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**USABILITY TESTING
FOR IMPROVING
INTERACTIVE
GEOVISUALIZATION
TECHNIQUES**

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Usability Testing for improving interactive Geovisualization techniques

Usability describes a product's fitness for use according to a set of predefined criteria. Whatever the aim of the product, it should facilitate users' tasks or enhance their performance by providing appropriate analysis tools. In both cases, the main interest is to satisfy users in terms of providing relevant functionality which they find fit for purpose. "Testing usability means making sure that people can find and work with [a product's] functions to meet their needs" (Dumas and Redish, 1999: 4). It is therefore concerned with establishing whether people can use a product to complete their tasks with ease and at the same time help them complete their jobs more effectively.

This document describes the findings of a usability study carried out on DecisionSite Map Interaction Services (Map IS). DecisionSite, a product of Spotfire, Inc.,¹ is an interactive system for the visual and dynamic exploration of data designed for supporting decision-making. The system was coupled to ArcExplorer (forming DecisionSite Map IS) to provide limited GIS functionality (simple user interface, basic tools, and data management) and support users of spatial data. Hence, this study set out to test the suitability of the coupling between the two software components (DecisionSite and ArcExplorer) for the purpose of exploring spatial data. The first section briefly discusses DecisionSite's visualization functionality. The second section describes the test goals, its design, the participants and data used. The following section concentrates on the analysis of results, while the final section discusses future areas of research and possible development.

Key words: Usability, Usability Testing, User's Mental Models, Software Integration.

1.1 Visual Data Exploration Tools

Visualization is a data analysis technique which relies on the human ability for pattern recognition as well as on flexible computer environments that can support the interactive exploration of data on-screen. Visualization is particularly useful and appropriate when little is known about datasets for learning about their characteristics, discovering unknowns and forming hypotheses about relations between their attributes. However, it is also appropriate for appreciating results as well as testing assumptions implicit in modelling data using other methodologies.

Visualization feeds from a number of fields—including Information Visualisation, Scientific Visualization, Geovisualization and Exploratory Data Analysis, among others—where research on types of displays and forms of encoding information has brought about graphics and techniques that are particularly useful for exploration purposes. These graphics may differ on the type of data they are best suited to investigate but their design shares the characteristic of being highly interactive and customizable by users. Visual data exploration tools put together an environment where a number of these graphics and techniques can be combined and customized to investigate traits of a dataset.

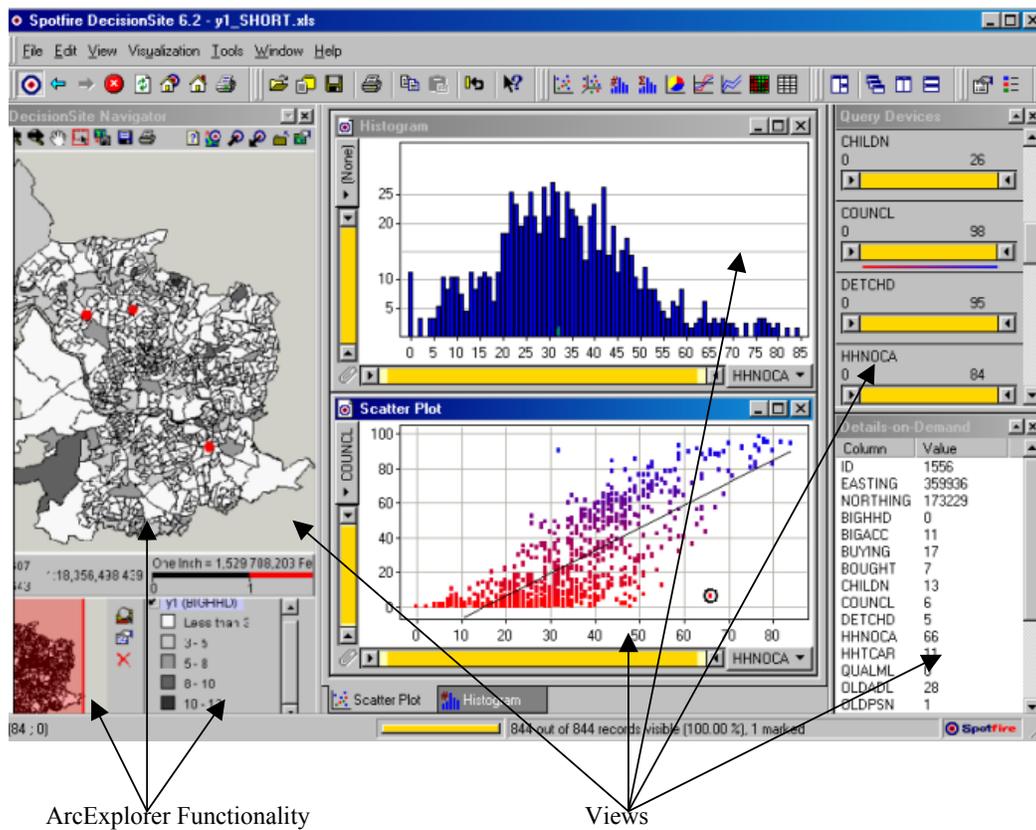


Figure 0.1 DecisionSite as a visual data exploration tool.

