GUIDELINES FOR THE DESIGN OF FLOW MAPS

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February, 2017

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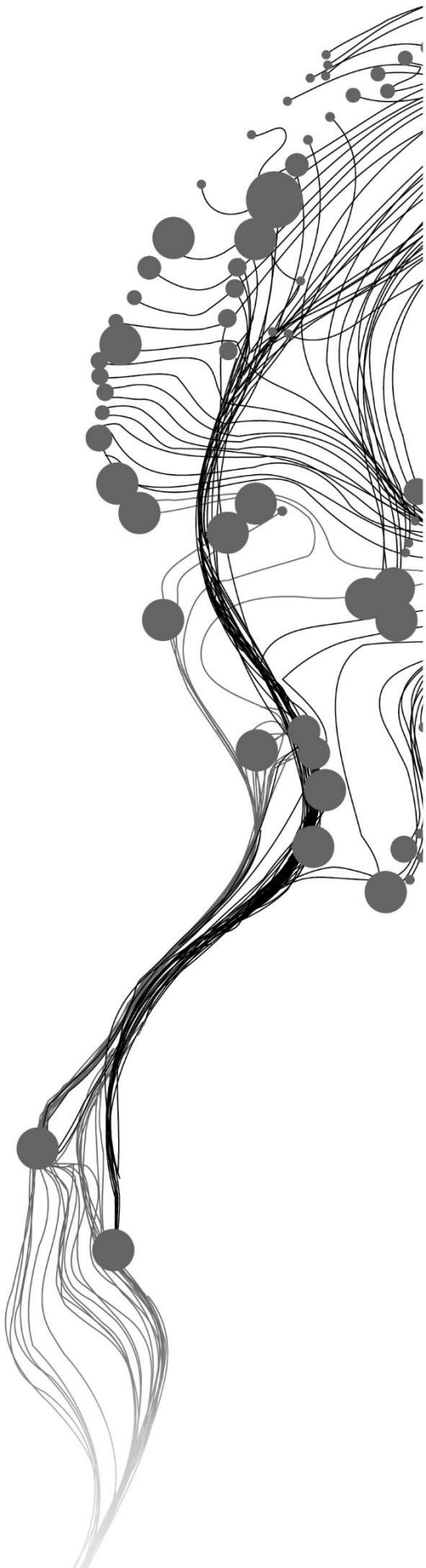

GUIDELINES FOR THE DESIGN OF FLOW MAPS

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinformatics

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ABSTRACT

The world is a dynamic system, as an indicator, movements are generated and recorded when humans, information, energy, global trade are moving. It is significant and useful for people to explore and utilize them in a suitable way. Nowadays, flow maps are commonly applied as a visualization approach to represent the movements, however, how to design and visualize with different movement attributes in order to help people discover the potential information is still a challenge.
The innovation of this research are the guidelines which could help the public to extract information from the flow maps and the potential users who are willing to make movements visible by using flow maps.
To understand flow maps, a set of criteria with six aspects were generated based on how to read a flow map. With the criteria, 183 flow maps from various sources were collected and assessed, which is the basis of this research. Different presentations were classified and ranked after the inventory in order to know which designs are the common ones. Apart from this, some design principles were given which were summarized from the existing flow maps.
Considering the criteria and the characteristics of the data in this practical case, airport data will be visualized in respect to Network, Quantitative as well as Qualitative and Direction with various representations by using flow maps. The representations are the most uses ones which were ranked in the previous step.
An online survey was designed and carried to test the performances of each representation. The feedbacks from more than 100 participants were evaluated in the aspect of Efficiency, Effectiveness, and satisfaction.
It is found that: When depicting the flow map connections, flow map with curved lines is more accurate in relation to answering questions correctly; People prefer to compare quantitative data using symbols of different sizes at O/D location rather than using varying thicknesses of flow lines; The label is a better representation to show the qualitative attributes; user preference of direction representations is: Animated-particle, Arrow-line, Coloured-line, Transparent-line, and Tapered; Transparent-to-solid line is preferred than solid-to-transparent line; thin-to-thick as the moving direction is more decipherable instead of the thick-to-thin direction. However, these conclusions were discovered based on the flow maps which visualized airport data. The reasons that could influence the results were discussed in the last part of this research.

Keywords: Flow map, Guidelines, Origin-destination data, Movement, Visualization

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1. INTRODUCTION

1.1. Motivation and problem statement

The world is a dynamic system, both for the physical environment and human society. Movement data is an indicator for the dynamic world. It is generated when humans, information, energy, global trade are moving. Nowadays, movement data can be easily recorded and visualized because of the sufficient technologies. It would be significant and useful if people explore and utilize movement data properly, but how to visualize this kind of data appropriately in order to help people discover the potential patterns and get insight is a challenge.

