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Modeling Distance Decay Effects in Web Server Information Flows

Previous studies have shown that there is a direct correlation between the popularity of a medium and the cost in transmitting information through that medium. On this basis the World Wide Web may become more important as a mass medium than radio and television. Yet despite the enormous growth in Internet information and Internet-supported businesses, there has been, as yet, little in the way of quantitative spatial analysis of information flows on the WWW. One major issue is whether or not distance influences the web sites that a user may visit. If distance is a factor, then the location of servers delivering content becomes important. In this paper an analysis of information flows from U.K. academic web servers to the rest of the world is carried out. Using a UNIX utility called ping, *the average time taken for a defined amount of information to travel between the United Kingdom and sixty-six other countries across the Internet was measured. This time measurement known as* latency *is used as a measure of distance on the Internet. The latency measurements are combined with counts of visitors from each of these countries to approximately one hundred U.K. academic WWW servers and used to build a simple gravity model of WWW information flows. The latency measurements between the United Kingdom and the other countries were gathered over a week in 1996. The counts of visitors relate to the total number of visits to the web servers over various timescales for the years 1995 and 1996. We make the assumption that the distance measurements used are relevant to the visit counts. We also assume that all visitors from the .edu domain are geographically located in the United States. The gravity model is used to determine the effect of Internet distance on the number of expected visits to a web server. The study shows that latency values are a useful metric for measuring Internet distance. The results also demonstrate that the number of visitors to a web site falls off with distance on the Internet, as measured by latency values.*

Information is a commodity and the role of information businesses (creators, collectors, vendors, and distributors) will become increasingly important in the coming decade. This will be particularly true for advanced economies, which are dependent on the service rather than manufacturing commercial sectors.

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The U.K. economy, for example, is already heavily dependent on this type of commerce. It is likely that the World Wide Web protocol and the Internet infrastructure will play a central role in information transactions. A recent study predicts that the on-line travel market alone will be worth $9 billion within the next five years (Gardner 1997). It is also suggested that approximately $2 billion worth of research and development on new Internet access services will be carried out by the private sector this year alone (Hertzberg 1997). That the Internet should be so important is not surprising, when it is considered that the number of Internet users is predicted to grow to over one hundred million within the next ten years (Cerf 1993).

The importance of this sector has not gone unrecognized at the government level and a number of strategic initiatives designed to support an information economy infrastructure have recently been implemented in the United Kingdom (UKERNA 1993), the United States (Clinton and Gore 1997), Malaysia (Durham 1997), and other states. The U.K. SuperJanet initiative, for example, aims to support and develop prototype applications, which require and utilize high-speed broadband communication networks. The Malaysian initiative involves the provision of a high-quality network infrastructure for one region, in the hope of attracting information businesses to that area. Although the various initiatives are diverse in implementation they all have the same basic aims, to develop the infrastructure and knowledge base that will allow them to compete for information business. Information business is attractive for a number of reasons, requiring no natural resources and involving minimal transportation costs for product delivery.

The growth of the information economy will also have major consequences on the way we work. If we have a truly effective global communication network there is no reason that a company's workforce should even be located in the same hemisphere. Businesses will be able to employ staff from any region without the complications of work visas or immigration legislation. British Airways recently moved some of their software development from the United Kingdom to India (Leung 1996) on this basis.

The Need for Quantitative Analysis

Although no one doubts that the WWW will provide opportunities for business, there are very few examples of financially successful on-line business ventures, such as Amazon's on-line book store (Amazon 1998), and numerous well-publicized failures, for example, the Microsoft Network (Hertzberg 1996). A successful business plan for any new commercial venture will usually include some estimation of the numbers of customers expected and the likely catchment areas for these customers. Using this information, probable turnover and profits can be calculated and, furthermore, services can be tailored to match customer requirements. In the case of WWW- or Internet-based businesses this type of calculation is impossible to carry out, since the whole commercial sector is still in its infancy and a number of basic questions remain unanswered.

If a WWW-based service is set up at one location on the Internet, it should, in theory, be accessible from any other Internet location. If the services offered are suitably global in nature, we might then expect customers using this service to be equally distributed around the Internet. Alternatively it may be the case that more customers would arise from Internet regions local to the server. There is currently no quantitative evidence to support either view. Another way of viewing this issue is to ask if distance will have an influence on Internet transactions. If distance is important, then a suitable metric is needed to measure it. Other related commercial issues also remain unexplored. Is it important where an on-line service is located, either geographically or in Internet terms? Or is there any relationship between geographical and Internet space (cyberspace)?

Part of the interest in potential Internet commerce is in high-volume businesses such as pay-per-view TV, global radio broadcasting, Internet telephone services, and video conferencing. A single video tape, for example, can store approximately four gigabytes of movie data. To view a film across the Internet would thus require a continuous information transfer of at least five hundred kilobytes of data per second over a two-hour period. This type of information transaction will require a sophisticated networking infrastructure to operate effectively. The topology of the existing infrastructure will therefore define the possible footprint or catchment area of the service. Analysis is needed to define the required improvements to make such services feasible.

While there is currently little quantitative spatial analysis in this area, there are indicators that the situation may soon change. In recent times there has been a growing interest in mapping the Internet, from a number of different perspectives, for visualization purposes (Dodge 1996; MIDS 1997; Quarterman, Smoot, and Gretchen 1994). Dodge, for example, plotted the different countries from which visits were made to one particular WWW server. It seems likely, based on the experience of GIS development, that initial attempts at quantitative cyberspatial analysis will follow the current mapping exercises.