DecisionSite is a visualization system originally designed for aspatial data. The snapshot in Figure 0.1 shows how it is designed for the user to explore different representations of the data simultaneously, a common characteristic in this type of software. DecisionSite provides some well known graphic displays such as 2D and 3D scatterplots, parallel coordinate plots (referred in the system as Profile Charts), pie charts, line charts, bar charts and histograms,

¹ Spotfire, Inc. is a provider of eAnalytic applications headquartered in Somerville, Massachusetts and Göteborg, Sweden.

All visualizations can be customised by users. For instance, points in a scatterplot can be colour coded or their shape defined by any attribute value, as shown in Figure 0.1. Lines in profile charts can also be colour coded or their line width determined by some attribute. Binning methods in histograms can be defined interactively by users. More generally, algebraic transformations of any variable can be performed from within the system and the result stored as a new variable. Clicking on an object (point, line, or bar) on any visualization will give the user details of the information it represents in a separate window (see lower right hand side view in Figure 0.1).

An interesting feature in this software, and one of the reasons for choosing it for this study, is the Dynamic Query Filters (Ahlberg and Shneiderman, 1994) used to perform SQL queries in near real time (see Figure 0.2 and upper right hand side view in Figure 0.1). These graphic devices, referred to in DecisionSite as Query Devices, are implemented as radio buttons, range sliders, check boxes, alphasliders and item sliders² for the purpose of selecting subsets of data based on the value of the attributes. Some of these need further explanation. Range sliders are two way sliders that can be dragged from either side to filter data records in or out. The whole slider itself can be moved to select a different range of a certain size. Alphasliders (Ahlberg and Shneiderman, 1994a) are used to perform queries on text data. Record values of a variable in the dataset that has been previously sorted from minimum to maximum can be inspected one by one using an item slider which selects each in turn. As it will be discussed in greater length in section 1.3.1, these devices were particularly useful in the participant's exploration process.

ArcExplorer was coupled to the system as a plug-in to support the investigation of spatial data. The GIS initially appears as another view for data exploration to the user (see the left panels of Figure 0.1). However, it is not dynamically linked to DecisionSite, which means that changes to the data being explored in any of the other views cannot be updated interactively in ArcExplorer. Nevertheless, their coupling was expected to provide sufficient functionality for investigating spatial data.

² Only the first three are shown in Figure 0.2 as they were the Query Devices demonstrated and used by participants in the study.

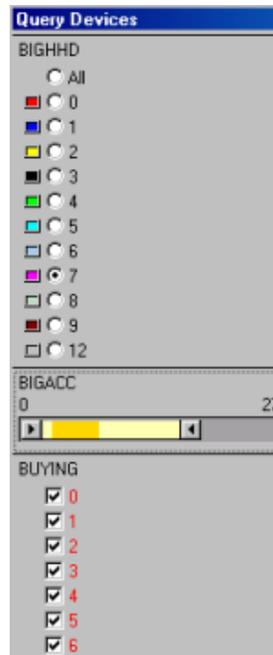


Figure 0.2 Query Devices. From top to bottom: Radio Buttons, Range Sliders and Check Buttons

1.2 Usability Study

1.2.1 Goals

This study set out to evaluate whether the functionality provided by DecisionSite Map IS served to enhance Spotfire's visualization software for the purpose of analysing and exploring spatial data. Ultimately, the aim was also to identify potential areas of research and development for enhancing visualization systems and hence the process of visual and interactive data exploration for (spatial) data users.

The main concern for carrying out this test came from thinking about the necessary and sufficient characteristics that software for visual spatial data analysis should provide. Two main approaches have been taken so far. The first has been implementing the coupling between Geographical Information Systems (GIS) and Exploratory Spatial Data Analysis (ESDA) systems for extending GIS functionality (see Anselin (1998) for a review) which include interactive visualization packages in the spirit of DecisionSite. The link between these systems has been achieved by a combination of loose and close couplings between them where objects are written to intermediate files, commands are called between them or routines are written in a system's macro or scripting language. Depending on the type of coupling, disadvantages of this approach have included: i) the limited size of the datasets that can be used; ii) inefficient algorithms being implemented due to the differences in data structures

between systems; or iii) slow execution not allowing real-time dynamic interaction because of the form of the communication between systems.

A second approach has been the development of systems supporting the visual analysis of spatially referenced data such as CDV (Dykes, 1997), Descartes (Andrienko and Andrienko, 1999) and GeoVISTA Studio (<http://www.geovista.psu.edu/>). The first two examples are designed for exploring lattice data and not intended to communicate or provide a visualization environment that can add—at least interactively—to GIS functionality. GeoVISTA Studio is an open software development environment that allows users to build applications for geocomputation and geographic visualization. This solution, however, is under development and is intended to provide an experimental environment to build up systems and “seek deeper understanding of the kinds of tools required for effective knowledge construction” (Takatsuka and Gahegan, in press).

DecisionSite provides an alternative approach by coupling ArcExplorer, a lightweight GIS data viewer developed by ESRI, where data can be transferred back and forth by the user from one component to the other. The transfer from DecisionSite to Map IS is in the form of image files that plot the location of selected observations in DecisionSite onto the map according to their geographical coordinates. This form of communication does not provide a real-time dynamic link between the two components nor does it take advantage of the GIS standard display and query functionality. A serious limitation of this approach is that ArcExplorer is a data browsing software, not a development tool, and is therefore non-customisable. Hence, the test was to find out whether the available functionality suffices for enabling DecisionSite as a spatial decision-making environment.

