



AFRL-AFOSR-JP-TR-2024-0028

Dashboard Design through Data Visualization (D3V) with big data analysis

Jangmee Lee
SAHMYOOK UNIVERSITY INDUSTRY-ACADEMY COOPERATION FOUNDATION
815 HWARANG-RO, NOWON-GU
SEOUL, SEOUL, 01795
KOR

12/12/2023
Final Technical Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory
Air Force Office of Scientific Research
Asian Office of Aerospace Research and Development
Unit 45002, APO AP 96338-5002

REPORT DOCUMENTATION PAGE

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE 20231212		2. REPORT TYPE Final		3. DATES COVERED	
				START DATE 20200925	END DATE 20220923
4. TITLE AND SUBTITLE Dashboard Design through Data Visualization (D3V) with big data analysis					
5a. CONTRACT NUMBER		5b. GRANT NUMBER FA2386-20-1-4046		5c. PROGRAM ELEMENT NUMBER	
5d. PROJECT NUMBER		5e. TASK NUMBER		5f. WORK UNIT NUMBER	
6. AUTHOR(S) Jangmee Lee					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SAHMYOOK UNIVERSITY INDUSTRY-ACADEMY COOPERATION FOUNDATION 815 HWARANG-RO, NOWON-GU SEOUL, SEOUL 01795 KOR					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AOARD UNIT 45002 APO AP 96338-5002			10. SPONSOR/MONITOR'S ACRONYM(S) AFRL/AFOSR IOA		11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-AFOSR-JP-TR-2024-0028
12. DISTRIBUTION/AVAILABILITY STATEMENT A Distribution Unlimited: PB Public Release					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT In the industry, dashboards are widely used to identify and utilize important data. In particular, dashboard design through data visualization is important for utilizing data. In this study, we studied a usability evaluation of dashboards produced through three-dimensional data visualization. Considering the usability evaluation criteria of ISO, We conducted an heuristic evaluation based on Jacob Nielsen's guidelines. What was discovered through this is that 3D-data visualization types are recognized professionally. We also find that 3D data visualization designs, there should be a clear distinction between visual elements such as graphs, colors, etc., and that a consistent scheme should be prioritized regardless of dimension.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT		18. NUMBER OF PAGES
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	SAR		9
19a. NAME OF RESPONSIBLE PERSON TONY KIM					19b. PHONE NUMBER (Include area code) 315-227-7008

Standard Form 298 (Rev.5/2020)
Prescribed by ANSI Std. Z39.18

Abstract

In the industry, dashboards are widely used to identify and utilize important data. In particular, dashboard design through data visualization is important for utilizing data. In this study, we studied a usability evaluation of dashboards produced through three-dimensional data visualization. Considering the usability evaluation criteria of ISO, We conducted an heuristic evaluation based on Jacob Nielsen's guidelines. What was discovered through this is that 3D-data visualization types are recognized professionally. We also find that 3D data visualization designs, there should be a clear distinction between visual elements such as graphs, colors, etc., and that a consistent scheme should be prioritized regardless of dimension.

Introduction

In the big data era, where a large amount of data is pouring out, it will become more important to find and analyze meaningful information. Presenting the vast amount of data that cannot be interpreted properly can become an obstacle to acquiring information from the user's point of view, and eventually, it can result in blocking information. Therefore, it is important to process data that provides users with information and insights at once. As a tool to efficiently grasp information in this background, dashboard design through data visualization(D3V) is being emphasized. In particular, it reminded us of the importance of dashboard design that immediately visualizes the spreading infection information while experiencing the covid-19 pandemic¹.

The dashboard is an information management interface for measuring and monitoring important task. Also, it is a visual expression tool that allows users to recognize the information they want at a glance. This helps increase work efficiency by providing immediate insight to users in situations where data is utilized. In particular, it delivers information realistically and vividly through three-dimensional visualization techniques.

Christa Kelleher² and Nick Cawthon³ stated that the effectiveness of a three-dimensional display is less effective than that of a two-dimensional display. However, this is the result of comparing graphs of different design types, and there is a limitation that it does not compare

¹ M.J.Kim., A Study on the Design Strategy of covid-19 Dashboard by User Evaluation., Journal of the Korean Society of Design Culture., 2021, pp.64-74.