1. A POSSIBLE MODEL OF WEB SERVER ACCESS BY CLIENTS

When a person uses one of the popular WWW browsers such as Netscape's Navigator or Microsoft's Internet Explorer to view information on a WWW server, a series of information transactions takes place. The user enters a location into the browser. The browser then looks up the Internet address (IP address) of the WWW server. Internet addresses consist of four numbers in the range of 0–255 separated by a full stop. For example, the Internet address of the WWW server www.geog.port.ac.uk is 148.197.55.119. Using this address, a request is sent by the browser to the WWW server for information. The WWW server processes the request and sends the information back to the browser. The browser then displays the information to the user. A typical WWW page may include some graphical elements such as icons or images. The browser initiates separate requests for each unique element in the WWW page and thus viewing a single web page may involve a number of distinct information transactions. The process of viewing a WWW page could be considered as a virtual "visit" to that WWW site. For the purposes of simplicity we will refer to each individual information request as a separate visit. The total number of visits involved in viewing any particular WWW page will thus be related to the complexity of that web page. The retrieval of information from the correct remote computer system, possibly situated many thousands of miles away, involves a complex communication system used not only by WWW servers and clients, but also by e-mail, news, and file transfer systems. The Internet physically consists of a large number of connected computer networks. Each computer connected to one of these subnetworks has a unique address. Each of the subnetworks that make up the Internet are linked together via devices known as routers or gateways. When one computer attempts to transfer information to another computer the information is broken down into small packets. Each packet of information has the sender's and receiver's addresses contained within it. The packets are initially delivered to the local router. The local router examines the destination address and decides where to send the packets next.

Individual packets may travel via different routes, being passed from one router or gateway to the next. The packets finally arrive at a router that can resolve the exact location of the destination computer and are passed to that machine. The receiving computer collects all the packets together and reassembles the original information. The distributed nature of the system ensures that information will almost certainly reach its destination as long as the addressing information is correct. The fact that the user of a web client need not address the issue of how the information gets from one computer to another is one of the reasons why WWW clients are so ubiquitous.

There are a number of possible factors that might influence the number of customers visiting a web site from a particular location. Possible factors might include the distance between any potential visitor and the WWW server on the Internet, how interesting the content of the WWW server is to potential visitors, or even the language used on the WWW server. The scope of this analysis will be limited to determining the potential effect of distance. The simple gravity model shown in equation (1) is used as the basis for modeling information flows.

$$N_i = \alpha P_i f(D_i) \tag{1}$$

where

- α represents the attraction of the information source. This would depend on factors such as the quality of the content, the reputation of the organization running the information service, etc.
- N_i is the number of visits to the web server from a client at point i in cyberspace.
- P_i is the total number of Internet users at i, that is, the number of potential customers at i.
- P_i is the cyberspace distance between location i and the web server (defined in terms of latency).
- $f()$ is a function applied to the distance between the client at i and the web server.

Quantitatively determining the attractiveness of a web site is a complex issue. Attempts have been made, using features such as the number of other sites that contain links to a site, as a measure of its visibility on the WWW (Bray 1996). However, with the growing importance and use of Internet search engines such as the AltaVista service by Digital, the utility of such measures is increasingly doubtful. Since it would be difficult to quantify α and since we are primarily interested in distance effects, the model outlined in equation (1) can be rewritten to the form shown in equation (2).

$$f(D_i) \propto \frac{N_i}{P_i}. \tag{2}$$

If sufficient data from examples at varying distances and locations can be gathered, the form of function f can be extracted. If f is a constant or is nearly constant, we can assume that distance has little influence on the number of visits to a web server.

1.1 Counting Visits to a Web Server (N)

The question of how to count visits to a web site is the subject of ongoing research, mainly in the commercial advertising sector, which is understandably

TABLE 1
Common Variants of Access Statistics Available from Websites

Software	Total transfers by time period	Total transfers by client domain		Total transfers by client sub-domain		Total transfers by object
	Requests	Requests	Bytes	Requests	Bytes	Requests
Getstats	√	√		√		√
Wwwstat	√	√	√	√	√	√
Analog	√	√	√	√	√	√
Wusage	√	Top ten only	Top ten only	Top ten only	Top ten only	√

interested in tracking individual visitors to web sites in which they place advertisements (Stehle 1996). For the purposes of the simple model used in this analysis, we count each individual information transfer from a WWW server to a client browser as a "visit." Thus the process of viewing a WWW page containing a number of images might entail a number of visits to that particular WWW server. The information required to count visits is often stored in the access logs of WWW servers. There are now a wide variety of programs or scripts available to web server administrators that allow them to create summaries of web server access statistics automatically. These summaries are often publicly available from the web servers. Unfortunately, there is also a wide variation in the quality of information made available in this way. Table 1 covers some of the main types of published statistics found. Many of these packages are highly customizable; the features listed here are simply the commonly found variants of reports produced.

If all that was needed was the number of information transfers from a server, any of these report types would be suitable. However, it is also necessary to obtain the number of information transfers to visitors in each country. Any access statistics provided by the Wusage package are incomplete and are often only available as a graphical image, which renders the information almost unusable. All of the other report formats give data on information transfers to clients aggregated at various levels. We visited the WWW sites of each of the universities in the United Kingdom in turn and collected any publicly accessible web server access statistics that were available in a suitable format. Access statistics suitable for use in our analysis were found at approximately one hundred U.K. academic WWW servers, representing forty-three of the U.K.'s universities. For this analysis we use only access statistics that provide a complete picture of visits to a particular web server. The server statistics published covered a variety of time periods, although the majority of the information related to the years 1995 and 1996. Some sites, for example, make available only the number of visits to that site for the previous month. At the other extreme some servers provide a detailed weekly breakdown of all visits made since the WWW server was set up. The access reports were collected and reprocessed using PERL (Practical Extraction Report Language) scripts to extract the total number of visits to each server by users in each country. The visit counts by country were determined solely from the information contained in the server logs. No real geographic information is contained in the logs; however, the domain name in the entry associated with a visit will usually contain a standard ISO3166 country code (RIPE 1997). It is impossible to be certain that a computer registered to a U.K. domain and thus having a U.K. country code (.uk, for example) is in fact located within the United Kingdom (Network Wizards 1998). In the absence of other information the assumption was made that the country codes were correct. Most of the domains that could not be mapped to individual countries, that is, the .com, .org, and .gov domains, were not included in the main analysis. Estimations are available relating to the percentage of .com domains that are in the United States; however, there is no reliable method of confirming these results (Quarterman 1997). The potential influence of visits from these domains on our results is included in our results and discussion sections. Visits by users from the .edu domain were included and were assumed to be originating from the United States. In total, approximately sixty-two million accesses (excluding the .com, .org, and .gov domains) were accounted for in the main analysis.

