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MAP ANIMATION OF SHIPPING TRAFFIC IN ADOBE AFTER EFFECTS FROM GIS DATA

Diploma thesis

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ANNOTATION

The aim of this thesis is to present the motion graphics software Adobe After Effects as a tool for creating animated visualizations of GIS data. The main part of the content deals with the practical creation of map animations based on spatial datasets from the topic of shipping traffic. A set of five created map animations is briefly introduced, and then the workflow that was followed to create these animations is explained in detail. The essential steps of the transfer of geodata from ArcGIS Pro to Adobe After Effects are described and important findings are shared. Then, in the theoretical part of the work, the quality and informative value of the created animations are assessed on the basis of a survey and personal findings. Finally, an evaluation is given, which assesses Adobe After Effects as a tool to visualize spatial data and shows strengths and limitations based on the gained experiences.

KEYWORDS

map animation, AIS data, Adobe After Effects, GIS data

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Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged and the thesis has not been previously submitted to the fulfilment of the higher degree.

20.05.2021, Olomouc

Nelson Schäfer

ASSIGNMENT OF DIPLOMA THESIS

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Theses guidelines

The main objective of the master's thesis is to compile a set of animations around the broad topic of ship routes in Adobe After Effects from GIS data. The student will establish a systematic concept for all the animations regarding to time, visualization and user issues. He will consider datasets for the Copernicus project and GIS tools. He also examines an efficient workflow for importing geospatial data into Adobe After Effects and evaluates the limits of map animation in Adobe After Effects regarding data-driven inputs. He will focus on determining the thresholds in the workflow at which point manual operations and adjustments are required. When interpreting his own achievements, he comments on whether the animations can be used to convey valuable, accurate and understandable information to the viewer, or whether they are nice to look at, but otherwise not useful. The student will attach all the collected datasets and all the animations to the thesis in digital form. The student will create a website about the thesis following the rules available on the department's website and a poster about the diploma thesis in A2 format. The student will submit entire text (text, attachments, poster, outputs, input and output data) in digital form on a storage medium and the text of the thesis in two bound copies to the secretary of the department.

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Harrower, M (2003): Visualizing Change: Using Cartographic Animation to Explore. Cartographic perspectives.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
3D	Three-dimensional
AI	Adobe Illustrator
AIS	Automatic Identification System
AIX	Adobe Illustrator Exchange file format
CC	Adobe Creative Cloud
CSV	Comma-separated Values
DEM	Digital Elevation Model
EEZ	Exclusive Economic Zones
EU	European Union
GIS	Geographic Information System
HD	High definition
JSON	JavaScript Object Notation
MMSI	Maritime Mobile Service Identity
netCDF	Network Common Data Form
NSR	Northern Sea Route
NWP	Northwest Passage
OSM	OpenStreetMap
PNG	Portable Network Graphics
SOG	Speed over ground
TIFF	Tag Image File Format

INTRODUCTION

Geographical data is universal. Not only does almost all information have a spatial component, but spatial data can also be a valuable asset for almost any industry. Since our world and our perception of this world consists of locations of objects and relationships between those, the description of such information is of enormous value. The industry domain of geoinformatics achieves exactly that — to describe and store spatial information. In addition, the tools of geographic information systems (GIS) make it possible to carry out calculations with geodata and to save the subsequent results as new geographic information. Since many industries know the value of geographical information, an effort is made to make use of spatial data in the respective special tools of the various industries. However, often the lack of interfaces and supported exchange formats of the applications do not allow a transfer of GIS data to other software. This thesis deals with an example of this so-called principle of *thin-pipe translation*, which describes the loss of information during the transfer of data between different software, in this case from GIS software to Adobe After Effects (Safe Software, 2021).

The software Adobe After Effects is considered an industry leader when it comes to motion graphics, visual effects and the creation of professional animations. The major GIS software providers have already integrated options for creating map animations from geodata. Although these toolsets are continuously expanded and improved, it seems impossible that the quality and possibilities of the GIS software will ever exceed the animation possibilities of a fully dedicated animation software. Thus, this thesis aims to combine the power and value of geographical data with the sophisticated animation capabilities of the Adobe software product.

With ever-rising amounts of available spatial data the need for efficient visualizations, especially when findings and results get presented, is continually growing. Map animations are unique because they allow to combine two of the most important parameters of human perception, namely location and time. Especially phenomena that involve a time component can be visualized best with animations, as progressing time can actually be depicted with time, and doesn't require alternative methods of presentation like in static maps. Location can best be described with maps, and time can best be described with animations. Thus, coupling these parameters in map animations together with the toolset of a specialized motion graphics software can result in an advanced and intuitive medium, that allows to easily perceive and understand the depicted phenomena.

1 OBJECTIVES

Creating map animations in the software Adobe After Effects is not in itself a popular or widespread topic, nor is it an established activity in the geospatial community. Therefore, this thesis is aimed to give an initial evaluation of the After Effects software with regard to its suitability as a tool for creating map animations based on rich GIS data. In order to test the possibilities of After Effects in practice, a set of five map animations is created and the applied workflow, encountered issues and the examined range of possibilities, explored in the process, are documented.

A multitude of datasets describing shipping traffic in several scales and locations are used as the basis to create the animated maps. Additionally, supplementary datasets to set the shipping data into logical or spatial context, are added to the pool of input data for the animations. After pre-processing of the datasets in dedicated GIS software, a workflow is established which achieves to transfer the spatial data from the GIS software into Adobe After Effects, while retaining the necessary properties of the data to use for the data-driven animation of the map contents. Since Adobe After Effects offers no native ways to import datasets of spatial file formats, a conversion of the data to an intermediate format which can be read by After Effects is crucial. Such conversion, however, comes with the challenge of potentially losing essential information such as attribute tables or spatial location. Thus, developing an optimized workflow is an critical objective of this thesis work.

Next, the tools of Adobe After Effects are used to create five animations on the common theme of shipping traffic, but each visualization constitutes of a unique dataset and animation style. This study explores and documents ways to animate GIS data in Adobe After Effects as well as the workflows and limitations concerning these methods. While doing so, plug-ins for Adobe After Effects are introduced to the reader as a way to extend animation capabilities and improve the animation quality.

Thresholds in the animation process at which point manual operations and adjustments are required, or where with the help of scripting and expressions automated results can be achieved, are determined. With this, the capabilities as well as limits of Adobe After Effects when working with large datasets and data-driven animations can be shown.

The output of the animation process are videos which have a duration of a couple of seconds up to a few minutes. The map animations are evaluated on whether they can be used to convey valuable, accurate and understandable information to the viewer or whether they are visually appealing but otherwise not useful. In addition, the ratio between effort and benefit of cartographic animations from GIS data in Adobe After Effects will be used to recommend worthwhile potential use cases.

Overall, the theoretical output of this thesis allows to draw conclusions to what extent Adobe After Effects can be used as a map animation tool for GIS data. In addition, the practically created set of animations can demonstrate the range of possibilities of the software and can give the reader an idea of what is achievable with the utilized tools and the established workflow.

2 METHODOLOGY

In the initial part of the work, the following sub-chapters introduce the methods, technologies and utilized datasets that were used to achieve the set objectives. The first section provides a comprehensive list of datasets, their types as well as sources. This is followed by a brief introduction of the used software and tools. Finally, the conducted workflow with the most important aspects is outlined.

2.1 Used data

Since the theme of the map animations is shipping traffic, a large variety of datasets about this and related topics had to be found. When it comes to ship traffic data, so-called AIS (Automatic Identification System) messages are the most common type of data that is used in the industry. Since 2002, AIS data transponders have been required to be attached to all vessels having a volume over 300 gross tonnage to send out data at intervals of a few seconds. AIS data consists of static information such as the unique MMSI (Maritime Mobile Service Identity), the shiptype, loaded cargo or destination. Furthermore, valuable dynamic details such as the current ship position, the speed and direction of travel are transmitted via AIS. A large global network of AIS receivers, including satellites, allows almost global coverage of rich vessel traffic data. For various reasons, such as coverage gaps or weather conditions, AIS can also have transmission gaps in data (Svanberg et al., 2019). This problem will also play a role in the processing of AIS data in this thesis.

AIS datasets usually consist of a very large number of transmissions, which are made available in the form of, for example, CSV tables. These datasets can have several million entries and reach several gigabytes in size. Alternatively, pre-processed products like vector line data where the single location points were already connected to routes are also offered.

Online, many sources, even several global continuous coverages of AIS data are available. However, these providers like *FleetMon* or *Marine Traffic* charge money to get access to their datasets. Despite requests to these two companies to provide AIS data for the work of this master's thesis for scientific purposes, no or no positive feedback was received.

On a country level scale, several governments offer free to use AIS data in different levels of quality and processing. Besides the used datasets in this thesis (see table 1) the following governmental departments with publicly available vector AIS data were discovered:

- United Kingdom - AIS track lines from the first week of each month:
<https://environment.data.gov.uk/DefraDataDownload/?mapService=MMO/AnonymisedAISderivedTrackLines2017&mode=spatial>
- Denmark - daily AIS points:
<https://www.dma.dk/SikkerhedTilSoes/Sejladsinformation/AIS/Sider/default.aspx>
- Australia – monthly datasets:
<https://www.operations.amsa.gov.au/Spatial/DataServices/DigitalData>

When it came to the choice of animation topics, the decision was heavily influenced on the availability of publicly available data on ship traffic. Additionally, the possibilities depended on the type of geometry, the quality of the data and the included attribute tables. In principle, each of the five created animations consists of a core data set, which describes ship traffic, and additional supplementary data of the environment.

For some animations, height information was added to create 3D environments or shaded basemaps. For this, free bathymetry and hypsometry data from different providers like

GEBCO, Copernicus or Natural Earth were used. Secondly, a large amount of geometry vector data of the depicted scenes was fetched to provide additional information for the viewer. A wide variety of vendors were used to obtain free vector data. Among those, OpenStreetMap and Living Atlas are the most prominent. The complete list of used data and data information sources are listed in the following table:

Table 1 Used data sources and descriptions (*the links were last accessed in April 2021*)

Product	Description	Link to source	Map
Living Atlas U.S. Vessel Tracks	Tracks of vessels in the USA.	https://livingatlas.arcgis.com/vessel-traffic/	1
OpenStreetMap	OSM administrative boundaries, land use and urban areas.	https://download.geofabrik.de/north-america.html	1
Great Lakes database	Administrative boundaries.	https://www.glahf.org/data	1
NGA ASAM Report	Worldwide threats to shipping dataset.	https://msi.nga.mil/Piracy	2
EEZ Boundaries	World maritime boundaries vector data.	https://www.marineregions.org/downloads.php	2
Blue Earth Bathymetry	Small-scale global DEM of ocean and land.	http://www.shadedrelief.com/blue-earth/	2
European Digital Elevation Model (EU-DEM), version 1.1	25m resolution elevation model.	https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1	3
GEBCO Gridded Bathymetry Data	Global terrain model for ocean and land, 15 arc second resolution.	https://www.gebco.net/data_and_products/gridded_bathymetry_data/	3
Hellenic Trench AIS data	AIS point data.	https://www.seanoe.org/data/00459/57040/	3
Port Areas of Port Piraeus	OSM vector data.	http://overpass-turbo.eu/	3
Admin 0 - Countries	Natural Earth country boundaries.	https://www.naturalearthdata.com/downloads/10m-cultural-vectors/10m-admin-0-countries/	2,4
Sea Ice Concentration	Daily gridded data of sea ice concentration in the Arctic.	https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-sea-ice-concentration	4
Firefly Grid Lines	World latitude and longitude grid lines.	https://hub.arcgis.com/datasets/6d95153b210b44f3a76de7039754b71d	4

World Georeference Lines	Significant latitude and longitude lines like the Arctic Circle.	https://www.arcgis.com/home/item.html?id=d279d187ea2b4664b4d0c998eff97b1e	4
NGR World Port Index	Worldwide locations of major ports.	https://msi.nga.mil/Publications/WPI	4,5
1:50m Cross-blended Hypsometric Tints	Shaded relief combined with custom elevation colours raster.	https://www.naturalearthdata.com/downloads/50m-raster-data/50m-cross-blend-hypso/	4
NWP Transits database	List of transit voyages through the Northwest Passage.	http://thenorthwestpassage.info/transit-statistics/transits-complete-data	4
NWP Routes	Established routes through the Northwest Passage.	http://thenorthwestpassage.info/routes	4
NSR Transit Voyages in 2019	Table of transits through the Northern Sea Route.	https://arctic-lio.com/transit-voyages-in-2019/	4
Open Periods of Shipping Passages	Weathernews news release on Arctic ship passages.	https://global.weathernews.com/wp-content/uploads/2020/07/20200703_1.pdf	4
SRTM15+ V2.1 elevation data	Global Bathymetry and Topography at 15 arc seconds resolution.	https://portal.opentopography.org/datasetMetadata?otCollectionID=OT.122019.4326.1	5
Esri World Imagery	Global satellite imagery.	https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9	5
MarineCadastre Vessel traffic data	AIS point data of the USA	https://marinecadastre.gov/ais/	5

2.2 Used software

Although the most important part of the work was conducted in Adobe After Effects, a series of complementary software are used to prepare, manipulate, import and control the data that was designated to be animated.

First and foremost, since spatial data is used, GIS software is utilized to handle it. For most tasks ArcGIS Pro by Esri in the version 2.7 was used to perform a broad variety of tasks like the management of the spatial datasets. Furthermore, the software was used for conducting filter operations, combining datasets, spatial analysis and for field calculations. In some cases, QGIS software version 3.16, proved to be more efficient in performing certain geoprocessing calculations and was in such cases used as complementary GIS software.

Particularly noteworthy is a geoprocessing tool for ArcGIS Pro which is not included in the standard software package and has to be downloaded manually. This tool was used for some operations to further process raw AIS data. The python toolbox *AIS Utilities 2018 Pro* comprises two scripts which were used to convert CSV tables to point feature and

afterwards connect points to ship route tracks. This script is made available for free by *MarineCadastre.gov*, an online portal of the U.S. government (MarineCadastre, 2021).

Additionally, software included in the Adobe Creative Cloud of 2021 was used for the later procedures. Adobe Illustrator is a vector-graphics editor software and was used in this project work as an intermediate step to transfer vector graphics from ArcGIS Pro to Adobe After Effects. In Illustrator the free plug-in *ArcGIS Maps for Adobe Creative Cloud* made by Esri, was used to import map layouts designed in ArcGIS Pro to Adobe Illustrator while maintaining important attributes of the map features like layer structure and object names (Esri, 2021a).

After that, Adobe After Effects served as the main application to create animations from the pre-processed geodata. Adobe After Effects is a software for digital visual effects and motion graphics in which a large variety of media types can be composited. The structure of an After Effects Project consists of layers which are arranged in a timeline and which properties like position, rotation or colour can be manipulated, and effects be applied. In this thesis the software is mainly used for the animation of vector graphics and to composite 3D scenes. However, the possibilities of the software are far more diverse and is thus used across many industries like web design or video post-production (Adobe Wiki, 2021).

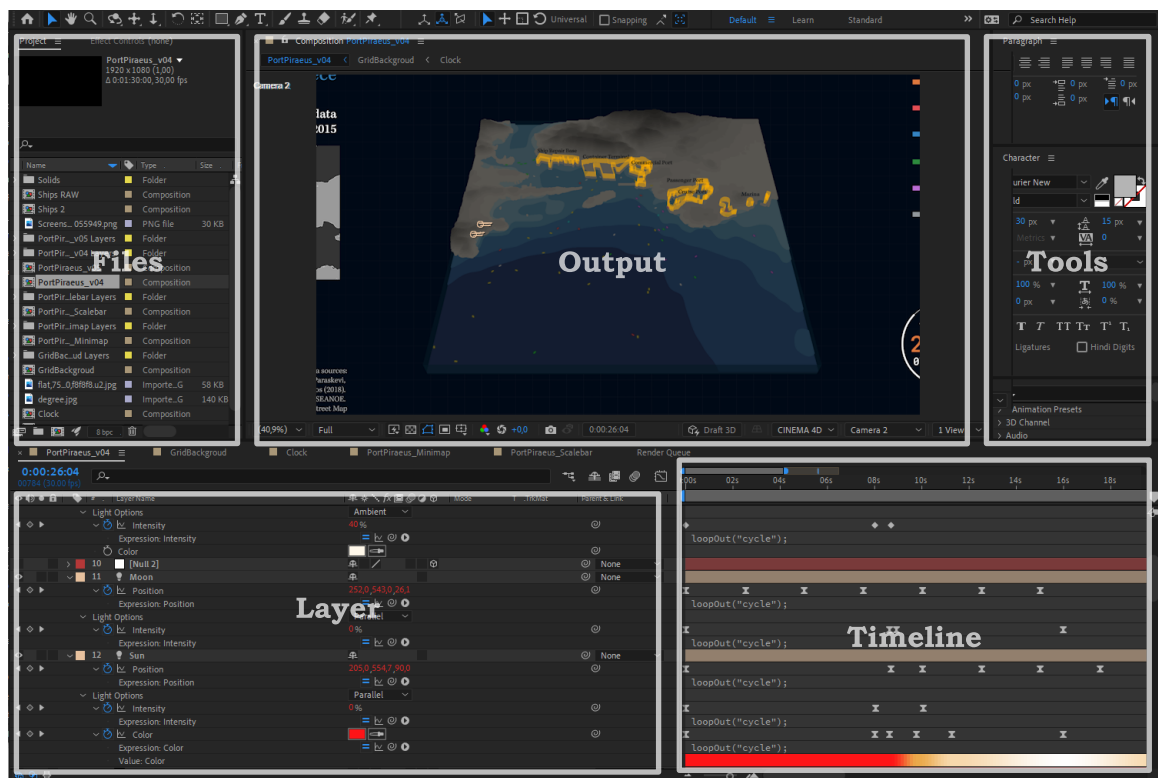


Figure 1 User interface elements of Adobe After Effects

To extend the possibilities of After Effects, a large market of third-party plugins exists. In this project the capabilities of two plug-ins are used in the process of creating map animations. *Terrain Builder Pro* is a template in After Effects and provides scripts with the help of which 3D landscapes can be generated from an input height map and a colour map (Envato Market, 2021). In one of the created animations this template is used to generate a three-dimensional terrain.

The free plugin *Video Copilot Orb* allows to create realistic 3D planetary spheres, thus also a representation of the Earth. Atmospheric effects, reflections, diffuse maps and shadow illuminations can be used to create a realistic three-dimensional representation of the Earth (Video Copilot, 2021).

Lastly, the program Adobe ExtendScript Toolkit CC was used. Its environment allows to write scripts in a programming language similar to JavaScript and with it control applications of the Adobe Creative Cloud, among those After Effects. Using this scripting tool enabled to automate data-driven processes which would have been impossible to achieve with manual labour.

In order to better assess some statements regarding the required rendering time of the animations and observed computing limits, it is helpful to know the rough specifications of the PC that was used for the work on the animations. The PC had an AMD Ryzen 7 1700X processing chip paired with 16 GB of installed RAM. For graphics the system used a NVIDIA GeForce GTX 1080 card.

2.3 Processing procedure

Before the practical implementation of the animation could begin, a considerable amount of research on literature, instructions and tutorials had to be made. Adobe After Effects is a very complex and versatile software that takes time to learn and understand. In order to get familiar with types, approaches and visual styles of map animations and particularly shipping traffic animations, examples were searched online and analysed. Based on this knowledge, the set of available tools in Adobe After Effects was explored. Functionalities that looked promising to be implemented in the process of creating map animations were documented and practiced. Especially extensive tutorial video series on the YouTube platform helped to learn to apply advanced techniques in the After Effects software. Among others, video series like *World of Expressions* (Animoplex, 2021) or *Monday Maps!* (Boone Loves Video, 2021) conveyed valuable knowledge.

The acquisition of data was conducted online via geoportals and search engines and led to a collection of potentially relevant datasets that were managed and analysed in ArcGIS Pro. Here, and occasionally in QGIS, the processing included calculations of statistics, spatial analysis or filtering of the data. Afterwards, a map composition with a proper symbology was created and exported as AIX file format. This data type is used to transfer map layouts from ArcGIS Pro as unchanged as possible into an Adobe Illustrator project, whereby things like layer names or classifications are retained. In order to read this file type, the *ArcGIS Maps for Adobe Creative Cloud* plug-in must be installed in Adobe Illustrator and the document imported with it. In this way generated Illustrator projects were then prepared for the subsequent import to Adobe After Effects.

In addition, the attribute table for some animations was exported from ArcGIS Pro and saved as JSON files. This was necessary because when the map layout is exported from the GIS environment, any attribute information is lost or at least not included in the exported file. Via scripting in Adobe ExtendScript Toolkit CC, the connection between the JSON table and the geometry layers was possible to be restored later in Adobe After Effects.

The compilation of the compositions in Adobe After Effects included the created Adobe Illustrator files but also many other elements like images, graphics or text. Then, with the tools of the animation software, with installed plug-ins and with scripting commands the animation process was conducted. The finished animation compositions were then exported as high-definition (HD) videos for presentation. In the following chapters 4.1 to

4.5 this presented workflow is explained in detail by the examples of the created map animations.

To evaluate the quality of animations from an audience, an online survey was prepared and filled by survey participants. Based on the results of this questionnaire, personal experience and individual feedback the quality of the animations was assessed. Additionally, conclusions about the suitability of Adobe After Effects for the creation of map animations were drawn and reported.

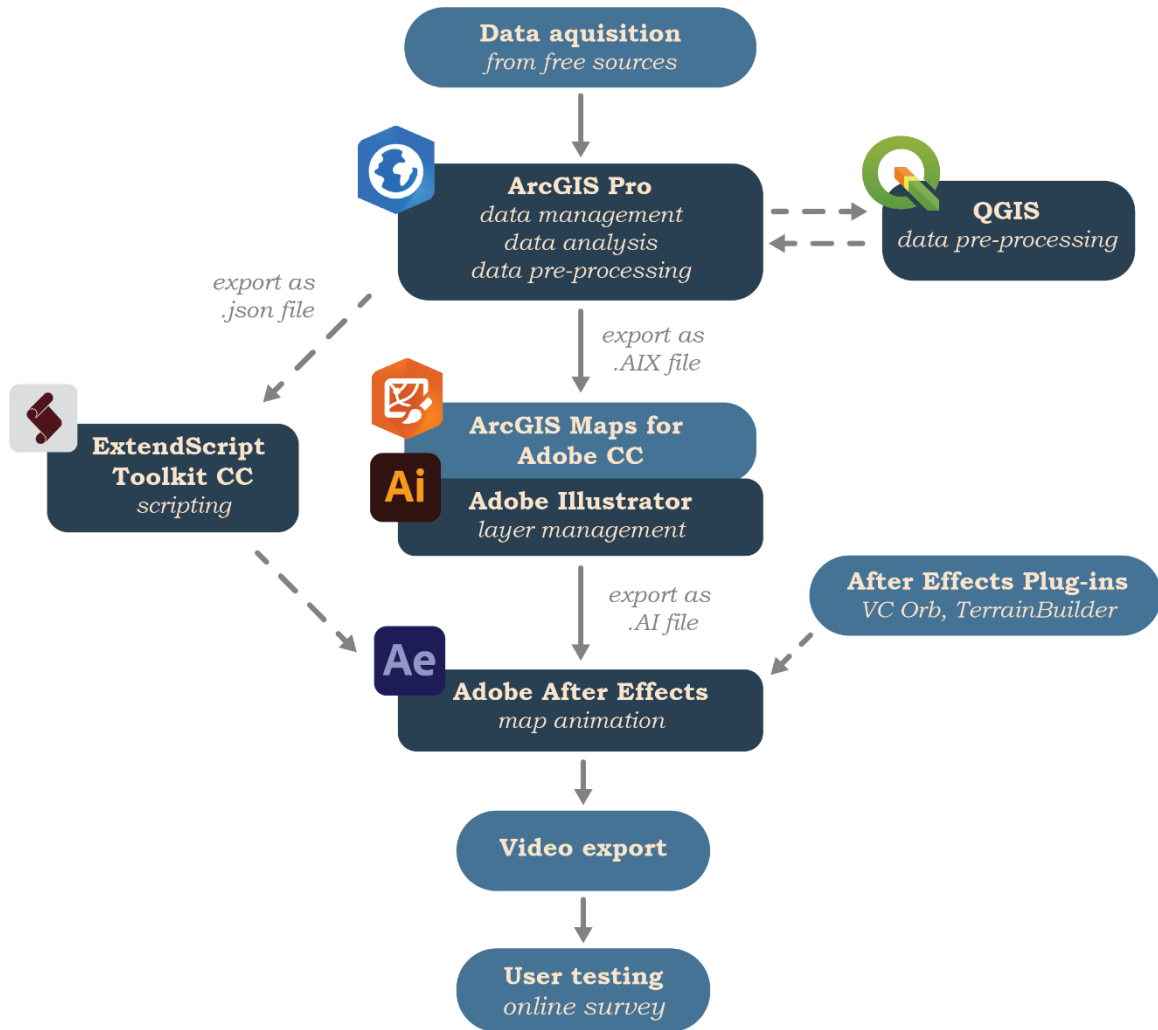


Figure 2 Workflow diagram of the thesis

3 STATE OF THE ART

Principles of map animations

A principle of cartography states that everything that is spatial can be mapped and following this principle, locations and attributes of phenomena have been successfully visualized with static maps for centuries. However, a just as universally present variable as space is time. For this variable, map animations are a commonly used method of cartographic visualization showing spatial, as well as temporal changes and most importantly their interrelations (Harrower, 2003). The use of animations to visualize spatial relations in a temporally logical and realistic sequence of images is the most natural and intuitive approach among all cartographic methods, as real-world time can just be translated into animation time (Nöllenburg, 2007).

