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Guidelines for Best Practice in User Interface for GIS

Section 3 “Overview of user-centred design of GIS user interfaces”

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3. Overview of user-centred design of GIS user interfaces

This section explains the state-of-the-art of user-centred design, existing principles, methods and results. The relevance of the user-centred design approach for GIS development and customisation is pointed out and recommendations how to apply user-centred design in GIS projects is provided. The main focus is on illustrating how GIS end-users and customers can proactively participate in GIS development and customisation in order to receive the most appropriate GIS application for their work objectives.

3.1 Introduction to user-centred design

In the last 15 years a mature professional practice has emerged which supports the development process of interactive software systems. It is based on the assumption that the success of new products depends on the efficiency and effectiveness of steering product development by user and customer feedback. User-Centred Design (UCD), a philosophy which places the user of a system at the centre of the development process, is the means to success. The UCD approach represents techniques, processes, methods, and procedures for designing usable systems for the prospective users (Gould & Lewis 1985, Norman 1986, Preece et al 1994, Rubin 1994, ISO 13407,1997).

GIS development is different compared to other software development processes. GIS user interfaces are so complex that in order to be usable they must be tailored to specific user needs. This customisation process - which is to a large extent user interface design¹ - is either performed by GIS vendors and suppliers, by experts offering customisation services, or by the end-users themselves. Personnel with different background and expertise (geographic information domain experts, GIS experts, end-users, and other) are involved in customisation.

In these guidelines the term "design" refers to the process of developing and customising a GIS and to the various GIS representations that are produced during the design process. User interface designers must be able to elicit and understand the requirements of GIS end-users, and to communicate these requirements to other experts in the GIS development or customisation team. Selecting suitable representations for requirements and design specifications is important for exploring, testing, recording and communicating design ideas and decisions with other experts from the development and customisation team as well as with end-users and customers. Identifying user requirements involves communication between designers and GIS end-users/customers. This is one goal of UCD.

Visualisation, especially of GI data, is a highly interactive and iterative task where the user modifies parameters and observes the effects on the screen. The ease of this interaction between the end user and the GIS is crucial in determining the success or failure of the system (Medyckyj-Scott 1994). Usability evaluation can tell how well the GIS supports user tasks. Therefore user validation, i.e. the evaluation by end-users, of GIS user interface designs, prototypes, and GIS products which are in use, and the investigation of user satisfaction with a GIS is another aim of UCD.

The major principles of user-centred design are:

- focus on end-users
- iterative design
- appropriate allocation of functions between end-user and GIS
- multidisciplinary design team.

¹ The user interface is that part of the system which is visible to the end-user: input/output components and the dialogue between the user and the GIS.

3.1.1 Focus on end-users

End-users can contribute a lot to GIS user interface design (during the GIS customisation as well as development) by providing information about:

- their knowledge of the geographic information task domain
- their prior experiences with GIS applications which they have used / are currently using
- their work objectives and responsibilities, tasks, and workflows
- the activities to perform tasks with a traditional method or using an existing GIS
- their work environment
- their subjective requirements for GIS applications.

Users can be either actively or passively involved in GIS user interface design. Passive user involvement is the case where users simply state their needs and requirements. Actively involved users participate in the design process by helping with the design of the GIS user interface or by creating the user interface designs themselves. Any user involvement will increase the likelihood of user satisfaction with the final GIS, of commitment and acceptance.

The degree of user involvement will to a large extent depend on the phase in the GIS development process. Regarding the use of GIS which are currently available on the market it is the customisation process where end-users should be actively involved. Companies and organisations procuring a GIS should proactively influence the design of the GIS user interface as the customisation process emerges. Alternative solutions of GIS user interfaces should be designed, tested and evaluated in cooperation with real end-users who will actually be working with the customised GIS.

The provision of user feedback about GIS use to GIS developers is an invaluable source for GIS evolution and for the development of new GIS.