² Kelleher, Wagener., Ten Guidelines for Effective Data Visualization in Specific Publications., Environmental Modeling& software16(2011) , pp.822-827.

³ N. Cawthon, A.V. Moere., The Effect of Aesthetic on the Usability of Data Visualization, International Conference Information Visualization, 2000.

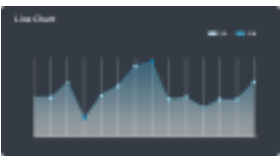

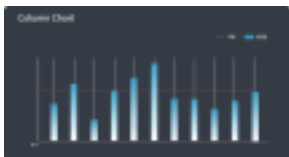
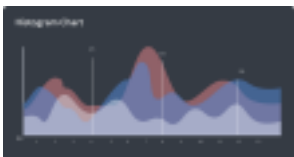
the two-dimensional and three-dimensional usability of the same data and design types. Therefore, in this study, the usability of 2D and 3D visualization types was tested in the same visualization method.

The purpose of this study is not to create a visually beautiful dashboard, but to validate important visual elements in identifying and analyzing information on the dashboard. To this end, design elements for data visualization that help users easily grasp information were derived, and dashboard design was conducted based on this. Finally, through usability evaluation, we tried to analyze how visual factors affect the usability of data analysis efficiency, effectiveness and satisfaction in dashboard design.

2. Methods

2.1. Pilot test

A pilot survey was conducted to derive the aesthetics of data visualization. Real-time production datasets that can be used for data visualization were collected. By aesthetically replacing metadata, 4 data visualizations were performed in the form of bar graphs, line graphs, and distribution 2D graphs. Dataset, color, and typography were applied equally, and dynamic elements were removed in this experiment only for the purpose of deriving visual elements. This was conducted to identify the preferred types of graphs in the same dimension prior to the visualization of 2D and 3D types of data. The visualization types for pilot tests presented under these conditions are as follows [Table 1].

			
Line	Stacked Area	Column	Histogram

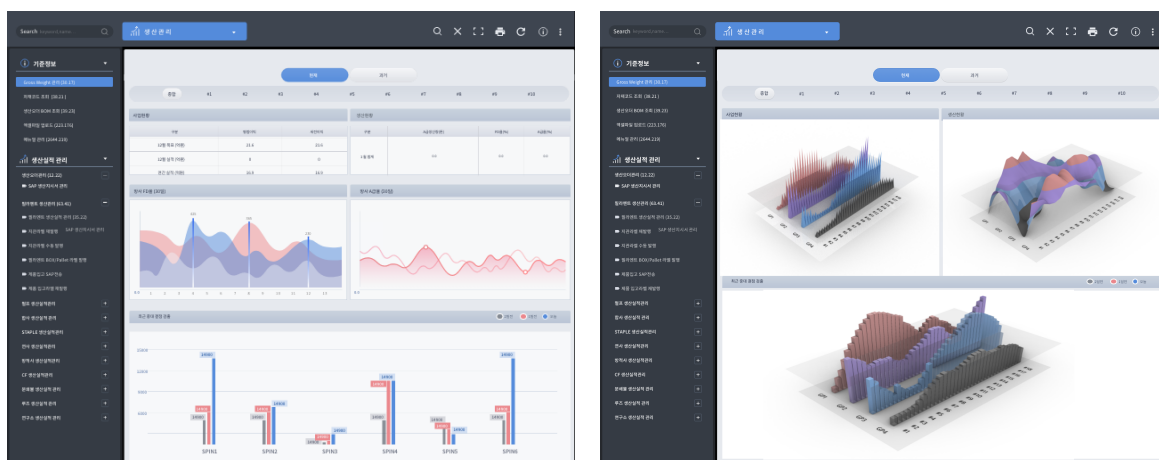
[Table 1] Data Visualization Types

It was requested to check all visual elements recognized by analyzing each data and to check the priority that was considered understandable and usable. The pilot survey was conducted online, and 32 people participated during the week. Answers that were not completed to the end were removed. Participants evaluated how they understood the information and what was visually beautiful through data visualization types.

2.2 Dashboard Design

The design elements derived from the pilot survey were applied to the dashboard design. What participants mentioned as an important factor in dashboard design is four graphic elements: graph shape, layout, color, and typeface. Based on this, the data visualization was produced according to the following criteria.

