Guidelines for Managing Complex Scenarios for Optimization of Infrastructure Transformations

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Abstract. Infrastructure transformation strategies in rural areas are influenced by a lot of diverse aspects such as climatic or demographic changes. The optimization of these strategies is based on scenarios, which are basically containers holding input data. This paper presents recommendations for the design of a scenario assistant system to generate complex, but complete, valid and consistent scenarios in an intuitive and simple way for experts and non-experts in the water supply and waste water disposal domain. Requirements were collected in several workshops with domain experts and end users. The concept recommendations have been derived to improve and speed up the development process of future scenario management assistants.

Keywords: Scenario generation · Usability · Design guidelines

1 Introduction

In many rural areas, the population and settlement structure will drastically change over the next decades. Not only the natural mortality rate combined with the low birth rate has led to a population decrease, but more and more people will move from the rural areas to the cities. Among other aspects such as climate change, changes in law and individual water demands, this will lead to many problems concerning functionality of the water and waste water infrastructure in most rural regions.

To tackle the questions of how to transform the infrastructure in rural areas, the German Federal Ministry of Education and Research (BMBF) funded the project SinOptiKom where a transformation optimization and decision support system has been developed based on a stakeholder analysis [5] across multiple sectors (sanitary environmental engineering, spatial and environmental planning, computer science, and mathematical optimization). Complex relations and a high number of parameters define different scenarios, the system then provides optimized transformation strategies and an analysis tool [3]. Defining and generation as well as managing these scenarios is challenging. Therefore, a scenario generation assistant has been developed. Depending on the target group, different basic design decisions influence the usability of the scenario generation tool. Therefore, a meaningful application of design principles can improve the efficiency, effectiveness and the user satisfaction.

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In the paper at hand, we describe the requirements on the design of the developed scenario generation assistant. Our contribution are the concept design recommendations for complex scenario management applications based on various design and simplicity guidelines.

2 Related Work

2.1 Design Guidelines

The user work flow in a tool is heavily influenced by its design [20]. Maeda defines ten laws of simplicity in 2006 [9] which serve as guidelines for the development and evaluation of tools since their publication [11]. Lemberger and Morel [10] describe the value of simplicity in information systems and propose best practices for designing those systems. However, there are limits of simplicity. At some point of simplification, there is not enough content left for the users to understand labels, title, charts, etc. in the same way as the creator intended to express [12]. Therefore, an appropriate balance of simplicity and complexity is needed, as also stated by Maeda's 5th law "Differences" [9]. This balance becomes an important challenge in the management of complex scenarios.

Further, following the Gestalt principles by Wertheimer [17, 18], the organization of elements has a large impact on the user's perception. The perception directly influences the performance as well as the size of and distance between interactive objects which is defined by Fitt's law [15]. MacKenzie and Ware extended Fitt's law to include lag in interactive systems [16].

Different devices such as desktop PCs or tablets have different display sizes and resolutions. Therefore, design guidelines for responsive design [13, 14] have been developed. Particularly, the use of touch-based devices needs special adaptations [19].

2.2 Scenario Definition

Following Heinecke and Schwager [1], scenarios describe alternative, plausible and consistent images of the future which consist of logical and internally correct assumptions or descriptions of development paths of possible future situations based on present structures leading to these images of the future. In contrast to simple forecasts, a scenario does not provide any information about probabilities. Therefore, it is important to develop scenarios systematically and comprehensible.

In this paper, we apply the following definition: a scenario defines a collection of assumptions for different drivers and a set of basic parameters. It includes the complete description of all aspects and information that are necessary to start potentially following processes: in our case, the optimization and the visualization of the results and the water infrastructure as well.

