GEOGRAPHIC INFORMATION SYSTEMS, SPATIAL NETWORK ANALYSIS, AND CONTRACEPTIVE CHOICE*

BARBARA ENTWISLE, RONALD R. RINDFUSS, STEPHEN J. WALSH, TOM P. EVANS, AND SARA R. CURRAN

How does family planning accessibility affect contraceptive choice? In this paper we use techniques of spatial analysis to develop measures of family planning accessibility, and evaluate the effects of these geographically derived measures in a multilevel statistical model of temporary method choice in Nang Rong, Thailand. In our analyses we combine spatial data obtained from maps and Global Positioning System (GPS) readings with sociodemographic data from surveys and administrative records. The new measures reveal (1) important travel time effects even when family planning outlets are close by; (2) independent effects of road composition; (3) the relevance of alternative sources of family planning supply; and (4) the importance of the local history of program placement.

How does family planning accessibility affect contraceptive choice? Despite several decades of research in this area, we do not know the answer (for reviews, see Hermalin and Entwisle 1987; Tsui 1985; Tsui and Ochoa 1989). The effects of service proximity on contraceptive choice vary from one study to the next, and often are quite weak. There are problems of data availability and measurement (Chayovan, Hermalin, and Knodel 1984) as well as disagreements about modeling and estimation (Gertler and Molyneaux 1994; Hermalin 1979; Hernandez 1984). Progress toward an answer is needed because family planning accessibility effects lie at the heart of program assessment (Lapham and Simmons 1987), but more generally because these effects are the key to a broader understanding of fertility behavior in the context of social change (Bulatao and Lee 1983).

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In this paper we introduce a new approach to measurement, capitalizing on research opportunities offered by geographic information systems (GIS). We borrow spatial network analytic techniques from geography (Aronoff 1989; Dijikstra 1959) to develop alternative measures of family planning accessibility. Some of these measures are based on estimates of travel time (e.g., travel time to the nearest and next nearest family planning outlets). Others are based on the road composition of the route likely to be taken, especially when the route includes seasonal roads and cart paths. The effects of the geographically derived measures are evaluated in the context of an already developed multilevel model of contraceptive choice based on data from Nang Rong, Thailand (Entwisle et al. 1996; Rindfuss et al. 1996). Of particular interest is what new information is learned about accessibility effects given a spatial and sociodemographic approach.

A previous analysis of Nang Rong data, conducted before the construction of a GIS for this site, pointed to the presence of a subdistrict health center in or near a village and proximity and ease of travel to Nang Rong town as potentially important aspects of family planning accessibility in this setting (Entwisle et al. 1996). In the previous analysis, it was not possible to explore differences in travel time to the subdistrict health centers, the history of establishment of these centers, road composition, and especially vulnerability to seasonal flooding because appropriate data were not available. In this paper we illustrate the potential of GIS and techniques of spatial analysis for developing new measures of family planning accessibility, and explore the implications of these new measures for method choice in the Nang Rong setting. In an earlier study, we developed an explanation of contraceptive choice that covered permanent and temporary methods, and considered a range of community effects, including but not limited to family planning accessibility (Entwisle et al. 1996; Rindfuss et al. 1996). Here we focus on temporary method choice, using our earlier model as a starting point for the assessment of new measures of accessibility developed within the GIS.

BACKGROUND

Family planning accessibility refers to the supply of contraceptive methods and services in a community. Its components include the proximity, variety, cost, and quality of contraceptive services (Hermalin and Entwisle 1987). In this paper, we are particularly concerned with the placement of family planning outlets vis-à-vis potential users of temporary methods, establishment dates, and the specific methods available at these sources.

Previous research on family planning accessibility has relied on surveys of users and potential users of services, interviews of key informants in communities, program records, or direct observation (e.g., driving to a source and recording the odometer reading) for information about the location of family planning outlets. In this paper we draw on a new type of data: a digitized and geocoded map of roads and the location of villages and outlets, organized and analyzed within a GIS. Applying spatial network analysis to our data on villages, roads, and source locations allows us to develop a range of travel time estimates and to address a variety of questions about the impact of source proximity. For example, to what extent is contraceptive choice influenced by travel time to the nearest and to the next nearest source type? Outlets occasionally may be out of supplies, in which case easy access to multiple centers might facilitate a choice of one of the methods available at that type of outlet. Alternatively, the quality of care may vary. The staff of one may be inefficient or crabby, or waiting times may be long. Another possibility is that contraceptive users might like to combine trips to a family planning outlet with other tasks, such as marketing or visiting relatives. Because the direction of these other tasks might change depending on the chore or activity, having several outlets nearby might make such combinations easier. A related question is whether the impact of proximity to one source type depends on proximity to other source types (Chayovan et al. 1984).

Whether based on spatial network analysis or on the reports of respondents or community informants, travel time estimates make assumptions about mode of travel and speed over different types of roads. In addition to travel time, mode of travel, comfort, and speed may affect behavior. Suppose it takes the same amount of time to travel to two different family planning outlets. In the first case, the woman catches a ride on the back of a moped, winding around potholes and mud puddles on an unpaved seasonal road. In the second case, she rides in the back of a small truck on all-weather paved roads. Which will she choose? Remember that travel time is the same for both routes. Because of differences in comfort and convenience, we expect her to choose the second outlet over the first. In a GIS, once a route is selected, it is possible to determine the fraction of that route involving travel on different kinds of roads. If mode of travel, comfort, and speed matter, then road composition will have an independent effect on contraceptive choice.

We also explore the historical dimension of family planning accessibility, a neglected topic. Typically data about family planning accessibility are collected simultaneously with data on contraceptive choice, sometimes even later. Analyses based on these data must assume that the effects of accessibility are immediate, or that the family planning environment has changed little. It is likely that it takes time for information about new sources to be disseminated, and that habit plays a role in couples' contraceptive choices. Indeed, qualitative data analyzed as part of our earlier research on contraceptive choice in Nang Rong pointed to the importance of village-based conversational networks as both a source of and a constraint on information about the various methods available in this setting (Entwisle et al. 1996). To test for lagged effects, we obtained establishment dates for family planning outlets and formed measures of accessibility based on outlet location for different years before the survey.

A related point concerns boundaries. Data on family planning accessibility often are collected with reference to political or administrative boundaries that may or may not be relevant to behavior. For example, information about distance or travel time may be collected only for service points within an administrative unit. Analyses based on these data implicitly assume that couple behavior is similarly constrained. It ought to be an empirical question whether political or administrative boundaries define the contextual borders for contraceptive choice, however. Political or administrative boundaries may not be relevant at all: Couples may simply choose the family planning outlet that is most convenient, even if it means crossing one of these boundaries. In this paper, we take account of facilities outside and inside the district being examined. The use of spatial network analytic techniques affords considerable flexibility in the identification of buffers and boundaries.[1]

We know of few instances of GIS and spatial analysis being used in family planning research (see Rosero-Bixby 1993, 1995 for exceptions). In health research, they are emerging as important new tools for planning and research (Albert, Gesler, and Wittie 1995). Examples of their use include location/allocation modeling of health care accessibility (Walsh et al. 1995), assessment of hospital service areas (Gesler et al. 1995), evaluation of spatial linkages between health care providers and consumers (Verhasselt 1993), and identification of exposure boundaries, environmental factors, and populations at risk (Stallones, Nickols, and Berry 1992). GIS and spatial analytic techniques have been slow to diffuse outside geography because of the lack of useful, accurate, and reliable information referenced to spatial coordinates suitable for examining spatial patterns and interrelationships (Heywood 1990; Matthews 1990; Twigg 1990). One goal of the present paper is to explore their application to a common social demographic question.

DATA AND SETTING

The particular application we explore in this paper is Nang Rong, Thailand. Nang Rong district is located approximately 350 kilometers northeast of Bangkok, 60 kilometers north of Cambodia, and 350 kilometers west of Laos. It is one of the

1. The routing algorithm of the spatial network analysis presumes a bounded study area. If we were to take the Nang Rong administrative district as our study area, the analyses would be limited to those villages, subdistrict health centers, and components of the transportation network within the administrative borders. Instead, we developed a 10 km spatial buffer around the administrative district to accommodate both the possible movement of villagers to subdistrict health centers located on the other side of the administrative boundary and the use of roads that extend outside the district (Bracken 1994; Flowerdew and Green 1989; Openshaw 1984).

poorest districts in the country, with a 1984 median per capita income of about $140 per year (Community-Based Rural Development Project (CBIRD) 1994). Most villagers are subsistence farmers, growing one crop of rice per year in their rainfed irrigated fields. The land in Nang Rong is limited in suitability for intensive farming because of poor soil quality and lack of water for irrigation (Grandstaff 1992).

In 1984, the Population and Community Development Association (PDA) began a Community-Based Rural Development (CBIRD) Project in selected Nang Rong villages to (1) improve skills and productive capacity in agriculture, animal husbandry, and cottage industry; and (2) upgrade waste disposal facilities, increase year-round availability of clean water, and promote improved individual health care practices. Data collected in 1984 in 51 of the approximately 300 villages making up Nang Rong district at that time provided a baseline against which to evaluate the success of the CBIRD project. These data were the starting point for our analyses of contraceptive choice in Nang Rong (Entwisle et al. 1996; Rindfuss et al. 1996).

A household census was conducted in 1984 in each of the 51 villages selected for base line data collection. The method of contraception used by each married woman of childbearing age was recorded.[2] According to these data, 55% were using a method of contraception. In addition, contraceptive use patterns in the 51 villages varied substantially. Overall prevalence ranged between 31% and 77%. Method-specific prevalence rates varied from 0%–40% for the pill, 0%–30% for the IUD, 0%–20% for injection, 0%–41% for vasectomy, and 2%–30% for female sterilization. A community survey was also conducted to obtain detailed information on a wide array of topics for the same 51 villages.

