Cartography M.Sc.

Usability of time-variant flow data visualizations for urban public transportation planning

April 20, 2020

1 Motivation and Problem Statement

As urban regions are getting more and more crowded and public transportation is indispensable, the analysis of temporal variations of the use of public transportation becomes vital to effective planning. With the omnipresence of smartphones, movement data is now rather easy to obtain and there has been significant research done within the field of Visual Analytics concerning its analytic visualization. However, collaboration with the transportation sector has been lacking (G. Andrienko, Andrienko, Chen, Maciejewski, & Zhao, 2017) which is what the proposed research will address.

The main context of this research is hence situated within the field of Visual Analytics, specifically making use of state-of-the-art visualization techniques for flow-graph data. Since the focus will be on the temporal component of said data, it will also be taking into account a wider historical perspective on the visualization of time and temporal data. Furthermore, the context of urban public transportation planning will be significant as the research will be conducted employing a user-centred-design approach.

2 Research Identification

2.1 Research Objectives and Research Questions

The aim of this research is to develop and evaluate different interactive visualizations of attributed time-variable flow-graph data in the context of urban public transportation planning. The data used will be provided by Fraunhofer IAIS as this thesis is part of an ongoing project on Extended Mobile Network Data. The project is concerned with making mobile network data accessible and usable for public transportation companies. Within the scope of this project, the proposed research is placed at the end of the data-pipeline as it is concerned with the usability of the data. Planners and decision makers working at the public transportation associations in Munich will be contacted for a survey and interviews to facilitate a user-centred design approach.

The research will be divided into the two main research objectives (1. and 2.) which are further structured by four sub-objectives (1.1, 1.2, 2.1 and 2.2). Each of the sub-objectives will be tackled by answering the corresponding research questions (a) to (k). The research objectives and questions are as follows.

1. Exploration of different ways of visualizing spatio-temporal data for planning purposes
   1.1 Context assessment
      (a) How have time and temporal data been visualized historically?
      (b) What is the state-of-the-art of visualizing movement-data in Visual Analytics?
   1.2 Exploration and Visualization of time-variable attributed flow graph data
      (c) How is the data at hand structured?
      (d) What kind of visualizations are applicable in the specific case?
      (e) How can those visualizations be generated, taking the intended level of interactivity into account?
2. Evaluation of the usability of different visualizations of time-variant flow graph data for urban public transportation planning
   2.1 Assessment of current analysis practices in urban public transportation planning
      (f) How are the intended users presently working?
      (g) Which visualizations, if any, are they used to?
      (h) How well does the current framework align with the users' needs and analytical questions?
   2.2 Evaluation of the usability of different visualizations of flow graph data for urban public transportation planning
      (i) Which methods for testing usability are appropriate in this specific case?
      (j) How good is the usability of the visualizations?
      (k) How can the visualizations be improved to possibly increase usability?

The scope of this research is limited by the available data as well as the time allocated. It will hence not attempt to compare the usability of different data sets or ways of generating these. Neither is the aim to develop a ready-to-use tool for decision makers within urban public transportation planning but rather to contribute to making such a development possible.

2.2 Innovation Aimed At

The innovation this research aims at lies in applying a user-centred design approach to visualizing flow-graph data for public transportation planning purposes. It aims to help establish a closer collaboration between the field of Visual Analytics and the transportation sector. This will help guide future visualization practices within the domain of cartography concerned with visualizations of spatio-temporal data to be used by decision makers.

2.3 Related Work

A full list of references can be found at the end of the document. Selected pieces of related work grouped by context area are as follows.