1.2 Using Latency as a Measure of Cyberspace Distance (D)

There a number of options available for measuring the network distance between two computers. Each information transaction results in information traffic along a variable route through the Internet network. On first inspection it would seem that the logical method for analyzing such information flows should involve network analysis tools. There is insufficient space here to provide more than a brief outline of why a network model was not used. Briefly stated, the global nature of the information flows examined in this study meant that the complexity of the required network analysis made such an approach problematical. In the interest of simplicity it was decided to use a point-to-point distance measure referred to as latency. For a more detailed examination of network models versus point-to-point distance measurements on the Internet, the interested reader is referred a recent discussion of the possible options (Murnion 1998). Latency is a measurement of the time taken for information to travel from one location to another on the Internet. A utility program called *ping* that originated in UNIX systems can be used to measure latency. When the ping command is executed on a computer, a single packet or multiple packets of information of defined size are sent to another computer usually referred to as the remote host. The remote host adds a time stamp to the packet and returns it to the original machine. By examining the time stamp information the round trip delay time can be calculated. Latency is a useful measure of Internet distance since it determines the speed of information transfer. Furthermore, users of the web are unaware of the routes taken by information, or of distances traveled, but are aware of the time taken to do so. Latency is already widely used in mapping of Internet information flows, creating what have been termed "Internet weather maps" (MIDS 1997). Latency measurements were used to define the cyberspace distance D in equation (1).

One problem with using latency as a measure of how fast information can flow across the WWW is the use of caches. Caching servers contain copies of information requested by a client and may be kept at a user level by the WWW client in use or at a higher level; for example, a cache is maintained for all users of JANET. If a large number of requests occur for a particular item, a copy of the item may be kept by the cache and subsequent users requesting the information will receive it from the cache rather than the original information source. Since the information is being delivered from a local source it will arrive much faster. Furthermore, if the cache copy is retrieved, this will not register as a visit on the original server's access logs. However, caching is unlikely to have a major impact on this analysis for three reasons. First, caches can only maintain copies of the most popular objects. This would tend to have a major impact on the number of access to popular services like Yahoo, for example, but it is unlikely that academic server content, as is examined in this work, features highly on national caching systems. Second, there is little evidence that the use of national caching services is widespread among WWW users, especially since the client must be specifically configured to use such a service. Finally, the local caches on a WWW client will affect only the number of visits recorded within a single viewing session. When the WWW client is restarted in a new session, any request for a locally cached document is preceded by a request from the WWW client to the WWW server for the header information of the requested document. From the header information the client can tell if the document has changed since the last access. If it has not changed, the document is loaded from the cache. Requests for headers are recorded as accesses on the web server logs and as such each visit is still noted. Thus while caching may have some impact on the results of this analysis, it is unlikely to have a major effect.

Although it has always been possible to measure latencies between the United Kingdom and other globally distributed locations, there are unfortunately no records available of latency measurements for previous years. This might suggest that the analysis could only include current web server access statistics, since the latency measurements might not be relevant to the latencies that were extant one or more years ago. To consider this effect, two large-scale latency studies were carried out, measuring the latency between the U.K. domain (as measured from Portsmouth University) and sixty-six other country domains. The first measurements were carried out over a one-week period in 1996, with a second set of measurements taken a year later in 1997. The results are shown in Figure 1.

As can be seen from Figure 1, although some of the latencies measured have fallen, the average latencies of many domains from the United Kingdom are similar to their values from one year before. Furthermore, since the number of accesses to WWW servers has been growing at an exponential rate, the majority of access statistics gathered from any records should arise from recent visits which would have occurred when latencies were similar to those measured in the 1996 survey. It was assumed in this analysis that as a result of this our latency measurements should be sufficiently relevant to the time period covered by our visit counts, although this assumption is tested later on.

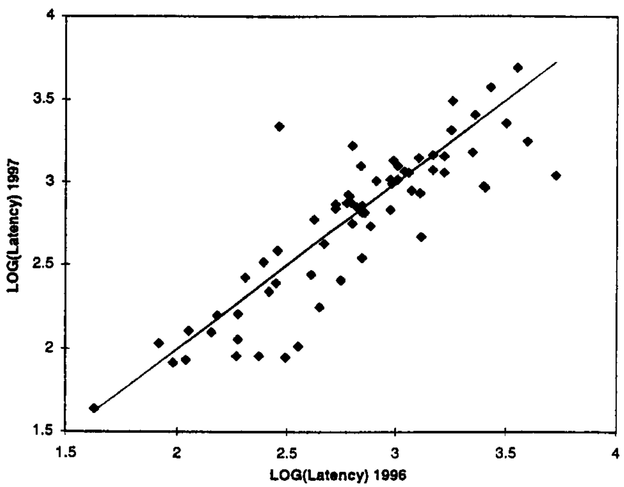

FIG. 1. Latency of Sixty-six Countries from the United Kingdom in 1997 versus Latency in 1996