To summarise, this evaluation had two main goals: assessing the coupling of ArcExplorer and DecisionSite for the specific purposes aforementioned as well as the identification of potential problems with the current implementation (Dix, *et al.*, 1998). To test this, particular attention was given to the users' performance with the system in terms of the 'correctness' of the information they obtained on each task. The test was designed to allow participants to obtain knowledge about trends in the data and relations between attributes, as well as to detect outliers and mistakes. It was not expected from participants to follow a strict series of steps to solve the tasks, but rather allow them to use the software as a means to learn about the data and satisfy their queries. Findings from this test, such as whether participants were able to complete the tasks and whether the available functionality supported their needs, are expected to illuminate further inspection of usability problems as well as software development for providing necessary functionality.

1.2.2 Participants

Ideally, profiles of “the actual and potential users of the product [are developed] long before the time for a usability test” (Dumas and Redish, 1999: 120). This test was performed on an enhancement (the integration of Map IS to DecisionSite) of an available product (DecisionSite) but no previous usability tests, surveys or interviews were available to define user profiles. The main strategy to overcome this difficulty was working with one of Spotfire’s usability engineers to understand the aims of providing Map IS as an add-on to the core software and prepare a user profile to select the participants for this preliminary test.

With Map IS, DecisionSite aimed to accommodate the requirements from a wide range of industries that “range from oil and gas professionals who need to determine the potential for finding oil, to retail analysts who need to identify the ideal site for a new store, or to pharmaceutical executives who need to measure sales territory performance or analyze clinical trial results” (<http://www.spotfire.com/products/mapper.asp>). Hence, software coupling was intended to enhance DecisionSite’s decision-making environment to include applications with a geographical component where variables or attributes of interest could be potentially located in space.

Although the system’s users may not be GIS experts, they would be exploring spatial or GIS data. Participants for this study were therefore chosen from the GIS industry and academia, as well as from other professions that share the characteristic of using geographical data regularly. They were expected to have experience with interacting with spatial data on-screen and with systems that rely heavily on the use of graphics to provide context to data manipulation. This selection would control for users that had to learn first about spatial data and rather concentrate on how providing limited GIS functionality can enhance the process of visual data exploration and spatial decision-making using powerful visualization software tools and functionality.

It could be argued that the selected participants were experienced users in terms of using spatial data and GIS, and might perhaps even be too experienced to detect basic problems for non-expert users. However, the main concern of this test was whether the available functionality provides an improved spatial context for visual data analysis of georeferenced information. Detecting other problems, for instance particular issues of interface design or the understanding of spatial data, was not the aim of this study. However, it can be mentioned at this point that even some of these so-called experienced users had difficulties in

understanding not only the connection and data transfer between DecisionSite and Map IS but also the data they were investigating in the two components simultaneously. It can be argued that if spatial data experts had these problems, less knowledgeable users are likely to have them as well.

The number of participants was also carefully considered. Nine participants who fulfilled the profile described above (plus two more who participated in the pilot studies) were invited and took part in the test. This number of people was considered appropriate to give sufficient evidence and depth to the study based on evidence found in previous tests: “Nielsen and Molich (1990) found that not quite half of all major usability problems were detected with three participants. Virzi (1992) found that 80% of the usability problems in a product were detected with between 4 and 5 participants and 90% were detected with 10 participants. In addition, all of the global problems in the product he tested were detected with 10 participants. Additional participants were less and less likely to reveal new information” (Dumas and Redish, 1999: 127). The number of people was also restricted to the likely minimum necessary to obtain significant results because only one person was to conduct the test and its analysis.

Table 0.1 Summary of goals, benefits and foreseen costs (Dumas and Redish, 1999).

User group	Tasks goals	Benefits	Costs
GIS users and users with knowledge of spatial datasets	To find whether Map IS enhances DecisionSite capabilities by facilitating the exploration of spatial data. To understand users' mental model of interactive visualization.	To explore spatial data visually, provide spatial context and GIS-like functionality. To improve design by incorporating functionality that facilitates users' process of visual data exploration.	Time to learn to use the system in terms of understanding how to use the visualization tools provided.

Summing up, the flexibility and effectiveness of the visualization software for exploring spatial data was the centre of the test (see Table 0.1 for a summary). DecisionSite Map IS to be tested had been recently released (July 2001) so the test (performed during September 2001) was designed for a fully operational system. The test, however, was designed to support a further research interest: refining understanding of how users explore spatial data visually to illuminate further product testing and serve as a guide for designing functionality in visualization packages that promote insight and information about large georeferenced datasets.

1.2.3 Test Design

The usability study was designed to test a limited set of functionality, as has been previously described, and to take about an hour of each participant's time. It was also planned to be executed during a three-week time span which included two pilot tests plus nine other participants. During the first week, two initial pilot tests were done in order to refine the tasks that the nine users would perform, as well as to detect any possible problems with the test environment, software and hardware required to hold and record the sessions. Furthermore, since the whole experiment was aimed at testing the benefits of MapIS, the two pilot tests were aimed at revealing obvious user interface problems or mistakes so participants would not waste time because of them on later sessions. The following two weeks were allocated for users to select a convenient time to do the test. Only one test per day possible due to limitations of resources. Each session was recorded using Matchware's ScreenCorder (<http://www.matchware.net/>), a software tool for recording users' on-screen actions and comments throughout the task. A post-test interview was carried out and recorded straight after each test (see Table 0.2 for a summary of these resources). Each one of these steps was recorded in a log as well as the decisions taken for each of the planning activities and the test itself and greatly informed the preparation of this chapter.