2.3 Transformation Support

The planning of infrastructure transformations and its supporting is a big challenge. Different approaches already exist, from integrated dynamic visualization in geographical information systems (GIS) [6] to combination of GIS and cellular automata theory [7] to model urban growth. The tool described by Kulawiak et al. [8] aims to support in different domains, infrastructure vulnerability assessment, diminish risks and strategic planning of city development. These approaches are focusing on cities where many aspects significantly differ from conditions in rural areas which has been focused in our project. Furthermore, the preparation of scenarios and the analysis part is integrated and cannot be used independently.

In the paper at hand, we present requirements, concept design recommendations and a use case of a scenario generation assistant.

3 Requirements

In the following section, basic requirements based on expert feedback are presented. Scenario generation and management tools in technical domains (e.g. environmental engineering) have to deal with various requirements. Most of the time, complex scenarios cover different domains, hence, multiple experts and stakeholders exist. To gather the requirements of a scenario generation tool, multiple workshops with many stakeholders from the waste water domain, including experts and end users, were conducted. Based on their feedback, we concluded the following needs which can be transferred to other domains.

Scalability: Obviously, different stakeholders belong to different user groups: e.g. starting from a local village major who wants to have an overview, mostly cares about costs and acceptance to the experts who are interested in and focused on technical details such as diameter of sewers or flow rates. Designing a tool which has to fulfill the needs of all user groups is very challenging. Therefore, the scalability across different user groups is crucial.

Another basic requirement that results from different user groups is the platform and device independence. The users use different systems (Windows, Linux, MacOS) and different devices(stationary desktop environment vs. mobile devices) at work. The use of tablets was rated as an important aspect which requires an adapted graphical user interface (GUI) design to provide scalability across devices.

Simplification: The complexity of the scenarios cannot be managed in its entirety at once. Instead, a separation in multiple smaller parts is needed where each part deals with a few aspects of the whole scenario. This multi-part management should lead the user through the scenario generation and management process.

Further, some kind of additional help functionality should always be available to guide the user in his current task. This is essential since most of the time the user is not an expert in all necessary domains.

Background Activity: In complex scenario definitions, and it is not unusual that many aspects influence each other, resulting in many internal data links and dependencies.

Hence, some configurations that are made by the user in the one part of the scenario may restrict options and configurations of other parts. This basically requires internal decision trees in the background so that an option is not selectable anymore. Otherwise, incorrect combinations might occur in the final scenario definition and further steps are more complicated or impossible.

File Management: Depending on its complexity, it might be very time consuming to define and generate a complete scenario. Thus, users might pause their work and continue later. To simplify and secure this process, one need a possibility to save the current state of the generation process and load it later to continue working. This should also enable a duplication of already defined scenarios to create similar and comparable scenarios by manipulating only a few configurations instead of starting from scratch.

Further feedback and requirements were directly related to environmental engineering domain. However, the presented requirements can similarly occur in other domains.

4 Concept

The following section focuses on the derived concept based on the above-mentioned requirements and taking into account related design guidelines and principles.

Platform and Device: Concerning the platform and device independence, important aspects have to be considered. While the platform independence is given by an adequate selection of development environment and programming language, the device independence leads to other challenges. Example: small hyperlinks in text passages can be clicked quite well in desktop environments using mouse and laptops with touchpad. However, in touch screen-based settings such as tablets, these links are hard to get. Here, at least larger text or alternative UI-elements like buttons are usually used nowadays to provide easier, more comfortable and mobile-device-adapted input possibilities. Furthermore, guidelines of responsive design propose grid based layouts amongst others. Structuring the contents that way, the display space can be efficiently used across different display sizes and resolutions.

Step-by-step: Based on the requirements for simplification, the scenario generation is split in multiple parts. To fully define a scenario, the user has to configure parameters and give inputs, a step-by-step workflow supports the user to not forget any part. To visualize the workflow, we recommend a progress bar consisting of single elements (one for each part) which can be enriched with additional details providing information, e.g. categorical names. Color-coding the progress bar elements assists the user to identify finished parts or parts that require input. Furthermore, the progress bar elements can directly be linked to the corresponding parts which simplifies the navigation.