GIS development should begin focusing on end-users early in the development process. Because the characteristics of the GIS user population vary considerably it is essential to involve representative users from all different user groups in the GIS development process, in order to take into account their varying needs and requirements.

3.1.2 Iterative Design

It is commonly accepted today that the quality of technology products is mainly a function of the number of completed 'design / test & evaluation / redesign' cycles. Testing is essential to the development and customisation process. The value of quantitative evaluation and the assessment of benefits and advantages which users will derive from GIS use is considerable. Usability Engineering and Human Computer Interaction disciplines provide various methods for efficient and effective evaluation. However, user testing and gathering user feedback is only useful, when it is taken into account for the improvement of GIS user interfaces. Two to three design iterations in a specific GIS development/customisation process are highly recommended.

Figure 1: The quality of a GIS user interface is mainly a function of the number of completed 'design / test & evaluation / redesign' cycles

Iterative design, whereby a GIS user interface design is improved repeatedly helps to shape the user interface according to user needs. It allows preliminary and alternative design solutions to be tested against real world scenarios, i.e. a realistic set of tasks the prospective end-users intend to perform with the GIS application.

The quality of GIS user interfaces will depend to a large extent on the effort (manpower and time) invested in the development process and the efficiency (use of experience and best practice) of development procedures. Iterative design if applied early in this process will help to avoid design errors and failures. This will speed up development so that new GIS can enter the market earlier, and the effort of customisation may be reduced.

Iterative design during GIS customisation will assure that the GIS application does not need further adaptations when the GIS is in use in order to optimise work procedures and to fulfil user requirements.

To conclude, the result of iterative design will be GIS of higher quality for the end-users. These GIS will reduce maintenance costs for the developers and customisers, and will have an extended lifetime. In the long term user-centred design will improve user satisfaction with GIS,

the quality image of the GIS developer and of organisations which customise GIS applications.

3.1.3 Appropriate allocation of functions between end-user and GIS

To some extent GIS user interface design will be concerned with the allocation of functions between the GIS and the user. GI tasks cannot always be fulfilled using a single GIS function. More often a procedure, i.e. a sequence of GIS functions, must be executed. It may be advantageous for end-users if GIS functions can be hidden behind macros for task execution which relate better to the end-users' knowledge and capabilities. It must be specified which functions shall be carried out by the GIS application and which by the end-users. This task is performed taking into account limited human information processing capabilities (Card, Moran and Newell 1983) and limited performance of technology in terms of reliability, speed, accuracy, flexibility of response, cost, importance of successful or timely accomplishment of tasks etc.

3.1.4 Multidisciplinary design team

GIS user interface design requires a variety of skills: substantial knowledge of the geographic information domain, expertise of GIS technology and user interface design skills. Representatives of all stakeholders, i.e. persons with an interest in GIS use and the results produced with a GIS application, should be involved in GIS user interface development and customisation: end-users, their managers, purchasers, trainers, etc. Such a multidisciplinary design team does not have to be large. It is only required that members of the user-centred design team represent all the relevant different roles and skills.

3.2 The role of end-users in user-centred design of GIS user interfaces

The GIS market potential is enormous, but the usability of GIS technology is still poor. Badly designed GIS user interfaces can be used only after considerable training, a solution which is not feasible from an economic point of view. A known problem of trained GIS users is that learning transfer to new GIS is low and causes problems. To obtain a wide diffusion of GIS technology its use must be efficient and effective for GIS end-users.

GIS user interfaces should be designed such that they fulfil user requirements instead of adapting the end-user to a GIS.

Although many GIS are customised through the use of macro programming, the user interfaces are often not found easier to use by the end-users compared to using the 'off-the-shelf' GIS version. End-users find it difficult to adjust the user interface to their preferences.

A prerequisite for GIS development and customisation therefore is the complete and precise knowledge of the user requirements. That is why end-users must be actively involved in the identification of their requirements. If the GIS customisation is carried out by the developer, supplier, or an external expert the customer and the end-users must communicate their requirements to an external customisation team. Even if the customisation process is performed in-house, e.g. by end-users themselves it must be based on explicitly stated requirements.