Much of today's significant science revolves around more and more large and complex systems such as climate change, globalisation and global networks. These systems are in constant change and thus, in addition to studying spatial patterns, the analysis of space-time processes is required (Harrower, 2003). The research in such significant fields also requires the use of more sophisticated and bigger datasets — an example being shipping traffic, where millions of AIS messages are transmitted daily. Attempts to appropriately map such processes on static maps would result in overly complex results.

However, animated maps can not replace static maps and can not per se be seen as better or worse. Instead, the different advantages of these map types have to be used deliberately (Harrower & Fabrikant, 2008). In addition to the cartographic challenges involved in creating two-dimensional static maps, cartographic animations entail even more complex processes when a third or fourth dimension such as vertical space and time is to be visualized (Łucjan, 2016). Furthermore, map animations are predominantly a visual method that is well suited to perform qualitative analyses in order to identify trends and relationships of the data. An animation on its own can hardly convey quantitative information to the viewer such as a number or a value of a phenomenon. Instead, animations serve more as an explanatory first step in the analysis of spatio-temporal data, which can then in further steps be analysed in more detail with other methods (Harrower, 2003).

History of map animations and the influence from other disciplines

According to estimates the first created map animations can already be recorded in the 1940s (Griffin et al., 2006). However, it should be noted that these animations were not yet visualizations created for or by cartographers, but rather that these early animations appeared in movies without any scientific claim. According to S. Caquard's (2009) assessments, map animations were first seen in movies because the cinemas were the only places where at the time animated maps could be watched and shared. Until the 1990s, animations with cartographic content did not establish as a significant part of the cartographic visualization spectrum. The authors Campbell and Egbert (1990) even bemoan in a journal article from 1990 that in the past 30 years no significant advancements in map animation have been made, so that they could be incorporated into professional design and work of cartographers. As a possible reason the authors state the lacking possibilities of distributing the animated outcomes. However, the authors also prophesied correctly that at the time the achievements in map animations only scratched the surface of what would be possible in the future.

Along with the rise of the Internet as one factor and the equally influential rapid advances in available software, powerful graphics-processing hardware and rich spatio-

temporal datasets, more and more favourable conditions emerged over the years and the field of map animations was able to thrive (Harrower & Fabrikant, 2008). Over the years, the cartographic methods for map animations have been refined more and more, but there was also considerable input of computer animation from the film industry and does so until today (Łucjan, 2016). Because of technical limitations, maps used to be just sequences of static images that have clear advantages until today, for example a better identification of specific time points of change in the animations. The technology for the more modern keyframe-based animation approach, where objects change dynamically between states using an interpolation process called *tweening*, was also not developed by cartographers but adapted from cinematic animations. (Griffin et al., 2006 & Peterson, 1994). As the historical development of map animation shows, the origin of contemporary map animation techniques is very complex and influenced by many other industries. Significant progress was made not only by filmmakers, but also by the military, architects and engineers who created animations with cartographic content as animated maps are not only used in cartography but also in many other disciplines (Caquard, 2009). For example, map animations are often used as an aid for education and learning, as they can be used to explain a wide range of earth and social sciences with multimedia support (Griffin et al., 2006).

A comparison of map animations used in movies and professional cartographic animations reveals a time delay between emerging technologies and concepts in the movie industry and the later implementation of similar functionalities in cartographic visualizations. This difference in quality and novelty can be explained by the number of constraints that cartographers have to face. Firstly, cartographic work is aspiring to be accurate, whereas cinematography has other purposes like narration or illusion. Secondly, data visualizations depend on data availability and data quality, whereas filmmakers can show maps that “must only look like they work” (Caquard, 2009). This delineated increase in complexity for animations by cartographic standards is large. However, maps created with tools from other disciplines, like Adobe After Effects, can nevertheless serve as technical and conceptual sources of inspiration.

Map animations with Adobe After Effects

Adobe After Effects is one of the most used software in cinematography and is capable of more advanced animation techniques than typical animation tools in GIS software. Research for this thesis revealed that only few publicly available examples exist where Adobe After Effects was used to create animations for professional cartographic purposes. Among the discovered examples the created animations were mainly used within video documentaries and only served as accompanying elements to a larger narrative. Typical use cases of the map animations were highlightings of country polygons or borders to depict actors of historical events, animations of travel routes or simple statistics in choropleth maps (see figure 3). One commonality among this type of map animations is that they only include very few map elements in their composition and lack complexity. In general, the nature of these animations and their usage suggests that these visualizations were not created by experts of geodata, but rather by professional filmmakers who do not have specific expert knowledge on map animations made for cartographic purposes.



Figure 3 Examples of map animations made with Adobe After Effects (Vox, 2019 & Boretskii, 2021)

Furthermore, a majority of these animations were created by using the same plug-in for Adobe After Effects called *GEOLayers 3*. This 280\$ costly extension allows to import spatial datasets such as GeoJSON files directly in After Effects and can place them on fully operational basemaps (Aescripts, 2021). However, due to the high price of this extension this tool could not be included for developing the map animations in the framework of this thesis. By using the *GEOLayers 3* tool, some of the work steps that were developed in this work could possibly be implemented differently and more easily. Specifically, with the help of this plugin, the step required in this work could be skipped in which the geodata is divided into a JSON file and the geometries in Adobe Illustrator, and later reassigned to each other with a part of the developed script. This is because this plug-in allows to access all attribute data from a GeoJSON file that could contain the geometry *and* attribute information of the datasets. However, the remainder of the workflow of this work, from pre-processing the data, developing scripts and expressions to animate the data based on its attributes, and creating all other elements of the animation would still have to be done the same or similar way.

It was noticed along the search for scientific publications dealing with Adobe After Effects in combination with map animations, that no scientific coverage of this topic has been made. One reason for this might be that available mapping technology is outpacing cartographic theory and scientifically elaborated reports and evaluations can not keep up with the fast pace of technological advancements (Harrower, 2008). Furthermore, only few documentations of possible workflows on how to work on map animations from geodata in Adobe After Effects were discovered.

When looking at map animations in general, that were not created with Adobe After Effects, but are similar in terms of style and animation quality, then plenty of examples can be found. However, also here no publicly available workflows or tutorials on how to reproduce such animations were discovered. Data visualization companies like *Esri*, *422 South* or *Ito World* publish their map animations but hints on used tools and software are not made public (Esri, 2021 & 422South, 2021 & Ito World, 2021).

For the work on this thesis, only two sources were found that directly deal with the animation of data from GIS in After Effects. On the one hand, an Esri workshop in which a sample project is created, and GIS data is exported from ArcGIS Pro to Adobe After Effects and then animated manually (Leiva & Umali, 2020). The second important source on which the concept of this thesis is based, is an official tutorial from Adobe, in which polygons were animated data-driven based on attributes in a JSON file (Scott, 2017). The knowledge from these two independent workshops was used to derive the in this thesis developed workflow. Since the core concept of this master's thesis was taken from these two sources, there is of course a lack of clarity as to whether these methods are efficient solutions. Since no scientific publications exist, the selected appraisal cannot be compared with other methods and is therefore to be assessed critically.

4 CREATION PROCESS OF THE MAP ANIMATIONS

The following five subchapters are each dedicated to one of the five created map animations. First, in a short introduction, the content and useful background information is given for each of the animation topics. In addition, the main findings that can be derived from viewing the animation videos are presented. Subsequently the workflow from the very beginning of acquiring the data until the final export of the animation video are elaborated. In the process, noteworthy tips as well as problems and their according solutions are presented in detail.

It should be noted that the chapters of the workflows of the animations build on one another. Many work steps and principles were used in the work for several animations, which is why they are explained in detail when they appear for the first time but are only briefly dealt with the second time they appear in the workflow.

4.1 Animation 1: Ship traffic density on Lake Superior

The Great Lakes of North America on the border of the United States and Canada cover a total surface area of approximately 250,000 km². Of the five lakes in this system, Lake Superior is the largest by surface area and considered the second-largest lake in the world. Besides using the waters for economic shipping lanes, the vessel tourism and recreation activities are a major industry of the region (Wikipedia, 2021). This animation shows shipping activities of pleasure vessels, which are crafts used for personal, sports or recreation activities. The time span of this animation of almost 3 years allows to see recurring seasonal differences of activity throughout the years. As on all the Great Lakes, the surface of Lake Superior can reach an average maximum coverage of 60% with sea ice between December and May annually, bringing the pleasure vessel activities to a stop in these months (NOAA, 2021a). In addition, port regions such as the Duluth-Superior Twin Ports in the western part of Lake Superior can be detected where a continuously high activity is appearing in the animation. The final animation video has a duration of 35 seconds and shows monthly ship density values from March 2017 to December 2019. In this animation the processing method of binning is utilized, in which the underlying data is grouped in a layer of polygons, in this case hexagons. Over the months, the height of the polygons is altered according to the amount of recorded vessel activity in each hexagon. This technique is used to avoid a convoluted map of thousands of single data points of the input data to create a meaningful visualization and avoiding unnecessary complexity and detail. The in this way achieved reduced complexity allows to give the viewer an overview of spatial and temporal pattern of the depicted phenomenon.

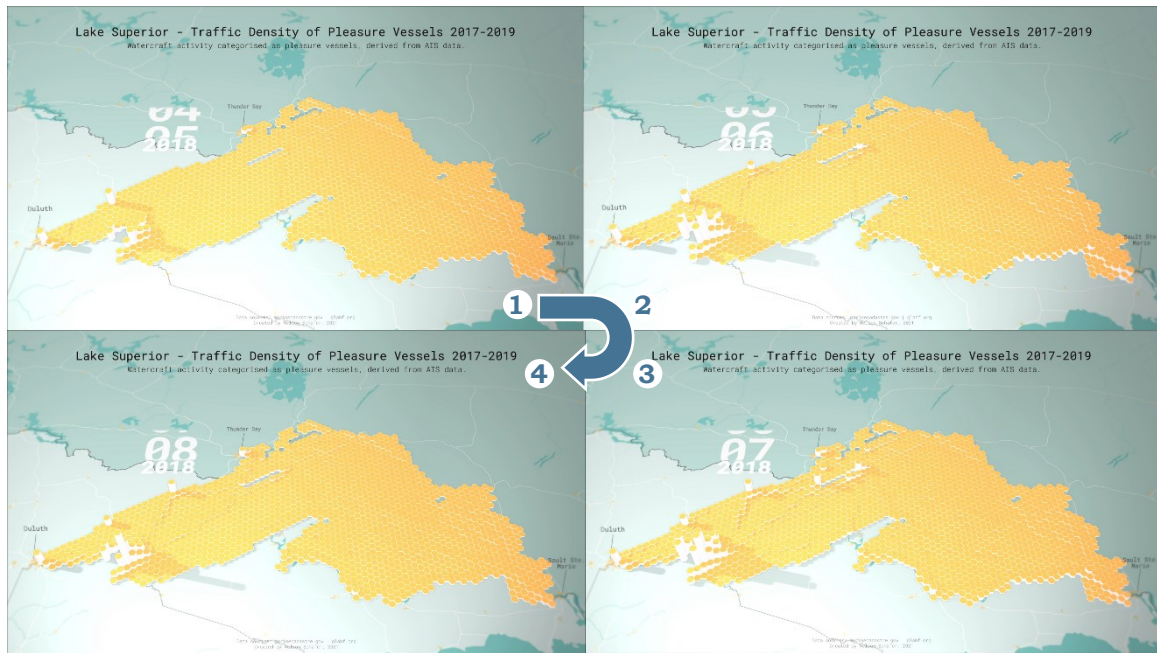


Figure 4 Sequence of images from the final output video

4.1.1 Data pre-processing in ArcGIS Pro

In the first step of the workflow, ArcGIS Pro is used to compose a custom basemap. For this purpose, free vector data are obtained from the websites of Geofabrik and Natural Earth (Geofabrik, 2021 & Natural Earth, 2021a). When creating the basemap, attention was paid to extend it significantly larger than the actual area of interest, as the animation looks down at an angle from above onto the 3D scene and thus covers a large area. In addition, the scale selected for the animation was already taken into account in this work step, since symbols can be adapted later, but this would have to be laboriously conducted in Adobe Illustrator. During the selection and subsequent filtering of the input data, care was taken to preserve only the major features of the landscape and to filter other objects based on, for example, the feature size or category. All in all, the result is a coherent and simple basemap which, with its symbology, does not distract the viewer and provides spatial and logical context for the area around Lake Superior.

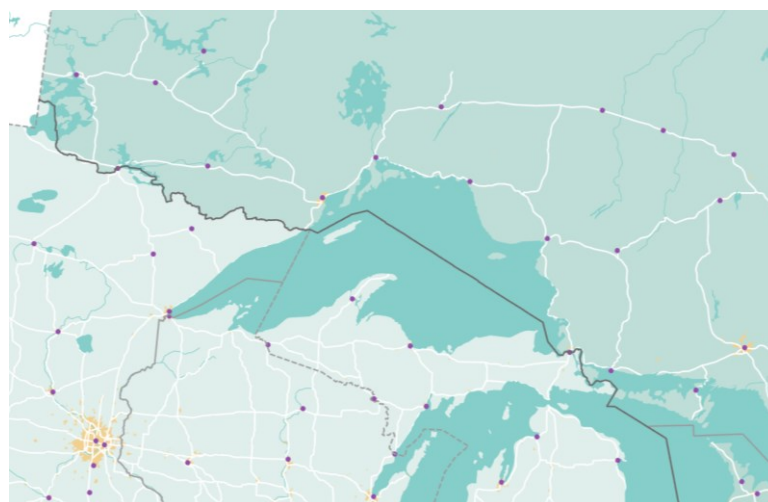


Figure 5 Basemap layout composed in ArcGIS Pro

The main dataset, on which this animation is based, was fetched from Esri's U.S. Vessel Traffic application which allows to download manageable subsets of maritime traffic lines of predefined areas in the United States of America (Esri, 2020). The data includes rich attribute data, however, for this workflow only the fields describing the type of vessel and the time code of each route were utilized. In ArcGIS Pro the downloaded data for each month from March 2017 to December 2019 was clipped to the surface area of Lake Superior and filtered by the vessel type attribute to only include vessel tracks that fall into the category of pleasure vessels.

Next, a grid of equally sized hexagons was generated by using the geoprocessing tool *Generate Tessellation*. It required a number of attempts to find an applicable size of the hexagon grid since a large number of hexagons heavily influences the required graphical processing power later in the animation process in Adobe After Effects. Eventually an area of 50 km² per hexagon was discovered as a good compromise between level of detail and the computing workload. This gives a total of 1,750 hexagon polygons which cover the area of Lake Superior. In the next step, a tool in ArcGIS Pro called *Spatial Join* was made use of in batch mode for each month of the shipping traffic input data. With this tool the number of features, in this case ship route lines, can be counted for every hexagon. The layers resulting from this process consist of the previously generated hexagonal grid with an attribute value for each polygon that indicates how many ships have passed this area in the month. Finally, the separate hexagon grids with shipping activity values of every month got combined into a single dataset using the *Merge* geoprocessing tool.

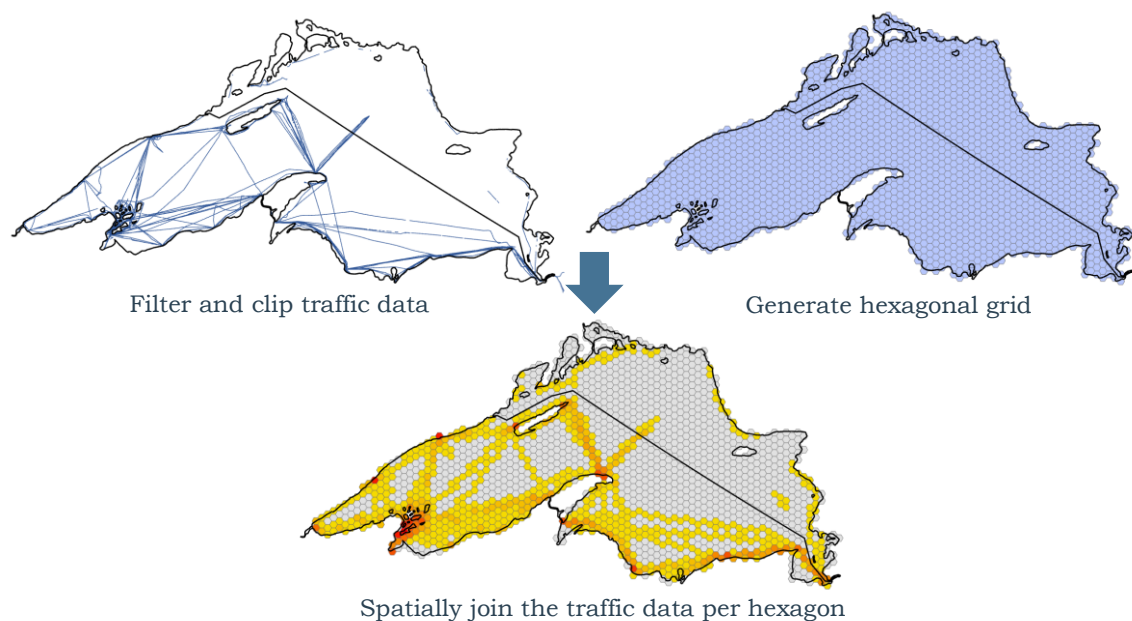


Figure 6 Workflow to create a hexagon grid with traffic density values for one month

4.1.2 Data import in Adobe After Effects

It is cumbersome to import these created map elements from ArcGIS Pro into Adobe After Effect for the animation process. In order to be able to achieve this, several additional steps of data preparation are required. Firstly, it is important to understand that in Adobe After Effects only objects which are in an own layer can be animated independently. This means that each hexagon had to be imported as a separate layer because all of them are designated to be animated differently based on their unique traffic activity values.

To achieve that all hexagons appear in a separate layer, the following steps were conducted. In the attribute table of the hexagon vector layer in ArcGIS Pro all polygons were sequentially numbered with an identification number (ID). This was achieved by using a python script published on Esri's technical support website (Esri, 2019). In the next step, the polygons of the hexagon grid were symbolized by classifying them by the just created unique ID value. This classification by the ID creates clearly separated elements in the layer hierarchy which are possible to split up into single layers in a later step.

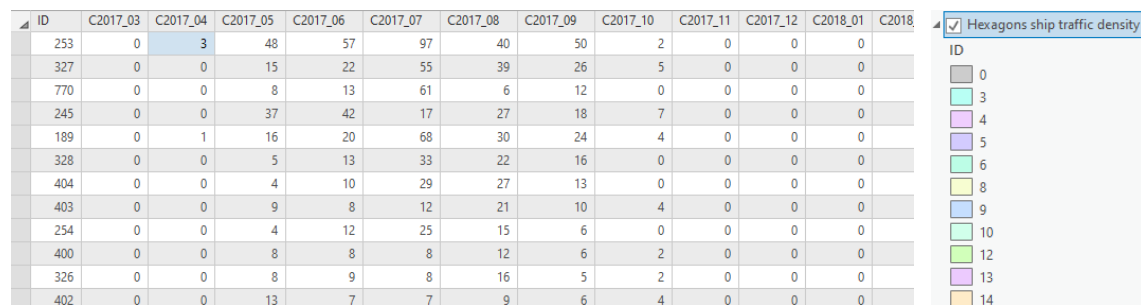


Figure 7 Left: Attribute table of the hexagon grid with the unique ID and the traffic values for each month. Right: the classification by ID in the contents pane

One trick that was used to reduce the hardware load later in After Effects caused by too many layers. All hexagons without any activity, meaning that according to the dataset zero ships moved through the hexagon throughout all months, were assigned the ID number 0. Like this, 379 out of 1,750 hexagons were assigned the same ID and would thus not get split up in separate layers in the next step. This prevents to demand unnecessary processor load in the animation process because the number of elements in the animation composition is reduced.

A second important principle to understand, is that in the established workflow the map contents lose all attached attribute information once the layout is exported. This means that all the information on shipping traffic density in the attribute table is lost after the export from ArcGIS Pro. To overcome this problem, the attribute table of the dataset can be exported as a JSON file, which will then be used in a later step to reassign the polygons to their according attribute values. This assignment is possible because the export from ArcGIS Pro to the Adobe Creative Cloud preserves the layer names of the map content (Esri, 2021c). Since the layer names of the hexagon polygons is their assigned ID, a connection between the ID and the attributes in the JSON file is possible.

In principle this developed workaround achieves to overcome the issue that Adobe After Effects does not have the capabilities to read spatial file formats. In summary, to circumvent the loss of attribute information of the geometry layers, the information of the spatial databases is split up into two components. On the one hand the geometry is transferred to Adobe After Effects by converting the symbol shapes into Adobe Illustrator files which can then be read by the animation software. Whereas on the other hand, the attribute information is saved as a JSON file. Based on the matching assigned ID numbers in both, the geometry files and the attribute files, a connection can be achieved in a later step via scripting in Adobe After Effects.

At this point in the workflow, the attribute information was exported as a JSON file and the vector geometry layers were prepared to be exported as well. For the transfer of the latter to Adobe After Effects, the map layout in ArcGIS Pro was exported as a document in the Adobe Illustrator Exchange (AIX) file format. With this output file format, the map

layout can be imported to software of the Adobe Creative Cloud with a mostly retained and organized layer structure (Esri, 2021c). As a next step, Adobe Illustrator was used to convert the just exported map layout from an AIX file to an AI (Adobe Illustrator) file. The AIX file format was developed by Esri and can not natively be read by software of the Adobe Creative Cloud. To make this possible anyway, plugin *ArcGIS Maps for Adobe Creative Cloud* developed by Esri is used to enable the import of the data into Adobe Illustrator. The download and basic use of this extension is complementary. However, a subscription to ArcGIS Online is required for advanced functionalities such as the in this workflow conducted import of AIX files from ArcGIS Pro (Esri, 2021a).

Running the import process in Adobe Illustrator creates a layer structure in Adobe Illustrator similar to the original content hierarchy saved in ArcGIS Pro. During this process, Adobe Illustrator, among other things, generates separate layers for each individual class if data records have been classified into different categories in ArcGIS Pro. As the hexagonal layer of Lake Superior had been classified by the unique ID of the single polygons, 1,371 layers containing a single hexagon each were generated in Adobe Illustrator. This result is desired because as mentioned in the beginning of this chapter, Adobe After Effects requires the division of all objects that are intended to get animated into individual layers. In addition to that, all these individual layers must be in the highest hierarchy level in Adobe Illustrator, meaning that they must not have any layers above. To achieve such a layer structure, simple selection and drag and drop operations can be performed in the Adobe Illustrator layer window. Additionally, a script published by a contributor on GitHub was used to allow batch renaming of layers, which further improved the readability and coherence of the layer hierarchy (Lavoie, 2015). After only little effort, the desired layer structure like shown in figure 8 can be achieved. With that, the management of the data in Adobe Illustrator was completed.