Of particular interest for the present paper are the temporary methods—pill, IUD, and injection—all of which involve current choices. We explicitly exclude sterilization from the analysis. The decision to have a sterilizing operation was made at some point before 1984 for those couples reporting themselves sterilized at the time of data collection; thus it is not appropriate to treat sterilization as representing a current choice.

Our previous analyses showed accessibility to be an important determinant of patterns of temporary method choice (Entwisle et al. 1996). Measurement of accessibility, however, was fairly crude: It was limited to whether a subdistrict health center was located in the village and a measure of village remoteness from Nang Rong town. Subdistrict health centers supply methods at the most local level in rural Thailand (Bennett et al. 1990). In 1984 in Nang Rong they distributed pills. The other methods could be obtained from district health centers and district hospitals located in district towns such as Nang Rong town. The presence of a subdistrict health center in the village encouraged use of a temporary method, and encouraged pill use over other temporary methods, especially the IUD. The pattern for remoteness is more difficult to interpret. Residents of more remote villages were more likely to use temporary contraception, and were likely to prefer the pill and IUD to injection. We will comment on these results later in the paper.

After this earlier analysis, we created a GIS that incorporates selected survey data but that also includes spatial data obtained from a variety of other sources. A GIS is an automated system for the capture, storage, retrieval, analysis, and display of spatial data (Clarke 1990:11). It consists of a relational data base linking the geographic portion of feature elements to their attributes and the integration of hardware, software, and geospatial information for conducting various types of spatial analysis, generating variables, displaying results, and creating maps. In our application, the road network and locations of villages, subdistrict health centers, and district towns comprise the feature elements; road type and travel speeds comprise the attributes. The type of spatial analysis we use is spatial network analysis (described in the next section). Travel time and road composition estimates based on the spatial network analysis were exported to statistical software for further analysis. Maps are the key to the display of descriptive results.

Fortuitously, a high-quality composite map of the Nang Rong area at a scale of 1:50,000 was prepared by the Thai Ministry of Defense for the same year in which the base line data for the CBIRD project were collected—1984. We digitized the roads, trails, and cart paths, as well as village centers[3] and district towns, and incorporated these data into the GIS referenced to the Universal Transverse Mercator (UTM) spatial coordinate system. As shown in Map 1, the road network in 1984 involved only a few paved all-weather roads. The east-west highway, built initially for military reasons in the late 1960s, linked Nang Rong to Korat (a regional city) and from there to Bangkok (the capital). The road leading to the northeast tied Nang Rong to Buriram (the provincial capital). The northerly route led to Lamplaimas district. Few villages were located directly on these highways, but most were close to passable dirt roads that led to them. A web of seasonal roads, trails, and foot paths linked villages with one another.

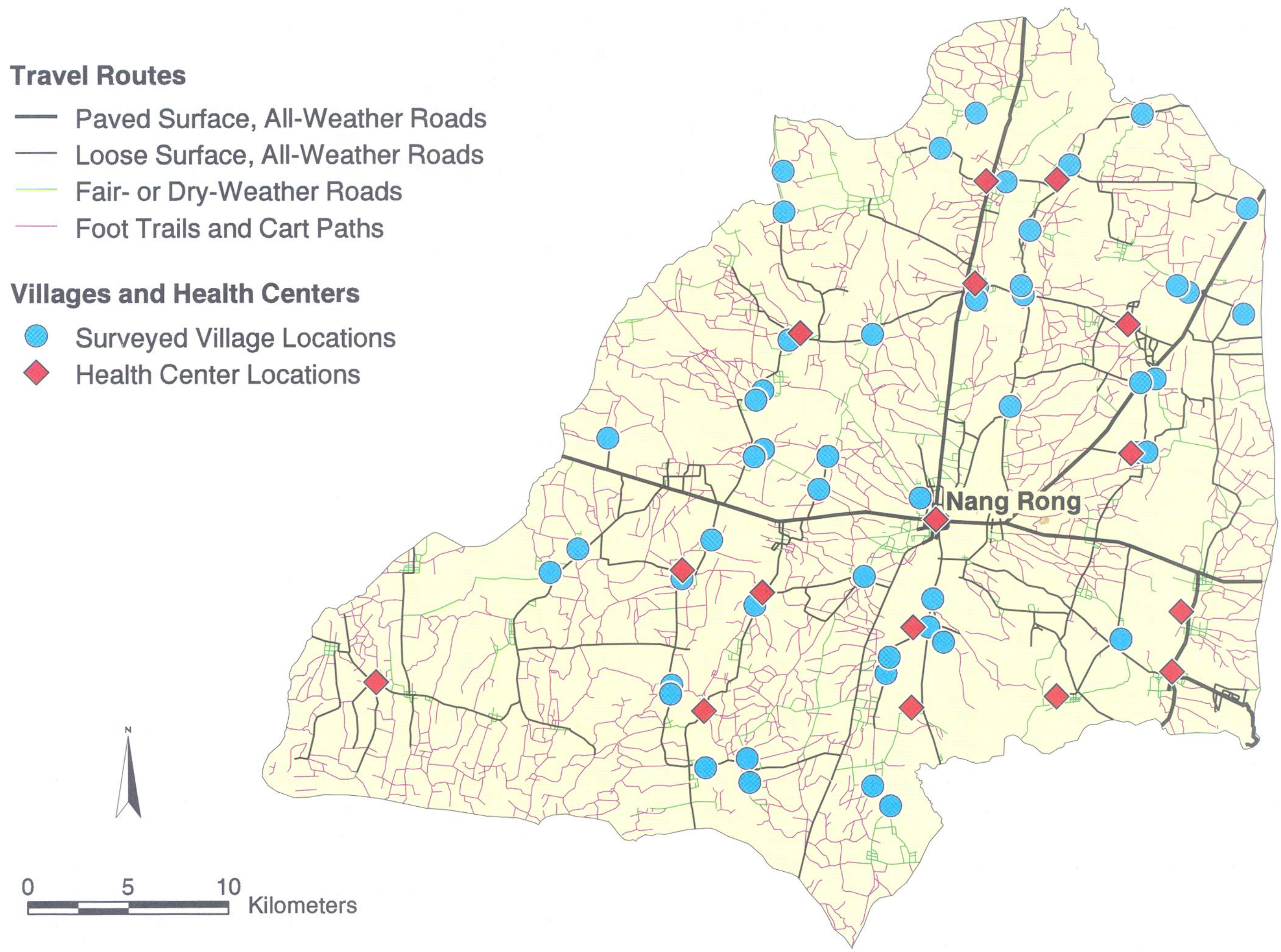
The locations of subdistrict health centers are also shown in Map 1. We recorded the spatial earth coordinates of these centers, which still exist, using a global positioning device (GPS).[4] From the early 1970s, when the national family planning program began and continuing through 1984, subdistrict health centers in Nang Rong specialized in the provision of the pill (Bennett et al. 1990; Rosenfield et al. 1982). We obtained founding dates for subdistrict health centers from administrative records. By 1984, there were 16 subdis-

2. A household informant provided information on behalf of all household members. As we have documented elsewhere (Entwisle et al. 1996), contraceptive choices are not private in Nang Rong.

3. Villages in Nang Rong are tightly clustered households surrounded by fields. For the purposes of digitizing, the village center was identified as a road intersection located within the cluster of households.

4. Through a constellation of 24 high-orbiting satellites, receivers on the ground use the precise known location of a cluster of three to four satellites as reference points for triangulating the position of the global positioning device. This position then can be associated with ground features such as schools or health centers.

MAP 1. VILLAGE AND HEALTH CENTER LOCATIONS, WITH TRAVEL NETWORK: NANG RONG DISTRICT, THAILAND



Note: Costs for color printing paid by authors.

trict health centers dispersed throughout the 1300 km² district; four of them were located in or near (see Map 1) our sample villages. In our earlier analyses (Entwisle et al. 1996; Rindfuss et al. 1996), we measured accessibility (in part) as the presence or absence of a subdistrict health center in each village—the only information available at the time. Before creating the GIS, we had no information about the proximity of subdistrict health centers to villages not having their own centers. Application of the spatial analytic techniques we describe in the next section of the paper led to an important realization: The level of family planning accessibility in Nang Rong in 1984 was quite high. In our sample 12 of the 51 villages were less than five minutes away from a subdistrict health center. Median travel time was 17 minutes, with the longest trip lasting 45 minutes.

SPATIAL NETWORK ANALYSIS

Spatial network analysis is an approach of routing and allocating resource flows (e.g., villagers seeking family planning services at prescribed locations) through a system connected by a set of linear features (e.g., roads and trails). Distance optimization decisions within the network depend on the nature of the travel conduits, links between conduits, location and characteristics of barriers to movement, directionality of resource flows, position and conditions of centers having specific resource capacities, and node locations where resources are deposited or collected along paths throughout the network (ESRI 1992; Lupien, Moreland, and Dangermond 1987). In this research, we used spatial network analysis to select the best (i.e., quickest) route through a road and trail network.

Travel time depends on the route and road type between village centers and specific destinations. A key assumption of our analyses is that the locations of the subdistrict health centers have not changed since the early 1970s—a reasonable assumption based on discussions with local officials. Given information about the travel time associated with each road type, spatial network analysis determines the quickest route between each village center and each subdistrict health center or district town based on distance optimization algorithms.