Table 0.2 Summary of Test's Resources

Time	1 hour 15 minutes per test
Hardware	1 PC connected to the internet Dictaphone
Software and data files	Spotfire DecisionSite and Map IS ScreenCorder Shapefiles (map and attribute data) Excel file with data subset
Instructions	Detecting relations, outliers and mistakes Choosing candidate locations

1.2.4 Invitation to Participate and Motivation

Prior to undertaking the usability test described below, users were emailed an invitation to participate. The invitation included: i) a brief description of the system they were going to be using and why their participation was relevant; ii) where the test was going to be held and how it was going to be structured (demonstration, recorded test and taped interview); iii) the duration of the test (about one hour and a quarter); and iv) the purpose of the test and its academic interest or potential benefit as a session on methods of visual data analysis. This last point was very important in this case as users were recruited through networking and their gain from participating was learning about a new piece of software and a powerful way of performing spatial data exploration.

Once users had confirmed their participation, they were given a short description of the dataset as shown in Table 0.3. The purpose of this description was two-fold: it provided users with information about the dataset they would explore and also aimed at motivating them to perform the tasks thoroughly by apprising them of the particular characteristics of the dataset. Careful consideration was given as to whether users should have *a priori* information about the dataset and how this would affect their performance and results. Was this appropriate if the test was aimed at evaluating whether DecisionSite Map IS provided a visual and interactive environment to understand and further form hypothesis about relations between spatial variables? Three arguments can explain the decision to provide this information. First, data users normally approach a dataset with a purpose. Be it decision-making, research, confirmation of hypotheses or exploration, investigating a dataset follows from posing a question or aiming to obtain some information. Hence, providing a description about the data was not seen as impeding the discovery process but rather as a means to motivate users to explore it in depth. Second, the information given was mostly descriptive and included a discussion on the relevance and interest of the dataset for participants who were expected to have some knowledge of sources of spatial data in the UK. Finally, there was a concern with limiting the time users will spend in the test to about an hour as all users were gathered from the GIS industry or academia and were expected to have very limited time. Providing a description of the dataset beforehand was expected to allow them to concentrate on learning to use the software and solving the tasks during the test.

1.2.5 The Tasks

On the day of the test, users were given a pre-test briefing aimed at demonstrating the system's functionality. None of the participants had used the software before so the system's demonstration was aimed at allowing them to learn and get comfortable with the functionality that was going to be tested. Also, any general questions about the dataset were discussed beforehand to ensure participants understood, at least theoretically, the dataset they would encounter.

**Table 0.3 Data definition and guideline sent previously to users
Lifestyles and Census SAS datasets**

Lifestyle databases contain individual-level data (or household data) about consumer habits and behaviours. They have been predominantly used for direct marketing, and are mostly obtained from responses to postal consumer surveys or questionnaires. Each survey usually consists of a few hundred questions on varied “lifestyles” topics ranging from income and occupation to shopping habits, holiday and travel preferences. These datasets are generally very diverse and frequently concatenated from disparate data sources using a common field, the residential address, to form a profile of individual households.

However, the lifestyles datasets have various limitations. For instance, since the data are collected for marketing purposes, answers to each question must be chosen from a set of pre-defined responses that are not suitable for all types of analysis. Also, there is no obligation to complete the questionnaires. Hence, the respondents are self-selecting and constitute a non-random sampling of the population (Harris, 1998). These limitations make lifestyles data “fundamentally more biased and unscientific” (Longley, 1998). Why then use this dataset as opposed to the more traditional and widely used UK Census of population? Without entering in the discussion of the limitations of the Census data, two reasons make the Lifestyles data an interesting option: 1) they are updated every year (as opposed to once every ten years as in the case of the Census data), and 2) they contain direct questions on income which the Census lacks. Hence, the Lifestyles increased geographic coverage, detail and periodicity offer an alternative source of information that can challenge the traditional use of Census-based geodemographic data both for marketing applications and academic research.

The dataset you will be exploring contains an Income Score variable (Y) derived from a Lifestyles dataset and a set of variables chosen from the 1991 Census’ Small Area Statistics (SAS). Hence, the data are aggregated to the Enumeration District (ED) level since that is the finest spatial resolution for publicly available Census data. Therefore, Y is an average score for each ED, where the average is across the ‘respondent’ households in that ED. The SAS variables are expressed as a percentage of households enumerated by the Census in each ED. Y ranges from 0-10 (where each score corresponds to an income band) and SAS data range from 0-100.

You will be looking at 19 variables available for 844 EDs in Bristol. Briefly, the variables are:

Bigacc:	% Households with 7+ rooms
Bighhld:	% Households with 6+ persons
Buying:	% Households in owner-occupied property buying it
Bought:	% Households in owner-occupied property, bought outright
Childn:	% Persons aged 5-14
Youths:	% Persons aged 15-24
Yngadl:	% Persons aged 25-44
Oldadl:	% Persons aged 45-64
Oldpsn:	% Persons aged 65-74
Council:	% Households in council or new town rented property
Detached:	% Unshared dwellings detached
Terrce:	% Unshared dwellings terraced
Hhnoca:	% Households with no car
Hhtcar:	% Households with 2 cars
Qualm:	% Adult, male residents qualified
Wkwife:	% Married females working
Y:	Income score variable
Unfrnt:	% Households in unfurnished rented property
Unemp:	% Economically active unemployed

HARRIS, R. J. (1999), *Geodemographics and the Analysis of Urban Lifestyles*, PhD Thesis, School of Geographical Sciences, University of Bristol, 383.