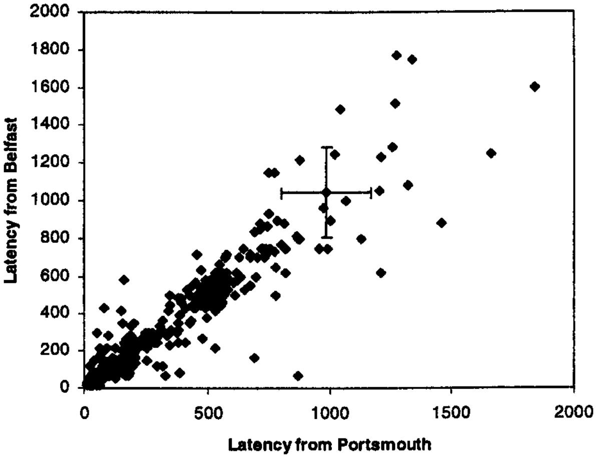

FIG. 2. Latency of 500 Internet Locations as Measured from Portsmouth versus Latency as Measured from Belfast. The error bars on one point represent +/− one standard deviation of one of the measurements.

A potential problem arises from the assumption that latency as measured from Portsmouth University is equivalent to latency measured elsewhere on the JANET (U.K. academic) network. Portsmouth University resides at a particular node on JANET and the local network environment may be different from that of other U.K. universities. In this work the assumption was made that latency as measured from Portsmouth would be very close to latencies as measured from anywhere on the JANET network. To check that the assumption is valid, a series of almost simultaneous latency measurements was carried out from a computer at Portsmouth University and a computer at The Queen's University of Belfast (QUB) in Northern Ireland. QUB is perhaps as distant from Portsmouth as it is possible to get both geographically and on the JANET network. Near-simultaneous latency measurements were taken of 497 globally distributed remote computer sites from both QUB and Portsmouth. By near simultaneous, we mean that the measurements at Portsmouth and Belfast were made within seconds of each other. The results are shown in Figure 2. The correlation between the two measurements gives an R^2 value of 0.9. On the basis of this result it should be reasonably valid to use latency measurements from Portsmouth as latency measurements for the United Kingdom as a whole.

To obtain the latency between the United Kingdom and the other sixty-six countries we identified the IP addresses of 1,016 computers distributed around the globe. The computers were selected from a global list of academic WWW servers. Yahoo (1998) currently maintains a similar list. Since these web servers are usually based at higher-education institutions, by visiting the web site the geographical location of the relevant institution can be determined. It was thus assumed that the web server was physically located near the institution it represented. Table 2 shows the location and distribution of approximately 50 percent the web servers used. As can be seen from Table 2, it was not possible to identify equal numbers of WWW servers in each country. This was due to the fact that at the time of the survey there were very few WWW servers in existence in some countries. It was possible to locate at least five servers for over forty of the countries.

The latency of each of the 1,016 computers from a computer based at

TABLE 2
Geographical Distribution of Servers Pinged

Country	Number of Servers Pinged	Percentage of Total
Japan	104	10.2%
United States	98	9.6%
United Kingdom	66	6.5%
Korea	48	4.7%
Germany	40	3.9%
Russia	39	3.8%
Canada	38	3.7%
Taiwan	31	3.0%
Italy	29	2.8%
Australia	28	2.7%
Rest of the world	501	49.0%

the University of Portsmouth was measured hourly over a one-week period, October 17–24, 1996. Since the visit counts are aggregated to the national level, an average latency value for each country was calculated, using the latency measurements gathered. Using the locations of the computers and the latency values measured between each of the computers and the computer based in Portsmouth, it is possible to generate an interpolated global latency map. This is shown in Figure 3. This map differs from the MIDS (1997) weather maps in its representation of latency values. MIDS maps use color-coded proportional circles to represent activity and latency. However, it is difficult to determine visually from MIDS diagrams isochronic regions, that is, regions of equal latency. To produce the map shown in Figure 3 the point measurements of latency were used to produce a triangular irregular network (TIN). Contour bands were calculated from the TIN using the ranges shown in the legend for Figure 3. Interpolation of latency values is not really valid except where the points are geographically close together; however, it is useful to plot the results in this way sacrificing a little accuracy in order to facilitate visualization of the results.

This interpolated map is a useful result in itself. Some services that may be delivered over the Internet, such as video-on-demand, will not operate successfully unless there is a sufficiently fast connection between the client and the server. If, for example, a video server based in the United Kingdom required a connection at least as fast as that represented by a latency of 200 milliseconds, then from Figure 3 it is possible to derive the catchment area for such a service. The catchment area for this example would be limited to the central and eastern United States, central Europe, Spain, and the Nordic states.

A comparison of the average national latency values with some national economic and telecommunication statistics reveals some interesting relationships. Figure 4 shows a comparison of GDP (Heinemann 1997) against the average national latency and Figure 5 shows the numbers of telephones per hundred persons against average national latency (United Nations 1996). As one might expect there are clear links between the economic and telecommunication development of countries and the quality of their Internet infrastructure.