In the context of Visual Analysis of movement-data and time-variable flow-graph data, much research has been conducted. Central related pieces are (in chronological order):

- Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach (N. Andrienko & Andrienko, 2006)
- Visual Methods for Analyzing Time-Oriented Data (Aigner, Miksch, Müller, Schumann, & Tominski, 2008)
- A conceptual framework and taxonomy of techniques for analyzing movement (G. Andrienko et al., 2011)
- Visual analytics methods for categoric spatio-temporal data (von Landesberger, Bremm, Andrienko, Andrienko, & Tekušová, 2012)
- Visual Analytics of Movement (G. Andrienko, Andrienko, Bak, Keim, & Wrobel, 2013)
- MobilityGraphs: Visual Analysis of Mass Mobility Dynamics via Spatio-Temporal Graphs and Clustering (von Landesberger et al., 2016)
- Visual Analytics of Mobility and Transportation: State of the Art and Further Research Directions (G. Andrienko, Andrienko, Chen, et al., 2017)

On the topic of user-centred design and usability within spatio-temporal data visualization, central pieces are:

- The usability engineering lifecycle (Mayhew, 1999)
- User-Centered Design for Interactive Maps: A Case Study in Crime Analysis (Roth, Ross, & MacEachren, 2015)
- User studies in cartography: opportunities for empirical research on interactive maps and visualizations (Roth et al., 2017)
- Designing Geovisual Analytics Environments and Displays with Humans in Mind (Çöltekin, Christophe, Robinson, & Demšar, 2019)
- Improving spatial decision making using interactive maps: An empirical study on interface complexity and decision complexity in the North American hazardous waste trade (Vincent et al., 2019)

Concerning the use of public transportation planning, the following literature has been found. A deeper review will follow in the research process.

- Visualizing Mobility of Public Transportation System (Zeng, Fu, Arisona, Erath, & Qu, 2014)
- Visual Analytics of Mobility and Transportation: State of the Art and Further Research Directions (G. Andrienko, Andrienko, Chen, et al., 2017)
- Revealing Patterns and Trends of Mass Mobility Through Spatial and Temporal Abstraction of Origin-Destination Movement Data (G. Andrienko, Andrienko, Fuchs, & Wood, 2017)

- Spatial Decision Support Systems: Three decades on (Keenan & Jankowski, 2019)

This project will deviate from the above mentioned related work as it is attempting to bridge the gap between Visual Analytics research and the application of Visual Analytics within the sector of public transportation planning. To do this, a limited dataset will be used. It will therefore not cover the possible width of visualizations that is generally explored within Visual Analytics. It will instead combine selected visualization methods for evaluation using methods from the context of user-centred design and usability research.