- **Graph:** The most important visual element of a dashboard is the graph type. The graph is a form of identifying and visualizing the core attributes of data characteristics, which are raw materials. Graphs are represented by various visual elements other than dots, lines, bars, and circles according to purpose of the data. In order to grasp the trend, the flow of sequential information is visualized through line, area and timeline charts. In this study, a graph was created that can analyze comparisons and trends together.
- **Layout:** The dashboard design may be classified into five methods- information, arrangement, size, grouping, and separation. Configuring a layout can help highlight important information or clarify specific purposes.
- **Color:** It is better to use a palette of specified colors than to use many colors. Information should be easily grasped through simple coloration and clear contrast. Dashboards should increase the recognition and visibility of important information because they need to efficiently convey important information in the field.
- **Text:** The most prominent feature of the text is the hierarchical structure. A text arrangement with good readability gives a sense of visual stability when it is visually structured according to importance. In this study, text was unified under the same conditions to focus on visualized images.
-



[Figure 1] Dashboard Design through Data Visualization Prototypes

A dashboard design prototype applying the derived elements was created as shown in [Figure 1]. If the same dataset is reflected, the graph placed later will affect the time of completion and understanding of the task. Therefore, each graph was created with a different dataset. The prototype of dashboard design is made of a web page.

2.3. Measures

2.3.1 Usability

The newly proposed definition of usability by the International Organization for Standardization (ISO 9241-11) is as follows: It is defined as a complex concept that has measurement factors such as whether the customer has properly achieved the desired purpose through interactive product (useful), whether the purpose has been used as conveniently as possible (usable), and how overall satisfaction with use is. Accordingly, it was evaluated as three factors: effectiveness, efficiency, and satisfaction as a measurement tool in accordance with the usability criteria of ISO.⁴

- Effectiveness: It focuses on whether the user has achieved the intended result as it means the accuracy and stability of achieving a specific goal.
- Efficiency: For this, the time it took to finish the work was collected. The required working hours were evaluated.
- Satisfaction: It is a subjective evaluation, and the measure of positive attitude toward the product felt by the user was evaluated.

2.3.2 Heuristic Evaluation

The dashboard design test was conducted using Jakob Nielsen's Heuristic evaluation guidelines. Heuristic evaluation, developed by Jacob Nielsen and Molich (Nielsen and Molich, 1990), was designed to evaluate the usability of interface design. It is a method of evaluating the usability of information in the interaction between humans and computers. The measurement tools used in the evaluation are shown in the following [table 2].

Nielsen's Heuristic Evaluation Checklists	
1. Visibility of system status	What is the current state of the system? What can be done at current state? Where can users go? What change is made after an action?

⁴ <https://www.iso.org/search.html?q=9241-11>

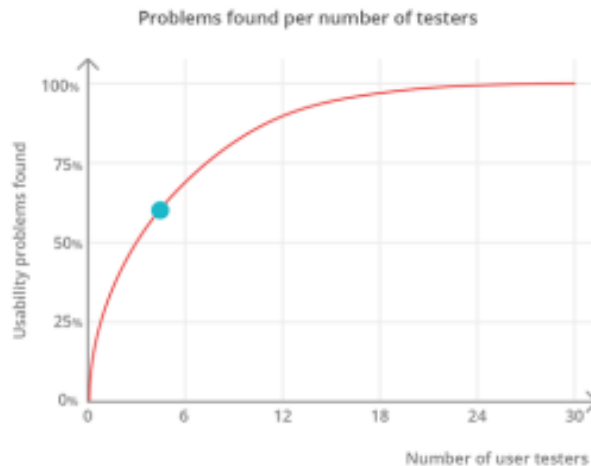
2.Match between system and real world	User model matches system image. Actions provided by the system should match actions performed by users. Objects on the system should match objects of the task.
3.User control and freedom	Users are initiators of actions, not responders to actions. Avoid surprising actions, unexpected outcomes, tedious sequences of actions.
4.Consistency and standards	Sequences of actions (skill acquisition) Color (categorization) Layout and position (spatial consistency) Font, capitalization (levels of organization) Terminology (delete > del, remove > rm) and language (words, phrases) Standards (for unvisited hyperlinks)
5.Error prevention	Interfaces that make errors impossible Avoid modes or use informative feedback Various types of slips and mistakes
6.Recognition rather than recall	Externalize information through visualization Perceptual procedures Hierarchical structure Default values Concrete examples Generic rules and actions
7.Flexibility and efficiency of use	Shortcuts or macros for frequently used operations Skill acquisition through chunking Examples function keys, hot keys, keys, macros, aliases, templates, ahead,
8.Aesthetic and minimalist design	Less is more. Simple is not equivalent to abstract and general. Simple is efficient. Progressive levels of detail. Context-sensitive help
9.Help user recognize, diagnose, and recover from errors	Phrased in clear language, avoid obscure codes Precise, not vague or general Constructive / Polite.
10. Help and Documentation	Context-sensitive help Help embedded in contents.