The number of visits to our academic web servers can be plotted against the latency between the visitor's country and the United Kingdom. The results, shown in Figure 6, show an indication of a relationship between the average latency of a country from the United Kingdom and the number of visits from that country to a U.K. WWW server. The regression line is not very meaningful since it may be describing effect rather than cause. The low number of visits

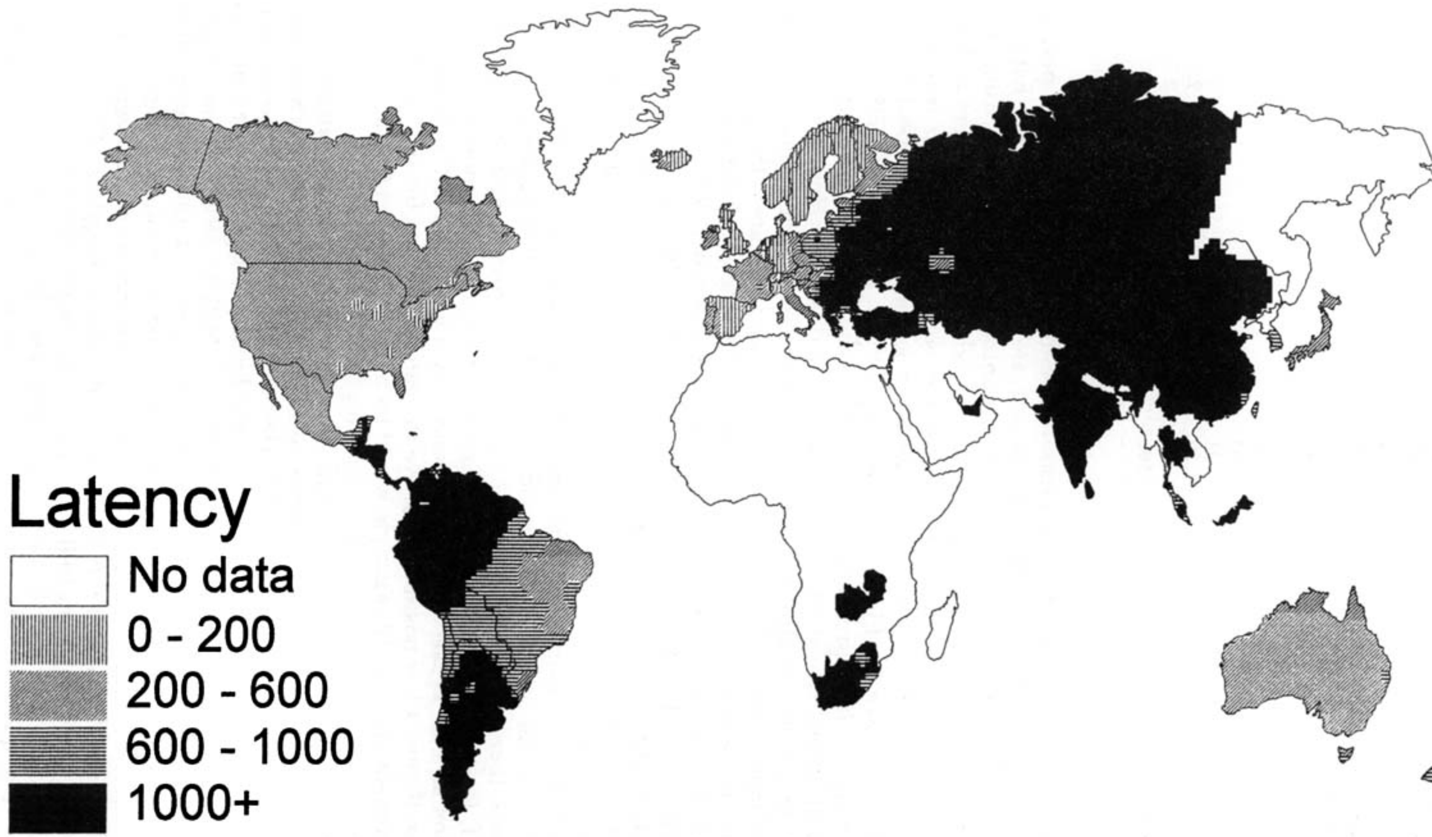

FIG. 3. Interpolated Global Latency Map. Latency figures are in milliseconds.

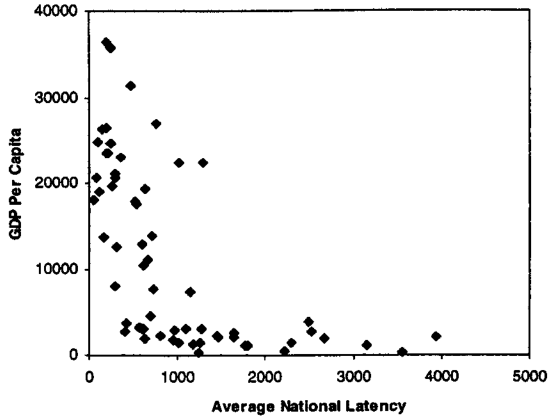

FIG. 4. GDP per Capita versus Average National Latency

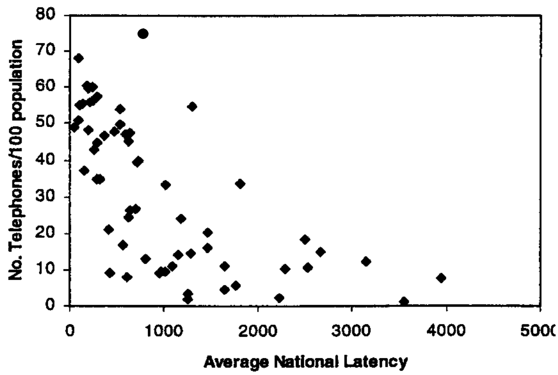

FIG. 5. Number of Telephones per Hundred of Population versus Average National Latency

from Fiji (.fj domain) might be because it is distant from the United Kingdom on the Internet, or simply because there are very few Internet users in Fiji. To clarify the effect of Internet distance on the number of visits seen, it is necessary to standardize our visit counts against the number of potential Internet users in each country.

1.3 Counting Internet Users or Potential Visitors (P)

It is in fact impossible to measure even the total number of all Internet users at the current time as limited Internet-related census information exists. A possible solution lies in the fact that every domain and subdomain, for example, ac.uk or port.ac.uk, must be registered centrally and statistics on the number of domains registered under each top-level domain are publicly available (Network Wizards 1997). Since there is an upper limit on the number of computers that can have an address in each subdomain, in this work it is assumed that the number of registered domains and the number of users are highly correlated. Therefore the number of registered domains can be used as a substitute for P in equation (1). As mentioned previously .edu domains are all assumed to be geographically located in the United States. The domain count used was the January 1996 survey.