3 Project Setup

3.1 Methods Adopted

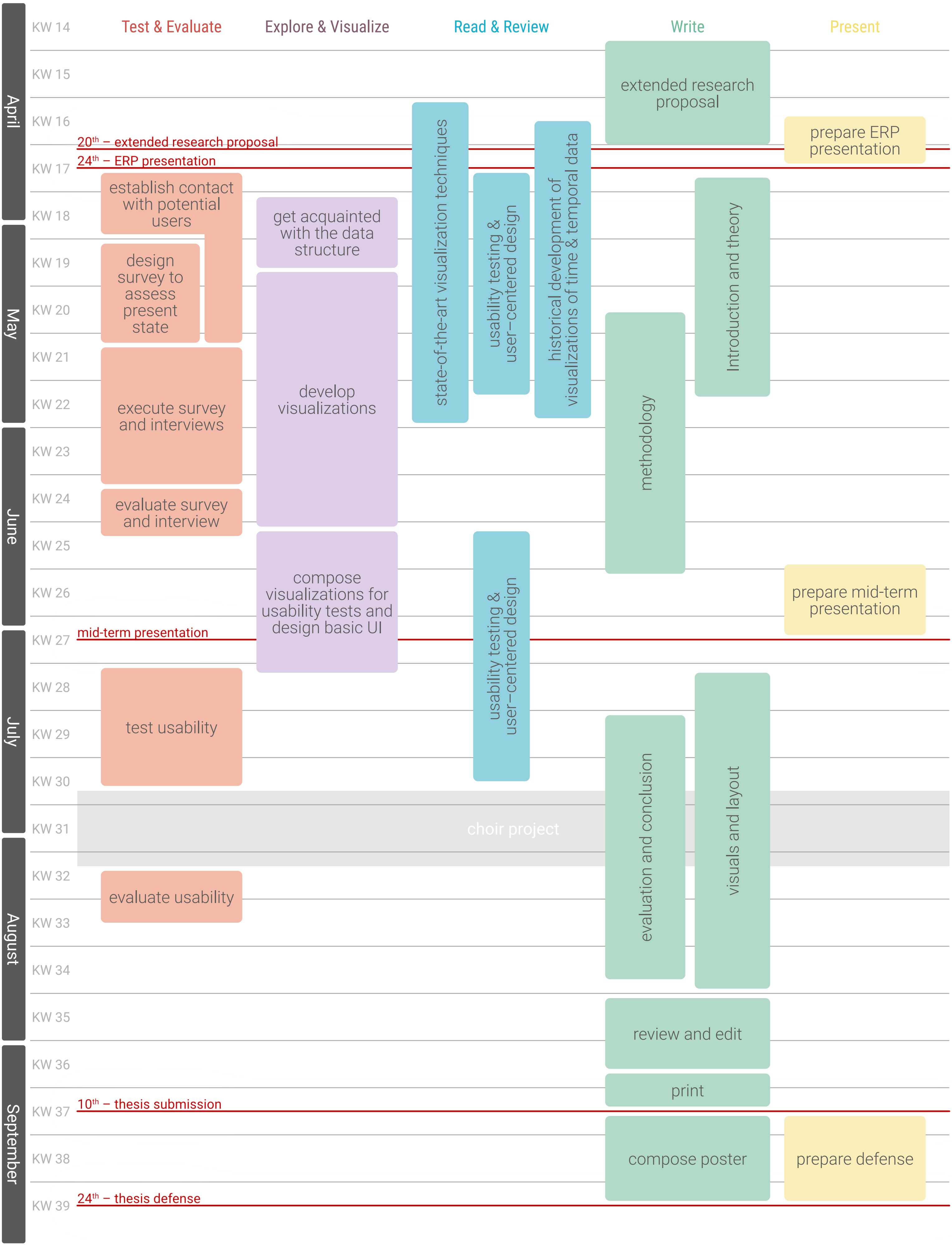
Literature reviews will be conducted to understand the context and obtain background knowledge in order to answer the research questions (a), (b) and (i).

An exploratory style of work in combination with consultation of the supervisors and advisors will be adopted to answer questions (c), (d) and (e). Choosing an exploratory methodology to develop the visualizations is appropriate since the type of visualization that is applicable largely depends on the structure of the data at hand and patterns within the data. Both have to be understood in depth before decisions on how to effectively visualize that data can be made.

As for questions (f), (g) and (h), a survey and interviews will be conducted among potential users. Finally, a usability test will be conducted to answer questions (j) and (k). It will most likely be making use of the thinking-aloud method and qualitative interviews with the test subjects. Adopting a qualitative way of testing usability is appropriate due to the limited number of possible test subjects and the complexity of questions that have to be answered using the visualizations.

3.2 Planned Schedule of the Project

The planned schedule of the project can be seen on the following page. Weekly meetings with the supervisors are planned and for now executed via video call. Depending on the topics up for discussion, different supervisors or advisors will be present.