Appearance of Options: Each part of the scenario is presented in one view. For the design within one view, Maeda's second law "Organize" [9] and the Gestalt laws [18] lead to a similar appearance which should be consistent across the application based on the above-mentioned grid layout. This is true as well for the presentation of options (settings which the user can select). Grid layout based and large UI-elements for the available options makes the system appear simpler. Large elements and short distances between the elements have another advantage: following Fitt's law [15], these two aspects positively influence the usability.

Following Maeda's first law "Reduce", the presented options should not be completely filled with information. Although more information about various options is available, it is recommended to reduce the content to few meaningful components such as short significant title, short description, and potentially a meaningful icon, image, or a chart.

In addition, so called "quick-access-options", i.e. predefined configurations, usually save a lot of time. These quick-access-options have to be prepared and defined by domain experts of the corresponding scenario part. It can be guaranteed that the selected option is internally consistent while the user does not need to care about the detailed parameters, instead he can select one of these options. As stated by Maeda's third law "Time", "savings in time feel like simplicity" [9] and hence, reduce the subjective complexity. However, it is essential to provide an additional option for individual input in case the proposed predefined quick-access-options do not represent the user's needs.

On-screen Help: Help functionality can be implemented in many different ways. The simplest way is to provide a manual accessible via menu item. However, an alternative is on-screen help, e.g. for possible next steps. On-screen help in this case means that information is provided directly inside the current application view as overlay text describing single elements. This is similar to the layer management in geographical information systems: the basic layer shows the map, a second layer overlays street names, city names, etc. While shading the GUI except the described elements the user's focus is guided towards them.

Hidden Calculation: As stated in the requirements section, usually a lot of background knowledge is necessary to calculate influences between different options by traversing decision trees. The user is not interested in the calculation process, so this complexity should be hidden in background activities (following again Maeda's first law "Reduce"). However, the user is interested in the outcome of those algorithms. Consequently, excluded options have to be displayed as disabled option but not hidden at all. Maeda's law "Differences" supports this: find a balance between simplicity and complexity. Hence, show that there are more options but not available in the current configuration of the scenario.

The presented concepts are generalizable and not restricted to the domain of water supply and waste water disposal infrastructure. They are easily transferrable to other similar assistant tools in other domains. In the following section, we present an application use case of a real-world project where we applied our concepts.

5 Application Use Case: Waste Water Infrastructure Planning

The research project SinOptiKom has been funded by BMBF in the context of "smart and multifunctional infrastructural systems for sustainable water supply, sanitation and storm water management" (INIS) and tackles the optimization of transformation processes of infrastructures in rural areas, focusing on water and waste water system. Future climatic, demographic or economic developments require adaptations to guarantee water supply and waste water disposal in the future. The intention has been to provide a software-based optimization and decision support system in which different possible futures can be optimized, analyzed, and derived for implementation in practice.

The system includes three main software modules: a scenario generation, a mathematical multi-criteria optimization [4], and a visual analysis tool [2]. The second module requires a formal description of the scenario which has to be optimized. The scenario generation module provides a tool to set key parameters (e.g. start and end year of the given period for the optimization, rainfall forecasts, water demand forecasts, or selection of available transformation measures) and weight criterions for mathematical objective functions such as water balance, costs, and recycling.

The optimization model is based on integer linear programming (ILP). Technical functional limits are analyzed and adaptation measures and transformation strategies are calculated, e.g. for sewers, shear stress and corrosion determine a functional limit for under-utilization [2, 4]. If the optimization locates values falling under this limit, in present or future supposed states of the sewer system, actions such as decreasing of sewer diameter are proposed.

Once the optimization has finished, the visual analysis tool loads the results and provides different views including a map-based visualization and different charts to support the analysis of the resulting transformation strategy [3].

Implementation: The implementation of the scenario generation assistant followed the concept recommendations which we derived from the requirements. In this section, we present our exemplary application of the concept and the resulting graphical user interface (GUI).

