyses that Account for Geography

Visual analysis of patterns in stock status

One of the first steps in conducting spatial analysis of the stock indicators is to visually inspect the data to look for any obvious patterns that would require further investigation. Figure 1, below, presents the data for stockout on the day of visit for oral contraceptives for the Zambia 2008 LIAT assessment.

Figure 1. Distribution of Stockouts on Day of Visit for Oral Contraception (Zambia LIAT)



An interesting aspect to note about the distribution of this particular variable is the relationship between stockouts at the District Health Offices (DHO) and the service delivery points (SDP) that they supply. In some instances SDPs experiencing stockout, shown as red circles, are located closer to the DHO, shown as triangles, than other SDPs with no stockout. Furthermore, one region in particular stands out on this map because of the concentration of stockout at both the DHO and SDP level for an entire district. While this type of visual

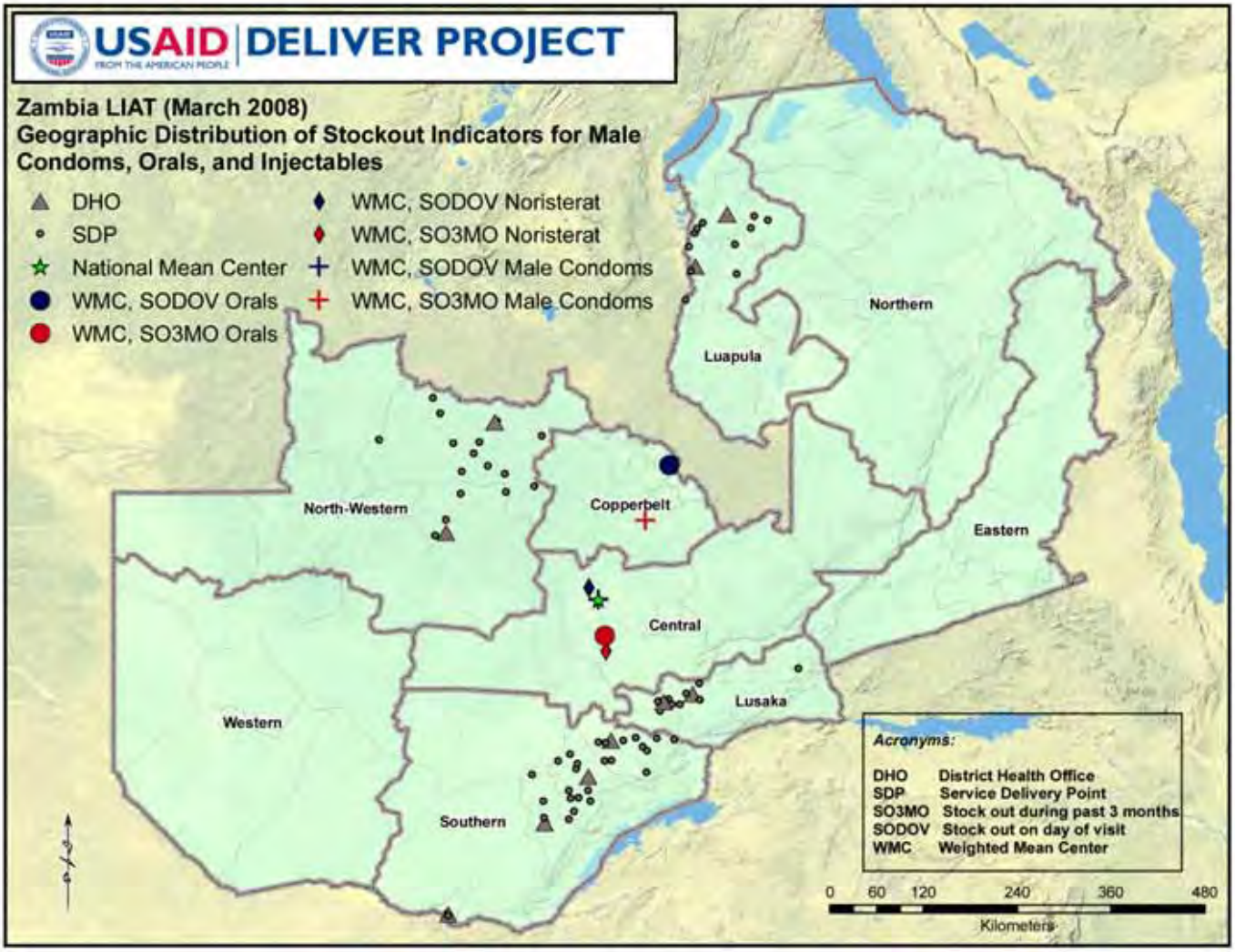
examination of the data on a map is not particularly rigorous from an analytic standpoint, it is useful in helping managers identify patterns in the data and generate questions to focus further analysis.