April
May
June
July
August
September
KW 14
KW 15
KW 16
KW 17
KW 18
KW 19
KW 20
KW 21
KW 22
KW 23
KW 24
KW 25
KW 26
KW 27
KW 28
KW 29
KW 30
KW 31
KW 32
KW 33
KW 34
KW 35
KW 36
KW 37
KW 38
KW 39
Test & Evaluate
Explore & Visualize
Read & Review
Write
Present
20th – extended research proposal
24th – ERP presentation
mid-term presentation
10th – thesis submission
24th – thesis defense
establish contact with potential users
design survey to assess present state
execute survey and interviews
evaluate survey and interview
test usability
evaluate usability
get acquainted with the data structure
develop visualizations
compose visualizations for usability tests and design basic UI
state-of-the-art visualization techniques
usability testing & user-centered design
historical development of visualizations of time & temporal data
usability testing & user-centered design
extended research proposal
methodology
Introduction and theory
evaluation and conclusion
visuals and layout
review and edit
print
compose poster
prepare ERP presentation
prepare mid-term presentation
prepare defense
choir project

3.3 Risks and Contingencies

One unknown is how well the cooperation with test subjects will go. In case of major difficulties in establishing contact to and / or working with potential users, the focus of the research might shift towards a deeper understanding of the historical development of visualizations of temporal data culminating in state-of-the-art visualization techniques within the field of Visual Analytics.

Another factor that might impact the evaluation of the usability of the visualizations is the data quality. Uncertainties and limitations will have to be communicated and taken into account when developing the visualizations to mitigate a potential negative impact on the evaluation.

4 Resources Required

The following resources will be required to carry out the proposed research.

Information

- Background information on the project that this research is part of will be provided by Dr. Georg Fuchs at Fraunhofer IAIS
- Detailed information on the data, its structure and preprossing will be provided by Fabian Patterson at Fraunhofer IAIS
- Information on the present style of work within the public transportation sector will be obtained through a survey and interviews

Data

- The underlying data set: preprocessed attributed time-variable flow-graph data on the Munich area, derived from aggregated extended mobile network data will be provided by Fraunhofer IAIS
- Possibly supporting context data with the same temporal extent

People

- Dr. Mathias Jahnke at TU Munich will be primarily supervising the thesis process
- Dr. Georg Fuchs and Fabian Patterson at Fraunhofer IAIS will be supervising and advising the research process
- About 4 test persons who are potential users of the visualizations will be needed for the user-centred design process including the evaluation of the visualizations

Software and hardware

- The data will be manageable on a laptop since it is already aggregated and preprocessed and therefore not exceeding manageable dimensions
- Depending on how the usability testing process will be designed, specific hardware such as a eye-tracking device might be needed. Such a device is accessible at TUM

Finances

- At this point, no financial resources are needed

References

Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2008, January). Visual Methods for Analyzing Time-Oriented Data. *IEEE Transactions on Visualization and Computer Graphics*, *14*(1), 47–60.

Andrienko, G., Andrienko, N., Bak, P., Keim, D., Kisilevich, S., & Wrobel, S. (2011, June). A conceptual framework and taxonomy of techniques for analyzing movement. *Journal of Visual Languages & Computing*, *22*(3), 213–232.

Andrienko, G., Andrienko, N., Bak, P., Keim, D., & Wrobel, S. (2013). *Visual Analytics of Movement*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Andrienko, G., Andrienko, N., Boldrini, C., Caldarelli, G., Cintia, P., Cresci, S., … Trasarti, R. (2020, March). (So) Big Data and the transformation of the city. *International Journal of Data Science and Analytics*.

Andrienko, G., Andrienko, N., Chen, W., Maciejewski, R., & Zhao, Y. (2017, August). Visual Analytics of Mobility and Transportation: State of the Art and Further Research Directions. *IEEE Transactions on Intelligent Transportation Systems*, *18*(8), 2232–2249.

Andrienko, G., Andrienko, N., Fuchs, G., & Wood, J. (2017, September). Revealing Patterns and Trends of Mass Mobility Through Spatial and Temporal Abstraction of Origin-Destination Movement Data. *IEEE Transactions on Visualization and Computer Graphics*, *23*(9), 2120–2136.