[Table 2] Jacob Nielsen's Heuristic Evaluation Guidelines

Jacob Nielsen noted that the five-person test alone is enough to detect problems. Heuristic evaluation is desirable for a person who has used the entire process for a product, and usability non-experts can also be used depending on the situation. Also, it was mentioned that if there are more than 5 test people, the problems found no matter how many people are there are are similar.

[Figure 2] Dashboard Design through Data Visualization Prototypes

2.4 Procedure



The heuristic evaluation of D3V was conducted with a design prototype at the working mockup level. Participants evaluated how they understood each information through graph types and visually beautiful. 8 participants tried to evaluate the understandability and learnability of dashboard design. All participants had experience in general digital software analysis, and about the level of analysis experience, 6 answered intermediate and 2 answered advanced. Participants were guided to perform the same task twice.

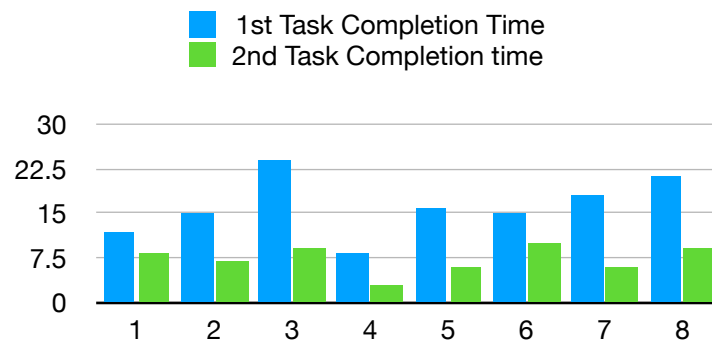
Through observation during the test, problems such as task completion time, the number of errors, the number of requests for help, task abandonment and other matters on the user interface were collected. On average, the test session lasted about 30 minutes, and there was no time limit for the test. In addition, help or intervention was minimized until the participant's request. After the test, an in-depth interview was conducted. This is to obtain in-depth answers to understand participants' behavior patterns and experiences. Participants performed a given task on the web page, analyzing and answering the data on the dashboard. We identified how the collected data influences the user's behavior (decision and situational judgment) based on visual elements.

3. Result

3.1. Usability Result

- **Efficiency:** All recorded tasks were analyzed for usability evaluation of quantitative items. An average execution time of 16.12 seconds was shown to grasp each information and complete the task. Even for first-time users, it is judged that it is designed to be intuitively used according to the service flow without learning. In particular, in the repetitive task, it

was confirmed that the average execution time was 7.25 seconds, which was quickly learned.



- **Efficacy:** An average of 1.75 errors occurred in the process of performing the task, but the usability was evaluated by intuitive judgment without understanding the use description. Major malfunctions and errors were shown as follows. In performing the task, there were results such as errors in finding the input value button, incorrect identification of information, and malfunction of input interface. Some delays occurred depending on each test, but the participants showed a pattern of solving the problem through several attempts. As a learning effect on errors, when the task was repeated, the efficiency was verified through a user experience that was clear enough to eliminate all errors. In addition, all participants performed all tasks, showing a high task performance rate.
- **Satisfaction:** It was found that the participants showed some satisfaction. In particular, different reactions could be confirmed in personal design evaluation. As a positive assessment, they said that the 3D design looks more professional, and they expected that it would be much more efficient after using it a few times, although it may be difficult when using it for the first time because information on the 3 axes can be checked at once. On the other hand, there was an opinion that it was not easily revealed in the three-dimensional part.