Summary spatial statistics to measure central tendency of stock indicators

The next level of analysis is to use spatial statistics to describe the distribution of data points collected during the LIAT survey and determine if there are any trends that can be measured for specific stock indicators. As a starting point, it is useful to calculate the Mean Center (MC) of the distribution, which is a theoretical point in space whose coordinates are derived by calculating the mean of the latitude coordinates, followed by the mean of the longitude coordinates, for all the points in the sample. The MC, therefore, can be thought of as a measure of the geographic center of an entire distribution of points, in this case surveyed health facilities.

By itself the MC is of little interest. However, if you calculate the MC and weight each coordinate pair in the distribution by a specific stock indicator of interest, the result is a Weighted Mean Center (WMC), which also provides a measure of central tendency, but weighted by the specific stock indicator. Now, when you compare the WMC for a given indicator to the MC, it is possible to infer a geographic tendency for that indicator both in terms of magnitude and ordinality. Furthermore, if you calculate a WMC for all of the stock indicators of interest, it is possible to compare these indicators to each other, in terms of their geographic distribution. For example, Figure 2 shows the MC for all the health facility locations in the Zambia LIAT sample, symbolized as a green star, as well as WMC points for multiple

Figure 2. Distribution of Stockouts for Male Condoms, Oral Contraception, and Injectables (Zambia LIAT)



indicators, including stockout on day of visit (SODOV) and stockout during the previous three months (SO3MO) for male condoms, injectables (Noristerat), and oral contraceptives. Relative to the MC, the WMC of SO3MO for both oral and injectable contraceptives trends in almost equal magnitude to the south, while the WMC of SODOV for orals trends much stronger to the northeast and for injectables sits closely to the MC. The interpretation for this analysis is that over a longer period of time, 3 months before the survey, the problem of stockout for orals and injectables has manifested more in the southern part of the country, and that on the day of the visit, stockout, at least for orals, was more prevalent towards the northeast.[2] Note that this simple statistical analysis is consistent with the preliminary visual inspection of the data, as previously described.

Comparing the MC with the WMC for different indicators is useful in describing the geographic variation in data for multiple indicators concisely. A consideration to make with these measures is that they describe a specific set of points in a spatial point pattern, so the statistics are themselves dependent upon the points. If a sample of facilities is not geographically representative, then the conclusions drawn from comparisons of the WMC to the MC is specific only to the sample and may not necessarily be extrapolated to the whole system.

Test for spatial autocorrelation (Moran's I)

The next level of statistical analysis that is useful in analyzing logistics data deals with the concept of spatial autocorrelation, which is the idea that things near each other are more alike than things that are farther apart, also commonly referred to as Tobler's Law.[3] One of the most widely used tests for spatial autocorrelation is the Moran's I statistic, which is a single derived value that analyzes an entire set of features, in this case the stock indicators for the health facilities sampled during a LIAT. It is furthermore a robust statistical measure of whether an indicator exhibits a clustered, disperse, or random pattern over the entire study area.

The Moran's I statistic is most useful when a sample of facilities is geographically representative of the all the facilities in a country, making it more useful for the Paraguay LIAT. Figure 3 displays the locations of health facilities visited during the survey in Paraguay, along with the stock status on the day of visit for one or

Figure 3. Distribution of Stockouts on Day of Visit for One or More Contraceptives (Paraguay LIAT)

[2] Note that when the MC and WMC coincide, as in the case with SODOV for male condoms, the indicator used to calculate the WMC is the same for all the survey points.
[3] Mitchell, Andy. 2005. The ESRI Guide to GIS Analysis, Volume 2: Spatial Measurements and Statistics. ESRI Press: Redlands, California.

more contraceptive commodities. In this particular case, the Moran's I calculation is consistent with a clustered pattern of stockout, which is consistent with a visual inspection of this data.