User requirements are the criteria against which the quality of a GIS is tested.

Quality of use (synonymously used for usability) is one aspect of the total GIS quality. It must be defined, measured, and developed in the same way as other, e.g. technical and economical, quality aspects. Quality of use is a multi-dimensional concept including aspects such as efficiency and effectiveness of use, learning effort, robustness, subjective user satisfaction of the GIS application.

Rather than just a GIS application which is easy to use, the customer in a competitive situation chooses that product which offers the best cost/benefit result to the end-users tasks and requirements. GIS applications with low quality of use are neither efficient nor effective to use and are therefore costly for the customer. The customer bases his/her decision on an estimate of highest utility, including quality aspects, from quantifiable cost aspects to subjective

factors and attitudes of the end-users. Measuring quality of use of competing GIS (benchmarking) is the precondition for an effective purchase strategy for the customer.

For the developers and customisers low quality GIS can cause high cost for error correction and support and therefore represent failed investments. In order to avoid costly market failures later, quality of use should be tested during the development and customisation process.

To conclude, the short-term perspective of end-users should be to help improving the GIS customisation processes by precisely stating user requirements. However, a major constraint for the customisation of GIS applications will always be the existing GIS on the market. Therefore, the long-term perspective must be to improve GIS development itself.

3.2.1 GIS end-users and other stakeholders

The community of GIS end-users is extremely diverse ranging from Geographic Information domain experts to general public users (with little GI knowledge) who are assumed to use Geographic Information much more frequently in the future. There are end-users with very specific knowledge of GIS technology and others without any GIS knowledge. Cases can be observed where GIS technology is accessed by GIS experts who perform tasks 'to order' for end-users not being able to use the GIS application themselves. Some users use the system regularly others use it only occasionally.

End-users can be distinguished with respect to their responsibility to perform tasks of varying complexity with a GIS (the figures in brackets give an estimate of the distribution of end-users in companies and organisations amongst the three categories of tasks):

- visualise geographic information (100)
- analyse geographic information (10)
- set up and maintain GI databases (1).

The utility of a GIS application within a company or an organisation can be greatly enhanced when separate staff is appointed to tasks which require the use of different subsets of GIS functions. The GIS user interface can then be tailored to specific user categories and will almost certainly be much easier for the end-users to learn compared to the user interface delivered with the package. The tailored user interface will cut down end-user training cost. This is why knowledge about the end-users and their tasks is so important for GIS customisation and development.

Another aspect needs consideration. End-users having hands-on experience with GIS applications are often not the customers, who make a purchase decision and buy a GIS. Both roles - end-user and customer - may be played by one and the same person in a small company, but in large companies this is unlikely. Requirements of these two groups and other stakeholders, i.e. users who don't use the GIS themselves but the output of GIS work, must be taken into account. It is essential to assure that the end-users are involved in the planning and selection of the most appropriate GIS.

3.2.2 Planning GIS purchase and customisation

The customer should plan a GIS purchase including customisation in cooperation with end-users and other stakeholders. This phase is in many respects very important.

The goals for purchase and customisation planning are:

- to describe end-user needs and requirements, including tasks and workflows in order to identify typical usage scenarios
- to compare GIS with respect to usage scenarios
- to estimate the cost / benefit of using alternative GIS
- to select the optimal system from a set of GIS offered by competing developers
- to set up a plan for user-centred GIS customisation.

Figure 2: GIS purchase and customisation planning

3.2.2.1 User requirements analysis

User requirements elicitation and analysis is the most crucial part. The success of UCD in GIS customisation will depend on how complete and precise user requirements can be specified.

The most important user requirements for a GIS are the identification of the adequate functionality to be provided by the GIS user interface. A prerequisite for efficient and effective performance of tasks with a GIS is that the GIS user interface neither provides more nor less functions needed by the end-users.