The aviation transportation industry had served more than 65 billion passengers since the first passenger was transported (David Oxley & David Goodger, 2016). Air traffic is a typical example which generates movement data. With the increase of air transport, it is a challenge for researchers to visualize and report to the public in an efficiently way (Buschmann & Trapp, 2016).

Movement information is usually represented by origin-destination (OD) data which is used to interpret spatial interactions as entity flows between origin and destination locations (Boyandin, 2013), such as flights from one to another place.

Flow maps are often applied as a visualization approach to represent the movement of objects (Phan, Xiao, Yeh, Hanrahan, & Winograd, 2005). Connections, directions, and attributes are depicted in flow maps in different kind of designs.

However, flow maps also have some limitations. Problems like occlusion, salience bias, and information overload were mentioned in 2011 (Wood, Slingsby, & Dykes, 2011). Guo (2009) defined three limitations of flow maps, the usage effect of large dataset visualization, the choice of geographic units when locations were grouped into different regions, and the visualization of multivariate information. Many representations of flow map exist but the incorrect use of them will cause flow maps to be unclear.

This research aims to generate guidelines to design flow maps based on the inventory of existing approaches in order to reduce the visual clutter in flow maps' and avoid the mistakes. Air traffic data will be used as a case in this research, visualized by flow maps that are designed and created according to the guidelines. Maps testing is also needed to ensure the usability and practicability of guidelines afterward.

1.2. Research Identification

1.2.1. Research objectives

The main objective of this research is defining guidelines for the design of flow maps. The guidelines will be generated based on the existing flow map designs. Follow the guidelines, flow maps will be designed and produced in the case of air traffic.

There are four sub-objectives that can be distinguished,

1. Understand the characteristics of flow maps.
2. Understand user requirements in the application context.
3. Develop design guidelines and create examples depend on the output of sub-objective1 and 2.
4. Evaluate the examples created in the application context.

1.2.2. Research questions

Research questions regarding to sub-objective one, understanding flow maps:

Question 1.1 What are flow maps, which kind of data do they present?

Question 1.2 How are different aspects of the data visually represented in a flow map?

Question 1.3 What are the (dis)advantages of flow maps?

Research questions regarding to sub-objective two, understanding user requirements in application context:

Question 2.1 What questions do the users have in relation to the data?

Research questions regarding to sub-objective three, formulation:

Question 3.1 What is the specific character of the implementation?

Question 3.2 Which of the design solutions can be found in the inventory to answer user questions?

Question 3.3 Are the found solutions sufficient to solve the problems?

Question 3.4 How are sample flow maps created for data visualization.

Research questions regarding to sub-objective four, usability test and improvement:

Question 4.1 Which of the qualitative and/or quantitative evaluation methods are suitable to test the example flow maps?

Question 4.2 How is the evaluation set-up and executed?

1.3. Innovation

The innovation of this research are the guidelines which could help the public to extract information from the flow maps and the potential users who are willing to make movements visible by using flow maps. This research could provide the representation summarize of existing flow maps, when it zooms in a particular situation, the guidelines could be referred to.

1.4. Project setup

1.4.1. Method adopted

The methods below have been suggested to achieve the research objectives:

1. Literature review

   Literature review is one of the most important methodologies of this research. This method is primarily based on reading state of the art researches and technological articles about the visualization of movement data. The inventory of flow maps is an important part of the work to be able to understand existing designs of flow maps. In this way, sub-objective one, understand the characteristics of flow maps will be achieved.

2. Requirements analysis

   A user requirement analysis is the key to design a legible flow map, because the requirements should be considered before the design part and be achieved in implementation part. Requirements supposed to be searched (e.g. search the air flows from one city to another) or compare (e.g. compare the number of flights between two pairs of airports). In this way, sub-objective two, understand the characteristics of flow maps will be achieved.

3. Conceptual design

   Based on the inventory of flow maps, existing designs will be systematically classified. Analysis of the inventory will result in a set of prevailing approaches of flow mapping. Taxonomy is the

discipline of the summarize of inventory. That will bring about a recommendation which design should be used under which circumstance.

4. Implementation

   For the implementation part, some visualization tools should be used to implement the practice. After the summary of the used tools from other academic articles, for the dataset which is not big Adobe Illustrator is a good choice. AI will be the primary tool for implementation, which is one of the best vector generators.

5. Evaluation and usability test

   Evaluation could be done in quantitative or/and qualitative ways (Van Elzakker & Wealands, 2007). Questionnaire is the qualitative method to be used in this research. Different questions will be asked for the test of different designs. Efficiency (how fast can people come with the answer?) Effectiveness (how good is the answer?) and Satisfaction are the three indicators for evaluation of different designs. Thesis structure

1.4.2. Thesis structure

The thesis consists of six chapters:
Chapter 1 – illustrate the motivation, research objectives, research questions, declare the innovation and project setup.
Chapter 2 – introduce the background information about OD-data, existing visualization methods, flow map history, classification as well as the limitations and the existing solutions of flow maps.
Chapter 3 – generate a set of criteria to assess flow maps, revisit and summarize the existing maps, ranking different designs.
Chapter 4 – based on the inventory of the current flow map designs, visualize the airport data with the commonly used representations.
Chapter 5 – design and implement the online survey to test the performance of different performances.
Chapter 6 – collect and summarize the survey results.
Chapter 7 –analysis the result, reflect the current works, discuss the reasons and further works.