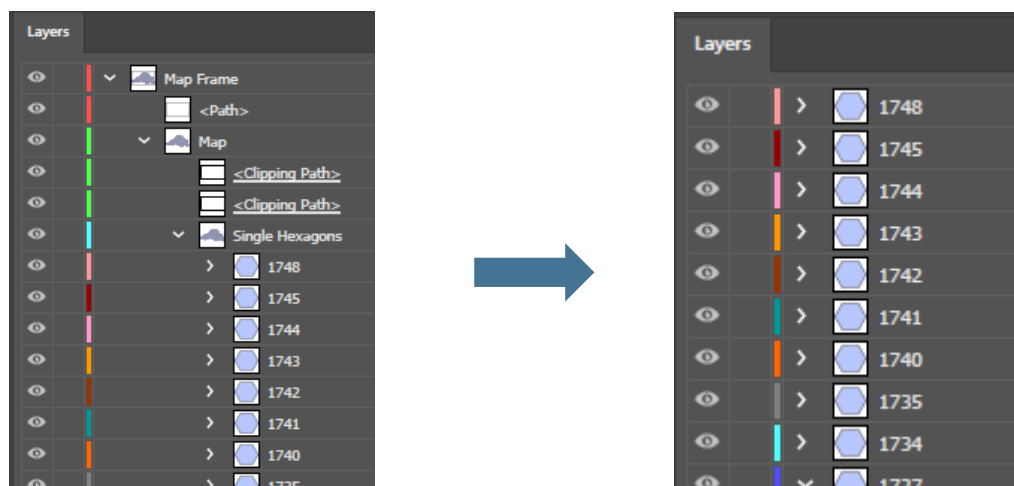


Figure 8 Restructuring of hexagon polygons from sublayers to top-level layers in Adobe Illustrator

Since Adobe Illustrator and Adobe After Effects are part of the same Creative Cloud ecosystem, an import of the created document is smoothly possible. One setting to be mindful of, is to import the AI file as a composition with the setting *retain layer sizes* selected. That way the anchor points of all objects will be carried over into After Effects.

Furthermore, after the import of the Adobe Illustrator project file, it is necessary to convert layers which are intended to get animated into vector layers of Adobe After Effects (see figure 9). Once this last step is conducted, all necessary parts of the workflow of importing animatable GIS geometries into Adobe After Effects are completed.

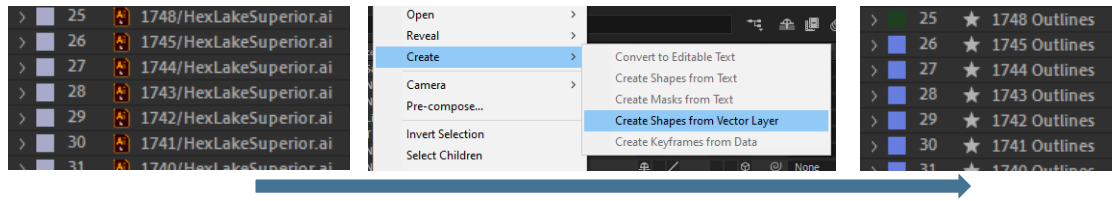


Figure 9 Conversion of AI layers to vector layers in Adobe After Effects

4.1.3 Animation in Adobe After Effects

The method of animation of this map composition was adapted from one of Adobe's tutorials on how to create data-driven changes in After Effects (Scott, 2017). The expressions from said workshop were used as a starting point from which the methodology of the animation about Lake Superior was further developed. The basic functionality of this animation is that each of the created hexagons is altered in its height according to the value of ship traffic density while time is progressing in monthly steps.

To implement this functionality, the height value of each hexagon was adjusted by using a so-called expression, in which the value for each frame of the animation is calculated by using the according attribute information from the JSON file.

In Adobe After Effects an expression is a short code, based on the syntax of JavaScript, which can be used to alter values of almost any layer property in After Effects (Animoplex, 2021). The expression that was developed for this animation starts by defining maximum and minimum values of both the maximum change of height of the hexagons as well as the range of occurring ship traffic density values. Hereafter, the layer name of each hexagon, which are the assigned ID numbers from ArcGIS Pro, are extracted and their matching counterpart located in the linked JSON file. Then, after reading the matching monthly ship traffic values the height value of the hexagon is altered accordingly. Simultaneously to the change of height, each hexagon is extruded to look like a three-dimensional pillar. The length of the extrusion is determined by a second expression that calculates the necessary amount of extrusion based on the current height of the hexagon. Lastly the fill colour of each hexagon is changed based on the current traffic density value by assigning an expression that sets the fill to an according value of a graduated colour ramp. An example of an assigned expression can be seen in figure 10. The complete source code of all used expressions with detailed comments can be found as attachment 1 of this thesis.

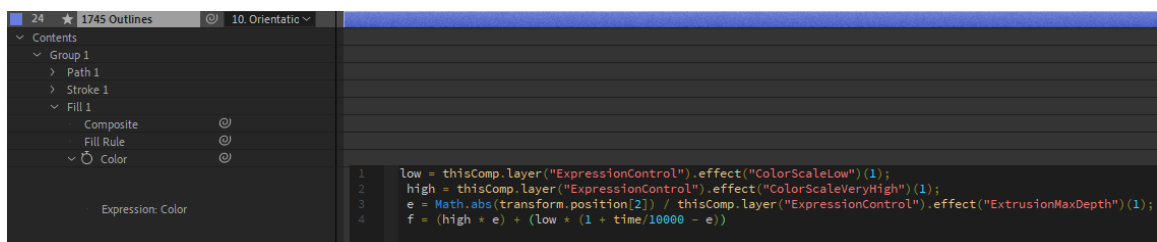


Figure 10 A layer in After Effects with a assigned expression to alter the colour

Since more than 1,371 hexagons in the scene are required to have the expressions assigned to their properties, a script was developed that iterates through all selected layers and adds the desired expressions. In Adobe After Effects scripts and expressions are two different components that need to be distinguished. Differently than the already mentioned expressions, the now used scripts are not executed in Adobe After Effects directly. Instead, the software Adobe ExtendScript Toolkit CC is used to develop and execute scripts that can access tools and automate processes within applications of the Adobe Creative Cloud.

In summary, expressions were used in Adobe After Effects to control dynamic changes of object properties, in this case the height, extrusion, and colour changes over time. These expressions incorporate in their calculations the according ship traffic density values by accessing the linked JSON file. Additionally, because each hexagon is an individual layer, ExtendScript Toolkit CC is used to execute a script that automatically assign the coded expressions to each selected object. This workflow and the interplay of scripts and expressions is schematically visualized in figure 11.

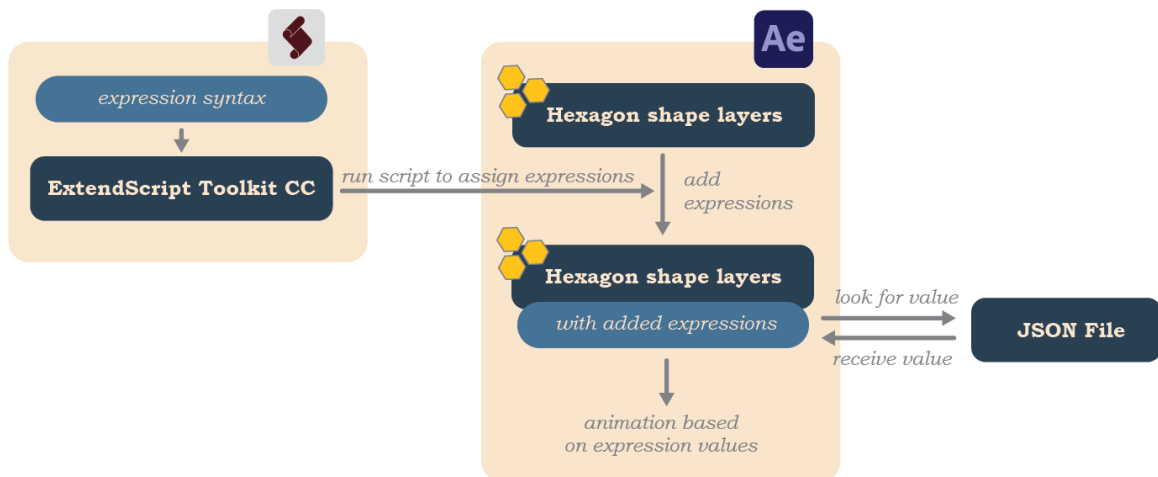


Figure 11 Workflow diagram for the setup of animation properties of the hexagons

After the just described setup of the main animation functionality, additional elements were added to the composition in Adobe After Effects. First and foremost, the basemap elements created in ArcGIS are added. In addition, to display the current time of the animation for the viewer, a time indicator was manually crafted which displays the current month of the shown data. The timer consists of a set of interacting text elements and mask layers and was manually timed to correspond to the animation speed of the hexagon objects. Finally, the timer was added as a 3D layer to the scene for a visually more interesting look. Furthermore, for improved spatial reference, three cities in the map were equipped with callout labels and animated manually. Other important elements include a moving camera, lights and text fields for the animation title and imprint. A collection of important composition elements can be seen in figure 12. The export of the animation to a 1920 by 1080 Full-HD video with 30 frames per second required a final render time of 14 hours.

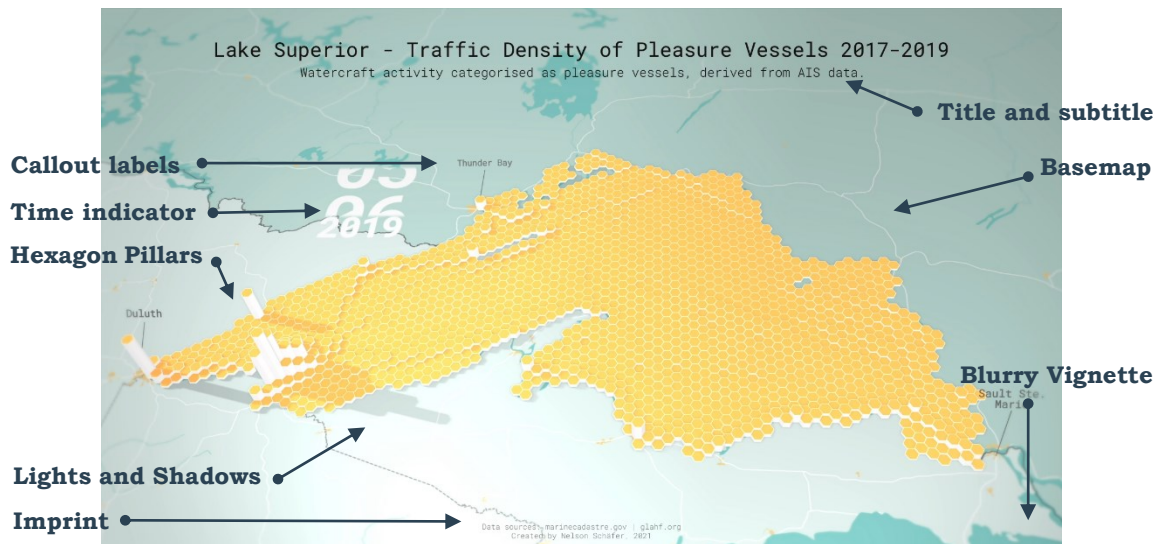


Figure 12 Composition elements of the animation

4.2 Animation 2: Piracy incidents in the Indian Ocean

Since 1990 more than 8,000 incidents of piracy and armed robbery have been recorded worldwide by the U.S. National Geospatial Intelligence Agency. Besides hijackings and kidnappings, the highest percentage of events were attempted boardings, attacks and robberies. A global hotspot for such incidents is for example the Gulf of Guinea along the coast of Ghana, Togo, Benin, Nigeria and Cameroon. But piracy is also tightly clustered in parts of the Indian Ocean and the South China Sea (ONI, 2021). This animation is showing 30 years, starting from 1990, of piracy reports in this area in a runtime of 128 seconds. It is targeting the general public as an audience and can be of educational and entertaining value by revealing trends and patterns.

In the first ten years of the animation comparatively few incidents were reported. The South China Sea and especially the surroundings of Singapore are the areas with culminations of the highest piracy activity. With the beginning of the 2000s a vast increase can be noticed. This can be seen most strongly in the area of the Arabian Sea, or in the Gulf of Aiden between Yemen and Somalia where an extreme accumulation occurs especially in 2009. Likewise, the sea around Sri Lanka seems to be a clear hotspot in these years but almost comes to a standstill in the 2010s years. Equally interesting is the area of the Somali coast in which the first clusters were formed in the early 2000s, but later shifted in 2009 to 2012 to take up the entire sea north of Madagascar. From 2013 onwards, the number of pirate incidents in the Arabian Sea has been steadily decreasing, while a relatively high density remains in the eastern Asian waters. Observations like all of the above can be a basis for follow up analyses to answer questions for example when combined with factors such as socioeconomic rationale (Nelson, 2020).

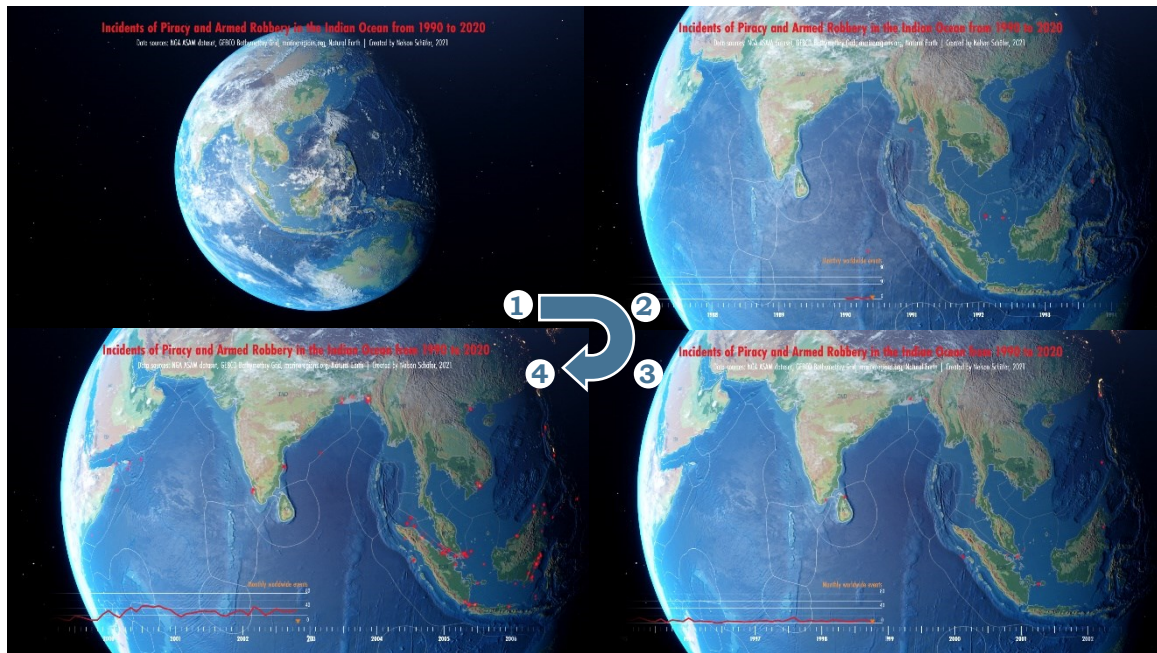


Figure 13 Sequence of images from the final output video

4.2.1 Data pre-processing in ArcGIS Pro

The information of so-called Anti-shiping Activity Messages (ASAM) is published by the National Geospatial Intelligence Agency of the United States of America (NGA, 2021). The location and date of the incidents are used in this animation to visualize spatial and temporal patterns in monthly intervals. For the pre-processing in ArcGIS Pro, the ASAM dataset is symbolized by classifying it by the month and year value of the attribute table. This is done out of the same reasons as explained in chapter 4.1.2, to achieve a division of the dataset into separate layers when transferring the data into the Adobe Creative Cloud environment. Auxiliary data in this animation are worldwide vector layers of country borders from Natural Earth and a dataset on Exclusive Economic Zones (EEZ), that is the maritime boundaries of sea territories. Furthermore, a TIFF image of worldwide ocean bottom and land elevation was stylized with a colour ramp that clearly divides between land and sea areas and added to the layout (see figure 14).

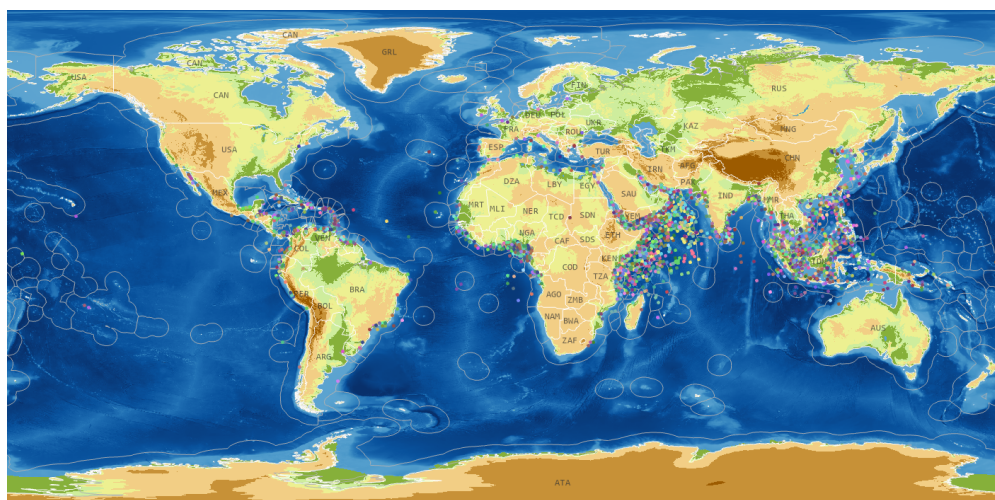


Figure 14 Map Layout of all elements in ArcGIS Pro

After the pre-processing and the map layout were finished in ArcGIS Pro the file was exported in the AIX file format, just as explained in the workflow documentation of the previous animation. Then the import into Adobe Illustrator with the Esri plug-in and the subsequent restructuring of the layer hierarchy took place, in order to import the data into Adobe After Effects.

In this animation no attribute information, in the form of a JSON table was utilized. Instead, additional side information was added to the animation by including a line chart of the total number of piracy incidents per month. This chart was generated in Microsoft Excel and subsequently exported to Adobe Illustrator. Here the graph and the chart elements were adjusted in their appearance and imported in the Adobe After Effects project. Lastly, as a third input data, the graphical elements for a timeline indicator were designed in Adobe Illustrator and added to the Adobe After Effects project as well.

4.2.2 Animation in Adobe After Effects

The symbolization and the animation of the points of the piracy incidents was designed as points that light up quickly and then fade out within a few seconds. Because of this design choice it is possible for the viewer to see connections over a longer period of time and thus adding information value to the animation. The latest events are highlighted in bright red and older events can only be recognized in light orange. This is achieved by a combination of changes in fill colour, glow effects and changes in opacity which was animated for one just layer and can then be copied to all other monthly point collection layers.

The individual layers of monthly incidents did not require any external JSON file to retrieve timestamp or attribute information as input for animation parameters. Instead, because each layer covers approximately the same time span of one month, a regular sequence of the monthly layers was sufficient to create a correct logical and temporal order. A standard tool in Adobe After Effects called *Sequence Layers* can be used for this purpose and generates the sequencing of selected layers. Additionally, parameters like overlap can be specified in the tool. The resulting structure in the timeline of Adobe After Effects can be seen in figure 15.

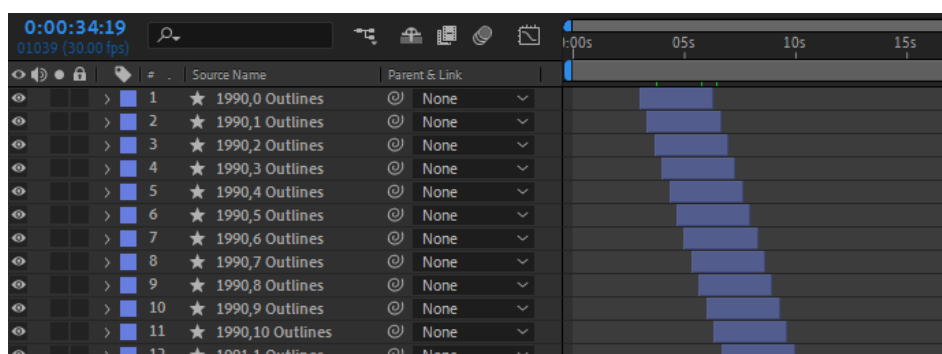


Figure 15 Sequentially ordered layers in the timeline of Adobe After Effects

For this animation the capabilities of a plug-in called *Video Copilot Orb* were taken advantage of. This free extension allows to generate a three-dimensional sphere and to wrap any image or 2D animation around the sphere. With the help of realistic layers this allows to recreate a representation of the Earth in After Effects. Textures for a cloud cover, a displacement map, an illumination map and atmospheric effects are included in the extension footage and were utilized in this animation (Video Copilot, 2021). Additionally, the prior created colour shaded relief was used as a texture map on the globe. Likewise,

any other two-dimensional data can be mapped onto the sphere which was utilized in this workflow to add the locations of ASAM events and the additional vector layers to the globe composition.

As the data imported from Adobe Illustrator into Adobe After Effects are just the geometries without any geographical reference, a technique had to be found to retain the correct positioning of the input data. A simple solution to this is to always use the same scale and map extent in the map layout of ArcGIS Pro. By doing so, all separately exported vector data have the same centre point and can be positioned spatially correct in Adobe After Effects without having to conduct manual adjustments.

The finished sequential animation of piracy point layers along with the other spatial datasets like country boundaries and maritime regions were then added as textures to the sphere from the *Video Copilot Orb* extension. Along with atmospheric effects, several layered effects and a slow spin of the sphere a visually impressive representation of the Earth was implemented on whose surface the locations of piracy event locations are animated sequentially.

In the final step, overlay elements like the title text, imprint and timer were added in Adobe After Effects. The graph of the line chart was animated in a way so that the current value is revealed coherent with the progression of time in the timeline. Finally, the export of the map animation video to a Full-HD video took three hours with the hardware as specified in chapter 2.2.

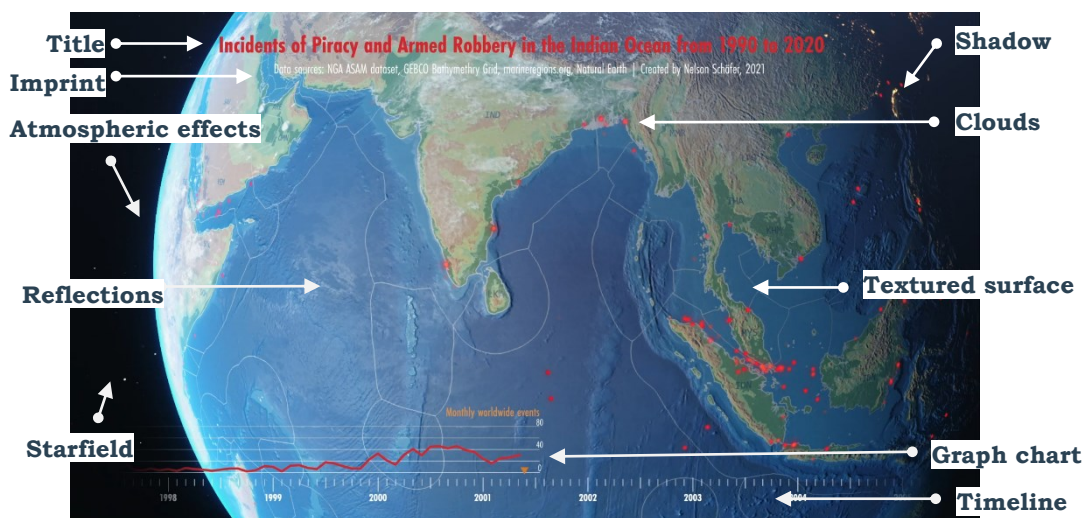


Figure 16 Composition elements of the animation

4.3 Animation 3: Vessel traffic in Port Piraeus

The chief port of the Greek capital, Athens is the Port of Piraeus. It is the largest port of the country and one of the busiest ports in the world. In an area of 39 km² more than 40,000 annual ship arrivals are managed. Traditionally the port was a passenger port for ferries and cruise ships, however since its privatization in 2009 its function as a hub of container and automobile shipments is growing. In 2013 more than 3 million containers, 15 million ferry passengers, 3 million vehicles and 2.3 million cruise passengers were served by the port (ESPO, 2014).