User requirements should be described in terms of measurable quality factors and criteria, i.e. values the quality measures shall assume. Quality factors are for example efficiency and effectiveness of task performance, learning and training effort, reliability, safety, performance, acceptance and user satisfaction, in addition to robustness. The following illustrates some examples of precise user requirements descriptions: "The GIS must provide simulation results within less than 15 minutes", "End-users must be able to learn how to use the basic functions within a week", "Input of data sets must be 30 % faster compared with the GIS currently in use", "Visualisation of GI must be 50 % faster compare with the GIS currently in use and 99 % reliable", etc.

For the identification of user requirements the user perspective must be considered. Three aspects need to be considered:

- The definition of GIS functions required by the user. To achieve this the user must describe the information and data required to fulfil Geographic Information tasks, access modes to this information, transactions, modifications of data, and visualisation of information. These functional requirements are derived from the results of a task and workflow analysis.
- The description of the context of use, i.e. when, where, how, and by whom the GIS

will be used, can be performed using checklists.

- The specification of non-functional requirements, such as cost constraints, subjective preferences and others should be derived by elaborating the results of this planning phase.

Valuable information about informal approaches to user needs and requirements analysis including task analysis are given by Kirwan & Ainsworth (1992). Practical checklists are provided in the RESPECT User Requirements Framework Handbook (1997).

Task and Workflow Analysis

Task and Workflow Analysis should include the overall work responsibility of a user, goals to achieve, tasks the user intends to perform in order to achieve objectives, and activities. To understand the functional requirements for GIS, particular attention must be paid to the analysis of the tasks the user intends to perform with the new GIS. The distinction between tasks and activities is crucial:

- Activities describe command sequences a user performs with a GIS in order to achieve a task or a goal. It will be misleading to transfer activities relating to existing GIS applications to new GIS applications. For example, new and more efficient methods for visualisation of the same data may be available with new GIS, and will induce very different user activities.
- Tasks describe the goals the user wants to achieve with as little reference as possible to the detailed technical realisation of the GIS. The description of tasks should be as independent as possible from existing GIS.

Understanding the tasks involves understanding and abstraction of why the user performs certain activities and what his constraints and preferences are. It involves how the user would make tradeoffs between different GIS, for example the goals he would like to achieve, provided new technology gives him the opportunity to do this comfortably and efficiently.

Consider a tradeoff between waiting time and cost: for a user working in the environmental domain producing information just-in-time may be essential. This user may accept paying a lot for a GIS which provides automatic procedures and results in a short time interval, e.g. minutes. A user working in the urban planning domain may not be confronted with time pressure and can cope with waiting several hours or even longer in order to obtain the same information. Important tradeoffs may occur between the quality of Geographic Information versus larger user effort to access and process the information, and higher learning effort to acquire more sophisticated access methods.

Task analysis is mostly done in the form of a hierarchical description of main tasks which are then separated into several levels of subtasks. Knowledge about the frequency of tasks as well as about task sequences and order, workflow and communication between users will help to optimise GIS functionality. For example tasks which are executed frequently should be easier to perform compared to tasks which are only performed a few times in the GIS life cycle.

Appropriate task and workflow analysis and the sound understanding of the user's tradeoffs and preferences are the best guide towards good solutions for the functional specification of the GIS, and the success of the resulting GIS user interface.

Performing task and workflow analysis is not easy and can be tedious. It may be accomplished through direct observation of end-users, interviews, analysis of the thinking aloud protocols of end-users performing tasks, questionnaires, or by obtaining performance measurements of current GIS usage, e.g. to detect the frequency in which subtasks are performed and the number of errors made with the currently used GIS.

Description of the context of use

Compared with task and workflow analysis, the identification and description of the work

context in which the GIS will be used is an easy task. A variety of checklists are available for this purpose. The idea is to describe when, where, how, and by whom the GIS will be used. This includes the description of the already available technical environment or platforms (hardware, software, telecommunication networks, and other materials), physical environment (workplace, lighting and noise conditions), the ambience in terms of temperature and humidity, and legal issues and standards to be taken into account. A description of the organisational structure and work practices as well as social and cultural issues may give hints about interrelationships between users and their work.