3.2 Heuristic Evaluation Result

- **Visibility of system status:** 3D design delivers an intuitive confirmation of the state and information of the system more vividly than 2D. The statistics that need to be checked at a glance are clearly divided and can be easily found through the screen. However, information placed in the front and information on outliers (high points or low points) can be found quickly, but in the case of information placed in the back, it is difficult to check the graph without rotating due to optical illusion.
- **Match between system and real world:** There was an opinion that 3D allowed the spatial layout of the site to be reflected as if it were real, and for the graphs presented in the

experiment, it was easy to understand because it was a three-dimensional version of the existing 2D graph type.

- User control and freedom: Dashboards in the production process are used for identifying and analyzing operational situations. In other words, dealing with emergencies immediately is a key factor. By placing the user control interface on the dashboard, user control may be strengthened.
- Consistency and standards: Color categorization has been well achieved, and in the case of dashboards, lowering the possibility of arbitrary interpretation with a simple configuration is a key factor in design.
- Error prevention: Using colors, information such as temperature may prevent malfunction in advance. It did not provide shortcuts or keys for repetitive actions, but it was not a problem due to the low complexity of the task.
- Recognition rather than recall: After grasping the operation method once, in the case of repetitive tasks, it was found that there was a learning effect, such as more than doubling the speed.
- Flexibility and efficiency of use: Major malfunctions and errors resulted in incorrect identification of information and malfunctions such as mice in performing tasks. Depending on each test, some delay time occurred, but the participants showed a pattern of solving the problem through several attempts.
- Aesthetic and minimalist design: The design was presented with minimal menu, function, and color, and was evaluated to show a neat layout. On the other hand, there was an opinion that clearer colors should be applied so that the graph can stand out more.

Based on the qualitative evaluation of the above eight items, the main suggestions for improving usability are as follows. First, it is necessary to prevent confusion through clear distinction of the height interval and color of the graph, and to increase the intuition and understanding of information by consistently applying the system to visual elements such as color and typeface. Second, improved design results should be derived by specifically presenting errors and warnings about information.

4. Discussion

This study was conducted to improve the efficiency of the design process through the usability evaluation of dashboard design for data visualization and to manage risk factors by early detection of problems. To this end, aesthetic elements of the data visualization type were

analyzed and dashboard design was conducted. In addition, the usability of dashboard design was analyzed for participants.

In this study, the efficiency, effectiveness, and satisfaction of the user's task performance were analyzed, and qualitative evaluation through observation and analysis was also conducted using heuristic evaluation indicators.

Through this study, problems in usability were found through Nielsons' heuristic evaluation. The dashboard design developed through this process is thought to provide a more improved experience and be effectively applied to the data analysis process that requires accuracy.

In particular, it can be said that the expression of a three-dimensional space is essential in data visualization in an era where immersive technology such as AR/VR is applied. This study was conducted in a laboratory and was limited to eight people. In the case of the qualitative research method conducted in this study, it has the advantage of being able to derive the meaning in depth. However, there is a limitation that it is not enough to generalize. In future studies, we intend to supplement this through a data driven UX usability.

References

- M.J.Kim., A Study on the Design Strategy of covid-19 Dashboard by User Evaluation., Journal of the Korean Society of Design Culture., 2021.
- C. Kelleher, Wagener., Ten Guidelines for Effective Data Visualization in Specific Publications., Environmental Modeling & software 16, 2011
- N. Cawthon, A.V. Moore., The Effect of Aesthetic on the Usability of Data Visualization, International Conference Information Visualization, 2000.
- Bahador Saket et al., Beyond Usability and Performance: A Review of User Experience-focused Evaluations in Visualization, Conference on Human Factors in Computing Systems, 2016.
- Lennert Loos et al., Data Visualisation as a Tool for Informed Structural Design, Computer-Aided Design, 115, 2019.
- J.M.Lee, A Study on Dashboard Convergence Design for Data Visualization, The Korean Society of science & Art, 38(5), 2020.
- <https://www.iso.org/search.html?q=9241-11>