The key question to ask here is why is the evaluation of spatial autocorrelation germane to the analysis of logistics indicators? To fully answer this question, and to understand what spatial autocorrelation tells us about the logistics system, there are a number of points that must be made:

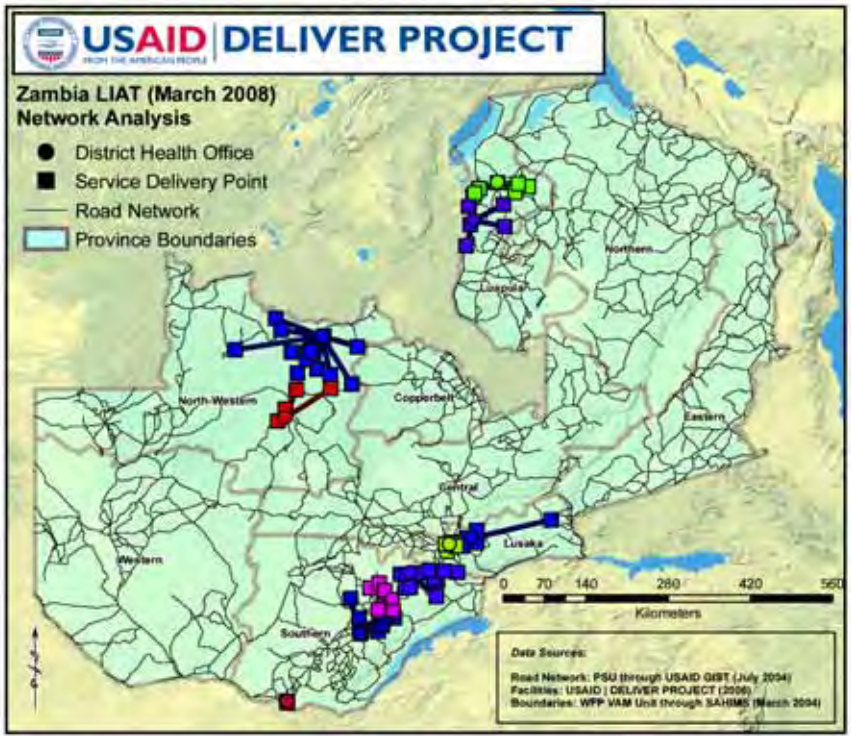
- If there is significant clustering of stockout, what factors could be contributing to this problem? (e.g., delayed shipments to a certain area, management issues, etc.)
- If the factor affecting stock availability can be identified, then focused interventions can be implemented to address the situation.
- If there is no significant spatial autocorrelation and the rate of stockout is low, then the system is most likely functioning well.
- If there is no significant spatial autocorrelation, but the rate of stockout is high, then the problem will most likely be more widespread and systematic. Addressing a systematic problem of stockout would require ongoing and potentially significant interventions at the highest levels of the system, and would need to percolate down to the SDP level.

The challenge of using the Moran's I statistic is that it is measured using Euclidean, or "as the crow flies," distance and does not account for topography or road networks. Logistics systems, by their very nature, are complex networks of roads and facilities, making it necessary to build off of the spatial autocorrelation analysis and investigate the problem of stock availability from a more network-oriented approach.

Network analysis

The network level of analysis uses the most representative factor connecting facilities—roads. The disadvantage of this approach, however, is that it requires substantial detailed data on roads (and their attributes) for an entire country to make valid estimates of distance and travel time. In developed countries this quality of data is fairly ubiquitous, however in many developing country scenarios it may not be possible to obtain the appropriate data, both in terms of representation and quality. For the case of the Zambia LIAT, road data was obtained from the USAID GIST data repository and is part of the larger vector map level 0 (V-Map 0) project, which provides worldwide vector data (roads, administrative boundaries, populated places, and other features of interest) for use in GIS analysis. Using tools within the GIS, a network model was created to link health facilities with the road network that connects them together (see Figure 4).