In this animation three days of maritime activity in the port area of Port Piraeus are visualized. Ships are depicted as small graphics that move along their dedicated route as time passes. A classification by ship type allows to detect more refined patterns of the

shipping traffic. Temporal regularities, such as the drastic increase in activity in the early morning hours, become visible through the animation. Additionally, spatial relationships and dynamics between the different port areas and the main shipping highways can be observed. For example, a continuous crossing of passenger ships in the northwest of the map, or the clear distribution of the ships according to the type into the various port areas become obvious. All in all, the interested viewer is able to get a good understanding of the daily amount and dynamic of the activity of this port area which would not be possible by statistical tables or static maps.

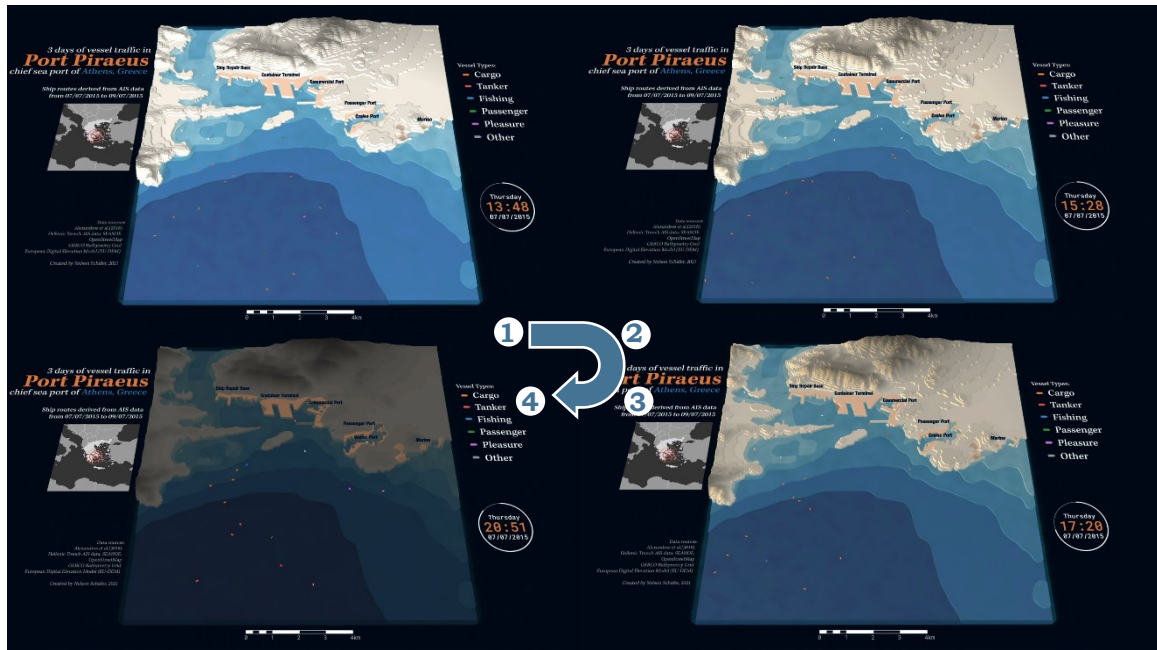


Figure 17 Sequence of images from the final output video

4.3.1 Data pre-processing in ArcGIS Pro

A great exception of the scarcity of high-quality ship traffic datasets mentioned in chapter 2.1, is an open dataset of AIS points of the Hellenic Trench region in the Mediterranean Sea covering one year of track records (Alexandros et al., 2018). From this dataset it was aimed to animate ships moving along their routes. In order to achieve this, extensive pre-processing of the data had to be conducted in ArcGIS Pro. First the data was clipped to the area of interest and filtered to a time span of three days to reduce hardware load in the animation process. Prior experience showed that heavy limitations in the usability of the animation software in form of lags and crashed occurs on the used PC when more than approximately 1,000 layers are loaded and visualized in the project.

From the filtering process more than 39,000 points remained available in the dataset. These points had to get connected to individual shipping routes distinguished by equal MMSI numbers of the AIS messages. The problem when connecting points of a ship route to a line is that the attribute information of the single points is lost. In this workflow this is important to consider because only the timestamp of the starting point and the end point of each line is preserved. In practice, this means that fluctuations in the speed or even complete standstill of a ship along the route cannot be taken into account. This can result in great distortions in the later animation, since the movement of a ship is based solely on the two time stamps from the beginning and the end of a route. Observing the data revealed that a large number of ships, while they were docked in port and then continued moving again, continuously sent AIS messages without significant movement.

To increase the accuracy of the ship animations, which assume a constant ship movement speed, AIS locations of stationary ships were filtered from the data set. For this, points with the value 0 in the SOG (speed over ground) attribute field were filtered out. The resulting reduction from 39,000 to 22,000 points confirms the necessity of this filter process.

The *Points to Line* tool can be used in ArcGIS Pro to connect AIS message points to individual ship routes. However, the online portal *MarineCadaastre.com* offers a set of Python tools that have been specially developed for the use of AIS data and also enable the calculation of ship route lines from input points. In addition, the Python script offers some additional functions such as thresholds of maximum distance or maximum time span between connecting points. Furthermore, the tool saves for each ship route the start time and the end time as values in the attribute table. Running this tool calculated 841 tracks from the input points of three days of AIS data in the area of interest of Port Piraeus.

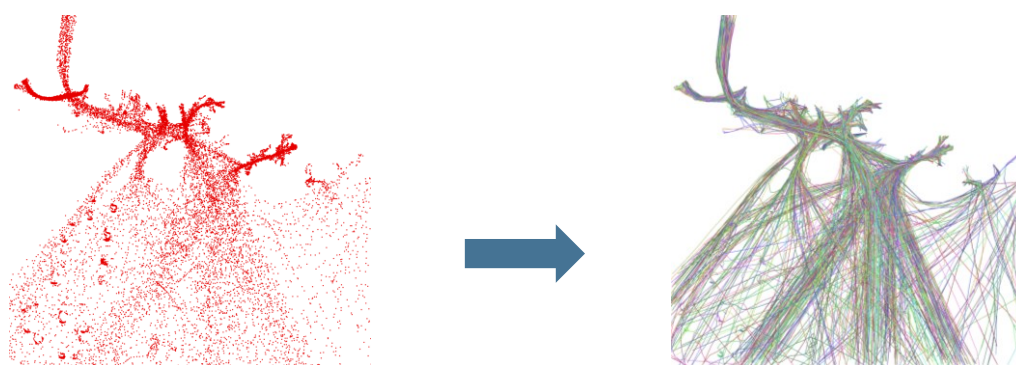


Figure 18 Connecting AIS point data to ship route lines

To further reduce the required computing power later during the creation of the animation, the line features were further processed. Since the lines were often composed of hundreds of input points, each generated ship route also contains a corresponding number of vector points from which the line was built. The average interval between AIS points from the same ship is approximately 10 minutes in this dataset. In most cases, however, this is an unnecessary level of detail for the animation purpose and can be simplified and thus save computing power, since the vector data is compressed.

For unknown reasons the executed tool *Simplify Line* in ArcGIS Pro had big problems to calculate the reduction of vertices of the lines. Instead, the tool *Simplify* was used in QGIS and was able to generate the desired result of simplified line features within seconds. The extent of the removal of vertices for the simplification of the lines is illustrated in figure 19.

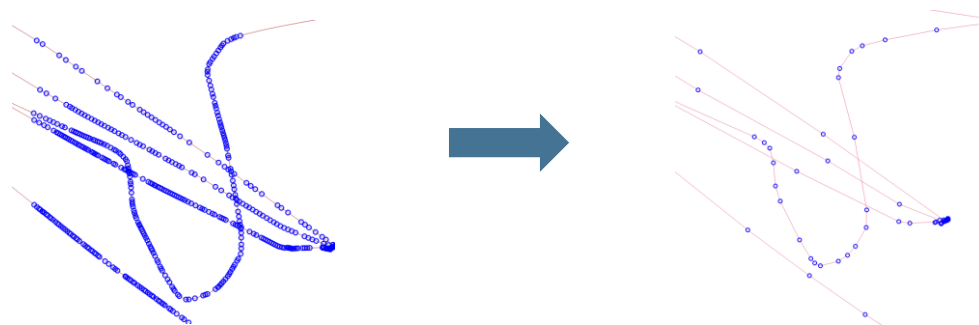


Figure 19 Reduction of vertices of the ship route lines

After this series of steps to prepare the geometry of the lines, the according attribute values had to be adjusted as well. First, just as in workflows of the previously created animations, an ID was generated that would serve as a connection key value between the geometry layer and the attribute table in Adobe After Effects. Furthermore, the columns *TrackStartTime* and *TrackEndTime* of the dataset were converted with Python scripting commands from a date format to their equivalent in the Unix time format, which describes a point in time in seconds since the 1st of January 1970 (Wikipedia, 2021b). This conversion was conducted because a linear time value like seconds can more easily be used programmatically to set animation parameters than a complex date format. From here the table was exported as JSON for further use as data-driven animation input in Adobe After Effects. The final set of columns in the attribute table, including the new time fields can be seen in figure 20.

OBJECTID *	Shape *	MMSI	TrackStartTime	TrackEndTime	SHIPTYPE	Shape_Length	ID	CETsStart	CETsEnd
1	Polyline	201100097	09/07/2015 10:12:26	09/07/2015 11:18:06	CARGO	0,145464	1	1436429546	1436433486
2	Polyline	201100121	09/07/2015 12:13:46	09/07/2015 13:17:25	CARGO	0,156516	2	1436436826	1436440645
21	Polyline	207829990	09/07/2015 18:27:08	09/07/2015 18:56:06	PLEASURE	0,055862	3	1436459228	1436460966
22	Polyline	207832330	07/07/2015 03:47:44	07/07/2015 04:10:14	PLEASURE	0,147665	4	1436233664	1436235014
23	Polyline	209074000	07/07/2015 00:47:26	07/07/2015 04:24:27	PLEASURE	0,089293	5	1436222846	1436235867
24	Polyline	209074000	07/07/2015 17:48:01	07/07/2015 23:52:54	PI PLEASURE	0,080636	6	1436284081	1436305974

Figure 20 Available attribute information for every generated ship route

Apart from the ship route information, the animation includes a terrain representation that was constructed from several layers of height data. Bathymetry data from GEBCO and land elevation data from the EU-DEM dataset were processed for the creation of the layer elements (BODC, 2021 & Copernicus Land Monitoring Service, 2021). However, the very coarse resolution of the available bathymetry data was not sufficient to be used as direct input to generate a three-dimensional terrain representation in the animation scene. This was a determining factor for the design decision of generating a stylized terrain in the form of a series of simplified stacked layers as shown in figure 21. To create the slices of terrain heights as vector polygons, a series of processing steps had to be conducted. First, the input data was resampled to a smaller pixel size and additionally altered with a low-pass filter to reduce dominant edges resulting from the large pixel size. Then the *Contour* tool of ArcGIS Pro was used to generate contour polygons from the height values of the raster file. After that, the tools *Simplify* and *Smooth Polygon* were used to further generalize the vector data until appropriate for the scale of the animation. Additionally, a detailed vector layer of the coastline from OpenStreetMap was added as height information at sea level to create a precise representation of the shape of the area. Lastly, a blue graduated colour ramp for the height slices below sea level and a white symbology for the land terrain slices was applied. The transformation of the input data into the final output can be seen in figure 21.

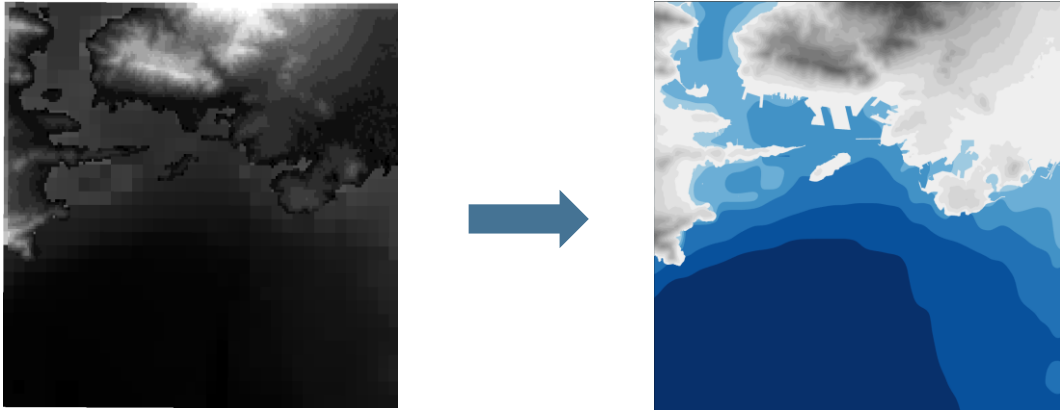


Figure 21 Processing of input height images to polygon vector layers

To improve the information content in the animation port regions of the Piraeus harbor were retrieved from OpenStreetMap via the *overpass turbo* query tool and added to the map layout (Raifer, 2021). Finally, an overview map to help the viewer locate the map content on a smaller scale was created with a dataset of country borders from the Natural Earth data portal (Natural Earth, 2021a).

Next, the established workflow, which is elaborated in previous chapters, was used to import the collection of vector layers from the map layout into After Effects via Adobe Illustrator.

4.3.2 Animation in Adobe After Effects using ExtendScript

The animation of the moving ships was created first in Adobe After Effects. The way the animation works is that the individual lines of the imported ship routes begin at their start time at the starting point and build up until the complete line is finally drawn at the respective end time. A symbol of a ship is then set so that it attaches to the continuously moving line. By making the actual line object of the route invisible and the symbol of the ship following the line, the impression of freely moving ships constructed. The methodology of this animation effect is shown in figure 22 and is explained in the subsequent paragraphs.

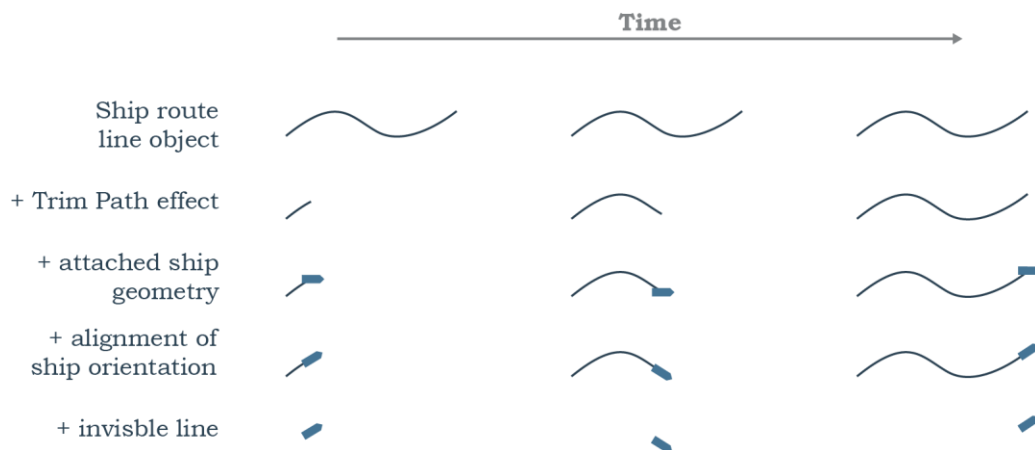


Figure 22 Stages in the workflow of creating moving ships from lines

As the data of the ship routes includes 841 lines and each feature requires its individual time to start and end the animated ship movement, a manual setting of the animation parameters is not feasible. Therefore, the Adobe ExtendScript Toolkit CC application is

utilized to programmatically define the animation parameters for each line individually by reading the according values from the JSON file. As an example how scripting with ExtendScript works for Adobe After Effects, the used script to generate data-driven ship animation parameters is explained in detail in the following. The whole script with comments can be found as attachment 2 to this thesis.

As preparation before running the script it is required to do two things. First, a graphical representation of a ship has to be created and moved to the first position of the layer list in Adobe After Effects. Secondly, in the same composition, all to be animated ship track layers have to be selected. The Script starts by linking to an external library called *json2.js*, which allows to parse JSON files with JavaScript, respectively ExtendScript, and was fetched from a public GitHub repository (Crockford, 2019). With the help of this library the JSON file with the attribute information of the shipping routes is parsed.

```
#include "json2.js";
var data
function readJSONFile(file){
    file.open("r");
    data = file.read();
    file.close();
    data = JSON.parse(data);
}
readJSONFile (File ("~/Desktop/Piraeus.json"));
```

In the next step of the script, the currently active composition in After Effects is determined and the currently selected layers in the composition, which are the ship routes, saved in an object array.

```
var proj = app.project;
var comp = app.project.activeItem;
var layersSelection = comp.selectedLayers;
var arrayLength = layersSelection.length;
```

Next, the duration of the animation is set to 90 seconds and the maximum and minimum time value of the ship movements is defined in Unix time seconds.

```
var output_start = 0;
var output_end = 90;
var input_start = 1436220004;
var input_end = 1436479107;
```

After the declaration of all needed variables, a loop is started which iterates through all selected layers and conducts from here onwards listed operations for each layer. First the name of the layer, which is for example *123 Outline* is read by the script and the number, which is the assigned ID, is extracted. The script then searches for the matching ID number in the JSON file and saves the desired values for the three needed variables of ship type, start time and end time of the route.

```
var name = layersSelection[i].name;
var nameparts = name.split(" ");
var number = parseInt(nameparts[0]) -1 ;
var input_begin = parseInt(data[number].CETsStart);
var input_end = parseInt(data[number].CETsEnd);
var shiptype = data[number].SHIPTYPE;
```

Subsequently the start and end time of the ship route gets converted to the time span of the ship animation, which was previously defined as 0 to 90 seconds.

```
output_trimbegin = output_start + ((output_end - output_start) /
(input_end - input_start)) * (input_begin - input_start);
output_trimend = output_start + ((output_end - output_start) /
(input_end - input_start)) * (input_end - input_start);
```

Based on these fetched and calculated variables, the animation parameters of the line object are set. First, a so-called *trim path effect* is added to the object, which allows to trim the ship route line between a set start and end value (Adobe, 2021).

```
layersSelection[i].property("ADBE Root Vectors
Group").addProperty("ADBE Vector Filter - Trim");
layersSelection[i].content("Trim Paths
1").end.setValueAtTime(output_trimbegin,0);
layersSelection[i].content("Trim Paths
1").end.setValueAtTime(output_trimend,100);
```

After this, all animation parameters for the line symbols are set. The result is a line that starts to get drawn at its dedicated start time inside the 90 seconds animation span and is fully drawn at its dedicated end time. In the next part of the script, the created layer of the ship geometry is changed in its parameters to follow the tip of the drawing line over time and to represent a ship moving along the route.

First, the parsed value of the ship type of the route is used to determine a fill colour of the created ship shape object.

```
Switch(shiptype) {
    case "CARGO":
        fillcolor = [223,120,62]/255;
        break;
    case "FISHING":
        fillcolor = [52,131,193]/255;
        break;
    case "PASSENGER":
        fillcolor = [45,139,62]/255;
        break;
    case "PLEASURE":
        fillcolor = [187,109,213]/255;
        break;
    case "TANKER":
        fillcolor = [228,78,84]/255;
        break;
    case "OTHER":
        fillcolor = [146,151,155]/255;
        break;
    default:
        fillcolor = [146,151,155]/255;
}
symbolLayer.content("Shape 1").content("Fill
1").color.setValue(strokecolor);
```

Then the behaviour is added, so that the ship object is following the tip of the ship route advancing with the trim path effect. Additionally, the orientation of the ship objects is adjusted accordingly. The source code for the expressions of this functionality were sourced from a tutorial blog by Motion Boutique (Motion Boutique, 2020).

```
var myExpression = "shapeGroup = thisComp.layer(\"" + layernamenumber + " Outlines\");myPath = shapeGroup.content(\"Group 1\").content(\"Path 1\").path;trimEnd = shapeGroup.content(\"Trim Paths 1\").end / 100;endPt = myPath.pointOnPath(trimEnd);endps = endPt + thisComp.layer(\"" + layernamenumber + " Outlines\").transform.position;";
symbolayer.transform.position.expression = myExpression;

var expressionrotation = "shapeGroup = thisComp.layer(\"" + layernamenumber + " Outlines\");myPath = shapeGroup.content(\"Group 1\").content(\"Path 1\").path;trimEnd = shapeGroup.content(\"Trim Paths 1\").end / 100;tg = myPath.tangentOnPath(trimEnd);a = Math.atan2(tg[1],tg[0]);radiansToDegrees(a)";
```

In a last step, the visibility of the ship object is animated with keyframes at the according start and end time of the ship movement so that it only becomes visible when the movement along the line is in motion.

```
symbolayer.transform.opacity.setValueAtTime(output_trimbegin-0.01, 0);
symbolayer.transform.opacity.setValueAtTime(output_trimbegin, 100);
symbolayer.transform.opacity.setValueAtTime(output_trimend, 100);
symbolayer.transform.opacity.setValueAtTime(output_trimend + 0.01, 0);
```

After this iteration for one ship object and one line object, the script duplicates the ship object.

```
comp.layer(1).duplicate();
```

Similarly, the next of the 841 ship routes is animated in the same way by referencing its individual parameters from the JSON file. In a last step the visibility of the ship lines is switches off so that only the ships are visible in the animation. With that the animation of the ship movements was completed and the scene could be created in which the animated ships would be played.

To create a three-dimensional representation of a terrain and the sea ground, the previously calculated polygons of different slices were used. First the terrain polygons were moved to different heights in regular increments. Next, the polygons were extruded vertically to fill the gaps between single layer to create a continuous terrain object with connected steps.

Another unique feature of this animation of Lake Piraeus is the complex system of applied lighting. Three light sources, an ambient light for general brightness, a light source from the sun and a light source from the moon, through their interaction, result in a realistic light representation of day and night cycles in the animation. This lighting technique can help the viewer to better understand the temporal relationships of the animation more intuitively as phases of day and night become obvious. Additionally, less time has to be spent at look at the time indicator of the animation. To visually improve this effect of day and night cycles the moving ships were animated to have a glow effect during the night.

With the help of several online applications a realistic course of the sun and the moon to simulate their light impact on the scene was created. The specific parameters of the region of Port Piraeus like the altitude, azimuth, light colour and intensity of the sun and moon light were investigated in hourly intervals for the depicted three days in July 2015 (Hoffmann, 2021). From the fetched information, angles were measured in the scene of Adobe After Effects and the light parameters were manually set for the light objects in order to imitate a realistic change of illumination. The paths of the light sources can be seen in figure 23, and the impact of the realistically moving sun is depicted in figure 24.

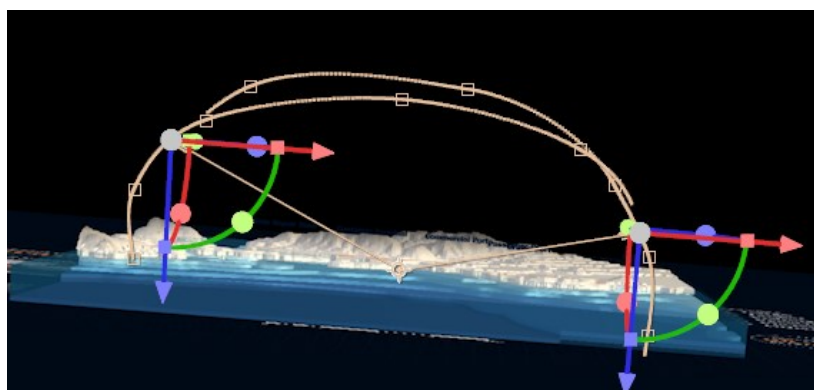


Figure 23 Motion path of the light source of the moon and sun throughout the animation



Figure 24 Realistic movement of casted shadows from the sun light source

A large number of other visual adjustments and animation elements were added to the animation project like vignettes, a water surface, text elements and the time indicator. In combination all these additional elements help to better understand the animated ship movements by giving logical, spatial and temporal context information and by improving the visual aesthetic of the map animation. A comprehensive overview of the map elements can be seen in figure 25. The rendering of the 90 seconds Full-HD video output lasted 19 hours on the hardware specified in chapter 2.2.