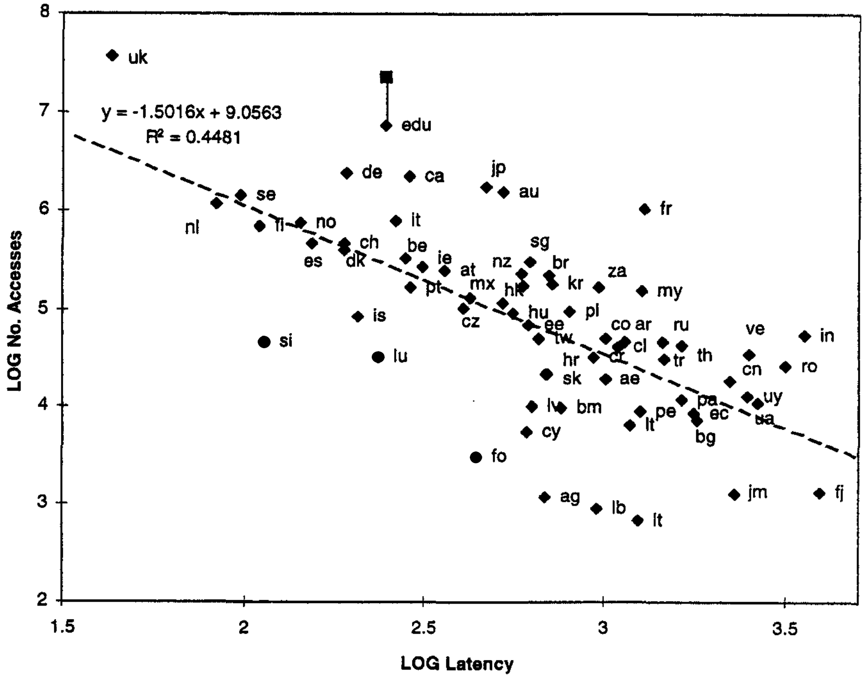

FIG. 6. Latency versus Visit Counts by Country. The square point connected to the .edu value represents the change in that value if all the visits from the .com, .gov, and .org domains are considered to originate from the United States.

2. EXTRACTING THE EFFECT OF DISTANCE

Using the domain registration information it is possible to produce N/P ratios for use in our model. However, when the N/P ratios are plotted against the latency values (D), an effectively random scatter plot is obtained. The correlation between N/P and D is very poor (0.168) with a significance of 0.176. An unfortunate side effect of standardizing visits by the number of potential users is that unusual behavior by a small number of individuals in nations with few users can have large effects in the resulting N/P ratios. It is possible to account for this with a simple weighted regression fit, using the actual number of visits from each location as the weight, which results in the same low correlation. However, using a weighted fit the significance falls to zero and a negative coefficient for latency is obtained; that is, the number of visits decreases with distance. It may also be the case that national bias and cultural influences are responsible for some of the variation and unfortunately there is no information available on this topic. Furthermore, only information about the Internet distances between each of the countries and the United Kingdom is available. The latency measurements provide no information about the distances from each country to other countries. It might be that the relatively low N/P ratio for Japan, for example, is due to the fact that the United Kingdom is relatively distant and that a much closer source of similar information can be found from academic web servers in the United States.

To dampen the effect of these influences it is useful to use cumulative counts of visits. Since the values at each point represent the results for all the previous

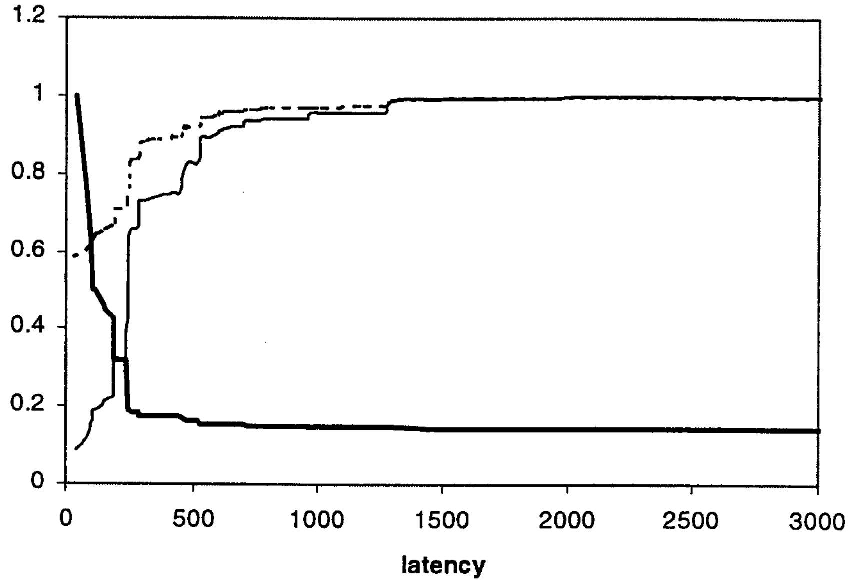

FIG. 7. Cumulative Results versus Latency. The fine solid line represents cumulative visits. The dashed line represents cumulative numbers of domains and the heavy solid line represents cumulative visits/cumulative domains or the ratio of potential customers who visited. All values have been normalized to values between 0 and 1. The value 1 on the y axis represents the total number of visits to the web servers (62 million) for cumulative visits, 6.7 million domains for cumulative domains, and 63.7 for visits/domains.