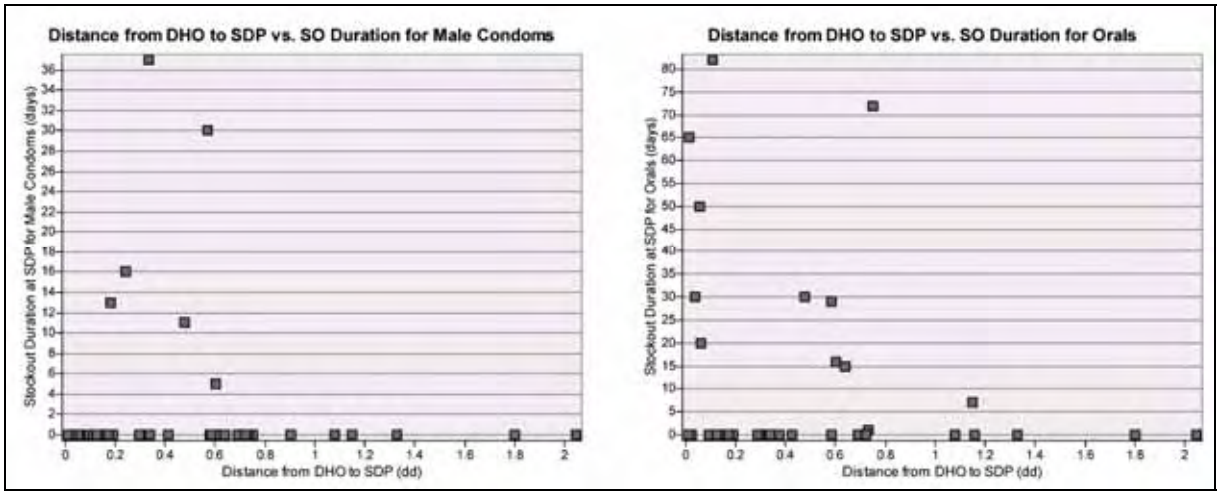
Figure 4. Network Model of District Health Office and Health Facilities (Zambia LIAT)



Since the DHO's supply commodities to all the SDPs within their district, the

model was then used to analyze the distance, through the road network, from all the SDPs to their respective DHO's. This distance calculation was then plotted against stockout duration for the 3 months prior to the survey for oral contraceptives and male condoms, as shown in Figure 5, below.

Figure 5. Stockout Duration at SDPs for Male Condoms and Orals Compared with Distance from DHOs (Zambia LIAT)



In general, it may be assumed that a logistics system experiences the most challenges in maintaining adequate stock levels at the SDPs located farthest from their supplier, in this case a DHO. In the Zambia case, however, it is clear for both male condoms and oral contraceptives that the facilities closest to the DHO are those with the longest periods of stockout for the commodities. In fact, all of the facilities that are located the farthest from their supplier exhibited no stockout at all for the commodities in question.

There are a few possible explanations for this phenomenon. First, the SDPs closest to the DHO are located in areas that are more heavily populated, and hence serve a greater number of clients. Since health personnel are responsible in this case for traveling to the DHO to pick up their resupply orders, it may be more difficult for them to leave their clinic unattended or understaffed for a period of time than it is to simply tell clients that they are stocked out. Second, since transportation is a significant obstacle in the most rural parts of the country, the health personnel at SDPs located farthest from their respective DHO may find it exceptionally difficult, from either a time or financial perspective, or both, to travel on a regular basis to pick up commodities. In this case they may choose to ration their stocks in order to maintain a positive balance. Third, the most rural parts of the country are also the least populated and most conservative, making the demand for contraceptives at the SDPs in these areas lower and more easy to manage than in the larger urban centers.

Conclusion

Beginning with visual examination of logistics indicator data within a geographic context and progressing to network analysis, each of the spatial analysis methods presented in this paper presents its own set of strengths and weaknesses, yet they all excel in providing insights into the logistics system that might not otherwise be understood or even observed by simply looking at tabular data of stock levels for different facilities in the health system. Since a logistics system is inherently a geographically heterogeneous entity, using cartographic and spatial analysis tools may prove to be a crucial asset in assisting managers to identify key questions related to the performance of the logistics system and focus on potential causes and solutions. Moving forward, it will be useful to build off of the descriptive strengths of the spatial analysis methods described herein and begin building more robust statistical models that measure correlation between different components of the logistics system and commodity availability, while still accounting for the geographical variability of the data.

The authors' views expressed in this publication do not necessarily reflect the views of the U.S. Agency for International Development or the United States Government.

USAID | DELIVER PROJECT

John Snow, Inc.

1616 Fort Myer Drive, 11th Floor

Arlington, VA 22209 USA

Phone: 703-528-7474

Fax: 703-528-7480

Email: askdeliver@jsi.com

Internet: deliver.jsi.com