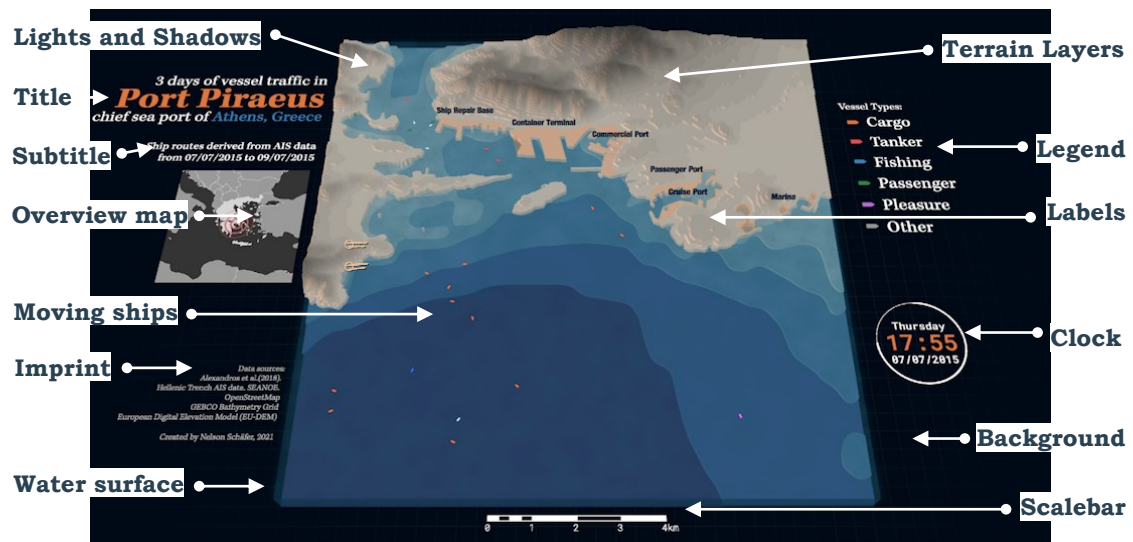


Figure 25 Composition elements of the animation

4.4 Animation 4: Transits of Arctic shipping routes

The opening of ship passages such as the Suez Canal has resulted in enormous savings in terms of travel distance and thus costs for the shipping industry. A similar alternative could be opened up in the coming decades by traveling through the Arctic. To this day, however, complete transits across the Arctic are rarely made, the reasons for this being, among others, the long months these routes are blocked by sea ice. In 2019 the minimum extent of sea ice was recorded in March and it reached its maximum peak in September. Sections of the Northwest Passage (NWP) and Northern Sea Route (NSR) are used throughout the year, but a complete transit between the Pacific and Atlantic oceans is only possible for a few weeks a year and subject to large annual fluctuations.

This animation shows the year 2019 and the influence of the developments of the sea ice concentration on the usability of the main Arctic sea routes for complete transits. The exact definition of when a ship trip is considered a complete transit depends on the documenting authority, but all statistics are in the low double-digit range per year. At the moment, the NWP route is mainly used by small vessels without commercial use, whereas the NSR is regularly used by a few cargo ships and tankers. With the further annual melting of sea ice due to the effects of global warming and potentially rising oil prices, the arctic routes could develop as worthwhile alternative global ship routes in the future (NOEP, 2020). In combination with the included infographic this animation can give a comprehensive understanding on the impact of sea ice on the temporal usability of the arctic sea routes.

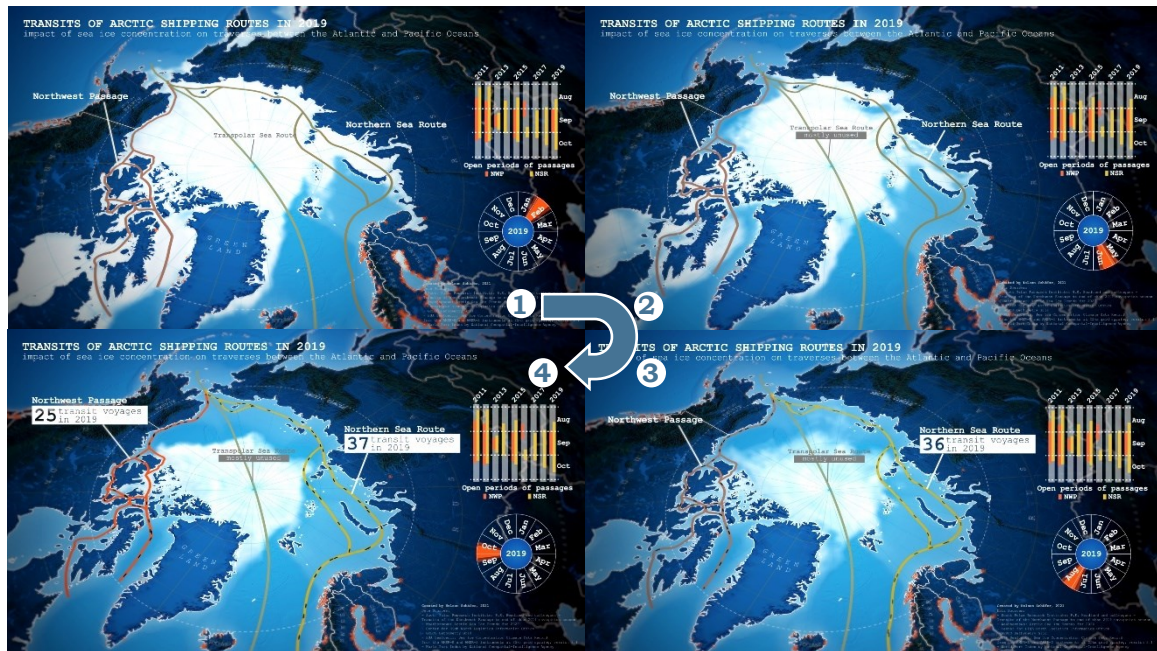


Figure 26 Sequence of images from the final animation

4.4.1 Data pre-processing in ArcGIS Pro

Only a small portion of the data used in this animation could be defined as GIS shipping traffic data, namely the vector lines of the three drawn Arctic shipping routes. Instead, the workflow for creating this animation is characterized by two special components. One the one hand this animation includes many small bits of information from a multitude of different sources that were combined in the animation to build a comprehensive informative visualization of the depicted phenomenon. The information on how many ships made transits on which route and when open periods of the passages were recorded was rather difficult to collect. In addition, this information is not spatial data, but statistics that have been compiled from tables, forums and newspaper articles online. Furthermore, a series of vector data was used to create a basemap that was as detailed as possible and provided with useful elements. Datasets for national borders, latitude and longitude grids lines, locations of ports, and manually placed country labels make up the elements of the basemap. The exact sources and origin of the input data can be found in table 1 in chapter 2.1. The main element of the basemap, however, is a detailed shaded relief, which was obtained as a raster file from Natural Earth (Natural Earth, 2021b).

The fact that this raster image of the basemap, along with 60 other raster files, is part of this animation is the second special characteristic of this visualization. The other 60 raster files are used in the animation to visualize change in the extend of the Arctic sea ice. Here, five images for each month of the year 2019 were compiled from raw data retrieved from the Copernicus Climate Data Store (Toudal Pedersen et al., 2017). The original files are made available as so-called netCDF files, a common machine-independent format to provide scientific data (NOAA, 2021b). Due to lack of experience of working with this kind of data and insufficient knowledge on the relevant automation, the pre-processing of these files resulted in not difficult but laborious manual work. In ArcGIS Pro each of the netCDF files of daily sea ice concentration were converted to raster information, assigned a fitting colour ramp and subsequently exported as 60 individual PNG images for further use in the animation software.

4.4.2 Data transfer to Adobe After Effects

Apart from the large number of different layers, the export of the vector data from ArcGIS and the subsequent transfer via Adobe Illustrator to After Effects was the same established workflow as explained in chapter 4.3. As the control of the animation properties would not be data-driven by attribute information, no additional fields had to be calculated and no JSON file was used in the further animation process.

Unlike the vector data, the image data of the map composition in ArcGIS Pro are not suitable for a transfer to Adobe After Effects via AIX file format. This is because one of the limitations of the AIX format is that some elements cannot be transferred to AI without loss. As an example, hatch fills and gradient symbols of feature symbology in ArcGIS Pro can lead to problems or cannot be transferred at all. Another restriction that is relevant for this workflow is that image layers from ArcGIS Pro can be transferred to AI via the AIX format, but in this process they get subdivided into a grid of tiles. This division of the image data can lead to unpleasant picture artifact, since the boundaries of the tiles that make up the picture are not seamless. Small tear lines as shown in figure 27 are visible and would thus also appear in the final animation output. For this reason, the raster files were prepared as separate map layouts in ArcGIS Pro and then exported as individual PNG files. By choosing the same parameters in the scale and the map frame extent as with the export values vector data, the vector data and the exported raster files can later be spatially matched in Adobe After Effects.

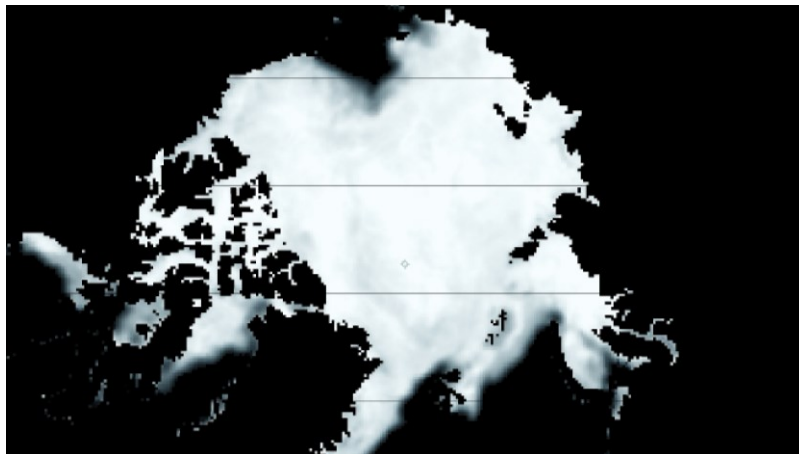


Figure 27 A raster file with clearly visible tile lines when exported via the AIX file format

4.4.3 Animation in Adobe After Effects

Once all required elements were imported in Adobe After Effects, the manual assembling of the animation could begin. As no scripts were used to generate data-driven animation settings, all map elements were animated manually. As a starting point to define the duration of one year, a sequence of the sea ice concentration raster files was generated in the same way as shown in chapter 4.2 with the piracy events.

Based on this set time frame, all other animation timings were derived from and manually placed along the timeline. For example, the timer that can be seen in the animation, whose graphic elements have been designed in AI, was animated to cover one year of time by simply setting keyframes to start and end the clock in accordance to the first and last image of the sea ice sequence. Also, the time of change in colour and the appearance of the callout labels of the Arctic sea routes were adjusted manually in accordance with the timing of other elements of the animation and not derived from attribute values.

An effect was added to the Arctic routes as soon as they are shown as traversable in the animation, which imitates the movement of ships. It should be noted that these are not real route data from ship movements, as no dataset on this matter was found. Instead, the movement of the ships is simulated by a simple dashed stroke effect at irregular intervals. This was done to visually better explain to the observer at what times the ships can navigate the routes. In addition to all these listed elements, a large number of other adjustments and effects were added to the animation. Among others, light sources, a slowly rotating camera movement, text elements and a chart depicting the open periods of the Arctic passages were added to the composition in Adobe After Effects. The final rendering of this 28 second animation required 4 hours.



Figure 28 Composition elements of the animation

4.5 Animation 5: Ship traffic in the Hawaiian Islands

Hawaii's location in the middle of the Pacific isolates the state from other economies. However, also because of its location, Hawaii plays a significant role to link the mainland United States with other countries of the Pacific Rim. In this animation one week of ship traffic of the Hawaiian Islands port network is visualized. The animation reveals major route patterns and in what way the single islands are connected to each other. For the inter-island cargo, the port of Honolulu on the island Oahu is serving as a hub (State of Hawaii, 2008). As visible in the animation, most ships from outside the system head towards this port first and subsequently the cargo is distributed to its destination on the neighbouring islands. Additionally, due to the classification of the ships, areas of a specific trade are revealed. For example, activities from fishing vessels mostly emerge from the Honolulu port. Furthermore, the animation reveals for example where passenger vessels are repeatedly crossing between the islands of Maui and Lanai. By interested viewers the dynamics of an isolated island system, connecting ship lanes between islands and commercial maritime centres can be observed with this animation.

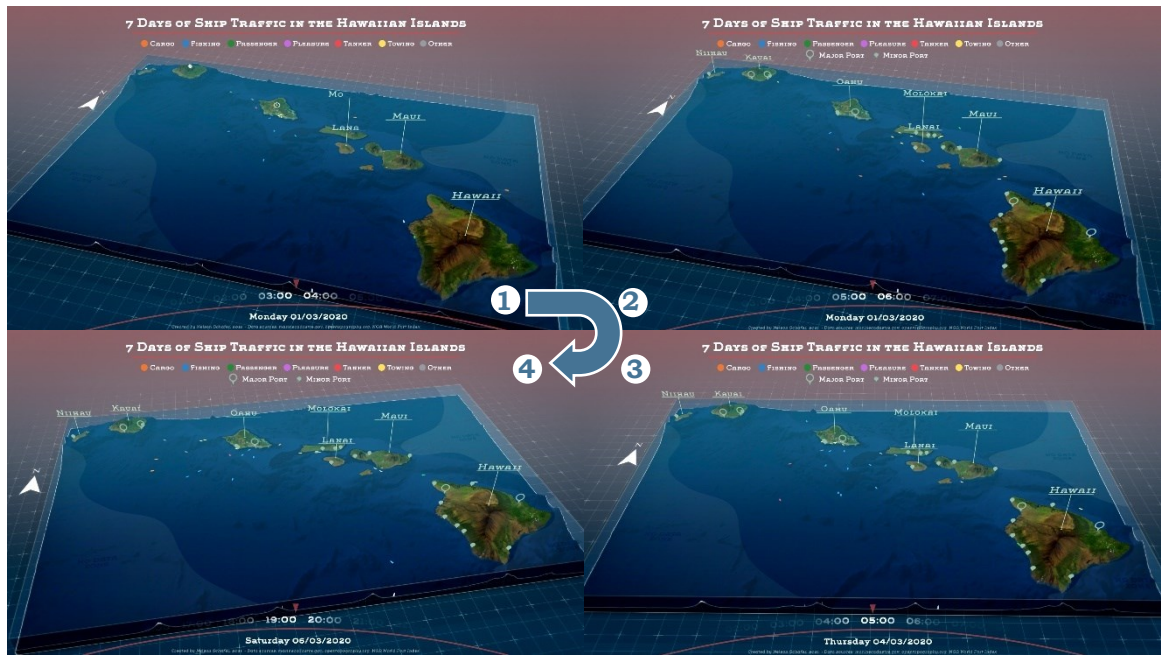


Figure 29 Sequence of images from the final output video

4.5.1 Pre-processing in ArcGIS Pro

The ship data animated in this visualization comes from *MarineCadastre.org*, a federal portal of several U.S. authorities on maritime topics, where daily AIS datasets are available for download as CSV tables. The entries in the CSV table were further processed with the Python toolsets for processing raw AIS data mentioned in Chapter 4.3, which are also available from this portal. The rest of the processing of the data is identical to the workflow from chapter 4.3 and thus only roughly repeated in the following paragraph. First, the individual AIS messages are converted into geo-referenced point objects and connected to route lines. Then the geometries are reduced in their number of vertices to remove unnecessary detail. AIS messages of a SOG below a value of 1 were not included in the calculations to improve the accuracy of the animation. In the attribute table the conversion of the time fields to Unix time in seconds and the assignment of unique identification numbers per route were conducted. Subsequently the attribute values were exported as a JSON file to be used as an input of the data-driven animation for the via Adobe Illustrator transferred shipping route geometries.

During the analysis of the ship data, it was noticed that in some unusual locations of the area no AIS messages were recorded. A reason for this could be insufficient coverage of AIS receivers in these areas. To indicate missing ship traffic information in these zones, polygons were drawn around these areas and later included in the map animation.



Figure 30 The map layout in ArcGIS Pro with zones of insufficient data in red

4.5.2 Terrain Builder Pro in Adobe After Effects

The unique feature in this animation of the Hawaiian Islands is the included terrain environment in the scene. This realistic representation of textured terrain was generated by using an extension for Adobe After Effects. The plug-in *Terrain Builder Pro* is available for purchase for 48\$ and allows to generate 3D terrain in Adobe After Effects (Envato Market, 2021). As input the script requires only two components, a colour map and a height map. The elevation data for this animation was retrieved from the Open Topography web portal and the matching the satellite images were extracted from Esri's World Imagery dataset (Open Topography, 2021 & Esri, 2021d).



Figure 31 User interface of the Terrain Builder Pro script

The plug-in provides functionalities to create a complete scene from the input data including the textured terrain, the background and lighting setup. In addition to this main purpose of the Terrain Builder plug-in, the extension also allows to manually place predefined elements onto the 3D environment terrain. As an example, the pin symbols of the harbors, as well as the labels of the island were created by using animation elements provided by the plug-in. Executing functions of the plug-in creates different elements in the scene but composes these by using building blocks from Adobe After Effects. Thus, the animation composition can be altered and expanded without limitations with all available tools of Adobe After Effects. This is proved by the integrated ship animation in the scene. For this, the imported layers of the ship routes were animated by using scripts in the same way as explained in chapter 4.3 in the animation of Port Piraeus. The output of this process, a two-dimensional layer of moving ships, was then simply placed in the height of the water surface in the three-dimensional scene of the Hawaiian Islands. For the process of combining the output of the *Terrain Builder Pro* script with other spatial data it is recommended to use the same extent of the map layout of the ship routes as the raster files that were used to generate the terrain in the plug-in. Since Adobe After Effects does not support any spatial coordinate systems all elements have to be placed manually in the animation composition. By using the same extent for all import data it is easy to place all components spatially accurate to each other, since only the centre point has to be matched manually.

Apart from the animated ships, the 3D landscape and the manually placed labels and markers, only few elements make up this animation. A simple title is explaining the viewer the content of the animation. Underneath the title a legend is defining the colour coding of the ship types and the symbols for the marked ports. A north arrow is helping the viewer to understand the location of the area of interest as the camera movement is changing the orientation of the scene slightly. Finally, a manually designed, timed and animated clock is indicating the current time and date. In the export it took almost 16 hours to render this 90 second animation to a Full-HD video.

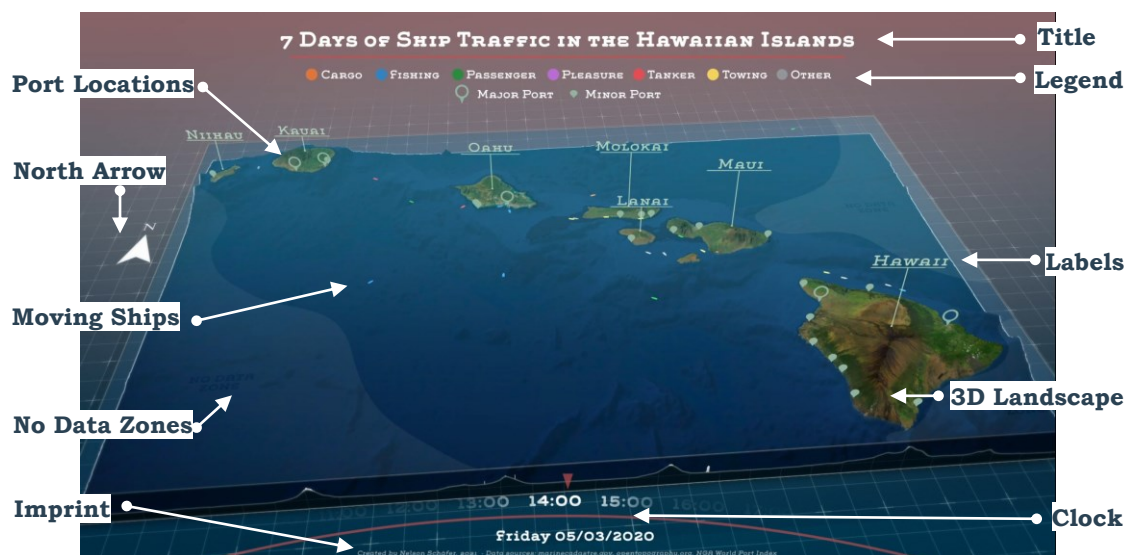


Figure 32 Composition elements of the animation

5 USER TESTING OF THE MAP ANIMATIONS

A survey was conducted to analyse the created map animations by end users. In the following sub-chapters, the methodology of the survey is presented first and then the collected answers are evaluated. In addition, for each of the five animations, the most frequently mentioned points of criticism are analysed and possible suggestions for improvement are made.

5.1 Survey setup

With a purpose to understand how well the created set of map animations achieve their objective as cartographic products, a survey was conducted to gather as many opinions as possible. The online platform *JotForm* was used to build a questionnaire in which the participants were first asked on their opinion of the animations and after that were requested to find answers to questions about the visualized information.

The questions of the survey were designed to cover numerous aspects that are relevant in the assessment of map animations. First, two details of personal information were requested from the 33 participants to better understand their bandwidth in terms of their expertise. The responses showed that a broad field of participants in different age groups and experience levels in dealing with geovisualization products were represented. However, because the requests for partaking in this survey were shared in peer groups and the academic environment, more than 50 percent of the participant stated to be between 25 to 34 years old. Furthermore, a high level of expertise was found among the responders, as 61% stated to have completed studies in the field of geovisualizations or a related discipline. But as figure 33 shows, participants with professional interest, personal interest or no experience with cartographic work also completed the questionnaire.

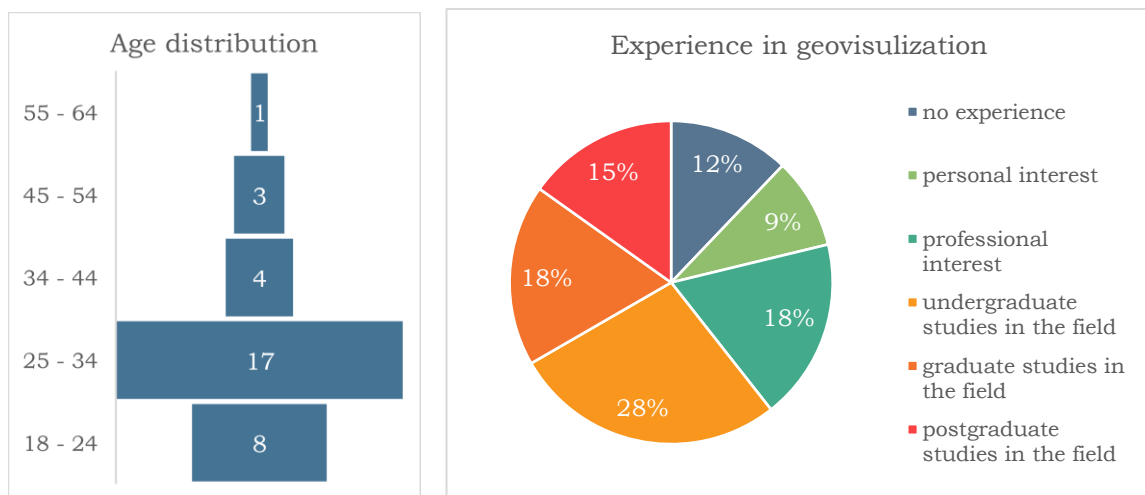


Figure 33 Statistics on the participants of the online survey

The participants were asked to watch one animation at a time and subsequently to rate the just seen video by choosing how much they agree or disagree with a series of statements. The eight given statements were:

- There are sufficient elements of supporting information to understand the animation.
- The animation provides appropriate spatial context to understand dimensions and locations.