LONGLEY, P. A. (1998), "Foundations," in P. A. Longley, S. M. Brooks, and R. McDonnell (eds) *Geocomputation: A Primer*, Chichester: John Wiley and Sons, 3-15.

“One of the essential requirements of every usability test is that the test participants attempt tasks that users of the product will want to do with it” (Dumas and Redish, 1999: 160). This implies a very careful design of the tasks to be performed, especially since the time available for testing was very limited. The test had two parts (see Table 0.4). The first part (Task 1) was deliberately ill-defined so as to leave room for users to explore the dataset at will. Some guidelines or ‘information to look for’ was provided only to limit the time users were to spend on the first part of the test to about 20 minutes. However, there was no unique answer to the problem and the interest was more on analysing how participants interacted with the system and used the visualization tools to obtain information from a dataset that had a familiar spatial element yet unknown information. Nevertheless, in terms of accuracy, it was expected that users would be able to obtain information that led them to discover ‘correct’ relations between variables as well as outliers or potential mistakes in the dataset. For instance, users had to be able to interpret that the ‘Income score’ variable was positively correlated to ‘Hhtcar’ (percentage of households with two cars) and furthermore the location of such correlation in space, if it existed.

Table 0.4 Tasks

Task 1

1. Find whether variables in this dataset are related in some way and whether their relations occur in any particular areas of Bristol.
2. Can you detect ‘outliers’ (unusual combinations of attribute values)?
3. Can you detect possible mistakes in the dataset entries?

Task 2

4. Having explored the data, can you choose candidate locations for (please take note of the polygon ID):
 - a) A secondary school
 - b) A gourmet shop
-

The second part (Task 2) was aimed at testing whether the software did provide an environment suitable for decision-making or problem solving of a task with a spatial component. They implied identifying candidate locations that would be potentially suitable for an activity. Since visualization tools are not intended to be confirmatory in nature but rather to enable the gathering of information and hypotheses, it was expected that users would select candidate locations in certain areas of Bristol but no single answer was correct or had to be achieved. The interest here was on how users would define a set of criteria to make a decision with the data provided and whether the system easily enabled this process. Table 0.5 summarises the two tasks and their aims.

Table 0.5 Tasks aims and description. Adapted from Dumas and Redish, 1999: 177.

Task 1	
Concern	Testing whether the present form in which Map IS and DecisionSite are coupled helps users to acquire information about or insight into a spatial dataset.
Test Setup	Users were asked to use all the demoed visualizations.
Task Description	Finding relations between variables and their location in space. Detecting outliers and/or mistakes in the dataset.
Task 2	
Concern	Detecting whether there were usability problems with the interaction between Map IS and DecisionSite for the purpose of supporting spatial data exploration.
Test Setup	Users were asked to choose locations.
Task Description	Deciding for a candidate location(s) for a school and a gourmet shop.

1.3 Results

This section discusses some of the participants' experiences with the software based on their interaction with the system and a post-test discussion. Their comments point towards functionality and features that either aid in the investigation of complex spatial datasets or hinder the visual exploration process. Even though the usability test was carried out for a specific piece of software, general lessons on necessary and sufficient functionality for exploring spatial data were obtained. Dix *et al.* (1998: 407) suggest that:

“In addition to evaluating the system design in terms of its functional capabilities it is important to be able to measure the impact of the design on the user. This includes considering aspects such as how easy the system is to learn, its usability and the user’s attitude to it. In addition, it is important to identify areas of the design which overload the user in some way, perhaps by requiring an excessive amount of information to be remembered.”

Since visual data exploration tools rely so heavily on the user for the exploration process to be successful, issues of usability are of prime importance not only to evaluate the fitness of purpose of a particular system but, more generally, to identify elements that can enhance the effectiveness of these environments for analysing spatial data. Although this is the first of a series of tests aimed at finding sufficient evidence to make these claims, initial results are described next.

1.3.1 Positive User Feedback

Although most participants (seven out of nine) were not familiar with visualization packages, they quickly recognized the benefits of investigating an unknown spatial dataset interactively. Users found the filtering of the data using the Query Devices previously described in section 1.1, together with the possibility of seeing the results on a map, to be the most innovative and salient functionality. Query Devices allow the rapid selection of attribute ranges with characteristics of interest. Hence, they control the scope (Goldstein and Roth, 1994) or the amount of data the user wishes to view. The SQL queries they perform give users feedback

from the displays within a few tenths of a second (Ahlberg and Shneiderman, 1994), while effectively hiding the actual query from the users and allowing them to concentrate on the exploration. This is so effectively achieved that at least one user did not perceive he was doing an SQL query when interacting with the Query Devices: *“You do not need to build the query by yourself”* (User 2). Combined with GIS functionality, these graphic devices were perceived as powerful tools that enabled users to focus on subsets of data and quickly find relevant information: *“You can find [spatial] relationships very directly using the map and the sliders”* (User 1).