We derived paths of optimal travel time between each village and each subdistrict health center, and between each village and each district town, using a pathfinding algorithm developed by Dijkstra (1959) and implemented within the NETWORK module of the ARC/INFO GIS software package. Route selection is determined by starting with a defined origin and destination, in this case a village center and subdistrict health center or district town, with possible paths defined and evaluated for minimization of travel time. As each intermediate node between links is identified, the path with the shortest travel time of the preceding links and nodes is assigned, and then summed when the final destination is reached. We calculated travel times for each origin and destination and then arrayed them in ascending order. We constructed variables indicating travel time to the nearest subdistrict health center, to the next nearest, and so forth, and defined similar variables for travel to district towns. We then transferred the travel times to statistical analysis software so that we could carry out the multinomial logistic regressions described below.

The key to our application of spatial network analysis is the estimate of travel time associated with each road type. Our analyses involve data collected in 1984, and this limits the options available. If we were estimating travel time for the present, we could sample segments of various road types and clock travel speed using different modes of transportation (walking, taking a bus, riding a moped, using a truck). Alternatively, we could directly ask villagers how they travel over different types of roads and how long it takes. Because more than a decade separates our analyses from the time the data were collected, however, these approaches are not possible. Instead, we consulted with individuals who lived in Nang Rong, or who had conducted fieldwork there, to develop estimates based on likely modes of travel and the speeds associated with particular modes and road types. In all cases, we estimated travel time for the average trip, recognizing that actual travel time would vary. The estimate for the average trip, of course, depends on the particular route selected. Unfortunately, we have no way to verify that the route selected in our application of spatial network analysis is the one villagers actually traveled in 1984.

The transportation coverage of the 1984 base map identified four types of roads: paved all-weather roads; loose surface, all-weather roads; fair- or dry-weather roads; and foot or cart paths. We made the following assumptions about each of these road types:

(1) **Paved, all-weather roads**. Although a car or truck could easily have traveled at 30 mph on these roads, the typical villager in 1984 would have taken a small bus or ridden a moped. Given frequent stops, the average speed of a bus was well below top speed. Mopeds had a top speed of about 15 mph. Balancing these considerations, we estimated an average travel speed of 20 mph.

(2) **Loose surface, all-weather roads**. These had a fair number of potholes, slowing travel speeds for cars and trucks. Mopeds are not significantly slowed because it is easier to avoid the potholes. Thus an average speed was only slightly below that of a paved road—15 mph.

(3) **Fair- or dry-weather roads**. In contrast to paved and loose surface all-weather roads, fair- or dry-weather roads were prone to flooding during the rainy season, and were impassible or passible with great difficulty at that time. Balancing travel speeds during dry and rainy seasons, we estimated average speed at 10 mph.

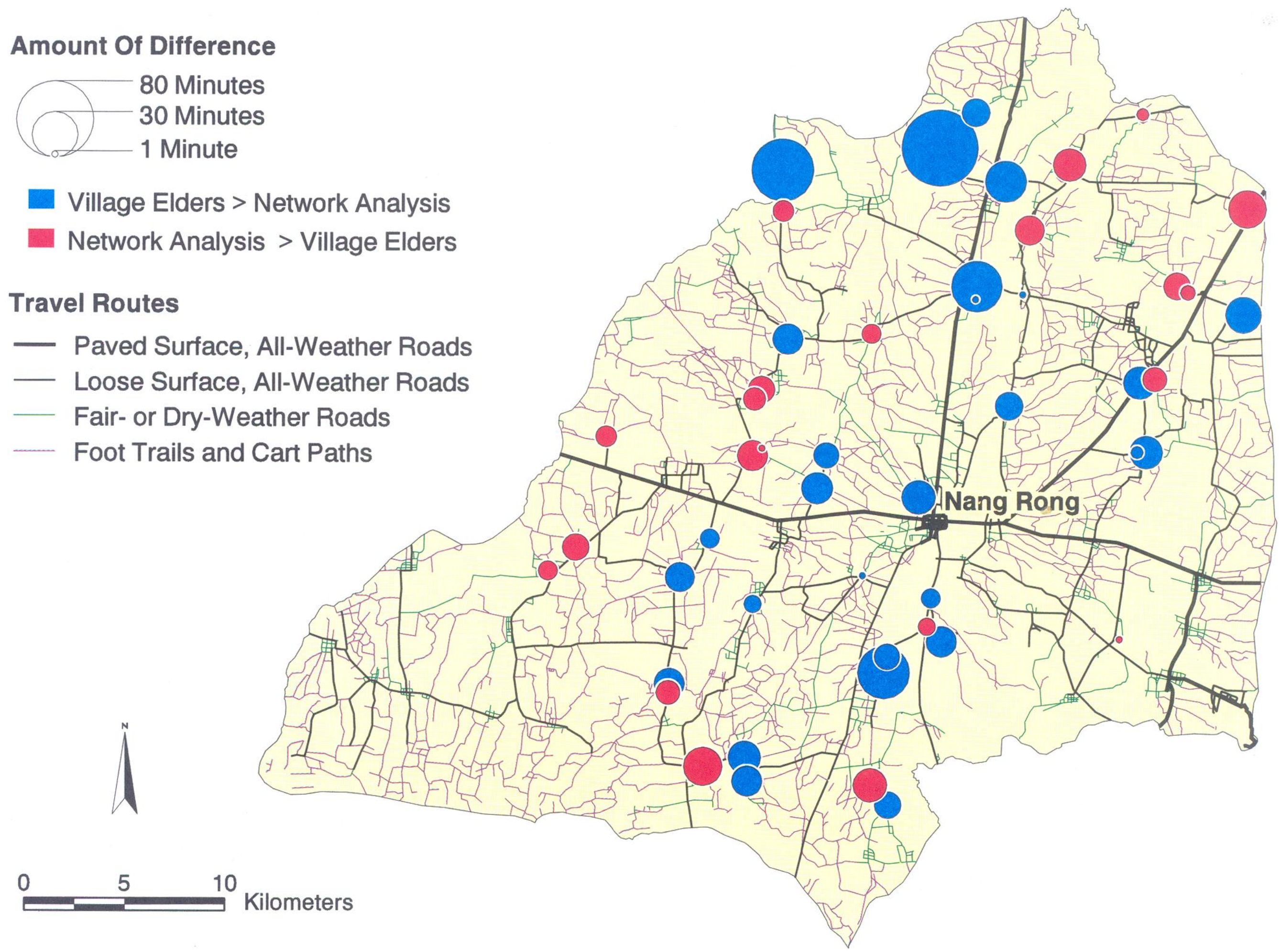
(4) **Foot or cart paths**. Typically villagers would use these roads for walking. Bicyclists and moped riders would use them also, but at significantly reduced speeds. The paths were too narrow for cars, trucks, or buses. We estimated travel speed to be 5 mph for this type of road.

We assessed the sensitivity of our travel time estimates to alternative assumptions about the travel speeds associated with different road types (Evans et al. 1995). Estimated travel time to the nearest subdistrict health center varies within relatively narrow bounds as assumptions about the travel speeds associated with different road types are allowed to change. We also examined Euclidean distances, which have lighter data and processing requirements than estimates based on spatial network analysis. Using Euclidean distances skewed the distribution of accessibility, making remote villages more remote (Evans et al. 1995).

Using the spatial network analytic approach, we can also determine the road composition of a route. Travel time estimates and road composition measures based on spatial network analysis presume a particular route. With respect to the nearest subdistrict health center established by the end of 1983, the route selected involves more than one road type for 37 of the 51 villages. Most often (in 24 of 37 villages), the route begins and/or ends with a seasonal road or cart path, with a paved and/or all-weather loose surface road in between. In a few cases (in 4 of 37 villages), travel involves all-weather and paved roads only. Sequences of road types for the remaining nine villages are more heterogeneous, and for three villages a cart path or foot trail falls in the middle of the selected route. A moped, of course, could negotiate these routes. Unfortunately, we have no data on source choice, so it is not possible to verify that the health center identified as the nearest is the one actually chosen. Nor, as already mentioned, do we have any way to verify the route taken.

To validate the estimates derived from the spatial network analysis, we compared travel times to Nang Rong town implied by our assumptions with those reported by village elders responding to the community questionnaire in 1984. As is generally true of travel time reports, the times reported by village elders are heaped on multiples of 30 minutes.

MAP 2. TRAVEL TIME TO NANG RONG: DIFFERENCES IN TRAVEL TIMES AS ESTIMATED BY VILLAGE ELDERS AND AS CALCULATED IN NETWORK ANALYSIS



Note: Costs for color printing paid by authors.

Travel time estimates developed from the spatial network analysis are not heaped, and so it is possible to examine functional form in greater detail. Another difference is that, in a survey it is usually possible to get travel time estimates for only a few destinations. The spatial network analysis is not constrained in this way. If the village elders reported travel times to Nang Rong town that generally agreed with those based on the spatial network analysis, we can be more confident in travel time estimates to other locations based on the network analysis.

Map 2 shows the difference between travel time to Nang Rong town reported by village elders and travel time to that destination based on the spatial network analysis. Each of the 51 villages in our sample is indicated with a circle. The size of the circle corresponds to the size of the difference between the pair of estimates, and the color of the circle shows the direction of difference: When the circle is blue, the village elders reported a longer travel time than we calculated based on spatial network analysis; when the circle is red, elders reported a shorter time than we calculated. In general, the village elders' reported travel times to Nang Rong town longer than those derived from the spatial network analysis. In Map 2, there are more blue than red circles, and the largest circles are blue. The map shows that the two villages with the largest discrepancies are close to the boundary of Nang Rong district, which leads us to question the accuracy of the elders reports. Elders in these two villages may not have traveled frequently to Nang Rong town, instead traveling to adjacent district towns. The map also shows several instances in which the discrepancy greatly differs for adjacent villages. This too suggests a lack of precision on the part of the village elders.