- The animation achieves to convey valuable information.
- The animation has an appealing visual aesthetic.
- Important animation elements and text elements are legible.
- The visual load of the animation is appropriate.
- Visual effects and elements do not distract from important information in the animation.
- All important map elements are listed in the map legend (or if no legend was included in the map: The animation works well without a map legend)

After that, two questions on the animation speed and the length of the animation video were asked. On a five-step scale, options were given to assess these animation characteristics. After these subjective assessments by the viewers, questions were asked about the information presented in the animations. Based on the visualized data in the animation, the answers to two questions for each video were asked to be answered correctly. Here, it was explicitly pointed out in the question text that the participants are allowed to watch the animations as often as needed to answer the questions.

5.2 Survey results

In the following subchapters the results of the survey are evaluated in detail. In addition to the presentation of the results, an attempt is made to identify the causes for the received opinions. As conclusions, together with individually received feedback and own assessments, the overall quality of the animations can be evaluated.

5.2.1 Animation 1: Ship traffic density on Lake Superior

Among all of the presented animations, the visualization of shipping traffic on Lake Superior was met with the most criticism. Altogether, the participants of the survey still had a positive impression of this animation, but the points of criticism can be clearly identified from the results of the questionnaire depicted in figure 34.

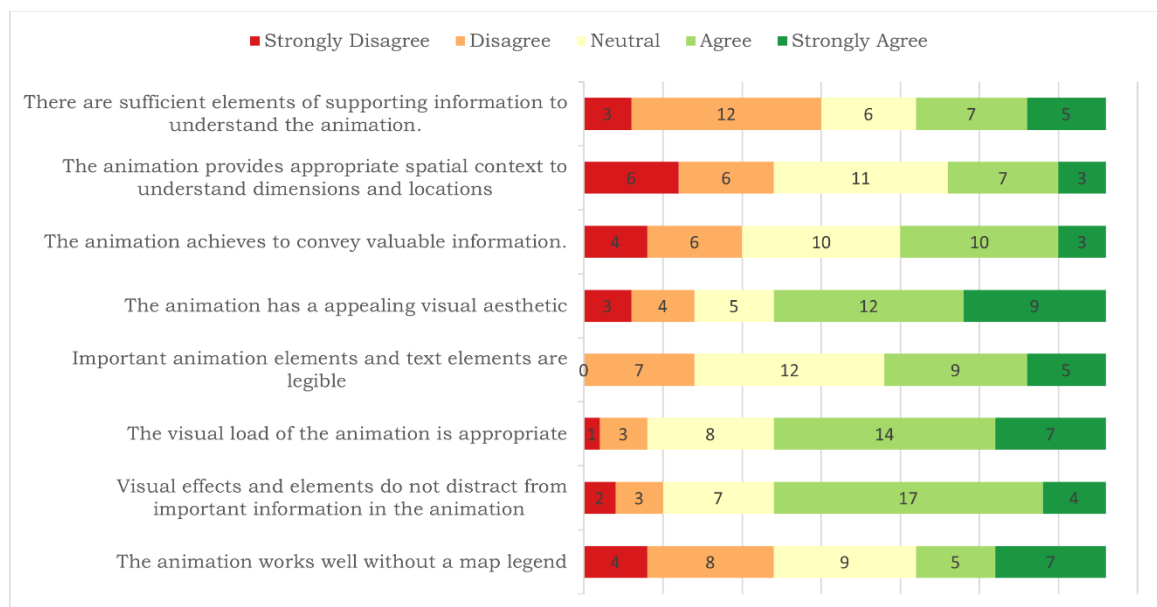


Figure 34 Survey results for animation 1

As the overview of the survey results shows, the aspects of visual load, appropriate use of visual effects and overall appealing visual aesthetics performed best out of the given statements. On the other hand, the viewers expressed difficulties in understanding the

spatial context of the depicted area of Lake Superior and to locate the map area in the world. Here it might help to add a small overview map to the animation. A more elegant solution, however, would be, for example, to label the USA and Canada, on whose borders the lake is, with large text labels in the basemap. In addition, it is difficult to understand the dimensions of Lake Superior in this animation and the actual size of the individual hexagons of 50km² are not obvious. This could be improved by displaying a scale bar.

Furthermore, the survey participants stated that too little explanatory information was provided about the animation content and that a legend would have been useful. This is appropriate criticism, because the method of binning and the varying height of the pillars are a rather unusual method of visualization that is not as natural and intuitive as actual moving ships like the other animations. It is also assumed that the definition of the vessel type *pleasure vessels* was not familiar to all participants and a reason for the wish for more supporting information on the map content. In addition, the yellow colour of the hexagons was criticized in personal feedback, as a blue colouring of the hexagons would have been more natural. However, the choice of the yellow colour was chosen because the presented information is not about water, but about the ships that move *on* the water. With regard to the video length of 38 seconds and the speed of the animation, both aspects were rated as appropriate. Only 24% of the participants wished for a longer video.

Finally, the participants were asked to solve two tasks for which the information for the correct answer could be found in the animation (see figure 35). Two thirds of the respondents were able to correctly identify the city with the highest shipping activity in its area, however 36% stated they were not able find the answer to this question. It is noticeable that not only for this question, but across the all five, at least 30% of the participants stated that they were unable to find the right answer.

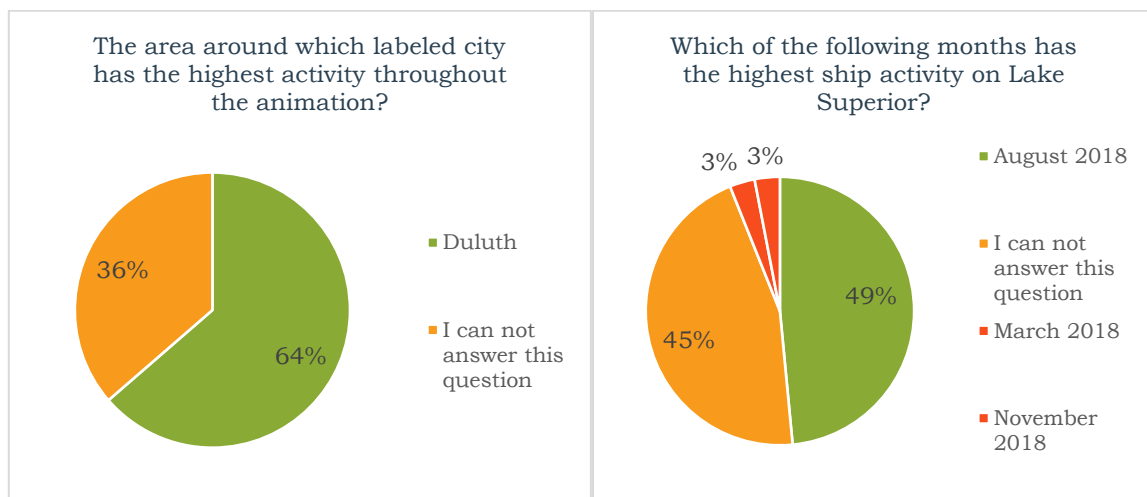


Figure 35 Answers of participants on the given tasks for animation 1

The questions of the survey that often received negative feedback can in summary be explained by insufficient information that is not included in the map animation or could have been implemented better. The well-rated aesthetics of the animation is partly due to the clean and simple look with few distracting elements. However, this design choice comes with disadvantages in terms of comprehensibility and the amount of information about the animated data.

5.2.2 Animation 2: Piracy incidents in the Indian Ocean

The animation on pirate activity in the Indian Ocean was very well received. Without exception, all of the characteristics queried in the survey received more than 50% good and very good ratings. Both the visual impression as well as the provision of all necessary information about the animation content were viewed as very good by the responders.

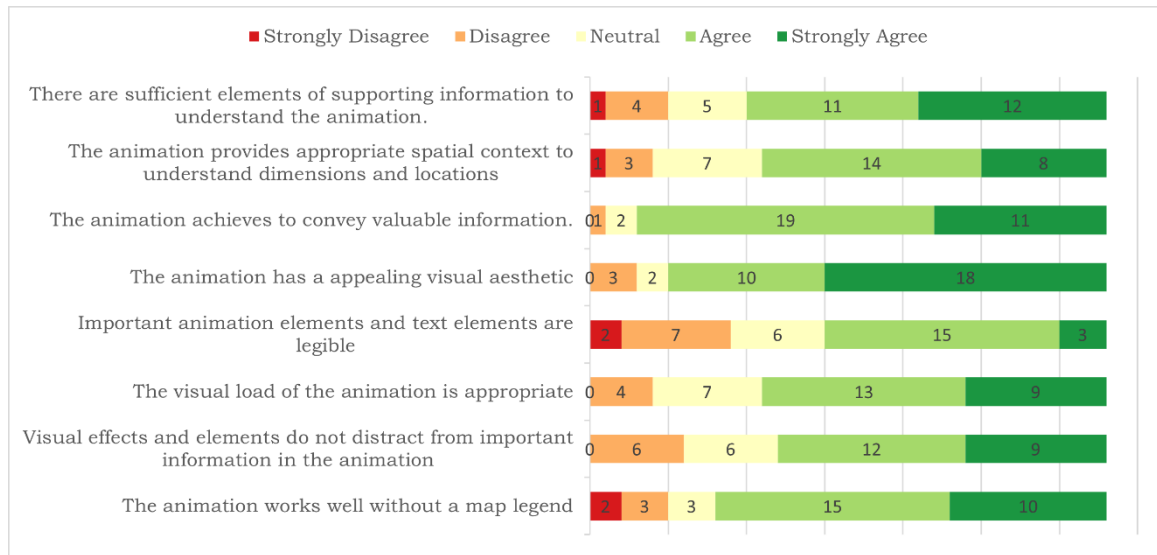


Figure 36 Survey results for animation 2

According to the survey, the greatest deficiency of this animation video are few text elements which are hard to read or even illegible. Subsequent analyses showed that in particular the labels on the animated graph and the year numbers on the timeline were designed very small, especially when viewers used smaller displays.

In addition, some elements on the map itself are also difficult to recognize. On one hand, the labelling of the countries by using their official abbreviations in a dark grey tone is difficult to recognize and also difficult to interpret because the used abbreviations are not always obvious. One criticism was that due to the curvature of the Earth the areas at the edges become hard to read. This criticism is valid, but the appropriateness of the design choices must be analysed in the context for which this animation was created. For a purely scientific visualization with a focus on analysing the presented data, the here created animations is not ideal and a simple 2D map might be a better method. The aim of these animations is, however, to leave a visually appealing impression and to combine it with the presentation of detailed information. That is the reason why some compromises in the interpretability of the animations are made here to create the animation visuals engaging and interesting.

Although the assessments of the survey participants saw little potential for improvement in the provided helpers for orientation and localization, the answers to the solved tasks show a different picture. When asked in which years the Arabian Sea recorded its highest pirate activity, around 24% of the respondents answered with a wrong answer, and only 43% of them were able to give the correct answer (see figure 37). This high number of wrong answers is due to the fact that it was difficult to locate the Arabian Sea in the animation, as no text labels for the ocean waters were included. The results show that the Arabian Sea has often been confused with the Gulf of Aden, where a similarly high level of activity was recorded.

When asked about the animation speed of the visualization the absolute majority found it appropriate. In addition, about half of the participants found the video to be a bit too long, the other half of the participants were satisfied with the duration of the animation of 2:08 minutes.

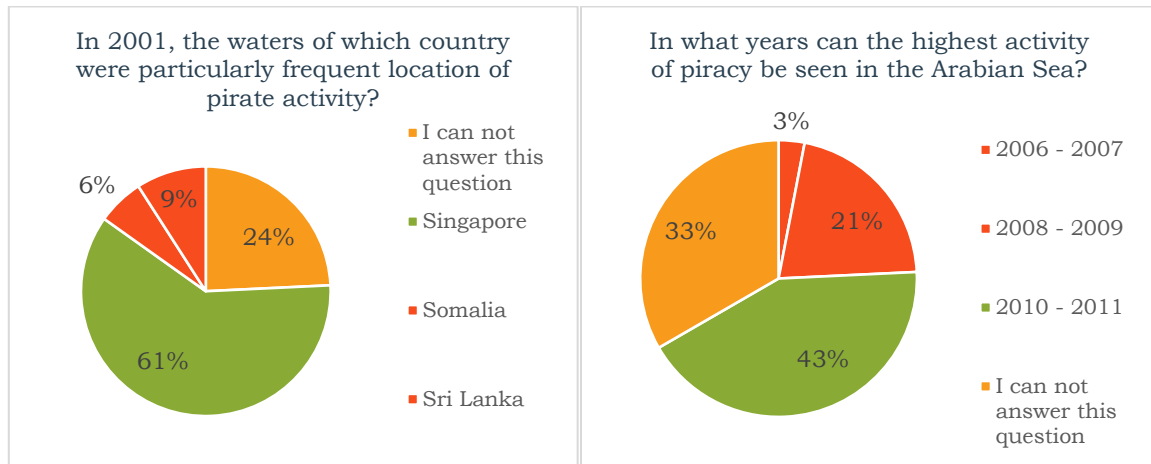


Figure 37 Answers of participants on the given tasks for animation 2

5.2.3 Animation 3: Vessel traffic in Port Piraeus

The feedback on the map animation about the ship traffic from Port Piraeus contained mostly neutral to positive reviews. The category on appropriate spatial context and communication of dimensions was rated the best among all the created animations. The built-in overview map, the scale bar and the additional labelling of the harbor areas contribute to this. The feedback on the visual aesthetics performed lightly worse than the average rating of the five animations. Through interrogation it was discovered that the stylized representation of the terrain layers was perceived as too artificial and a textured landscape like in the animation about the Hawaiian Islands is more popular.

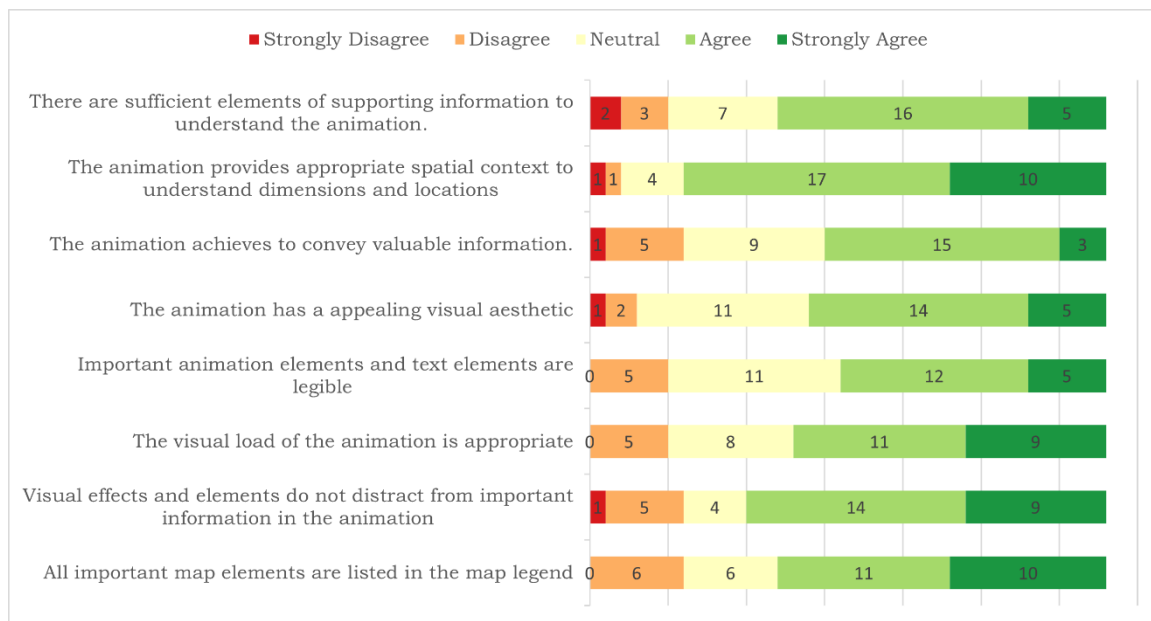


Figure 38 Survey results for animation 3

The movement of the single ships was considered as too fast by approximately a third of those surveyed and a reduction of the animation speed would be preferred. In addition, this animation can be improved with regard to the information quality. On one hand, the ships are shown quite small in the animation and are therefore difficult to discern. In addition, due to the small size of the ships, the colours according to the ship categories are hardly recognizable. Out of these reasons, the participants might have had difficulties to answers to the questions that are presented in figure 39. The given task to identify the port area with the least activity in the animation was only solved correctly by 30% of the viewers. And also the time period with the highest ship activity in Port Piraeus was only correctly identified by a third of the respondents. To improve the information value of this animation, the movement speed of the ships could be reduced. Furthermore, one could let the ships draw lines in order to see the traces longer and more clearly. In addition, this would make it clearer to which port region the fewest shipping lines lead.

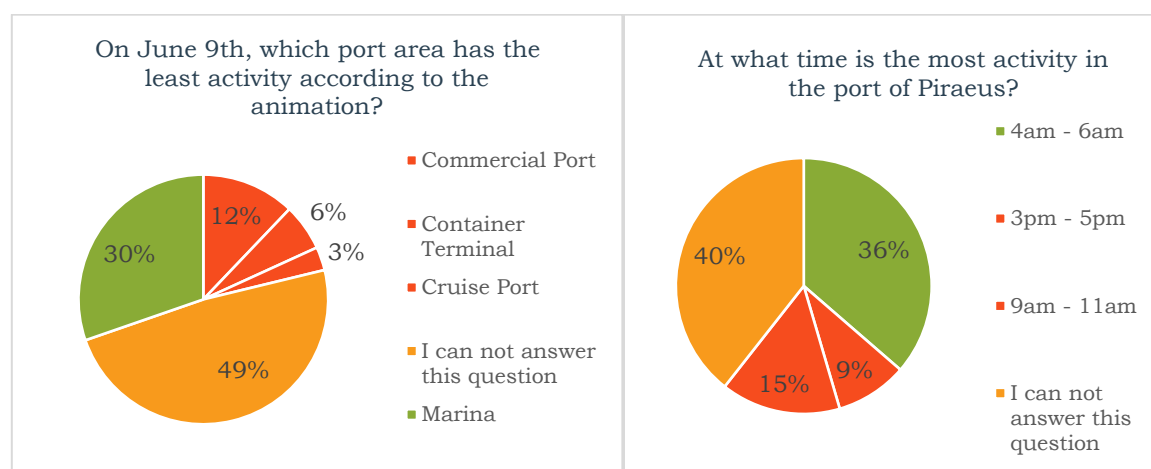


Figure 39 Answers of participants on the given tasks for animation 3

5.2.4 Animation 4: Transits on Arctic shipping routes

As already reported in the workflow for creating the animation of the Arctic ship routes in chapter 4.4, this visualization has been provided with many different elements and additional information. From the survey results in figure 40 the advantages and drawback of these design choices can be derived. On one hand, the animation gets a very good rating with regard to the comprehensibility of space and dimensions, but on the other hand, many viewers perceived a lack additional explanatory information about the content of the map animation to be a problem, despite the numerous provided elements. This contrast between the many elements of information in the animation and the lack of understanding shows that this animation is too overloaded, and the most important components are not in the focus of the viewer. This feeling of overload is reflected in the submitted reviews. For example, a third of the test persons stated that the visual load was too high and furthermore that some animations and effects distract from the important information in the animation. In addition, conversations with users revealed that the rotation of the camera makes it more difficult to orientate oneself and to better understand the content in a short time.

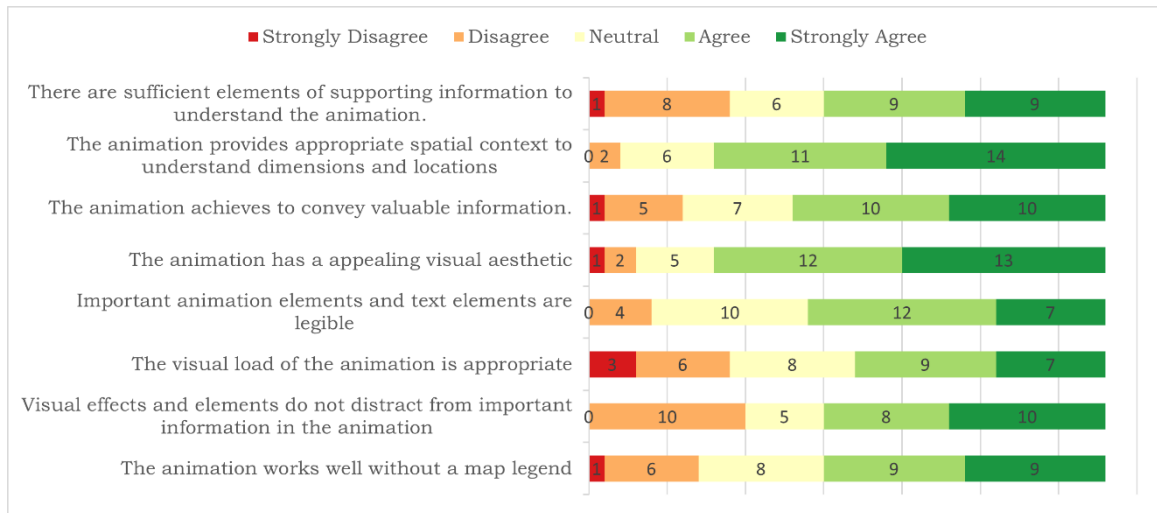


Figure 40 Survey results for animation 4

The high rate of wrong answers to the question in figure 41 was caused by an error in the animation. The change in the colour of the Northwest Passage is carried out too early in the animation, giving the impression that was already usable for complete transits in August 2019. The occurrence of this error can be explained by the fact that in this case the timing of the animation elements was conducted manually. Another cause of confusion among viewers was no clarity about the term *transit* and its meaning in the context of shipping routes of the Arctic.

In terms of animation speed, the visualization was rated as adequate, and the length of the video was also mostly considered good. However, 40% of those surveyed, stated that the video length was too short. The reason for this evaluation are the many different elements that appear on the screen at the same time. A longer video length would give the viewer more time to study the individual elements closely and then combine the shown information to get a profound understanding of the topic

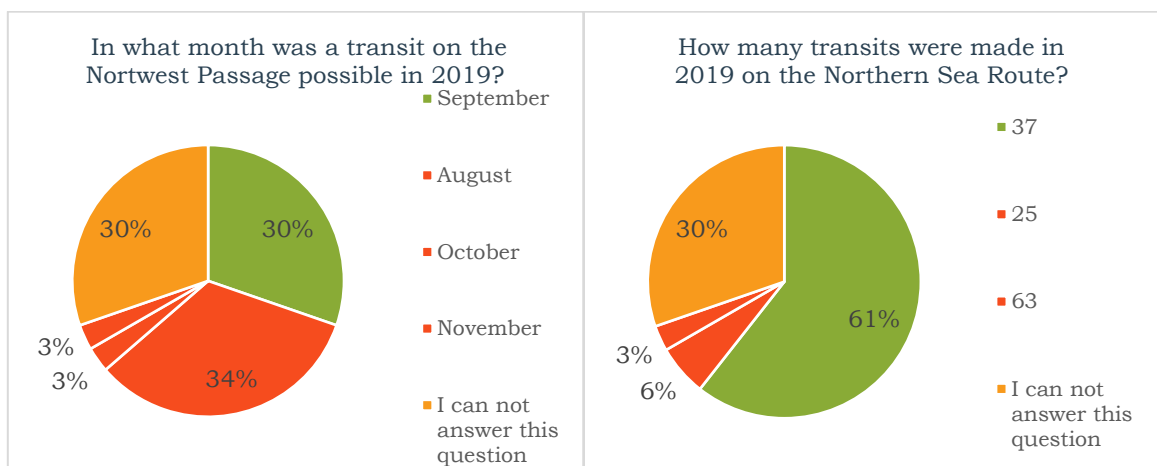


Figure 41 Answers of participants on the given tasks for animation 4

5.2.5 Animation 5: Ship traffic in the Hawaiian Islands

Overall, the animation of ship traffic in the Hawaiian Islands was rated the best of all videos and was able to perform well in all categories of the assessments by the survey participants. Of all the animations, the visual impression in this animation was most appreciated, which is mainly due to the realistic 3D landscapes, which help to convey an impressive but also familiar looking visual impression.