The Query Devices can therefore be said to be easy to use;³ interactive (in terms of their response to user action);⁴ and effective in terms of ‘unloading’ information from the users’ minds. In this case, they are relieved from the whole task of performing complex SQL queries on the dataset to explore pockets of interesting records. Both for expert and novice users, this task is far from trivial and can be time consuming. Put in the words of one participant, *“Filtering is the best [tool in the system] because you can immediately take away the data you are not interested in”* (User 4). This points towards the importance of allowing users to easily concentrate on subsets of information to discover facts and hypothesise about attribute relations.

A second feature, increasingly common in Windows based software, is manipulating available views from a single Properties Dialog Window. This feature was perceived by users as an advantage, especially over doing the same operations with menus: *“You don’t have to go to look in menus to find what you want to do, which I think is really good because menus are only good when you remember where things are”* (User 3). Its use was rapidly learned and preferred in some cases to doing changes directly to a view. For instance, when adding, deleting or changing the order of a number of axes in a parallel coordinate plot, the Properties Dialog Window was preferred by users as a rapid means to introduce a number of changes.

Visualization systems are expected to be highly interactive in terms of allowing graphic displays to conform to users’ needs. Manipulating views can be time consuming when many are explored simultaneously or a large number of variables are considered. Hence, a crucial design issue is whether interactivity is enabled as ‘direct’ screen interaction or whether other strategies could be provided that may save the user time. However, facilitating the use and

³ For further evidence on the usability of Dynamic Query Filters see Ahlberg and Shneiderman (1994a).

⁴ Up to about 8,000 records, when response time begins to slow down.

understanding of the information provided by the visualization should be the central consideration.

Table 0.6 Users' frequently liked features		
Advantages	Frequency	User Comments
Ease of learning the product	8/9	<i>"The graphics capabilities resemble S+" (User 6); "Similar things I've seen before in Data Desk" (User 4); "Looks like Excel" (User 5).</i>
Ease of using the product	8/9	<i>"It is really quick and very effective" (User 4).</i>
Interaction between Map IS and DecisionSite	7/9	<i>"The ability to dynamically select points and to be able to see them on the map I think is very useful, because generally otherwise [...] you really have to juggle between applications to do that" (User7)</i>
Ease of using/understanding the Scatterplot	9/9	<i>"The Scatterplot is probably the most useful [tool] for finding relationships. It is also the one I'm most familiar with [...] It shows outliers and it shows not only the relationship but the strength of the relationship at the same time" (User 4).</i>
Ease of using/understanding the Profile Chart	4/9	<i>"It first looked like it was just loads of lines but once you learn how to use it, it was probably the most useful" (User 1); "It's quite a useful graph as you have more variables" (User 7).</i>
Ease of using/understanding Line Chart	4/9	<i>"Looks like Excel so it's very easy to get used to" (User 6).</i>
Ease of using/understanding the Properties Dialog Window	8/9	<i>"All I need to control the look of the windows is right here" (User 8).</i>
Ease of using/understanding the Query Devices	7/9	<i>"Filtering is the best [tool] because you can immediately take away the data you are not interested in" (User 4).</i>

For this purpose, usability guidelines may aid in the design of the view or interface. Using a common metaphor (Preece, 1993) can be a simple solution. For example, graphic displays in DecisionSite such as scatterplots and line charts were comparable, from the point of view of users, to similar functionality in other more familiar systems (see user comments about ease of learning the product, the scatterplot and the line chart in Table 0.6). Hence, by analogy, they were quickly able to use the various data visualizations. Where this is not possible, for instance because existing metaphors are not appropriate for the functionality of the system or display, tasks should be kept as simple as possible and "each function and the method of operating it [should] be apparent" (Raskin, 2000, 63). Properties Dialog Windows as a means to control visualizations is a good example. Although they are becoming common, at the time of the test at least seven out of nine participants had not used them before. Nevertheless, the

comment in Table 0.6 about their use shows that they can easily reveal to a user all the possible changes that can be performed on a single view.

1.3.2 Sources of User Frustration

The main downsides of the interaction between DecisionSite and ArcExplorer for users familiar with spatial data were: i) not being able to brush (or dynamically link) the map view with the rest of the visualizations in DecisionSite; ii) not being able to update data in the GIS as data selection changes in DecisionSite; and iii) not being able to spatially explore the attributes of data plotted into ArcExplorer. Solving these limitations could translate in a more seamless integration between the systems where the GIS can appear to the user as a tool for visual spatial data analysis.

Dynamic linking or highlighting is an effective way of relating information provided by the re-expression of data in various views. Technically, it is also simpler. However, ArcExplorer is a data viewer and may not allow this type of customisation. Coping with the second disadvantage—for instance filtering data in and out in a GIS as Query Devices are used in DecisionSite—is also a means of relating information of a set of visualizations from the same dataset. This, however, is not possible using ArcExplorer. In the existing implementation, however, if a new data selection is made in DecisionSite and the user wishes to see it in ArcExplorer, a command (button) must be used to transfer the information across. Similarly, if data is selected in ArcExplorer, it must be transferred as a *new* dataset if the selection is to be seen in the visualization software. Not surprisingly, users found having to load their queries back and forth between the systems to be problematic at least in two ways. On the one hand, it was difficult for users to recognise they were investigating the same information in views representing different aspects of the data: the attribute values in DecisionSite vs. their spatial arrangement and distribution in the GIS. On the other, the constant transferring of data was a heavy burden to the users and inhibited the exploration process by frequently making them loose track of the initial idea they were investigating. As a user explained, *“You tend to think of things on the fly and if you don’t satisfy your query within a couple of seconds you lose interest and go on to something else especially when you have such a huge data set”* (User 4).