Overall, the travel time estimates derived from spatial network analysis appear reasonable: They correspond fairly well to times reported in 1984 by village elders, and differ by six minutes on average, with a few outliers contributing disproportionately to this difference. The discrepancies seem due as much or more to error and rounding in the village elders' reports as to incorrect assumptions about travel speeds associated with particular road types in the spatial network analysis. The advantage of the network calculations is that because we have the complete road system for the district and buffering areas, we can estimate travel time from each village to any destination—to the nearest subdistrict health center, to the next nearest, and so on.

ACCESSIBILITY AND CONTRACEPTIVE CHOICE

In 1984, couples in Nang Rong chose from a wide range of contraceptive methods: pills, the IUD, injection, vasectomy, and female sterilization. Our earlier analyses distinguished temporary choices (the pill, IUD, injection, no method) from the decision about whether or not to undergo a sterilizing operation. We found that both the presence of a subdistrict health center in the village and the difficulty of travel to Nang Rong town affected temporary method choice; but only the latter influenced sterilization (Entwisle et al. 1996). Modeling either temporary method choice or sterilization suffices to demonstrate the application of spatial methods, and given the greater responsiveness of temporary method choice to family planning accessibility in our previous analysis, we focus on this aspect of contraceptive choice here.

Our strategy is to substitute alternative measures of accessibility into a simplified version of the original model and to compare the results. This procedure will allow us to consider the issue of measurement in the context of an already well-developed model of contraceptive choice and to answer the question: What do we learn by taking a spatial approach that we did not already know based on a more standard social demographic approach? In the first part of the analysis we focus on travel time to subdistrict health centers, in the second part on travel to district towns (including but not limited to Nang Rong town), and in the third part on road composition.

The analyses of temporary method choice are based on data for 2,703 married couples where the wife was aged 20–44 and neither she nor her husband was sterilized at the time of the 1984 data collection.[5] Contraceptive choice refers to choice among an array of contraceptive methods, including the option of not using any method. It is modeled as an outcome of individual, household, and community variables:

$$\log\frac{\Pr(M_{ij}=k)}{\Pr(M_{ij}=1)}=\alpha_k C_j+\beta_k X_{ij}+\mu_j .$$

The dependent variable is the log-odds that couple i in village j chooses method k (pill, IUD, or injection) relative to method 1 (no method). X_{ij} is a vector of characteristics associated with couple i in village j, including age of the wife, whether the household is extended, an interaction between the wife's age and household structure, age of the husband, schooling, occupation, land ownership, and the value of agriculture assets. C_j is a vector of attributes associated with village j. The specific village variables included in our analyses are the productivity of rice and involvement in jute production and measures of family planning accessibility. In these models, accessibility is just one aspect of village context relevant to contraceptive choice. The μ_j values capture unique aspects of village environments that may affect the choices couples make. To obtain estimates of the coefficients in the preceding equation, and especially of their standard errors, we apply procedures developed and described by Guilkey (1992; also see Rindfuss et al. 1996).[6]

The results for our base line model are displayed in Table 1. The presence of a subdistrict health center in the village encourages pill use and discourages use of the IUD and injection. This makes sense because in 1984 in Nang Rong, subdistrict health centers distributed pills exclusively; IUDs and injection were obtained from other sources. One of our goals here is to explore this result: What does it mean for a village to be near a subdistrict health center? Another goal is to explore the potential effect of proximity aside from whether the subdistrict health center is near. The supplementary locational data we collected in combination with the spatial network analyses allow us to transcend some of the limitations of the data on family planning sources previously available to us. We now can consider a variety of measures of travel time to the subdistrict health center.

Table 1 also indicates a positive relationship between village remoteness and IUD use. Remoteness is an index that sums obstacles to travel to Nang Rong town (a distance of 20 km or more, travel time of more than 60 minutes, reported travel difficulty for four or more months of the previous year, the need to use cart paths and foot trails to get from the village to a paved road, and the absence of bus service). What the positive relationship means is not entirely clear. In 1984, obtaining an IUD required a trip to town. We expected residents of more remote villages to avoid the IUD, but the results run counter to this hypothesis. In our previous paper, we suggested several possible reasons for this contrary result: (1) If women elect not to have their IUDs checked on a routine basis, there is no resupply issue and women living in more remote villages are not disadvantaged in terms of access (Janowitz et al. 1994); (2) If IUD insertion causes embarrassment, greater physical (and social) distance between

5. Of the 2,703 couples: 1,416 did not use contraception, 742 used the pill, 322 used the IUD, and 223 used injection.

6. Based on a Monte Carlo simulation, Rodriguez and Goldman (1995) suggest that the coefficient estimates based on this approach will be biased toward 0 under some circumstances. It is therefore possible that we underestimate accessibility effects. The structure of our data, however, differs from that used by Rodriguez and Goldman. Whereas they had relatively few individuals per macro unit, we have relatively many. More research is needed to establish the extent and nature of bias associated with different data structures. The development of alternative estimation procedures is an active area of research in the statistical literature.

TABLE 1. MULTILEVEL LOGISTIC COEFFICIENTS FOR REGRESSION OF CONTRACEPTIVE CHOICE ON SELECTED INDEPENDENT VARIABLES: NANG RONG, 1984

Variable	Pill vs. None	IUD vs. None	Injection vs. None	IUD vs. Pill	Injection vs. Pill	Injection vs. IUD
Constant	–.132	–2.477*	–1.526*	–2.345*	–1.394*	.951
	(.383)	(.408)	(.421)	(.554)	(.543)	(.608)
Individual and Household						
Age						
20–23	–.084	–.713*	–.220	–.629*	–.136	.493
	(.209)	(.285)	(.252)	(.301)	(.297)	(.385)
36–44	–.338*	–.253	–.617*	.085	–.279	–.364
	(.149)	(.148)	(.193)	(.167)	(.225)	(.194)
Extended Household	–.284*	–.449*	–.461*	–.165	–.177	–.012
	(.121)	(.176)	(.194)	(.177)	(.195)	(.231)
Age 20–23, by Extended Household	–.617*	–.520	–.696	.096	–.080	–.176
	(.308)	(.358)	(.465)	(.470)	(.447)	(.473)
Older Husband	–.233	–.479*	–.558*	–.247	–.325	–.079
	(.121)	(.157)	(.209)	(.151)	(.233)	(.263)
Education						
Low	–.174	–.234	–.338	–.060	–.164	–.104
	(.148)	(.210)	(.264)	(.236)	(.256)	(.338)
High	–.314	.501*	–.517	.814*	–.204	–1.018*
	(.175)	(.200)	(.313)	(.248)	(.326)	(.398)
High-Status Occupation	–.074	.456	.176	.530*	.250	–.280
	(.196)	(.273)	(.282)	(.256)	(.330)	(.343)
Large Landowner	–.381*	–.341	.262	.040	.642*	.602*
	(.116)	(.258)	(.202)	(.282)	(.233)	(.288)
Agricultural Assets	.037	.020	.068*	–.017	.030	.047
	(.020)	(.026)	(.032)	(.030)	(.033)	(.038)
Community						
Health center in village	.770*	–1.655*	–.749*	–2.425*	–1.519*	.906
	(.207)	(.540)	(.321)	(.580)	(.342)	(.691)
Remoteness	.139	.315*	–.169	.177	–.308	–.484*
	(.085)	(.092)	(.134)	(.133)	(.161)	(.168)
Agricultural productivity	–.002*	.002*	–.000	.004*	.001	–.002
	(.001)	(.001)	(.001)	(.001)	(.001)	(.001)
Jute production	–.441*	–.016	–.257	.425	.185	–.240
	(.195)	(.264)	(.263)	(.344)	(.315)	(.401)

Notes: χ^2 = 356.0, df = 42. Number of couples = 2,703. Numbers in parentheses are standard errors.

*p < .05 (two-tailed test)

the home village and the service site may be an advantage; (3) Villages remote from Nang Rong town may not be remote from other district towns, where IUDs may also be obtained. Capitalizing on the flexibility offered by spatial network analysis in forming measures of accessibility, we can perform an initial test of hypothesis (3) by evaluating the impact on contraceptive choice of travel to the nearest district town, rather than to Nang Rong town. We can also shed light on hypotheses (1) and (2).

SUBDISTRICT HEALTH CENTERS

Using an administrative list obtained from the public health source, we identified the study villages that were administratively linked to subdistrict health centers in the district. Four villages were so classified in 1984. Our earlier analyses found that contraceptive choice in these villages differed from that in other villages. How many of the subdistrict health centers are actually in the village to which they are

TABLE 2. BEING NEAR A SUBDISTRICT HEALTH CENTER AND CONTRACEPTIVE CHOICE, DIFFERENT MEASURES OF "NEAR"

Measure of "Near"	Pill vs. None	IUD vs. None	Injection vs. None	IUD vs. Pill	Injection vs. Pill	Injection vs. IUD
"In the Village"	.770*	−1.655*	−.749*	−2.425*	−1.519*	.906
	(.207)	(.540)	(.321)	(.580)	(.342)	(.691)
Less than 5 Minutes	.548*	−.403	−.752*	−.951*	−1.300*	−.349
	(.162)	(.390)	(.298)	(.455)	(.330)	(.517)
Less than 3 Minutes	.623*	−1.023*	−.726	−1.646*	−1.349*	.297
	(.199)	(.418)	(.401)	(.554)	(.470)	(.637)
Less than 4 km	.459*	.059	−.072	−.400	−.531	−.131
	(.167)	(.299)	(.285)	(.371)	(.297)	(.436)

Notes: Numbers in parenetheses are standard errors. The coefficient estimates in this table come from four separate models of contraceptive choice. The estimates shown for "in the village" are the same as those reported for "health center in village" in Table 1. The estimates shown for the other measures of "near" were obtained by substituting the alternative measure for "health center in village." The other variables in the model are exactly as they are in Table 1, although the effects of these other variables are not presented.