3.2.2.2 Benchmarking: The comparison of GIS applications

Benchmarking of existing GIS competing for the same users is important when planning GIS purchase and customisation. The principle of benchmarking is to measure and compare performance parameters, strengths and weaknesses of currently available GIS with respect to the previously identified user requirements. When a GIS application is already in use it may be sufficient to compare only those GIS representing major competition for the GIS application in use. The benchmarking results will provide the basis for making a purchase decision.

Benchmarking is important, but may often be too costly. For the future, the potential for sharing the cost of such activities amongst organisations applying GIS should be investigated.

The information provided in sections 6 and 7 of these guidelines is intended to provide background information for benchmarking. Section 6 contains an overview of specific technological features of GIS user interfaces, section 7 provides recommendations for the best use of GIS functions. This information is supposed to help the mapping of user requirements determined with the techniques described in sections 4 and 5 into more technology oriented requirements to establish a basis for comparing different GIS.

3.2.2.3 Cost / Benefit assessment of GIS use

Although end-user needs are the most important requirements there may be additional, e.g. organisational, economic and other requirements from a customer's viewpoint which must be fulfilled by a GIS application. It should be checked if customer requirements are in conflict with and define constraints for user requirements. Such a situation requires a reasonable conflict solution. Section 9 describes the most relevant cost and benefit factors to be taken into account from the point of view of the organisation who purchases a GIS.

Having followed the steps described above a well planned and deliberate purchase decision can be made. Now the customisation plan should be set up including iterations of:

- GIS user interface design for the various end-user groups identified
- user validation, i.e. testing the designs with real end-users representing all the different end-user groups
- improving the user interface if necessary until the stated user requirements are fulfilled.

3.3 User-centred design in the GIS development process and during the customisation of GIS applications

3.3.1 User and customer orientation

The degree of end-user and customer involvement in GIS development and customisation is a very important factor. Managers sometimes take the view that end-user involvement is not necessary assuming they know what the end-users want. Even when this is true, a resulting system, developed without user consultation, can be seen by the users as something imposed from above, resulting in a poor or even zero level of acceptance. Users should be involved from the start and their feedback must be actively sought at every stage in GIS development and customisation.

A major problem is that very often users cannot state how they want the user interface to look, however, they are very capable of saying whether a user interface is acceptable or not. **Therefore customisation and development strategies should be based on step-by-step releases to ensure delivery of appropriate functionality. End-users must be provided with the chance to interact with prototypes and influence the design of the next stage. Expensive failures will largely be avoided this way.**

3.3.2 End-user involvement

Usability engineering provides a sufficient number of methods (described in section 3.4) to support GIS development and customisation in an iterative fashion. The cycle is based on user interface design specifications, if possible throw-away prototypes, and the execution of a number of 'design / test and evaluate / redesign' cycles. The quality from the user point of view will improve as a function of the number of executions of the design cycle, but of course each cycle costs time and effort. The effort for testing with the involvement of users must be in an appropriate relation to the total effort for the GIS development process or the customisation of a GIS.

User validation during GIS customisation and when the GIS is in use

The goal of customisation is to tailor the GIS user interface to specific user groups, tasks and workflows. The main objective of testing during customisation is therefore to detect shortcomings in the allocation of functionality and user interface design deficiencies which may lead to inefficient and ineffective use of the GIS and to an increase of the workload for the user. The effect of testing and redesign of the GIS user interface on further customisation and need for testing must be taken into account: Design modifications should always be verified by making sure that they do indeed improve the resulting quality of the GIS user interface.

It will be most effective when end-users and the customisation team have direct contact, so that the problems of end-users can be observed. User tests should be performed with real end-users and focus on typical task scenarios the end-users intend to perform with the GIS application.

Empirical performance measurements (e.g. time to learn how to use GIS functions, time to perform tasks, errors) of using the customised GIS in situations which are comparable to real use is important to assess efficiency and effectiveness.