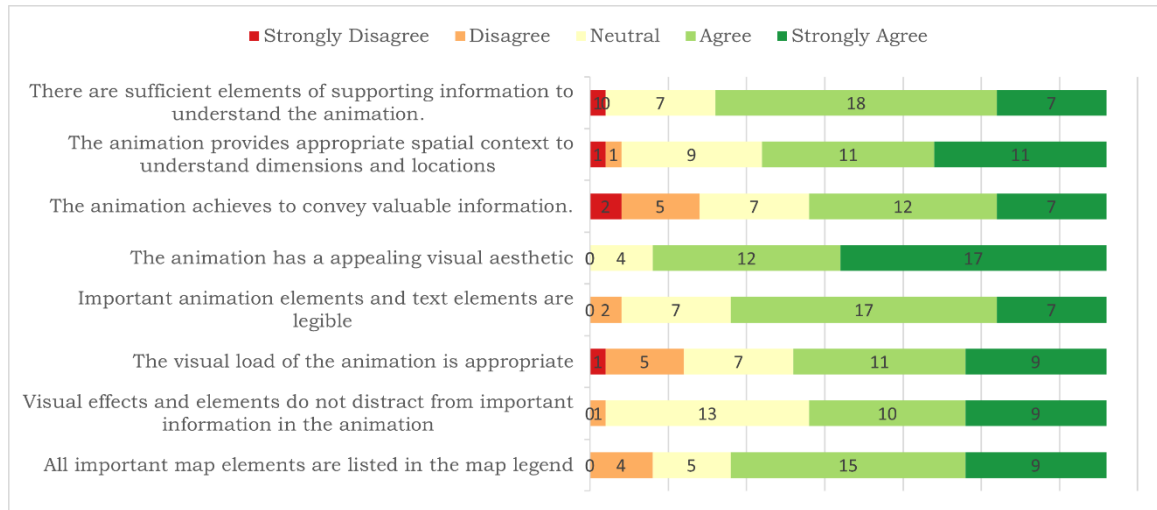


Figure 42 Survey results for animation 5

As visible in figure 42, the only points of major criticism, were the visual load of the animation and the usual criticism, as with any of the animations, that no valuable information is conveyed with these visualizations. The first point of criticism could be explained by the fact that the included different types of ports, the polygons of the no-data zones, as well as the rotating movement of the camera demands a lot of attention. However, the main reason for the high visual load is likely the animation of the time indicator, which is in constant rapid motion and thus attracts a lot of attention. Out of all the created clocks and timers for the animations presented in this thesis, this is the most noticeable and fastest moving element and therefore distracts from main animation content.

Although almost no criticism was made regarding the readability or distinguishability of the individual map elements, the answers to the question in figure 43 let presume some faced difficulties. The frequent passenger ships that go back and forth between the islands of Lanai and Maui were only recognized correctly by 30% of the survey participants. The majority of respondents stated that they could not find an answer to this question. This can be explained by the fact that the ships were designed as small and quickly moving symbols and thus the colours of the ship categories are difficult to see.

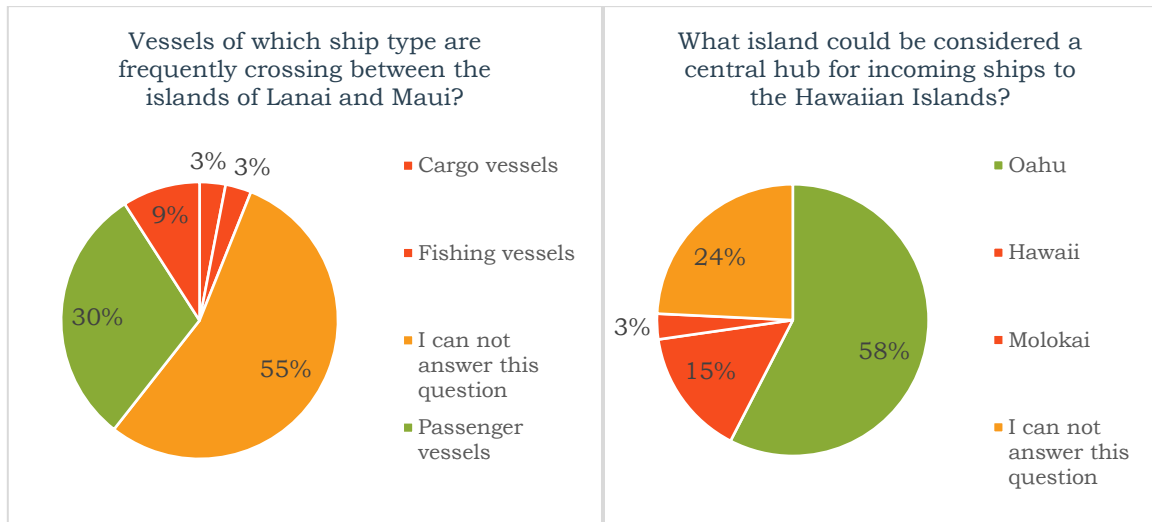


Figure 43 Answers of participants on the given tasks for animation 5

6 RESULTS

The results achieved through work conducted as part of this thesis is summarized in the following chapter. Accomplishments regarding the established workflow which allow data-driven animations of GIS data in Adobe After Effects are summarized. Then each created map animation is introduced shortly. Finally, this chapter concludes with the summary of the overall evaluation of the developed map animations.

6.1 Animations

The main result of this thesis comprises a set of five map animations that visualize in different ways phenomena related to the topic of shipping traffic. To create the animations, data pre-processing methodologies of various kinds were applied in ArcGIS Pro to prepare the raw data for the further workflow. Based on a workflow published by Esri an approach was developed to transfer the desired GIS data to the animation software Adobe After Effects (Leiva & Umali, 2020). In combination with a capability of Adobe After Effects, presented in one of Adobes workshop on how to create data-driven animations by using JSON files, a workflow was developed to be able to have access to GIS geometries and attributes in the animation software (Scott, 2017). By using self-developed scripts to automatically generate animation parameters from attribute values in JSON files, complex cartographic animations were created. In addition, the tools of Adobe After Effects and the capabilities of two plug-ins were used to design visually advanced cartographic products.

Each of the created animations has a runtime between 28 and a maximum of 128 seconds and was exported with 30 frames per second in full-HD resolution with 1920 by 1080 pixels. All created animations were published on the video platform YouTube and are therefore accessible to the public at the following URL:

https://www.youtube.com/playlist?list=PL4C_0c5D0AwpKvqaCgoNShEOjN29h-HWE

Animation 1: Ship traffic density on Lake Superior

The first created animation deals with Lake Superior and the activity of vessels of the category pleasure vessels in a period from March 2017 to December 2019. In the 35 seconds duration of the animation video, the heights of 1,371 hexagons are shifted at monthly intervals based on the recorded activity in the respective areas of the lake. From this animation, phases and areas can be recognized in which there is a particularly high level of activity and how this activity changes over the months.

Animation 2: Piracy incidents in the Indian Ocean

Second, a map animation was designed, which visualized piracy incidents and similarly classified events between 1990 and 2020. On a slightly rotating globe, the incidents in the Indian Ocean and the adjacent seas are shown over time by using flashing illuminated points. During its 2:08 minute runtime, the animation video additionally shows the development of worldwide piracy events using an animated graph.

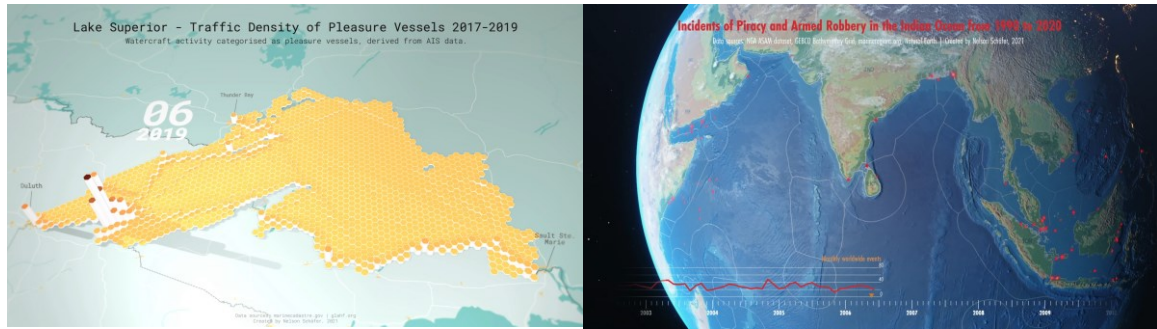


Figure 44 Frames of the animations on Lake Superior and the Indian Ocean

Animation 3: Vessel traffic in port Piraeus

The third map animation shows the region around the port of Piraeus in Athens and the shipping traffic for three consecutive days in July 2015. During the 90 seconds animation individually moving ships, which are coloured differently according to their vessel categories, move in a three-dimensional scene consisting of a series of height layers. In addition, a number of auxiliary elements improve the information content and thus the comprehensibility of the animation. Among other things, a dynamic change of light indicates the currently displayed time of day, and an included overview map clarifies the location of the depicted area. In addition, the different port regions of Piraeus are shown and allow of a better interpretation of the observed ship movements.

Animation 4: Transits on Arctic shipping routes

In the animation about the Arctic ship routes in 2019, many different components were combined. The animation, which lasts 28 seconds, explains the relationship between the change in the expansion of the Arctic sea ice and complete traverses of the Arctic ship routes. The animation contains the changing extent of the sea ice as well as statistics on transits between the oceans on the various Arctic ship routes. The visualized content of this animation is supported by, among other things, a rich basemap and a chart of statistics from the last few years.

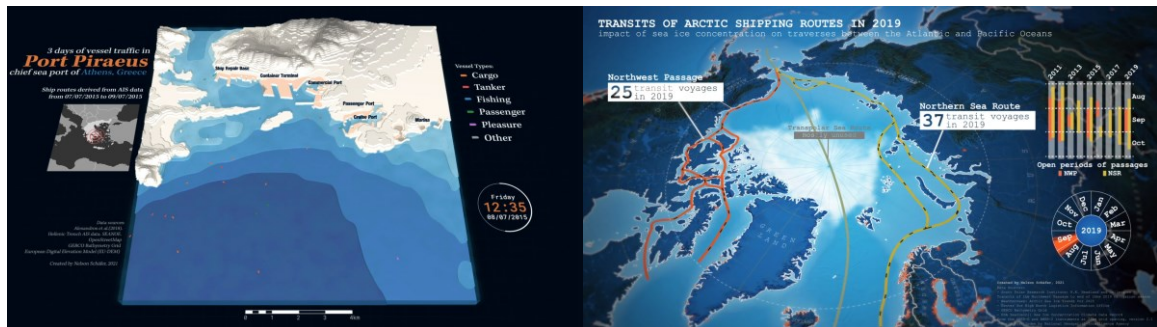


Figure 45 Frames of the animations of Port Piraeus and the Arctic ship routes

Animation 5: Ship traffic in the Hawaiian Islands

For the last map animation the shipping traffic on the Hawaiian Islands was visualized. In the 90 seconds of the animation, ships are moving individually over a period of one week. In addition, this animation is characterized by the realistic landscape with three-dimensional terrain and textures from satellite images. The categories of different ship types are reflected by uniquely coloured vessels, and the most important ports of the regions are displayed to give more context about the ship routes.

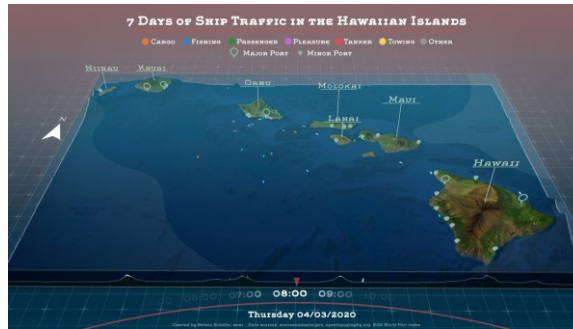


Figure 46 Frame of the animation of the Hawaiian Islands

6.2 User testing

Following the creation of the cartographic animations, extensive user testing was carried out. Using an online survey with questions and tasks for each of the map animations, a good picture of the respective strengths and weaknesses of the animations could be determined. Figure 47 shows the overall positive reaction to all five animations in all categories. The efficiency of the animations, the compliance with cartographic principles as well as the general visual impression were well received by the respondents. One of the main criticisms was the inadequate legibility and recognizability of different texts and elements. According to later analyses, this was due to, on the one hand, too small font sizes and map elements, such as the individual ships. On the other hand, the speed of the animation videos was seen as too fast by the viewers and caused difficulties to understand and interpret the visualized data.

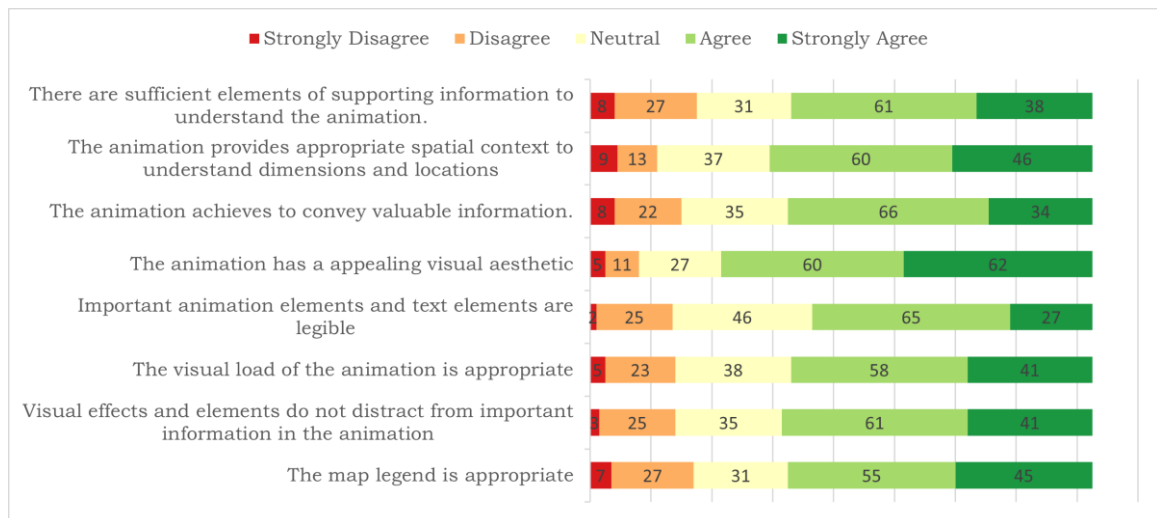


Figure 47 Survey result across all animations

In addition to these subjective assessments of the respondents, the participants were also asked to solve some tasks, the answers of which could be found by extracting information from the animations. As shown in figure 48, in total, only 48% of the answers were given correctly. However, it should also be noted that only 14% of the answers were wrong and the remaining 38% were classified as unanswerable questions by the participants.

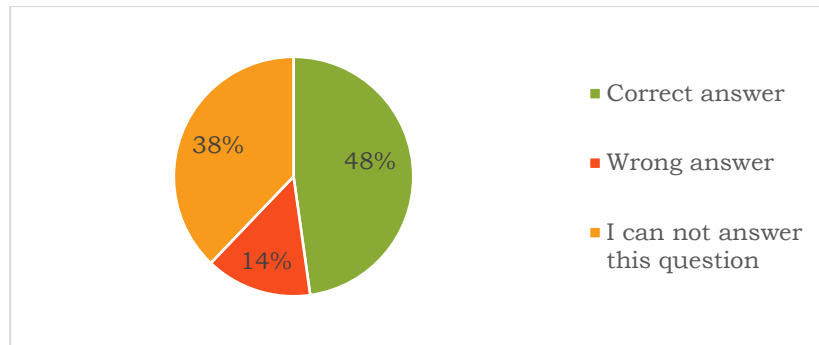


Figure 48 Rates of given answers across all questions

It can be concluded from this distribution of answers that at their core the animation videos were correct and mostly did not lead to misunderstandings. This is because the share of submissions that declared not to be able to solve the task is high, but the rate of wrong given answers is low. The animations are provided with too little explanatory information and at the same time too many distracting effects and elements, so that the core information of the animations is not clear in some cases. Improvements like the incorporation of scalebars for more spatial context, the enlargement of the individual ship elements and slowing down of the movement of ships could help to achieve a higher rate of correct answers. The results depict the need of a necessary balancing act between clearly communicated information and inviting and enjoyable visualizations.

7 DISCUSSION

By applying the developed workflows presented in this thesis, a set of five advanced animated maps were created by successfully utilizing the potential of rich spatial data in combination with the sophisticated visualization methods of Adobe After Effects. However, a critical examination of the conducted work reveals several weaknesses in the presented results.

Accuracy of the map animations

In contrast to animation processes in GIS software, the Adobe After Effects is not entirely based on automatic data-driven animation properties and hence has to rely on manual effort which could result in inaccuracies. The possible imprecisions caused by the manual creation of many parameters of the animations manifests itself in two aspects.

First, the in chapter 4.3.1 developed method of animating for the visualizations of Port Piraeus and the Hawaiian Islands is not precise due to the fact that continuous ship routes were generated from the existing AIS data points. As a result, important attribute information was lost in this process. In the created ship routes, the different times and distances of the individual points are not taken into account. Instead, only the start and end time of each ship route is saved, and a constant movement speed of the ships is assumed on the route in between. To mitigate this inaccuracy as much as possible the AIS messages of ships that are not in movement were not incorporated into the calculation of the ship routes. In addition, with the help of the tools from *MarineCadastre.org*, AIS data points having a gap of more than 60 minutes apart, were not connected to continuous ship route lines. These measures make it possible to increase the degree of precision of the correct ship movement speeds. In the animation about the Hawaiian Islands this methodology for the animation of the ships works best as the mapped area covers large parts of the open sea where ships mostly travel at constant speed. However, on a larger scale, as in the animation of the Port of Piraeus, it is common for ships to change their speed frequently, especially when manoeuvring in the port area. Thus, some ships moving at unusual speeds can still be spotted when observing this map animation closely.

Another possible source of inaccuracies in the animations is the large amount of manual adjustments. For example, the five different time indicators in the animations are manually designed, timed and animated. Likewise, other elements of the animations, such as the animated graph in the piracy incidents output, were manually adjusted with keyframes to reveal in coordination with the timeline. Further examples of manual animation processes are the opening of the ship routes in the Arctic and the dynamic change in the lighting conditions created in the animation about Port Piraeus. A slight error in the manual timing of the change of appearance of the Northwest Passage is also reflected in the survey results. As depicted in figure 41, many survey participants gave a wrong answer because the animation had a small error of changing its colour too early. To prevent mistakes caused by manual adjustments all elements in Adobe After Effects could also be generated by controlling animation parameters using scripts and expressions. However, developing the script code is tedious work and not always worthwhile and was thus not considered appropriate for minor adjustments like this.

Visual overload of the map animations

One important design decision in the creation process is the amount of information that is visualized at what animation speed. Because of the limited visual capacity of human cognition, it is important to make the animation readable and understandable so that the

viewer does not miss important information. As the presented evaluations in chapter 5 showed, the created map animations have a tendency to overwhelm or confuse the users by the incoming stream of information. Partly the high visual load of the animations originated from auxiliary map elements like graphs, charts, scalebars and animated time indicators. These so-called multi-component displays are important as they provide supporting information and make the map animation more effective. The clock in the animation of the Hawaiian Islands is an example where due to the high animation frequency the users were distracted, and the attention was split negatively (Opach et al., 2014). The static chart in the animation on Arctic shipping routes does not draw much attention but adds too much information to the animation that can not be properly observed in the runtime of the short video. Thus, the improvement of the animations with carefully designed auxiliary components should be improved in future work.

In scientific research many different approaches have been explored to reduce the visual complexity of map animations. The chosen approach of aggregation and binning from chapter 4.1 is one example of an established method to reduce the level of detail of the geometry of the input data (MacEachren & DiBiase, 1991). But also approaches of generalizing values instead of geometries proved to be effective in studies. By retaining and emphasizing the spatial patterns and reducing unnecessary outliers which would have not been observed anyway, the visual load of animations can be improved (Traun & Mayrhofer, 2018). Depending on the degree of generalization the animations would provide only a rough understanding of the directional flow or the location of incidents rather than including exact positions of individually moving ships. However, in this thesis the created cartographic animations had an increased focus to attract attention and to be inviting due to their visual aesthetics, their uniqueness, their novelty, and their methods of data visualization. For the most part, the map animations manage to successfully communicate the displayed data and provide the viewer with valuable and interesting results. Chapter 5 shows that there is only clear criticism in about 20% of the cases, when different components of the animations have not been implemented optimally. This criticism differs from animation to animation and can therefore be used to combine the positively rated aspects of the individual animations to combine the findings to create more optimized and refined map animations in future projects.

Ratio of effort and benefit

In the course of this chapter, the mentioned considerations raise the question whether the creation of map animations in Adobe After Effects is worthwhile. As the extensive workflow documentation in chapter 4 shows, the work on the created animations took a long time and was very complicated. Compared to animation tools in GIS software the advantages of working with spatial and temporal attributes that are tightly integrated in the program logic is missing in Adobe After Effects and requires custom solutions. Not only does manual labour and the development of scripts take a long time, but also the conductible work in Adobe After Effects is limited. As soon as a certain number of individual elements are added to a composition the software is slowed down heavily, requiring inconvenient solutions and preventing from a smooth editing experience. Especially the live preview when the number of layers exceeded approximately 1000 caused heavy load on the computer processor. In addition, the export of the animations demands between 4 and 16 hours of rendering time. The heavy processor load caused by the advanced visual effects makes it challenging to adjust animations on a quick basis. For use in the economy, it is conceivable that such long waiting times can be a hindrance, especially since fast revision processes and short deadlines are required.

The motivation of this thesis to choose Adobe After Effects as a tool to create cartographic animations originated from the desire to extend the scope of what is possible in terms of visualizations of GIS data. Sophisticated animation capabilities were successfully used, however the exploration of potential of Adobe After Effect is far from being exhausted. More time and more experience in the software could result in more refined workflows and new ways to visualize spatial data. As described, the limitations when working with large data sets have shown that Adobe After Effects is certainly not suitable as an animation tool for every type of data set and every kind of visualization. In addition, the purpose for animations created with Adobe After Effects should not be scientific visualizations on the basis of which important decisions are made. Rather, Adobe After Effects is ideal for creating visually appealing and highly customizable animations. With the knowledge of the strengths and weaknesses of the software, unique animations can be created, which clearly stand out from the standard solutions from other animation tools. The amount of effort required to create an animation is well worth it if the purpose of the animation is to do exactly what Adobe After Effects is capable of. Taking into account the cartographic principles, which ensure that visualized spatial information is effectively and correctly presented, animations created in Adobe After Effects can reach new target groups with cartography. This is exactly what has been achieved with these animations: visually impactful animations that attract attention, that are visually enjoyable, that possibly introduce uninterested people to explore the topic.

8 CONCLUSION

The aim of this thesis was to create a set of map animations that were created using the motion graphics software Adobe After Effects. In the course of this work, the creation of animations in Adobe After Effects with GIS data was demonstrated and then evaluated in detail. The topic of shipping traffic was chosen as the common theme of all animations and corresponding datasets were obtained for further processing. Among many others, the main types of input datasets for the animations were AIS datasets, which were then pre-processed in GIS software. In addition to the analysis and management of data in ArcGIS Pro, the datasets had to be prepared to meet requirements that allow the creation of an animation of the data in the later steps. To transfer the spatial data to Adobe After Effect a workflow was developed to split up the data into a JSON file for the attribute values and to use Adobe Illustrator to transfer the geometries to Adobe After Effects. By using the capabilities of scripting tools, the geometry objects of GIS datasets were animated through utilization of their JSON data attributes. Furthermore, the advanced animation and abilities of Adobe After Effects were employed to add effects and to compose map animations with various elements.