*$p < .05$ (two-tailed test)

administratively linked? How many villages not administratively linked to subdistrict health centers are just as close to them as villages having these links? Does our original result reflect proximity, administrative linkage, or both?

Villages in Nang Rong district are clusters of dwellings surrounded by agricultural fields. The question we seek to answer is not whether the subdistrict health center is located within the administrative boundaries of the village, which would include the fields, but whether it is located in the central cluster of dwellings. Typically villages consist of about 100 households. Based on location as determined with a GPS, and considering establishment dates, only one subdistrict health center in existence by 1984 was actually in a village cluster, although the others administratively linked to particular villages were close (ranging from less than one minute to not quite four minutes away).

An administrative link between a subdistrict health center and a village proxies service proximity; but with additional information provided by spatial network analysis and more precise locational data, we find that it is an imperfect proxy. Some villages in our sample are just as close to subdistrict health centers as those villages administratively linked to them. There were six villages with subdistrict health centers located less than three minutes away, including three of the four villages with administrative links to centers.

Does the estimated effect of being near a subdistrict health center vary according to the particular measure chosen? Table 2 shows coefficient estimates and adjusted standard errors for four different measures of near: "in the village" (the original measure, based on administrative records), less than five minutes travel time from the village, less than three minutes from the village, and less than four kilometers from the village (i.e., walking distance). Each row of coefficient estimates corresponds to a separate multinomial logistic regression model. These models include the full set of life-course indicators, socioeconomic characteristics, and village variables included in Table 1, although the effects of these other variables are not shown in Table 2.

The original variable has the strongest effects on temporary method choice. Consider the contrast between pill use and no method. Regardless of the measure, being near a subdistrict health center encourages pill use, but the estimated size of this impact varies. If the subdistrict health center is administratively linked to the village, the coefficient estimate is at least 25% larger than if the center is within three minutes, five minutes, or four kilometers of the village. Consider now the contrast between injection and no method. For three of the four measures, the estimated effects are roughly similar (although the adjusted standard errors vary), suggesting that proximity to a subdistrict health center discourages injection use. The largest coefficient is found for "in the village," but differences are too small to interpret. The fourth measure—whether a center is within walking distance—has no effect, however. Finally, consider the contrast between IUD use and no method. Proximity to a subdistrict health center discourages IUD use; but the estimated effect of having a center "in the village" is 50% larger than having one within three minutes of the village, which in turn is more than twice as large as the effects of the other two measures combined.

Our previous research relied on a measure of family planning availability based on reports about the presence of a subdistrict health center "in the village." Quite fortuitously, this measure produces the strongest effects. The measure that comes closest to replicating its effects is that identifying villages within three minutes of a subdistrict health center. Clearly, proximity is important. In addition, there appears to be something in the identification of a health center with a village that affects the contraceptive choices made by couples living in that village. The administrative link to a particular village may enable residents to better get to know the service providers better. Thus accessibility may reflect social as well as physical distance, reinforcing and extending one of the key findings of our earlier work (Entwisle et al. 1996).

The discussion so far has focused on villages quite close to a subdistrict health center. Of course, it is possible that differences in the proximity of villages farther away matter for contraceptive choice. To investigate this possibility, we subdivided the travel time (in minutes) variable into eight categories for centers established by the end of 1983: less than 3, 3–5, 6–8, 9–11, 12–14, 15–17, 18–20, 21 or more. Examination of the coefficients estimated revealed that the effects of travel time are concentrated in the lower regions of the range.[7] The best summary distinguishes travel times of less than 3 minutes, 3–5 minutes, and 6 or more minutes.[8]

We also examined the extent to which travel time to the next nearest subdistrict health center affected contraceptive choice once travel time to the nearest subdistrict health center was controlled. The results, not shown here, indicate that once travel time to the nearest subdistrict health center is controlled, travel time to other subdistrict health centers adds little to the explanation of contraceptive choice. The results in Table 3 suggest why: What seems to matter is having a health center very near—within six minutes. Time to the second nearest subdistrict health center ranges from 10 to 40 minutes, and time to the third nearest ranges from 14 to 50 minutes. For the same reason, it does not matter whether we include subdistrict health centers outside of the administrative boundaries of Nang Rong. Lack of sensitivity to the buffer may be peculiar to settings with a relatively high density of services.

How important is the timing of the establishment of subdistrict health centers? The national family planning program in Thailand emphasized the provision of methods through preexisting health centers. Subdistrict health centers played a key role in rural areas. Training of personnel began in the late 1960s, even before the national policy was declared in 1970 (Bennett et al. 1990; Rosenfield et al. 1982); thus the stage was set for a rapid increase in the availability of contraception in the early 1970s. Within Nang Rong district, nine subdistrict health centers were in place by the end of 1971. No new subdistrict health centers were built for several years—a discontinuity that permits us to test whether centers established early on played a distinctive role in choices made more than a decade later. After the hiatus, one subdistrict health center was built in 1978, two more in 1980, and four more in 1982 and 1983. Looking again at Map 1, subdistrict health centers in place by 1984 form an oval around Nang Rong, suggesting the influence of faraway planners. Each center is located at a road intersection.

Figure 1 illustrates one way in which the more recently established subdistrict health centers changed travel times for the 51 villages in our sample. The top panel arrays the villages from the shortest to the longest travel times based on the location of centers established by the end of 1971. The bottom panel shows travel times to centers established by the end of 1983 and the difference between 1971 and 1983 (with villages in the same order as in the top panel). The establishment of new subdistrict health centers in the early 1980s decreased travel times for the more remote villages. It had little effect on the bottom third of the distribution—the end of the distribution that has a large impact on contraceptive choice. Road improvements also may have changed travel time in the 1970s and early 1980s, and access to mopeds, trucks, and

TABLE 3. TRAVEL TIME TO THE NEAREST SUBDISTRICT HEALTH CENTER: HISTORICAL AND LAGGED EFFECTS

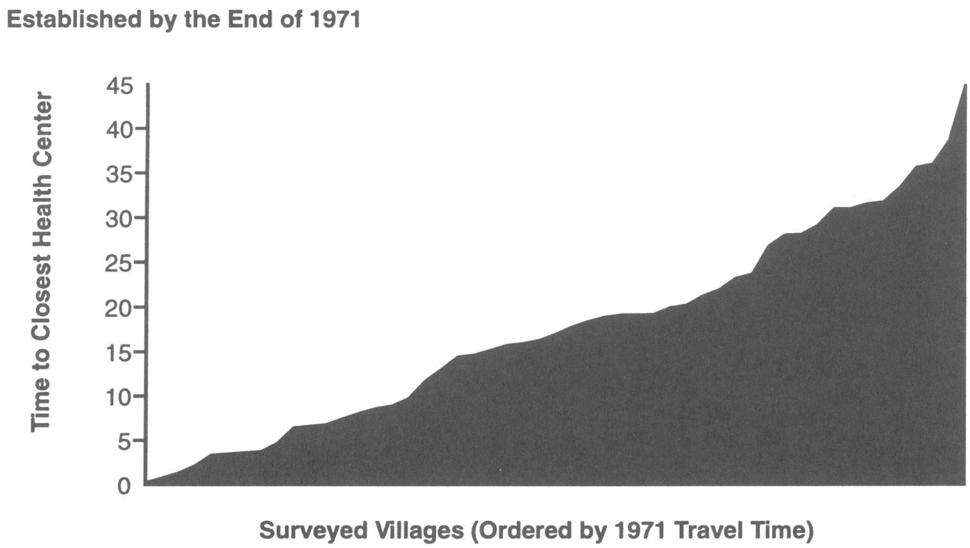
	1971	1981	1983
Pill vs. None			
Less than 3 minutes	.832*	.692*	.688*
3–5 minutes	.453*	.460*	.383*
IUD vs. None			
Less than 3 minutes	−1.300*	−1.020*	−1.064*
3–5 minutes	.048	.046	−.213
Injection vs. None			
Less than 3 minutes	−1.119*	−.796*	−.796*
3–5 minutes	−.559	−.565	−.523
IUD vs. Pill			
Less than 3 minutes	−2.133*	−1.712*	−1.753
3–5 minutes	−.404	−.414	−.596
Injection vs. Pill			
Less than 3 minutes	−1.951*	−1.488*	−1.484*
3–5 minutes	−1.011*	−1.025*	−.905*
Injection vs. IUD			
Less than 3 minutes	.182	.224	.268
3–5 minutes	−.607	−.611	−.310

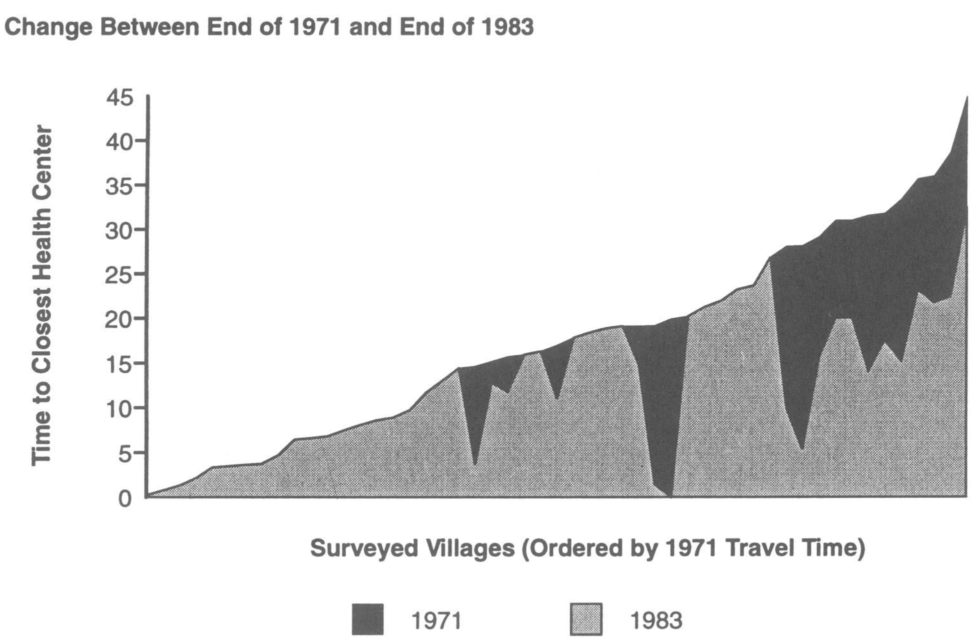
Notes: Each column of coefficient estimates comes from a separate model of contraceptive choice. In each model, travel time to the nearest subdistrict health center is represented as two dummy variables: less than 3 minutes and 3–5 minutes. Travel times of 6 minutes or more comprise the omitted category. The models vary in terms of the period by which subdistrict health centers were established. The other variables in the models are exactly as in Table 1.