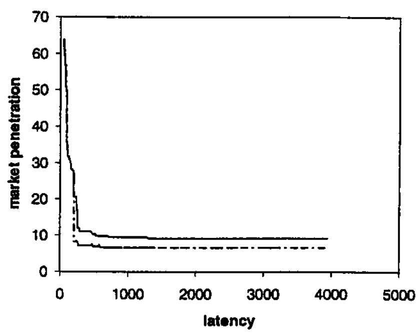

FIG. 8. Market Penetration versus Latency. The solid line represents the results excluding visits from .com, .org, and .gov domains. The dashed line represents the results if these visits are included.

countries, anomalies associated with a particular country should be removed. This process also has the effect of filtering out noise in visit counts from nations with small numbers of registered domains. The results are shown in Figure 7. The heavy solid line represents roughly the number of visits recorded per potential visitor and could be used as a measure of Internet market penetration. Figure 8 shows the market penetration result including and excluding the visits from .com, .org, and .gov domains. If it is assumed that all the visits from these domains originate from the United States, then the dashed line in Figure

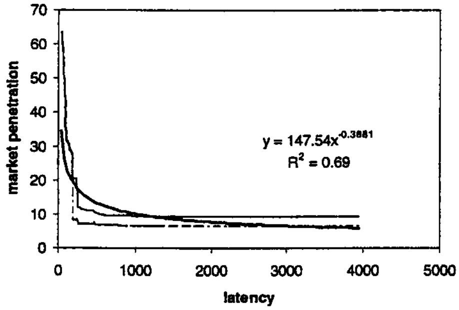

FIG. 9. Power Law Curve Fitted to the Cumulative Results (heavy line). The equation of the curve and the quality of the fit are shown.

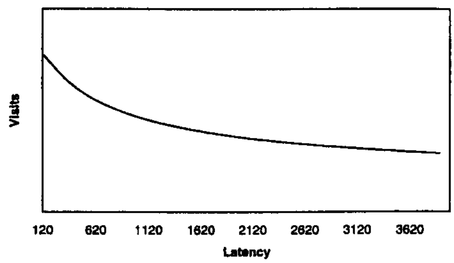

FIG. 10. Logarithmic Distance Decay Function *f* Derived from the Results

8 is obtained. If these visits are excluded, then the solid line shown in Figure 8 is the result. The real number of visits from the United States will lie somewhere between these two extremes.

Figure 8 shows a dramatic drop off in market penetration with latency. The U.K. academic WWW servers received sixty-four visitors from the United Kingdom for every registered U.K. domain, whereas for all domains at latencies of 1000 or more, only approximately 10 visitors per registered domain are received. It is possible to fit a smooth curve to the data shown in Figure 8. A power law relationship curve was fitted as shown in Figure 9 giving an R^2 of 0.69.

The fitted smooth curve represents the integral of visits per registered domain against latency. This curve can be differentiated and applied to the hypothetical situation where there are an equal number of potential Internet users at all latencies. The result of the differentiation is a logarithmic curve, shown in Figure 10, which represents the relative number of visits that would be received by U.K. academic servers against latency. Having smoothed out individual national differences this curve represents the shape of the distance decay function *f* in equation (1).

This curve shown has a plausible shape, that is, the web servers receive fewer visitors from regions that have a slow connection to the United Kingdom than from users in areas that have a fast connection. The decay curves shown in Figures 7 and 8 show a much steeper decay than the distance function shown in Figure 10. This is due to a combination of the distance effect and the rapidly declining number of potential visitors at larger latencies.

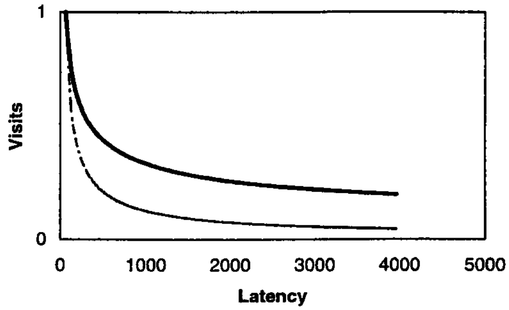

FIG. 11. Logarithmic Distance Decay Function Derived from the Results of the Validation Test (fine line) Compared with the Distance Decay Function for the Main U.K. Data Set (heavy line)

3. VALIDATING THE MODEL

A number of assumptions were made in the process of building the model. Perhaps the most important assumption was that the latency measurements taken were valid for the period covered by the visit counts. In an attempt to test this assumption a small-scale survey was carried out using the WWW server in the geography department at Portsmouth University. The survey involved examining visits to this particular web server for a period of two months. Every time a non-U.K. user visited one of the pages on the web server, ping was executed immediately to measure the distance between that visitor's client and the WWW server. This provided an accurate measurement of the latency as experienced by the visitor. The latency values were recorded along with the domain of the visitor. One advantage of this method was that since geographical location or nationality was not used to provide latency values, visitors from geographically distributed domains such as the .com domain did not have to be treated separately. Cumulative counts of visits, normalized by the number of domains, were collected. A smooth curve was fitted to the results and differentiated. The resulting function was applied to a situation where equal numbers of domains exist at all latencies. If the assumption is valid then the resulting graph should exhibit a similar shape to that shown in Figure 10. The result is shown in Figure 11.

It is noticeable that although the shapes of the curves are similar in nature, the distance decay is more pronounced for the Portsmouth data set than for the U.K. data set. It is likely this is because the Portsmouth web site is less attractive to a global audience than the overall attractiveness of the combined U.K. academic web sites. During the exercise only 5,471 visits were recorded so the statistical uncertainty in the values shown in Figure 11 will be high. The agreement with the shape of the decay curve shown in Figure 10 is reasonable considering the limitations of the data sets used.