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A., & Wrobel, S. (2007, September). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, *21*(8), 839–857. (_eprint: https://doi.org/10.1080/13658810701349011)

Andrienko, N., & Andrienko, G. (2006). *Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach*. Berlin ; New York: Springer.

Andrienko, N., & Andrienko, G. (2013, January). Visual analytics of movement: An overview of methods, tools and procedures. *Information Visualization*, *12*(1), 3–24.

Big Data Visualization and Analytics: Future Research Challenges and Emerging Applications – Part 1 – ACM SIGMOD Blog. (n.d.).

Blade, R. A., Padgett, M. L., & Padgett, M. L. (2002, January). *Virtual Environments Standards and Terminology*. https://www.taylorfrancis.com/. CRC Press.

Chuprikova, E., MacEachren, A. M., Cron, J., & Meng, L. (2018). Visual Analytics-enabled Bayesian Network Approach to Reasoning about Public Camera Data. *EuroVis Workshop on Reproducibility*, *Verification*, 5 pages.

Chuprikova, E., & Meng, L. (2019, May). Reasoning about socio-economic data: A visual analytics approach to Bayesian network. *International Journal of Cartography*, *5*(2-3), 225–241. (_eprint: https://doi.org/10.1080/23729333.2019.1613073)

Çöltekin, A., Christophe, S., Robinson, A., & Demšar, U. (2019, December). Designing Geovisual Analytics Environments and Displays with Humans in Mind. *ISPRS International Journal of Geo-Information*, *8*(12), 572.

Couclelis, H. (1992). Location, Place, Region, and Space. In *Geography's Inner Worlds - Pervasive Themes in Contemporary American Geography*. New Brunswick, New Jersey: Rutgers University Press.

Cui, W. (2019). Visual Analytics: A Comprehensive Overview. *IEEE Access*, *7*, 81555–81573.

Ding, L. (2016). Visual Analysis of Large Floating Car Data - A Bridge-Maker between Thematic Mapping and Scientific Visualization. , 153.

Ding, L., Fan, H., & Meng, L. (2015). Understanding Taxi Driving Behaviors from Movement

Data. In F. Bacao, M. Y. Santos, & M. Painho (Eds.), *AGILE 2015* (pp. 219–234). Cham: Springer International Publishing.

Ding, L., Yang, J., & Meng, L. (n.d.). Visual Analytics for Understanding Traffic Flows of Transport Hubs from Movement Data. , 13.

Dutton, G. (1999, January). Scale, Sinuosity, and Point Selection in Digital Line Generalization. *Cartography and Geographic Information Science*, *26*(1), 33–54.

Hardin, G. (1968, December). The Tragedy of the Commons. *Science*, *162*(3859), 1243–1248.

Helzel, K. P. (2019). *Supporting enhanced disaster management with interactive 3D and Mixed Reality Maps* (Master's Thesis). Technische Universität München, München.

Keenan, P. B., & Jankowski, P. (2019, January). Spatial Decision Support Systems: Three decades on. *Decision Support Systems*, *116*, 64–76.

Keim, D. (Ed.). (2010). *Mastering the information age: Solving problems with visual analytics*. Goslar: Eurographics Association. (OCLC: 835305616)

MacEachren, A. M. (2004). *How Maps Work: Representation, Visualization, and Design*. Guilford Press.

MacEachren, A. M., & Taylor, D. R. F. (2013). *Visualization in Modern Cartography*. Elsevier.

Malczewski, J., & Jankowski, P. (2020, January). Emerging trends and research frontiers in spatial multicriteria analysis. *International Journal of Geographical Information Science*, *0*(0), 1–26. (_eprint: https://doi.org/10.1080/13658816.2020.1712403)

Mayhew, D. J. (1999, May). The usability engineering lifecycle. In *CHI '99 Extended Abstracts on Human Factors in Computing Systems* (pp. 147–148). Pittsburgh, Pennsylvania: Association for Computing Machinery.