7. Suppose we define dummy variables for each of these travel time categories, omitting the last. The pattern of coefficient estimates resulting when accessibility is represented as this set of dummy variables (and controlling for the other individual, household, and village variables listed in Table 1) is the source for the claim made in the text. The comparison between a travel time of 21 minutes or more and a travel time less than 3 minutes is statistically significant for contrasts between pill and no use, IUD and no use, IUD and pill use, and injection and pill use. The comparison between a travel time of 21 minutes or more and a travel time of 3–5 minutes is statistically significant for the contrast between pill and IUD use, and nearly significant for the contrast between pill and no use. None of the other contrasts are significant, and none follow a linear pattern.

8. This specification of the travel time effect is a significant improvement over a linear specification (in the log-odds), although the latter was also statistically significant.

FIGURE 1. TRAVEL TIME TO CLOSEST HEALTH CENTER





other vehicles probably increased over this period. These transportation changes are not reflected in Figure 1 and, indeed, we have no direct information about them.

It is possible that the availability of services in the early years of the national family planning program helped set the context for contraceptive choices later on. The idea is that women may have been more aware of long-time sources than of those recently established, that behavioral effects may have become deeply ingrained, and that these effects may be passed as a historical legacy to newer generations of potential users (Entwisle et al. 1996). Our earlier research suggested that within villages, discussion about contraceptive methods tended to promote conformity in method choice, and a similar dynamic would predict conformity in source choice:

Just as the method choices of early users of contraception had a profound effect on the subsequent trajectory of method choices in the village, the source choices of these early users may have had similar historical consequences. Coefficient estimates reported in Table 3 are consistent with this reasoning. Travel time to the nearest subdistrict health center established by the end of 1971 has stronger effects on contraceptive choice in 1984 than travel time to the nearest center established by the end of 1981 or 1983.

In interpreting the results in Table 3, remember that the calculated travel times are based on the road system in place in 1984. If we assume that the road system changed little during the 1970s, one explanation for these results is that habit plays a powerful role in determining the effects of accessibility on contraceptive choice. Relaxing the assumption about changes in the road system, the results in Table 3 are consistent with an argument that women are more aware of well-established family planning outlets, but in their decision-making take into account current travel time. Although it is possible that what we are seeing in Table 3 are the effects of accessibility at the time when women first were choosing their method, or the effects on long-time users, we do not think these alternative interpretations hold. There is no evidence for an interaction between travel time and age group (results not shown).

To see more directly the size and nature of the accessibility effects in Table 3, we simulate the proportion of women using each temporary method, setting travel time to the nearest subdistrict health center established by 1971 equal to less than three minutes, three to five minutes, and six or more minutes, respectively, and holding constant the other independent variables in the model.[9] The simulated proportions of women using each method are displayed in Table 4.

Shifts in pill use are especially striking. The likelihood of using this method is 13 percentage points lower in villages three to five minutes away from a subdistrict health center than in villages less than three minutes away; it is 10 points lower in villages six or more minutes away than in those three to five minutes away. An increase of nine percentage points in IUD use largely counterbalances the former, and an increase of four points in injection use accounts for about half of the latter. There are, therefore important substitutions between methods associated with changes in family planning accessibility. In addition, accessibility affects the choice to use a temporary method. Residents of villages six or more minutes away from a subdistrict health center are less likely to use a method than those less than six minutes away—a difference of five percentage points. All of these effects are net of the other individual, household, and village variables listed in Table 1.

9. The procedure is as follows. To begin, we first set travel time to one of its three values. Then, we apply estimated coefficients to the preset value for travel time and to the actual values of the other independent variables in the data set to generate the predicted probability that each couple will choose particular contraceptive methods. We average these predicted probabilities over all couples. We go through this process once for each of the three preset values of travel time.

TABLE 4. SIMULATED PROPORTIONS OF WOMEN USING EACH METHOD

Travel Time to Nearest Health Center	Method			
	None	Pill	IUD	Injection
< 3 minutes	.47	.47	.03	.03
3–5 minutes	.48	.34	.12	.05
6+ minutes	.53	.24	.13	.09

DISTRICT TOWNS

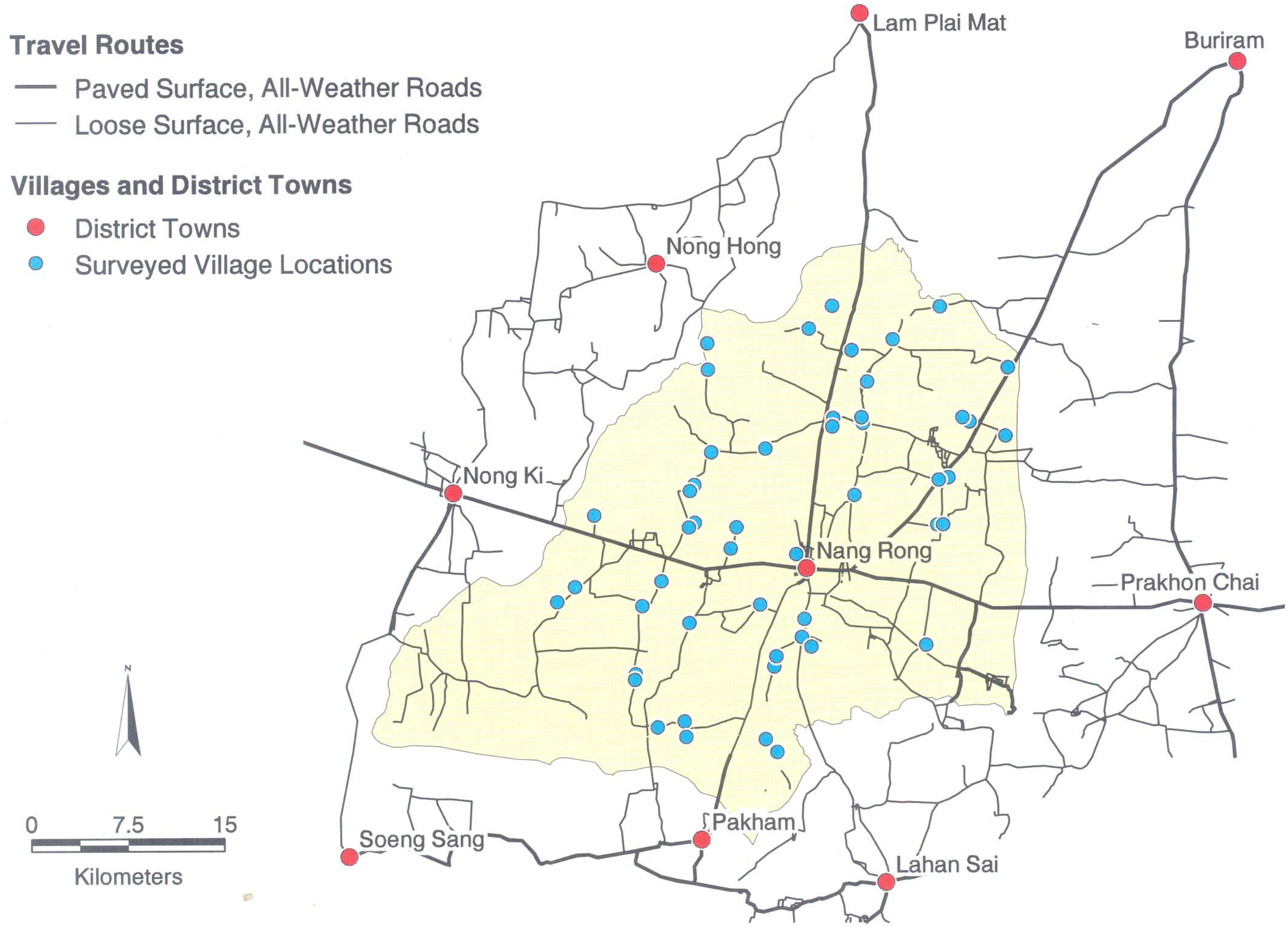
Up to this point, we have discussed proximity to subdistrict health centers, the most local unit for rural service delivery in Thailand's national family planning program. Next in the hierarchy are district health centers and district hospitals, both located in district towns. Whereas only pills could be obtained from the subdistrict health centers in 1984, IUDs, injections and pills could be obtained from the district health centers and hospitals. (If private sources of family planning were relevant to contraceptive choice at that time, they too were likely to have been located in the district towns.)