4. DISCUSSION AND CONCLUSIONS

The work carried out here is a preliminary analysis, but this work highlights some interesting points and suggests some areas for future research. The most significant result from this analysis is the evidence supporting the view that there exists a distance decay effect in web server audiences with cyberspace distance. We have also attempted to determine the shape of this distance decay curve with the caveat that the analysis was based on some simplifying assumptions.

If there is a distance effect, we need to consider how it could arise. Users of the Internet will commonly use one of the Internet search engines such as Lycos or AltaVista to find information. When users conduct searches, it is possible that they identify the location of a server from its address and choose a suitable information source that is geographically close to them. By choosing a nearer source, they are perhaps naturally choosing an information source with a lower latency. Alternatively it may be that users may try a number of suitable information sources and commonly return to use those services that return information rapidly, again selecting sources with lower latency. Either situation would result in the distance decay effect observed in our analysis.

Distance and Latency and Developing Nations

The relationship between virtual or cyberspace and geographical space is not a simple one, as is obvious from Figure 3. However, the cyberspace distance map as measured from Portsmouth is similar in nature to other isochronic communication maps [for example, the isochronic travel maps by Gould (1991)]. In fact, latency maps should be similar to other isochronic communication maps where the communication of information, objects, or people travels along network routes. As such latency maps are not a new idea, instead they are an application of traditional communication geography to a new communication medium.

The differences between geographical space and latency space explain why the economic consequences of the Internet should be so profound. Areas that have been until now geographically remote have become accessible as markets for service industries. Businesses in the Quaternary sector such as Insurance and Banking will certainly benefit since these business sectors have for many years essentially involved nothing more than the transfer of information or money in electronic form and as such are perfectly suited to Internet type commerce. However, the increased accessibility of developing regions may in fact be disadvantageous for those regions. Previous studies of telecommunication network growth from urban to rural regions in the United States and elsewhere show that businesses based in the developed urban centers tend to dominate over rural-based businesses (Abler 1991). This pattern is likely to repeat itself in the relationship between businesses in the developed and developing regions. A further area of concern for developing regions is the asymmetry of latency space. Consider the hypothetical situation of a region A that has a poor Internet-connected network exhibiting high latency values. For customers within the region all Internet services delivered from sites on the local network will appear far away in latency space. If the network borders a highly developed network from a developed region B with very low latency values, then services based in B will appear to be almost as close as their own internal services. Furthermore, with the enhanced levels of Internet expertise and business experience available within developed regions, B's services may well be superior in quality to A's. As a result customers will tend to import services from B rather than use their own region's services. However for customers within the B region any service originating from A will seem much farther away in latency space than their own internal services and as such they are unlikely to use them. Thus it seems that the inequalities between developed and developing regions will be exacerbated by Internet commerce.

Economic Considerations for WWW-based Service Providers

If Internet distance does influence the location and number of visitors to a WWW site, then it becomes important for businesses to determine carefully the optimum number and location of their service delivery points on the Internet. By doing this organizations can ensure that their services will be easily accessible to their intended audiences. However, to carry out such an analysis, some method is needed for determining the latency values experienced at a remote location on the Internet. There is also a methodological requirement for some form of Internet gazetteer or automatic method of determining simultaneously the geographical location and Internet address of computers connected to the Internet. This is, in fact, an area of current study (Davis 1997; Harrington 1996). If suitable methods were available to carry out these tasks, it would become possible to determine good locations for siting Internet services. First, potential customers must be located. Second, the latency between the potential customers and potential sites for the service should be measured. Finally, the service sites should be selected that minimize latency values for the maximum number of customers.

Further Work

In this analysis we examined only visits to U.K. academic information services. A natural progression of this study would be to extend the analysis and examine the access statistics of web servers from other domains and for other types of services. It should be noted, however, that other issues might arise when analyzing flows to and from popular commercial services. Access to academic WWW services generally involves low levels of information transactions. As such almost any computer platform is powerful enough to cater to customer demands. However, when dealing with very high volume services such as Netscape download servers, then the technical specification of the machines that deliver these services may be an important factor in deciding the speed of the service delivery. This information will almost certainly be commercially sensitive and as such may not be available to the researcher. Analyzing flows to and from multiple Internet domains would allow us to move beyond the simple model given in equation (1) to a full spatial interaction model. One problem with an extensive study of this kind would be the requirement of enormous number of ping executions that would be needed to measure the cyberspace distance between every domain and subdomain. Some simple method is needed of calculating the cyberspace distance between two locations on the Internet without unduly loading an already congested network. With this type of study it may be possible to determine which nations are currently net importers of information and information services and which are exporters. Currently the vast majority of information and services on the WWW are free; however, as commercial Internet services grow, nations who are net information importers may eventually experience adverse effects on their balance of payments.

It would also be useful to study the change in information import/export balances over time. It may be that as countries initially become connected to the Internet they import information. As their internal on-line services start to appear and mature the import/export balance may improve. An alternate possibility is that, as in many areas of technology, while their internal services are improving, so too are the external services resulting in a steady import situation.

Another potential area of study involves the type of information being delivered over the Internet. Information transfers are currently dominated by flows of low-volume material in plain text/HTML format. As richer document formats for distributing material such as video become more popular, it would be reasonable to expect an even more extreme relationship between distance and customer numbers appearing. It would be useful to study how object size influences the number of times an object is downloaded by users with varying latencies.

Finally, it can be seen from this work that the WWW server logs held by each of the universities provide a valuable source of material which is unfortunately not widely available and in some cases is not even archived. There is a strong argument for the provision of some central server log archive, at national or international level. In parallel to this there is a strong need for a further archive of high-quality, detailed latency measurements carried out on a global basis that would allow this server log data set to be analyzed cyberspatially. If the privacy of an individual's information transactions is an issue, then guidelines must be developed that would meet the needs of both researchers and WWW users. The experience of limited access to national census information should provide some useful starting points for that discussion.

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