The third disadvantage relates and adds to the previous discussion. Data needs to be transferred from DecisionSite into ArcExplorer to find the spatial distribution of attribute data selected in the visualization software. However, this transfer occurs in the form of an image layer plotted into ArcExplorer with the points. Relating the information in the two

visualizations was made more difficult in this case because data on DecisionSite was in point form representing the centroids of enumeration districts (ED) in Bristol, while that on ArcExplorer showed the EDs as areal representations (see Figure 0.1): *“I found it very difficult to relate the data points spatially from the data [visualizations] to the map”* (User 1). Also, an image does not allow users to inspect the properties or attribute values of the points as it is possible to do with other layers loaded into the GIS. Furthermore, users could not revert to previous queries plotted in Map IS unless they were saved as image files, which would not permit any further interaction with the recorded scenario. This was seen as a further constraint in the exploration process, as users wanted to compare queries to evaluate their hypothesis. Nevertheless, this problem could be potentially solved by addressing the first limitation and enabling real interaction between the visualizations in DecisionSite and the map. If a user touches a point in DecisionSite and a polygon or area (or any corresponding feature represented on the map) is highlighted in the GIS simultaneously, the relation between the two data representations and the two system modules would be straightforward.

An available alternative at present is loading the map as an image into DecisionSite. This requires the use of a scatterplot in which axes are fixed to Latitude (x axis) and Longitude (y axis). In this way, the map can provide a further visual aid to finding relations between attribute values, as any other visualizations used simultaneously in DecisionSite would be dynamically linked to this ‘map’ view. This approach, however, excludes any possibility of manipulating and interacting with mapped data and obtaining information about the dataset from spatial analysis.

In summary, MapIS is intended to permit “users to visualize and interact with [GIS] data within the Spotfire DecisionSite environment” (<http://www.spotfire.com/products/mapper.asp>). However, in the opinion of one of the respondents, Map IS *“allows you to visualize results spatially but is not enabled to really act as a further tool for exploration”* (User 7) in the sense that queries plotted in the form of points from DecisionSite onto Map IS cannot be further transformed or their attribute values inspected. Although users found their way around this by using other views to obtain the information they needed, this was cumbersome and inhibited the exploration process. Users found themselves tangled in searching for information plotted on MapIS and were frequently diverted from their train of thought or original idea.

Table 0.7 summarises these problems from the perspective of users, the frequency with which test participants reported the same problem, and excerpts from their comments to exemplify

their views. They mostly prompt from the current coupling between two systems that aims at enhancing visualization software to support spatial data exploration when it is not originally planned to do so. Section **Error! Reference source not found.** discusses some usability problems related to the particular visualization system used in this case study but that point towards general issues that should be avoided to facilitate user interaction.

Table 0.7 Users' frequent problems

Problems	Frequency	User Comments
Map IS/DecisionSite Link: Trying to select points on map	7/9	<i>"Brushing would be very useful now because I selected 5 points and plotted them on the map but now I want to know where they are on this scatterplot".</i>
Expecting dynamic link between Map IS and DecisionSite	7/9	<i>"The software is not good at relating spatial information. It is good at relating trends between datasets".</i>
Use of the map as exploration tool	7/9	<i>"You don't really use the map to find things".</i>
Viewing previous queries	7/9	<i>"I would like to have more interaction with the map, because if I need to find an area where there are certain characteristics, I would like to perhaps choose [some points first], then I would like to display them on the map, and then select some of them or then perhaps investigate the selection that I've done from the map. So, a kind of two step investigation, forth and back, which I would find a lot easier".</i>
Using/understanding the Query Devices	7/9	<i>"I didn't really remember I could filter". "I need to move all the sliders to get rid of these points, right?"</i>

1.4 Internal User Models

Apart from identifying limitations in the linking of two systems that could potentially enhance the exploration of spatial data, the purpose of this study was also to comprehend how users investigate (georeferenced) information by formulating a model that can explain how the process evolves. Spence (2001a) suggests that visual investigation of data implies a four stage cycle (Figure 0.3) that loops as many times as users deem necessary. In such a process, users look at data displayed in a view searching for content or some recognisable pattern. The user must then remember this information and attempt to build an internal model with which to interpret the data. If the observed information can be explained by the cognitive model, users must decide where to look next in order either to test it with other data or refine it. Otherwise,

if the internal model has to be modified they must decide where to look next to find information that may aid in its improvement.

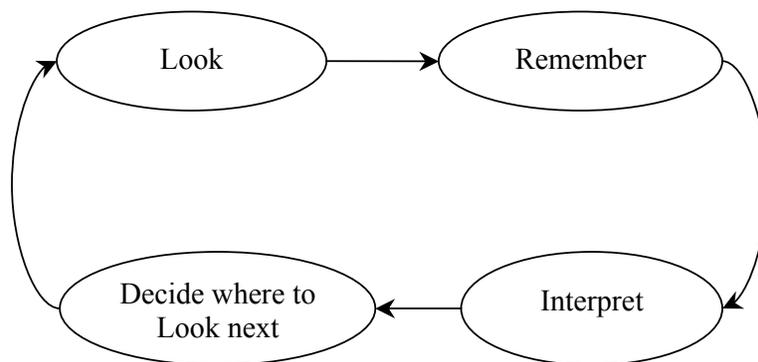


Figure 0.3 Visualization Process (Spence, 2001a)

Figure 0.4 builds upon the basic model in Figure 0.3 to include the actions that users are likely to perform to explore a dataset visually and hence must be supported by the system. Users' exploration of the information starts by browsing through it to look for content that can prompt ideas. Users must then gather more information and evidence to support their hypotheses. In a visualization system, this is done by re-expressing data in various forms or views that help to explain their meaning. With the gathered information and the formulated ideas, users can interpret the data and evaluate their initial propositions. If necessary, they can then amend or completely discard their initial hypotheses and continue looping through these steps until they are satisfied with the information they obtain.