The tool has been implemented in Java 8 using JavaFX for building the GUI. Hence, the scenario assistant is platform independent and can be used on desktop PCs as well as on tablets (e.g. Microsoft surface). The layout of our tool is grid based (Fig. 1) and therefore offers a responsive design.

The concept of the step-by-step workflow has been applied so that the user is able to navigate through the different categories of the generation process back and forth. A progress bar was placed above the content of the current category and, as can be seen in Fig. 1, a color-coding has been applied to indicate the state of the category. A category can have one out of four possible states: *unseen*, *current*, *in work*, *ready*. The *unseen*-state (grey) simply means that this category has not been opened yet. As soon as the user sees a category the first time, its state is *in work* (yellow). This means that the user has opened this category at least once, but there are still some parameters to adjust or set. *Ready* (green) indicates that the corresponding category is complete,

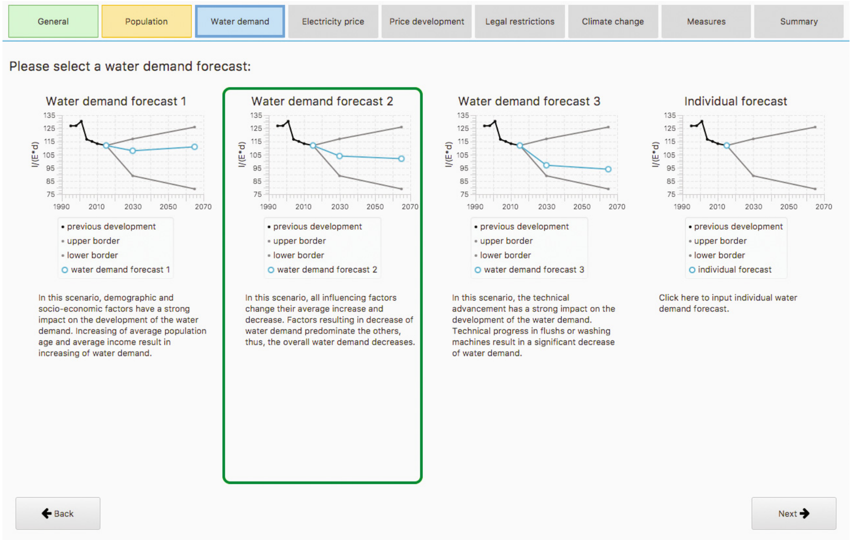

Fig. 1. Screenshot of the water demand selection.

i.e. all input fields are filled, required selections are made, and so on. Finally, the *current*-state (blue) marks a category which is currently open and can be edited by the user.

The screenshot in Fig. 1 shows the step where the user can select a future water demand development. The first three options are quick-access-options and based on real expert analysis, while the forth option offers the possibility to input individual values of water demand for future years. Each option consists of short title, a self-explanatory chart and additional short description. A green frame always indicates the current selection of the user.

The design of the other categories such as population or electricity price has been similar to the example in Fig. 1. Several options are presented in the same style, quick-access-options and additional individual option can be selected. On-screen helping hints and descriptions can be displayed as overlay via menu.

The final scenario generation assistant with its consistent design allowed users to create up to one thousand scenarios in the context of the project. Even though these scenarios are complex, experts, non-experts, and first time users were able to effectively use our tool with no difficulties.

6 Conclusion

In the paper at hand, we presented concept design recommendations for complex scenario generation and management assistants. Based on requirements gathered in workshops together with experts and end users, we conclude concepts such as step-by-step workflow with multiple usable progress bar. They incorporate the Gestalt principles, the laws of simplicity and responsive design guidelines. The application of the concepts in a real-world project context are presented in a use case in environmental engineering domain. Researchers of this domain were able to create different scenarios faster and with less effort. Overall, the presented generalizable concepts can be transferred to scenario management assistants in other domains.

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