Our earlier analyses included a measure of village remoteness, which tabulates obstacles to travel to Nang Rong town, and models reported here in Tables 1–3 control for village remoteness. Having evaluated measures of travel time to the nearest subdistrict health center, settling on the measure that refers to centers established by 1971, we now explore some components of village remoteness. In this section we consider travel time to district towns, and in the next we consider road composition.

One source of ambiguity in the interpretation of the original measure of village remoteness is its focus on Nang Rong town. In the community profiles collected in 1984, village officials were asked about distance and travel time only to this destination. Villages far from Nang Rong town, however, may be close to other district towns. In surveys, it is possible to ask about travel only to a few destinations before respondents become fatigued with this line of questioning. With locational data organized within a GIS and with tools provided by spatial network analysis, we can redefine remoteness in terms of the nearest district town. Map 3 shows the location of Nang Rong town and of the district towns in each of the adjacent districts. The map shows a number of Nang Rong villages that are closer to towns in other districts than to Nang Rong town.

We substituted travel time to the nearest district town for the remoteness index in the model of contraceptive choice. (This model also contains travel time to the nearest subdistrict health center established by the end of 1971 and the other socioeconomic and demographic variables shown in Table 1.) Contrary to the initial results (see Table 1), there is no positive or negative impact of travel time to the nearest

MAP 3. DISTRICT TOWN LOCATIONS



Note: Costs for color printing paid by authors.

district town on IUD use. The positive effect of the remoteness index on IUD use does not appear to be due to the fact that villages remote from Nang Rong town are actually close to other district towns where IUDs are also available.

ROAD COMPOSITION

An advantage of using the GIS is that once a particular route between the village and some destination is selected, it is possible to measure characteristics of that route. One characteristic of potential relevance to family planning accessibility is the composition of the roads traversed.

Our interest in road composition reflects an underlying hypothesis that ease and convenience of travel and travel time are important to an understanding of family planning accessibility and its effects. Suppose travel time to the nearest subdistrict health center is the same for two villages, but that residents of the first village travel the entire distance on paved all-weather roads, whereas residents of the second village travel on rutted dry-weather roads that are nearly impassable during the monsoon season. Travel time from each village is the same, but we would argue that accessibility is greater for the first village than for the second.

We examine two measures of road composition. The first concerns the route to the nearest subdistrict health center established by the end of 1971—specifically, whether 50% or more of this route involves seasonal roads, cart paths, or trails. The second concerns the route to the nearest district town—specifically, whether any part of this route involves seasonal roads, cart paths, or trails. Both routes affect contraceptive choice. As shown in Table 5, when 50% or more of the route to the nearest subdistrict health center is on seasonal roads, couples are more likely to choose the IUD and less likely to choose the pill. Results shown in Table 5 also indicate that when some of the route to the

TABLE 5. ACCESSIBILITY AND CONTRACEPTIVE CHOICE

Aspects of Accessibility	Pill vs. None	IUD vs. None	Injection vs. None	IUD vs. Pill	Injection vs. Pill	Injection vs. IUD
Nearest Subdistrict Health Center Established by 1971						
Travel time						
< 3 minutes	1.130*	–1.775*	–1.021*	–2.904*	–2.151*	.754
	(.216)	(.563)	(.419)	(.628)	(.470)	(.840)
3–5 minutes	.657*	–.028	–.647	–.686	–1.304*	–.619
	(.192)	(.452)	(.418)	(.538)	(.395)	(.604)
Seasonal roads						
> 50%	–.549*	.799*	–.328	1.348*	.221	–1.127
	(.244)	(.270)	(.533)	(.395)	(.580)	(.610)
Nearest District Town						
Some seasonal roads	.498*	.123	–.276	–.375	–.774*	–.399
	(.161)	(.311)	(.278)	(.342)	(.298)	(.436)

*$p < .05$ (two-tailed test)

Notes: $\chi^2 = 396.4$ with 48 df. Psuedo $R^2 = .152$. Numbers in parentheses are standard errors. The coefficient estimates in this table are from a full multilevel model of contraceptive choice. Only the accessibility variables are shown here. The other variables in the model are exactly as they are in Table 1, although the effects of these other variables are not presented.

nearest district town involves travel on seasonal roads, couples are more likely to choose the pill, especially over injection. Subdistrict health centers apparently are less attractive if travel there is uncomfortable, inconvenient, or difficult during the rainy season.

These results help us to sharpen the interpretation of our original results. In the absence of a GIS and spatial analysis tools, we had created a measure of accessibility, called remoteness, that combined information about travel time and distance to Nang Rong town along with road conditions. Remoteness encouraged pill and IUD use, and discouraged use of injection. Having created a GIS and travel time estimates based on spatial network analysis, we now can measure separately components that were formerly combined into the single index of remoteness.

Consider the unexpected positive effect of remoteness on IUD use. Results in Table 5 suggest that the quality of the roads from the village to the nearest subdistrict health center is responsible for this finding. The method then available at the subdistrict health centers (pills) required frequent resupply. Poor quality roads, especially those prone to flooding, were an obstacle to the use of pills. Among the two alternative temporary methods, the IUD and injection, the former may have seemed attractive because its resupply is less of an issue. Factors reducing the accessibility of subdistrict health centers—travel time and road composition—increase use of the IUD, largely at the expense of the pill. How large are these effects? According to simulations based on the coefficients reported in Table 5, poor quality roads increase the fraction using the IUD by 13 percentage points (from 10% to 23%), but decrease pill use by 11 percentage points (from 29% to 18%).

The quality of roads linking villages to the nearest district town affects pill use. If the route to the nearest district town involved some travel on cart paths, trails, or seasonal roads, villagers were more likely to choose the pill, available locally. According to simulations, a nine-point difference in the percentage using the pill is associated with this aspect of road quality. In addition, better road quality is associated with a six percentage-point increase in *nonuse*. This result is not likely due to the selectivity of sterilization (Entwisle et al. 1996; Rindfuss et al. 1996). Remember that this increase in nonuse refers to nonuse of *temporary* methods. Our earlier analyses showed that couples in less remote villages were more likely to have become sterilized between 1984 and 1988, and this pattern probably held before 1984. The likelihood of having a sterilizing operation was unrelated to the presence or absence of a subdistrict health center in the village, and so selectivity is probably not relevant to the interpretation of the results presented here.

Our results suggest that road composition and travel time are distinct dimensions of family planning accessibility. Each has an effect when we control for the other. Moreover, at least for Nang Rong, if we do not take road composition into account in the analysis of travel time we risk obscuring some of the effects of the latter, more common measure of accessibility. The inclusion of the road composition variables strengthens the measured effects of travel time to the nearest subdistrict health center on contraceptive choice (compare Tables 3 and 5).

CONCLUSION

In this paper, we have experimented with a new approach to measuring family planning accessibility, capitalizing on opportunities offered by GIS and techniques of spatial analysis. We did so in the context of an already developed model of contraceptive choice in Nang Rong, Thailand. This model gives us a clear base line with which to assess the *additional* insights afforded by a spatial approach. Reanalyzing the data using new spatially based measures of family planning accessibility has led to new findings regarding its effects—most importantly the need to consider the history of accessibility in a locale, the importance of road composition and travel time, and the relevance of alternative sources to the choices couples make.

With respect to history, determining the establishment dates for each of the subdistrict health centers and incorporating this information into the GIS made it possible to describe the local history of program placement for more than a decade before our measurement of contraceptive choice. We found that the family planning environment changed in important ways, especially in the four years before the survey. These recent changes turned out to be less important in defining the context of choice than outlets in place for a long time. It appears that the availability of services in the early years of the family planning program helped set the context for decision-making over the next decade. This is an important result: It has implications for the interpretation of accessibility effects in evaluation research more generally, where the focus is typically on accessibility in the present rather than in the past, and may explain the lack of consistent findings in the literature. For Nang Rong, it is consistent with an explanation of contraceptive choice that emphasizes a preference for the known, familiar methods and sources over the unknown (Entwisle et al. 1996).

Our results also suggest that convenience of local family planning outlets encourages use of methods offered by those outlets, and discourages use of alternative methods and sources. Convenience of alternative sources (in the district towns) produces the opposite result, although not as strongly. A significant advantage of the approach we have taken is that it allows us flexibility to consider travel to a variety of destinations. In our analyses of the Nang Rong data, we were able to examine travel time to the nearest district town rather than to Nang Rong town, the focal destination in the data collected in 1984. We were able to evaluate the relative effects of the convenience of two alternative destinations, the nearest subdistrict health center and the nearest district town. We were also able to see whether the next nearest subdistrict health center or town was important to an understanding of choice (it was not).

Another finding of interest is that road composition matters. Even if a family planning outlet is close to a village, villagers will not necessarily use it if roads are poor and washed out part of the year. Contraceptive choice also is responsive to the quality of roads linking the village to the nearest district town. Our interpretation views road surface as a proxy for travel comfort, but other interpretations are possible. For example, paved roads offer a wider array of transportation options as well as a more comfortable ride. Mopeds can navigate the main highways, but trucks cannot negotiate foot paths and trails. Another possibility is that road quality measures access to modern services generally, not just family planning services. This possibility is especially relevant to the interpretation of links to the district towns, where crops could be marketed, supplies purchased, and a wide array of medical services obtained. It is not clear, however, why easier access to this broader array of services would discourage pill use, which is the particular effect that we find for this variable. Finally, it is possible that some village headmen are better than others at obtaining modern amenities for village residents. Road improvements may be a sign of political success, and strong local leaders also may have played an important role in spreading family planning. Though plausible, this scenario is not confirmed in qualitative data collected as part of another project (Entwisle et al. 1996).