However, the loop in Figure 0.4 would not always occur so smoothly. For example, at least one user out of the nine who took the test was unable to obtain any ideas or form any hypothesis from browsing through and inspecting data on-screen. This user could not see the benefit of having a certain number of tools to re-express and investigate the data and hence was unable to use the package to her advantage. This may suggest that investigating data visually is not necessarily as simple as is frequently implied. Although humans might be good at visual pattern recognition, in a software system they have to understand views where information has been encoded according to some criteria. Decoding such information from graphic displays not only depends on the appropriateness of a particular view for the type of data portrayed, but may also entail training the user. For instance, all participants had initial difficulties understanding the information provided by a Profile Chart as they had not used one before. Once explained, at least three out of the nine participants found it to be the most useful tool for exploring multi-dimensional data. Hence, the sole manipulation of the visualization cannot always hint at the information it can provide.

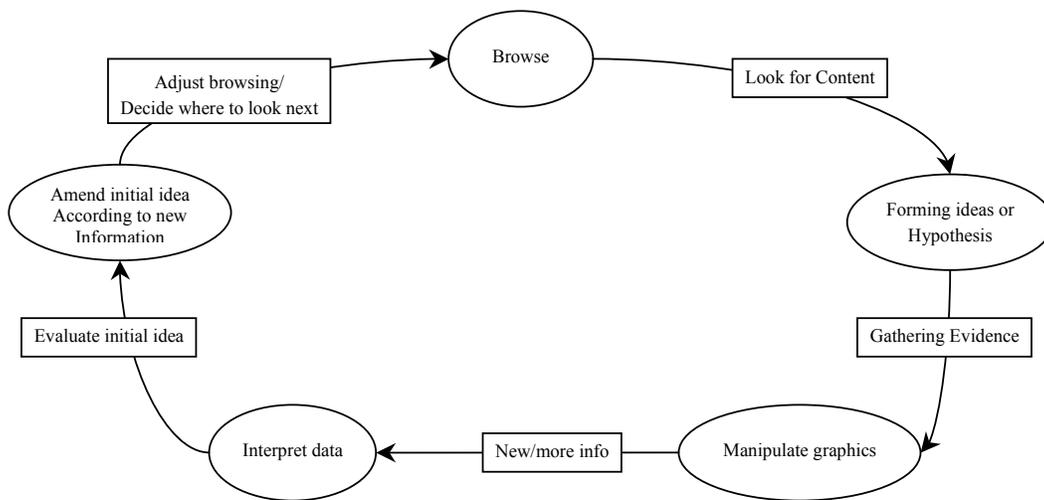


Figure 0.4 Visualization Process (2)

It was also often the case that users went a few times around the loop without out any suggestion that they had obtained any insight into the data. Even if the visualization system aimed at providing an environment for exploring data and not necessarily for confirming results, users were reluctant to advance hypotheses until they had some certainty about their feasibility. This might be a by-product of users feeling that they were being tested and hence had to perform to some standard. For instance, users were more prone to ask questions or ‘think aloud’ during the second test task (see Table 0.4) when they were more familiar both with the dataset and the available graphical displays.

Finally, the diagram in Figure 0.4 may suggest that the visual exploration process occurs in a systematic fashion where users incrementally improve their understanding of the dataset as they loop though the cycle. However, users often investigated data or relations that caught their attention and were far from methodical in their exploration. Only three out of the nine participants seemed to explore information systematically—for instance trying as many combinations of variables in a scatterplot as time permitted—and test their ideas against alternative hypotheses. However, at different points in the exploration process they went though the steps in Figure 0.4 and were able to obtain rich insights following various routes.

Figure 0.5 illustrates two-way relations in the loop that may better describe individual ways of forming hypotheses. It shows how users can go backwards and forwards between steps before proceeding to higher levels of abstraction. Furthermore, it shows how some steps are skipped in some cases. For example, as users gained familiarity with the dataset and the use of the

struggle initially to understand the meaning of some of the visualizations and especially with the link to the GIS. Usability studies can enhance the understanding of the problems and advantages of a system's functionality and suggest ways of improving features to facilitate their learning. This appears to be crucial in visualization systems where results depend greatly on the users' interaction with the software.

It is clear from this first usability study that much can be done to provide a better integration of packages for this purpose. Integration of DecisionSite to ArcGIS and ArcIMS is the next step in this research project as a means to investigate the benefits of providing a better link to a GIS and support other spatial analysis functionality. Hopefully these exercises will provide stronger evidence on the benefits of using visualization techniques for spatial data exploration than is available to date. More importantly, the aim is to formulate a typology of visualization tools that are efficient for this purpose.

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