Nielsen, J. (1992, March). The usability engineering life cycle. *Computer*, *25*(3), 12–22.

Nielsen, J. (1994). *Usability Engineering*. Morgan Kaufmann.

Nielsen, J., & Landauer, T. K. (1993, May). A mathematical model of the finding of usability problems. In *Proceedings of the INTERACT '93 and CHI '93 Conference on Human Factors in Computing Systems* (pp. 206–213). Amsterdam, The Netherlands: Association for Computing Machinery.

Norman, D. A. (2013). *The design of everyday things* (Revised and expanded edition ed.). New York, New York: Basic Books.

Popova, M. (2012, February). *Cartographies of Time: A Visual History of the Timeline.*

Popova, M. (2019, July). *Visionary Maps of Time, Space, and Thought by America's First Female Cartographer and Information Visualization Designer.*

Prommaharaj, P., Phithakkitnukoon, S., Demissie, M. G., Kattan, L., & Ratti, C. (2020, April). Visualizing public transit system operation with GTFS data: A case study of Calgary, Canada. *Heliyon*, *6*(4), e03729.

Rosenberg, D., & Grafton, A. (2012). *Cartographies of Time*. London: Abrams & Chronicle Books.

Roth, R. E. (2013, June). Interactive maps: What we know and what we need to know. *Journal of Spatial Information Science*, *2013*(6), 59–115.

Roth, R. E., Çöltekin, A., Delazari, L., Filho, H. F., Griffin, A., Hall, A., … van Elzakker, C. P. J. M. (2017, October). User studies in cartography: Opportunities for empirical research on interactive maps and visualizations. *International Journal of Cartography*, *3*(sup1), 61–89. (_eprint: https://doi.org/10.1080/23729333.2017.1288534)

Roth, R. E., Ross, K. S., & MacEachren, A. M. (2015, March). User-Centered Design for Interactive Maps: A Case Study in Crime Analysis. *ISPRS International Journal of Geo-Information*, *4*(1), 262–301.

Rühringer, M. (2018). *Use and User Requirements of Ecosystem Service Maps* (Master's

Thesis).
Sarodnick, F., & Brau, H. (2006). *Methoden der Usability Evaluation* (Second ed.). Verlag Hans Huber.
Streeb, D., El-Assady, M., Keim, D., & Chen, M. (2019). Why Visualize? Untangling a Large Network of Arguments. *IEEE Transactions on Visualization and Computer Graphics*, 1–1.
Vincent, K., Roth, R. E., Moore, S. A., Huang, Q., Lally, N., Sack, C. M., … Rosenfeld, H. (2019, November). Improving spatial decision making using interactive maps: An empirical study on interface complexity and decision complexity in the North American hazardous waste trade. *Environment and Planning B: Urban Analytics and City Science*, *46*(9), 1706–1723.
Virrantaus, K., Fairbairn, D., & Kraak, M.-J. (2009, May). ICA Research Agenda on Cartography and GI Science. *The Cartographic Journal*, *46*(2), 63–75.
von Landesberger, T., Bremm, S., Andrienko, N., Andrienko, G., & Tekušová, M. (2012, October). Visual analytics methods for categoric spatio-temporal data. In *2012 IEEE Conference on Visual Analytics Science and Technology (VAST)* (pp. 183–192).
von Landesberger, T., Brodkorb, F., Roskosch, P., Andrienko, N., Andrienko, G., & Kerren, A. (2016, January). MobilityGraphs: Visual Analysis of Mass Mobility Dynamics via Spatio-Temporal Graphs and Clustering. *IEEE Transactions on Visualization and Computer Graphics*, *22*(1), 11–20.
Zeng, W., Fu, C.-W., Arisona, S. M., Erath, A., & Qu, H. (2014, December). Visualizing Mobility of Public Transportation System. *IEEE Transactions on Visualization and Computer Graphics*, *20*(12), 1833–1842.