The result of this process are five individual animated maps which were exported as videos with a maximum duration of 128 seconds. Each of these map animations has its own style and special features to show the possibilities in Adobe After Effects and its plug-ins. The following topics are covered in the animations:

- Ship traffic density on Lake Superior from 2017 to 2019
- Piracy incidents in the Indian Ocean from 1990 to 2020
- Three days of vessel traffic in port Piraeus
- Transits on Arctic shipping routes in 2019
- One week of ship traffic in the Hawaiian Islands

After the creation of the animation was completed, an online survey was carried out to evaluate the quality and effectiveness of the cartographic visualizations. The evaluation results showed that the animations made a largely positive impression on the survey participants. However, one of the most frequent points of criticism was the visual overload due to too many elements, too small elements, or too quickly moving elements in the animations. Based on the collected feedback and the gained experiences from the practical work on the animations, conclusions can be drawn to what extent Adobe After Effects is suitable for creating map animations based on GIS data. Although the effort of creating map animations in Adobe After Effects is high and is limited by many factors, the software still offers the advantage that it can be used to create unique and visually impressive animations.

REFERENCES AND INFORMATION SOURCES

422 SOUTH [online]. 2021 [cit. 2021-05-15]. 422 South Homepage. Available online: <https://422south.com/>

ADOBE [online]. 2021 [cit. 2021-05-01] After Effects User Guide: Alter shapes with path operations. Available online: https://helpx.adobe.com/after-effects/user-guide.html/after-effects/using/shape-attributes-paint-operations-path ug.html#alter_shapes_with_path_operations

ADOBE WIKI [online]. 2021 [cit. 2021-04-26]. Fandom Wiki Adobe After Effects. Available online: https://adobe.fandom.com/wiki/Adobe_After_Effects

AESCRIPTS [online]. 2021 [cit. 2021-05-15]. GEOlayers 3 by Markus Bergelt. Available online: <https://aescrpts.com/geolayers/>.

ALEXANDROS F., RUSSEL L., PARASKEVI A., ARISTIDES P., DIMITROS L. (2018): Hellenic Trench AIS data. SENA OE. <https://doi.org/10.17882/57040>

ANIMOPLEX [online]. 2021 [cit. 2021-04-29] YouTube Playlist – World of Expressions-After Effects Training. Available online: <https://www.youtube.com/playlist?list=PLvr5U5ZSt6IzHyvSL9fo0M9NRPsTvra31>

BODC [online]. 2021 [cit.2021-11-05] GEBCO Gridded Bathymetry Data. Available online: https://www.gebco.net/data_and_products/gridded_bathymetry_data/

BOONE LOVES VIDEO [online]. 2021 [cit. 2021-04-29] YouTube Playlist – Monday Maps! Available online: <https://www.youtube.com/playlist?list=PLAKq3CHj8bHhRtWLn5VxrrVB2Iz5QUGJl>

BORETSKII, I., NYAMADOR E. S. [online]. 2021 [cit. 2021-05-15]. Impact of COVID-19 on open-wheel motorsport in 2020. Available online: <https://cartographymaster.eu/studentwork/mp-group10/>

CAMPBELL, C. S., EGBERT S. L. (1990): Animated Cartography / Thirty Years of Scratching the Surface. In: Cartographica: The International Journal for Geographic Information and Geovisualization 27:2, pp. 24-46, <https://doi.org/10.3138/V321-5367-W742-1587>

CAQUARD, S. (2009): Foreshadowing Contemporary Digital Cartography: A Historical Review of Cinematic Maps in Films, In: The Cartographic Journal, 46:1, pp. 46-55, <https://doi.org/10.1179/000870409X415589>

COPERNICUS LAND MONITORING SERVCIE [online]. 2021 [cit.2021-11-05] EU-DEM v1.1. Available online: <https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1>

CROCKFORD Douglas. JSON-js GitHub repository. Available online: <https://github.com/douglascrockford/JSON-js>

ENVATO MARKET [online]. 2021 [cit. 2021-04-25]. Terrain Builder Pro by Prizrak_kd. Available online: <https://videohive.net/item/3d-map-path-builder/20788566>

ESPO [online]. 2014 [cit. 2021-04-29]. Port of the month: Piraeus Port Authority. Available online: <https://www.espo.be/news/port-of-the-month-piraeus-port-authority>

ESRI [online]. 2019 [cit. 2021-05-01]. Technical Support - How To: Create sequential numbers in a field using Python in the Field Calculator. Available online: <https://support.esri.com/en/technical-article/000011137>

ESRI [online]. 2020 [cit. 2021-05-01]. U.S. Vessel Traffic Application. Available online: <https://livingatlas.arcgis.com/vessel-traffic/>

ESRI [online]. 2021a [cit. 2021-04-24]. ArcGIS Maps for Adobe Creative Cloud. Available online: <https://www.esri.com/en-us/arcgis/products/maps-for-adobecc/overview>

ESRI [online]. 2021b [cit. 2021-05-15]. Esri YouTube Playlist – Animated Maps. Available online: <https://www.youtube.com/playlist?list=PL1U1yOIVhnz8dpchCXdM4XP7GIIKgJZto>

ESRI [online]. 2021c [cit. 2021-05-01]. ArcGIS Maps for Adobe Creative Cloud – Use .aix files from ArcGIS Pro. Available online: <https://doc.arcgis.com/en/maps-for-adobecc/install/using-aix-files.htm>

ESRI [online]. 2021d [cit. 2021-11-05]. World Imagery (for Export). Available online: <https://www.arcgis.com/home/item.html?id=226d23f076da478bba4589e7eae95952>

GEOFABRIK [online]. 2021 [cit. 2021-05-01]. Geofabrik OpenStreetMap downloads. Available online: <https://download.geofabrik.de/>

GRIFFIN, A. L., MACEACHREN A. M., HARDISTY F., STEINER E. & LI, B. (2006): A Comparison of Animated Maps with Static Small-Multiple Maps for Visually Identifying Space-Time Clusters, *Annals of the Association of American Geographers*, 96:4, pp. 740-753, <https://doi.org/10.1111/j.1467-8306.2006.00514.x>

HARROWER M. (2003): Tips for Effective Animated Maps. In: CP (44), pp. 63-65. <https://doi.org/10.14714/CP44.516>

HARROWER, M., FABRIKANT, S. (2008): The Role of Map Animation for Geographic Visualization. In: Dodge, M. *Geographic Visualization: Concepts, Tools and Applications*. Chichester, UK: Wiley, pp 49-65, <https://doi.org/10.5167/uzh-8979>

HOFFMAN T. [online]. 2021. Sonnenverlauf.de [course of the sun]. Available online: <https://www.sonnenverlauf.de/> (in German)

<https://doi.org/10.1080/15230406.2017.1308836>

ITOWORLD [online]. 2021 [cit. 2021-05-15]. Ito World Homepage. Available online: <https://www.itoworld.com/>

LAVOIE S. [online]. 2015 [cit. 2021-05-01]. Adobe Illustrator Layer Renamer - GitHub Repository. Available online: <https://github.com/seblavoie/adobe-illustrator-layer-renamer>

LEIVA, E., UMALI R. [online]. 2020 [cit. 2021-04-13]. How to Make Animated Maps with ArcGIS Maps for Adobe and Adobe After Effects. Available online:

<https://www.esri.com/arcgis-blog/products/maps-for-adobecc/mapping/how-to-make-animated-maps/>

LUCJAN, K. (2016): Perception of the contents of animated maps. In: Polish Cartographical Review 48, no.4, pp.149-160, <https://doi.org/10.1515/pcr-2016-0015>

MACEACHREN, A., & DIBIASE, D. (1991): Animated maps of aggregate data: Conceptual and practical problems. Cartography and Geographic Information Systems, 18(4), 221-229. <https://doi.org/10.1080/152304091783786790>

MARINECADASTRE [online]. 2021 [cit. 2021-04-24]. MarineCadastre.gov | Vessel Traffic Data. Available online: <https://marinecadastre.gov/ais/>

MOTION BOUTIQUE [online]. 2020 [cit.2021-04-04]. Trim Path Tricks. Available online: <https://www.motionboutique.com/trim-path-tricks/>

NATURAL EARTH [online]. 2021 [cit. 2021-05-02]. Natural Earth vector map data. Available online: <https://www.naturalearthdata.com/downloads/>

NATURAL EARTH [online]. 2021b [cit. 2021-11-05]. Natural Earth 1:50m Cross-blended hypsometric Tints. Available online: <https://www.naturalearthdata.com/downloads/50m-raster-data/50m-cross-blend-hypso/>

NELSON, J. [online]. 2020 [cit. 2021-04-29]. Piracy & Time Travel – Thirty years of nautical piracy through slices of the calendar. Available online: <https://storymaps.arcgis.com/stories/fd50650e95214fdd844d39b3c5cca180>

NGA [online]. 2021 [cit. 2021-05-04]. Maritime Safety Information – Anti-shipping Activity Messages. Available online: <https://msi.nga.mil/Piracy>

NOAA [online]. 2021a [cit. 2021-04-28] Great Lakes Environmental Research Laboratory - Ice Cover Forecasting. Available online: <https://www.glerl.noaa.gov/data/ice/#forecast>

NOAA [online]. 2021b [cit. 2021-05-10]. Data Resources: What is netCDF? Available online: <https://psl.noaa.gov/data/gridded/whatsnetCDF.html>

NOEP [online]. 2020 [cit. 2021-04-30]. Arctic Ocean Transits. Available online: https://www.oceaneconomics.org/arctic/arctic_transport/aboutTransitsPop.aspx

NÖLLENBURG M. (2007) Geographic Visualization. In: Kerren A., Ebert A., Meyer J. (eds) Human-Centered Visualization Environments. Lecture Notes in Computer Science, vol 4417. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-71949-6_6

ONI [online]. 2021 [cit. 2021-04-29]. Annual Worldwide Threat to Shipping Summary 2020. Available online: https://www.oni.navy.mil/Portals/12/Intel%20agencies/piracy/WTS/20210209_Annual_WTS_2020_Summary.pdf?ver=nCI-GtK3AuUDHoPifKvmxw%3d%3d

OPACH, T., GOŁĘBIEWSKA, I., FABRIKANT, S. I. (2014): How Do People View Multi-Component Animated Maps? In The Cartographic Journal 51 (4), pp. 330–342, <https://doi.org/10.1179/1743277413Y.0000000049>

OPEN TOPOGRAPHY [online]. 2021 [cit. 2021-11-05]. Global Bathymetry and topography at 15 ArcSec: SRTM15+V2.1. Available online: <https://portal.opentopography.org/datasetMetadata?otCollectionID=OT.122019.4326.1>

PETERSON, M. P. (1994): Spatial Visualization through Cartographic Animation: Theory and Practice. In: Proceedings of Geographic Information Systems / Land Information Systems GIS/LIS, pp. 250-258. Available online: <http://maps.unomaha.edu/mp/Articles/GISLIS/VisAnim.html>

RAIFER M. [online]. 2021 [cit. 2021-11-05] overpass turbo. Available online: <https://overpass-turbo.eu/>

SAFE SOFTWARE [online]. 2021 [cit. 2021-13-04]. What is FME?. Available online: https://docs.safe.com/fme/html/FME_Desktop_Documentation/FME_Workbench/Workbench/What_is_FME.htm

SCOTT Daniel Walter [online]. 2017 [cit. 2021-05-02]. Animate graphics with data. Available online: <https://helpx.adobe.com/after-effects/how-to/create-data-driven-animations.html>

STATE OF HAWAII [online]. 2008 [cit. 2021-04-30]. A Guide to Port Hawaii. Available online: <https://hidot.hawaii.gov/harbors/files/2012/10/A-Guide-To-Port-Hawaii.pdf>

SVANBERG, M., SANTÉN, V., HÖRBERG A., HOLM H., FINNSGÅRD C. (2019): AIS in maritime research. Marine Policy, Volume 16, 103520, pp. 1-2, <https://doi.org/10.1016/j.marpol.2019.103520>

TOUDAL PEDERSEN, L.; DYBKJÆR, G.; EASTWOOD, S.; HEYGSTER, G.; IVANOVA, N.; KERN, S.; LAVERGNE, T.; SALDO, R.; SANDVEN, S.; SØRENSEN, A.; TONBOE, R. (2017): ESA Sea Ice Climate Change Initiative (SeaIcecci): Sea Ice Concentration Climate Data Record from the AMSR-E and AMSR-2 instruments at 25km grid spacing, version 2.1. Centre for Environmental Data Analysis, 05 October 2017, <https://doi.org/10.5285/f17f146a31b14dfd960cde0874236ee5>

TRAUN, C., MAYRHOFER, C. (2018): Complexity reduction in choropleth map animations by autocorrelation weighted generalization of time-series data. In Cartography and Geographic Information Science 45 (3), pp. 221–237, <https://doi.org/10.1080/15230406.2017.1308836>

VIDEO COPILOT [online]. 2021 [cit. 2021-04-25]. Video Copilot Orb – The ultimate 3D sphere plug-in. Available online: <https://www.videocopilot.net/orb/>

VOX [online]. 2019 [cit-2021-05-15]. The conflict in Kashmir, explained. Available online: https://www.youtube.com/watch?v=cyayif_nla8

WIKIPEDIA [online]. 2021a [cit. 2021-04-28] Great Lakes. Available online: https://en.wikipedia.org/wiki/Great_Lakes

WIKIPEDIA [online]. 2021b [cit. 2021-11-05] Unix time. Available online: https://en.wikipedia.org/wiki/Unix_time

ATTACHMENTS

LIST OF ATTACHMENTS

Bound attachments:

- Attachment 1 Source code used for animation 1
Attachment 2 Source code used for animation 3 and 5

Free attachments

- Attachment 3 Poster
Attachment 4 Flash drive

Structure Flash Drive

Folders:

- Input_Data
 - A1_LakeSuperior_ProjectFiles
 - 1_ArcGISPro
 - 2_ArcGISMapsforAdobeCC
 - 3_AdobeIllustrator
 - 4_AdobeAfterEffects
 - 5_AdobeExtendScriptToolkitCC
 - A2_Piracy_ProjectFiles
 - ...
 - A3_PortPiraeus_ProjectFiles
 - ...
 - A4_ArcticRoutes_ProjectFiles
 - ...
 - A5_Hawaii_ProjectFiles
 - ...
- Online_Survey
- Output_AnimationVideos
- Poster
- Thesis_Text
- Website

Attachment 1 Source code used for animation 1

This expression reads the traffic density value from the JSON file and adjusts the height position of the shape layer accordingly. It is used for the position property of every hexagon in the animation of Lake Superior. The script code is based on Scott, 2017.

```
//create variables
segDur = thisComp.layer("ExpressionControl").effect("SegmentDuration")(1);
exDepth =
thisComp.layer("ExpressionControl").effect("ExtrusionMaxDepth")(1)*-1;
min = Math.floor(thisComp.layer("ExpressionControl").effect("MinValue")(1));
max = Math.floor(thisComp.layer("ExpressionControl").effect("MaxValue")(1));
delta = max - min;

//Determine the layer name
layerNumber = thisLayer.name.split(" ")[0];
dataNumber = parseInt(layerNumber);
var data = footage("LakeSuperior_Table.json").sourceData;

//get values from json file based on layer name
v1=data[dataNumber].C2017_03; v2=data[dataNumber].C2017_04;
v3=data[dataNumber].C2017_05; v4=data[dataNumber].C2017_06;
v5=data[dataNumber].C2017_07; v6=data[dataNumber].C2017_08;
v7=data[dataNumber].C2017_09; v8=data[dataNumber].C2017_10;
v9=data[dataNumber].C2017_11; v10=data[dataNumber].C2017_012;
v11=data[dataNumber].C2018_01; v12=data[dataNumber].C2018_02;
v13=data[dataNumber].C2018_03; v14=data[dataNumber].C2018_04;
v15=data[dataNumber].C2018_05; v16=data[dataNumber].C2018_06;
v17=data[dataNumber].C2018_07; v18=data[dataNumber].C2018_08;
v19=data[dataNumber].C2018_09; v20=data[dataNumber].C2018_10;
v21=data[dataNumber].C2018_11; v22=data[dataNumber].C2018_12;
v23=data[dataNumber].C2019_01; v24=data[dataNumber].C2019_02;
v25=data[dataNumber].C2019_03; v26=data[dataNumber].C2019_04;
v27=data[dataNumber].C2019_05; v28=data[dataNumber].C2019_06;
v29=data[dataNumber].C2019_07; v30=data[dataNumber].C2019_08;
v31=data[dataNumber].C2019_09; v32=data[dataNumber].C2019_10;
v33=data[dataNumber].C2019_11; v34=data[dataNumber].C2019_12;

//load values in array
valuesArray = [v1, v2, v3, v4, v5, v6, v7, v8, v9, v10, v11, v12, v13, v14,
v15, v16, v17, v18, v19, v20, v21, v22, v23, v24, v25, v26, v27, v28, v29,
v30, v31, v32, v33, v34];

//determine length of time between keyframes
x = Math.floor(time/segDur);
segStart = x * segDur;
if(x > (34-1)) {x = 34-1};
startVal = valuesArray[x];

//check to see if at end of array and stop animation if so
if( x == (34-1) ) { endVal = valuesArray[x] }
else {endVal = valuesArray[x+1]};

//animate between the keyframes
z = ease(time, segStart,segStart + segDur,startVal,endVal);
zF = ((z - min) / delta) * exDepth;
[value[0],value[1],zF] //position output
```

The following expression is adjusting the fill colour of the shape layer according to the current height value of the layer.

```
low = thisComp.layer("ExpressionControl").effect("ColorScaleLow")(1);
high = thisComp.layer("ExpressionControl").effect("ColorScaleVeryHigh")(1);
e = Math.abs(transform.position[2]) /
thisComp.layer("ExpressionControl").effect("ExtrusionMaxDepth")(1);
f = (high * e) + (low * (1 - e))
```

The following expression adjusts the extrusion depth of the shape layer according to its current height value.

```
Math.abs(transform.position[2]) + 4
```

The following ExtendScript code is used to assign expression to all selected layers

```
//Running this Script will add an expression to alter the fill of a selected
array of shape objects

//the project that is currently loaded
var proj = app.project;

//select active composition
var comp = app.project.activeItem;

//create array with all layers that are selected in After Effects
var layersSelection = comp.selectedLayers;

//define the expression
var myExpression = "low =
thisComp.layer(\"ExpressionControl\").effect(\"ColorScaleLow\")(1); \n high =
thisComp.layer(\"ExpressionControl\").effect(\"ColorScaleVeryHigh\")(1); \n e
= Math.abs(transform.position[2]) /
thisComp.layer(\"ExpressionControl\").effect(\"ExtrusionMaxDepth\")(1); \n f
= (high * e) + (low * (1 + time/10000 - e))";

//loop through array and assign expression to each layer
var arrayLength = layersSelection.length;
for (var i = 0; i < arrayLength; i++) {
    layersSelection[i].content("Group 1").content("Fill 1").color.expression
= myExpression;
}

//alert when done
alert ("Done");
```

Attachment 2 Source code used for animations 3 and 5

This code is executed in ExtendScript Toolkit CC and reads specific information from JSON files for selected layers. The script then uses the acquired values to generate animation parameters in Adobe After Effects to animate ship movements along paths.

```
//include external library to add json parsing functionality
(https://github.com/douglascrockford/JSON-js)
#include "json2.js";

//the project that is currently loaded
var proj = app.project;

//active composition
var comp = app.project.activeItem;
$.writeln("Composition name is : " + comp.name);

//read JSON file
var data
function readJSONFile(file){
    file.open("r");
    data = file.read();
    file.close();
    data = JSON.parse(data);
}
readJSONFile (File ("~/Desktop/Piraeus.json"));

//set variables for time conversion
var output_start = 0; //start of animation in seconds
var output_end = 90; //end of animation in seconds
var input_start = 1436220004; //lowest time/date from json table
var input_end = 1436479107; //highest time/date from json table

//create array with all layers that are selected in After Effects
var layersSelection = comp.selectedLayers;
//number of selected layers
var arrayLength = layersSelection.length;

// iterate through all selected layers
for (var i = 0; i < arrayLength; i++) {
    //read name of layer
    var name = layersSelection[i].name;
    // split name
    var nameparts = name.split(" ");
    //retrive first part of name = ID
    var number = parseInt(nameparts[0]) -1 ;

    //read attribute information from json file
    var input_begin = parseInt(data[number].CETsStart);
    var input_ende = parseInt(data[number].CETsEnd);
    var shiptype = data[number].SHIPTYPE;
```

...

```

...

    //calculate keyframes for animation based on attributes from json file
    (time conversion)
    output_trimbegin = output_start + ((output_end - output_start) /
    (input_end - input_start)) * (input_begin - input_start);
    output_trimende = output_start + ((output_end - output_start) /
    (input_end - input_start)) * (input_ende - input_start);

    // Add Trim Path Effect to layer and set start and end time
    layersSelection[i].property("ADBE Root Vectors Group").addProperty("ADBE
    Vector Filter - Trim");
    layersSelection[i].content("Trim Paths
    1").end.setValueAtTime(output_trimbegin,0); //seconds, value
    layersSelection[i].content("Trim Paths
    1").end.setValueAtTime(output_trimende,100); //seconds, value

    //determine color based on shiptype attribute from json file
    switch(shiptype) {
        case "CARGO":
            fillcolor = [223,120,62]/255;
            break;
        case "FISHING":
            fillcolor = [52,131,193]/255;
            break;
        case "PASSENGER":
            fillcolor = [45,139,62]/255;
            break;
        case "PLEASURE":
            fillcolor = [187,109,213]/255;
            break;
        case "TANKER":
            fillcolor = [228,78,84]/255;
            break;
        case "OTHER":
            fillcolor = [146,151,155]/255;
            break;
        default:
            fillcolor = [146,151,155]/255;
    }

    //assign expression to the ship symbol instance layer, so that it follows the
    trim path
    var symbollayer = comp.layer(1);
    var layernamenumber = parseInt(nameparts[0]);
    var myExpression = "shapeGroup = thisComp.layer(\"" + layernamenumber + "
    Outlines\");myPath = shapeGroup.content(\"Group 1\").content(\"Path
    1\").path;trimEnd = shapeGroup.content(\"Trim Paths 1\").end / 100;endPt =
    myPath.pointOnPath(trimEnd);endps = endPt + thisComp.layer(\"" +
    layernamenumber + " Outlines\").transform.position;";
    symbollayer.transform.position.expression = myExpression;

...

```

```

...

    //expression for the shape layer to rotate with path direction
    var expressionrotation = "shapeGroup = thisComp.layer(\"" +
layername + " Outlines\");myPath = shapeGroup.content(\"Group
1\").content(\"Path 1\").path;trimEnd = shapeGroup.content(\"Trim Paths
1\").end / 100;tg = myPath.tangentOnPath(trimEnd);a =
Math.atan2(tg[1],tg[0]);radiansToDegrees(a)";
    symbollayer.transform.rotation.expression = expressionrotation;

    //set colour of
    symbollayer.content("Shape 1").content("Fill
1").color.setValue(fillcolor);

    //remove old opacity keyframes from duplicate instance
    symbollayer.transform.opacity.removeKey(4);
    symbollayer.transform.opacity.removeKey(3);
    symbollayer.transform.opacity.removeKey(2);
    symbollayer.transform.opacity.removeKey(1);

    //set new keyframes for opacity
    symbollayer.transform.opacity.setValueAtTime(output_trimbegin - 0.01, 0);
    //seconds, value
    symbollayer.transform.opacity.setValueAtTime(output_trimbegin, 100);
    //seconds, value
    symbollayer.transform.opacity.setValueAtTime(output_trimende, 100);
    //seconds, value
    symbollayer.transform.opacity.setValueAtTime(output_trimende + 0.01, 0);
    //seconds, value

    //create new instance of ship symbol for the next line
    comp.layer(1).duplicate();
}

//When finished
alert("Trim Path Script executed");

```