The particulars of the Nang Rong setting clearly are not generalizable. The density of family planning services is not typical of Third World settings. That small differences in travel time make such a difference in contraceptive choices may not be found elsewhere in the Third World (although it might be quite relevant to understanding accessibility effects in other high density settings, such as the United States). At the same time, there is no reason to suppose that the benefits of taking a spatial approach are somehow unique to this setting. The flexibility to consider travel to a variety of destinations, the absence of response heaping in travel time measures, and the ability to distinguish different aspects of convenience have the potential to provide important research opportunities in virtually any setting. Further, the benefits of a spatial approach are not limited to studies of family planning accessibility, but apply to any contextually oriented study of reproductive behavior. Clues about density of settlement, patterns of land use, and land fragmentation can be gleaned from archived satellite data, for example, and taken into account in analyses of fertility.

In considering the benefits of GIS and spatial analysis tools to family planning evaluation, and to the analysis of fertility determinants more generally, we should consider what aspects of the Nang Rong data helped facilitate their application in the analyses we have described. Most important was the availability of spatial and sociodemographic data for the same locations and time period. The ability to move between spatial network analysis—in the development of measures—and multinomial logit analysis—in an assessment of their effects on contraceptive choice—was crucial. It helped that we were studying a single district, rather than villages scattered across the country (e.g., as produced by a stratified multistage cluster design in a social survey). It also helped that, at least so far, family planning outlets have been added in Nang Rong and none subtracted. This made it possible to visit outlets easily, to obtain coordinates, and to collect establishment dates. These are significant advantages.

Their absence, however, would not preclude the creation of a GIS or its use in an analysis of fertility determinants. Although a substantial amount of geographic information has been acquired and encoded into our GIS, the amount and type of data is not unique to this study nor to this geographic location. Map products can be obtained from a variety of sources, including local, regional, and federal governments; international organizations such as the World Bank; and national map archives. Digital data sets and associated boundary files for a particular application may already be available. Satellite image data are available worldwide and with sufficient temporal depth for change-detection studies of landscape conditions and direct mapping of a host of phenomena, including road systems. The GIS data base developed for our research, though substantial and time-consuming to generate, is not so unique and specialized that other investigators would be unable to follow our example in other settings. Each study area offers its own set of opportunities and challenges.

REFERENCES

Albert, D.P., W.M. Gesler, and P. Wittie. 1995. "Geographic Information Systems and Health: An Educational Resource." *Journal of Geography* 94:314–21.

Aronoff, S. 1989. *Geographic Information Systems: A Management Perspective*. Ottawa, Canada: WDL Publications.

Bennett, A., C. Frisen, P. Kamnuansilpa, and J. McWilliam. 1990. "How Thailand's Family Planning Program Reached Replacement Level Fertility: Lessons Learned." Occasional Paper 4. Arlington, VA: Population Technical Assistance Project.

Bracken, I. 1994. "A Surface Model Approach to the Representation of Population-Related Social Indicators." Pp. 247–59 in *Spatial Analysis and GIS*, edited by S. Fotheringham and P. Rogerson. London: Taylor & Frances Publishers.

Bulato, R. and R. Lee (eds.). 1983. *Determinants of Fertility in Developing Countries*, Vols. 1 and 2. New York: Academic Press.

Community-Based Rural Development (CBIRD) Project. 1994. "Information Packet for the Visit of the CIDA Team to CBIRD Nang Rong on April 22–23, 1994." Unpublished document, Department/Division, Institution/Organization.

Chayovan, N., A.I. Hermalin, and J. Knodel. 1984. "Measuring Accessibility to Family Planning Services in Rural Thailand." *Studies in Family Planning* 15:201–11.

Clarke, K. 1990. *Analytical and Computer Cartography*. Englewood Cliffs, NJ: Prentice Hall.

Dijkstra, E.W. 1959. "A Note on Two Problems in Connection with Graphs." *Numerische Mathematik* 1:269–71.

Entwisle, B., R.R. Rindfuss, D.K. Guilkey, A. Chamratrithirong, and Y. Sawangdee. 1996. "Community and Contraceptive Choice in Rural Thailand: A Case Study of Nang Rong." *Demography* 33:1–11.

Environmental Systems Research Institute (ESRI). 1992. *ARC/INFO User's Guide*. Redlands, CA: ESRI.

Evans, T.P., S.J. Walsh, B. Entwisle, and R.R. Rindfuss. 1995. "Testing Model Parameters of Transportation Network Analyses in Rural Thailand." Pp. 302–11 in *Proceedings GIS/LIS 1995*, Vol. I. Bethesda, MD: American Society for Photogrammetry and Remote Sensing, American Congress on Surveying and Mapping.

Flowerdew, R. and M. Green. 1989. "Statistical Methods for Inference Between Incompatible Zonal Systems." Pp. 239–48 in *Accuracy of Spatial Databases*, edited by M.F. Goodchild and S. Gopal. London: Taylor & Francis.

Gertler, P.J. and J.W. Molyneaux. 1994. "How Economic Development and Family Planning Programs Combined to Reduce Indonesian Fertility." *Demography* 31:33–63.

Gesler, W.M., S.J. Walsh, T.W. Crawford, P.S. Wittie, and T.C. Ricketts. 1995. "Analysis of Hospital Service Areas in the Charlotte/Mecklenburg Region of North Carolina, USA Through GIS Approaches." Pp. 85–99 in *Proceedings, Geography and Socio-Economics of Health*. Paris: CREDES.

Grandstaff, T. 1992. "Northeast, the Human Environment: Variation and Uncertainty." *Pacific Viewpoint* 33:135–44.

Guilkey, D.K. 1992. "Community Effects in Demography and Health Survey Data." Working Paper, IRD/Macro Working Paper. Columbia, MD: Macro International.

Hermalin, A.I. 1979. "Multivariate Areal Analysis." Pp. 97–111 *The Methodology of Measuring the Impact of Family Planning Programmes on Fertility*. Population Studies No. 66. Department of International Economic and Social Affairs, United Nations.

Hermalin, A.I. and B. Entwisle. 1987. "The Availability and Accessibility of Contraceptive Services." Pp. 583–96 in *Organizing for Effective Family Planning Programs*, edited by R.J. Lapham and G.B. Simmons. Washington, DC: National Academy Press.

Hernandez, D.J. 1984. *Success or Failure? Family Planning Programs in the Third World*. Westport, CT: Greenwood Press.

Heywood, I. 1990. "Geographic Information Systems in the Social Sciences." *Environment and Planning A* 22:849–54.

Janowitz, B., D Hubacher, T. Petrick, and N. Dighe. 1994. "Should the Recommended Number of IUD Visits Be Reduced?" *Studies in Family Planning* 25:362–67.

Lapham, R.J. and G.B. Simmons. 1987. "Overview and Framework." Pp. 3–26 in *Organizing for Effective Family Planning Programs*, edited by R.J. Lapham and G.B. Simmons. Washington, DC: National Academy Press.

Lupien, A.E., W.H. Moreland, and J. Dangermond. 1987. "Network Analysis in Geographic Information Systems." *Photogrammetric Engineering and Remote Sensing* 53:1417–21.

Matthews, S.A. 1990. "Epidemiology Using a GIS: The Need for Caution." *Computers, Environment, and Planning* 17:213–21.

Openshaw, S. 1984. "The Modifiable Areal Unit Problem." *Concepts and Techniques in Modern Geography*, No. 38. Norwich, CT: Geo Books.

Rindfuss, R.R., D.K. Guilkey, B. Entwisle, A. Chamratrithirong, and Y. Sawangdee. 1996. "The Family Building Life Course and Contraception Use: Nang Rong, Thailand." *Population Research and Policy Review* 15:341–58.

Rodriguez, G. and N. Goldman. 1995. "An Assessment of Estimation Procedures for Multilevel Models with Binary Response." *Journal of the Royal Statistical Society A* (Part 1):73–89.

Rosenfield, A.A., A. Bennett, S. Varakamin, and D. Lauro. 1982. "Thailand's Family Planning Program: An Asian Success Story." *International Family Planning Perspectives* 8:43–51.

Rosero-Bixby, L. 1993. "Physical Accessibility to Health Facilities in Costa Rica." Pp. 185–90, in *Proceedings of the International Population Conference, Montreal*. Vol. 3. Liege, Belgium: International Union for the Scientific Study of Population.

———. 1995. "Spatial Dimensions of Family Planning in Costa Rica: The Value of Geocoding Surveys." Paper presented at the annual meetings of the Population Association of America, San Francisco.

Stallones, L., J.R. Nickols, and B.K. Berry. 1992. "Surveillance Around Hazardous Waste Sites: Geographic Information Systems and Reproductive Outcomes." *Environmental Research* 59:81–92.

Tsui, A.O. 1985. "Community Effects on Contraceptive Use." Pp. 77–99 in *The Collection and Analysis of Community Data*, edited by John B. Casterline. Voorburg, Netherlands: The International Statistical Institute.

Tsui, A.O. and L.H. Ochoa. 1989. "Service Proximity as a Determinant of Contraceptive Behavior: Evidence from Cross-National Studies of Survey Data." Carolina Population Center Papers No. 89–105, Univesity of North Carolina.

Twigg, L. 1990. "Health Based Geographical Information Systems: Their Potential in the Light of Existing Data Sources." *Social Science and Medicine* 30:143–55.

Verhasselt, Y. 1993. "Geography of Health: Some Trends and Perspectives." *Social Science and Medicine* 36:119–23.

Walsh, S.J., W.M. Gesler, P.H. Page, and T.C. Ricketts. 1995. "Modeling Health Care Accessibility Through an Integration of Network Analysis and Geographic Information Systems." Pp. 25–36 in *Proceedings, Geography and Socio-Economics of Health*. Paris: CREDES.