Conformance to the EC Directive on the minimum health and safety requirements for work with display screen equipment (90/270/EEC) should be tested as part of an acceptance test by the end-user and customer. Section 8 provides a checklist for this purpose. The "ISO 9241 evaluator" (developed by Oppermann & Reitere, (1997) is another, however much more comprehensive tool, for conformance testing of ISO 9241 standards.

Even a user interface which is optimal from an objective point of view, may not frequently be used because the end-users do not like it. Subjective user satisfaction and attitude towards a

GIS application can be measured with standardised user satisfaction questionnaires (e.g. SUMI and QUIS questionnaires).

End-users will need some time learning how to use the GIS application and their performance will improve the more often they use the GIS. After the GIS has been in use for some time it is reasonable to measure end-user performance to check if there is potential for further optimisation and additional GIS customisation.

User validation during GIS development

The goal of testing during GIS development is to recognise user problems and design deficiencies or shortcomings, and to support design, rather than to present precise quantitative data.

In an early first cycle, 'quick & dirty' and cheap tests are often adequate to find the serious user problems and design deficiencies. More thorough tests should follow when the interface design advances. It is important to include the need for redesign as a consequence of testing in the planning of development effort.

The effect of testing and redesign on both the design and further need for testing must be taken into account. Design modifications should always be verified by making sure that they do indeed improve the resulting quality of the system.

It will be most effective when the developers, especially user interface designers, have direct contact with real end-users and when they can observe as directly as possible the problems of users (for example in the form of clips on video tape). **However, performing the testing procedures should always be in the hands of persons independent of the design team. When user tests are performed, make sure that real end-users are involved in the tests, not their managers and not GIS experts! The focus should be on end-user needs and not on technical questions!**

Appropriate methods early in the design cycle are inspection methods such as heuristic evaluation (Nielsen 1993). A much more costly and elaborate method, but appropriate for GIS development projects which are usually large projects, are 'usability lab' tests (Nielsen 1994) including video recording, thinking aloud protocols, and cognitive walkthroughs of user behaviour. The aim of these tests are to recognise important episodes of the user.

Checking the use of standards and design guidelines where available should be performed during development. Standards have advantages for the user, they require less learning for known functions. The advantages for the developer are lower risk and less effort. There are also corresponding disadvantages: standard applications are uniform, less differentiated, and cannot be tuned so closely to the application and the user tasks.

Conformance to standards such as the EC Directive on the minimum health and safety requirements for work with display screen equipment (90/270/EEC) should be tested during development. However, it should be taken into account that such standards can only define minimum requirements for user quality. Therefore tests designed to verify conformance to standards do mostly not represent a means to fulfil the requirements for adequate end-user involvement.

3.4 Appropriate methods for GIS user interface evaluation

This section gives an overview of methods for user interface evaluation. The methods are organised according to the phase in the GIS life cycle where it is appropriate to apply them. References to detailed information about each of the methods are provided.

Phases in GIS development and customisation	Requirements specification	Design and Prototyping	Development	Customisation	GIS in use
Methods					
Informal approaches:					
(Structured) Interview	x				
Questionnaire	x				
GIS requirements checklist (section 5)	x				
Task and Workflow Analysis	x	x		x	x
Focus Group	x	x		x	x
Thinking Aloud	x				
Inspection method:					
Heuristic Evaluation		x		x	
Performance tests:					
Measurements of "time to learn", "time to perform task", "number of errors", "time for error recovery"			x	x	x
DRUM (Diagnostic Recorder for Usability Measurement)			x	x	x
Cognitive workload questionnaires:					
SMEQ			x	x	x
NASA TLX			x	x	x
Checklists for user interface quality:					
Ravden & Johnson checklist			x	x	x
EC dir. 90/270 checklist (section 8)			x	x	x
ISO 9241 evaluator			x	x	x
Questionnaires for the valuation of subjective factors:					
SUMI				x	x
QUIS				x	x

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