2. BACKGROUND INFORMARION OF FLOW MAP

2.1. Origin-destination data

2.1.1. Introduction of Origin-destination data

OD (origin destination) data, is used to store and represents movements data. It represents the origins, destinations and the attributes between the OD pairs. Origin and destination refer to two locations while attributes are the features between the corresponding OD pairs.

	D_1	D_2	D_3	...	D_n
O_1					
O_2					
O_3					
...			A		
O_n					

Figure 2-1: OD-matrix (A: attributes)

	Almelo	Borne	Dalfsen	Deventer	Dinkelland	Enschede
Almelo	6	27	12	5	-	6
Borne	-	4	-	3	-	2
Dalfsen	-	48	1	97	34	5
Deventer	4	18	14	8	2	9
Dinkelland	-	1	-	1	-	-
Enschede	6	23	18	9	3	7

Figure 2-2: An example of migration OD matrix: Part of the 2005 Overijssel migration data, the columns refer to the origin cities and the rows are the destination cities, the numbers are the amount of migration between corresponding cities

OD-data is normally stored and interpreted as an OD-matrix (Boyandin, 2013), where rows and columns represent origins and destinations severally, the number of each cell in OD-matrix is the attribute of each movement. Figure 2-1 shows the typical format of OD-matrix. When OD-data is used to represent the transfer of funds, OD refers to the accounts and the attributes represent the amount of money. When it used to illustrate the information flows, O/D could be two email addresses and attributes are the transferred information. OD-data usually describes the movements of real objects, such as migration between municipalities or air traffic. Figure 2-2 shows a part of the 2005 Overijssel migration data, where columns and rows are the origins and destinations municipalities separately, numbers refers the amount of migrations.

Time is also a characteristic of OD-data, OD data with time component is called temporal OD-data. Time is an element of OD-matrix, Figure 2.3 shows the multiple temporal OD-matrix, compare with the general temporal OD-matrix in Figure 2.4, the sequences of origins and destinations (rows and columns) are not changed but more tables are overlapped. In Figure 2.4, the first two columns of OD-matric come to the origin and the destination and the others represent to other specific information.

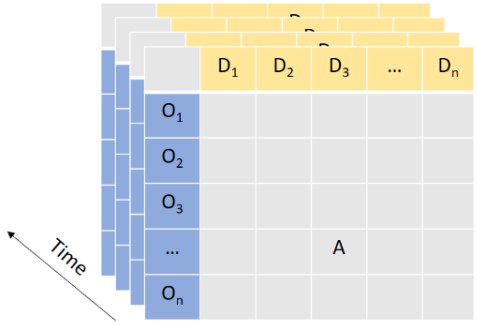


Figure 2-3: Multiple temporal OD-matrix

O_1	D_1	A_1	$Time_1$
O_2	D_2	A_2	$Time_2$
O_3	D_3	A_3	$Time_3$
...	...	...	...
O_n	D_n	A_n	$Time_n$

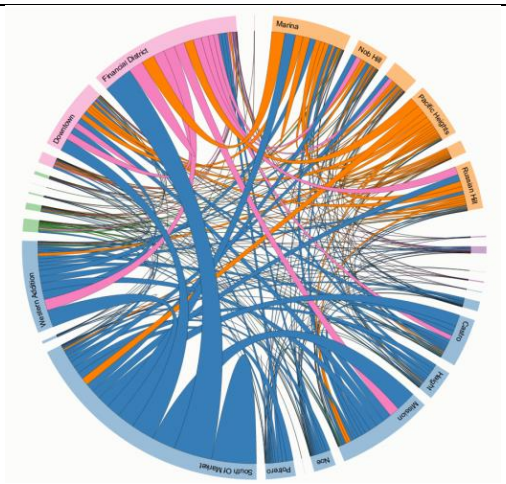
Figure 2-4: Temporal OD-matrix

2.1.2. Visualization of Origin-Destination data

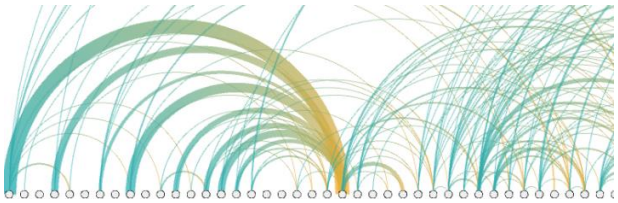
Nowadays, a plenty of multi-attribute OD-data is generated with the movements of this dynamic world. Visualization is a way to discover the relations between pairs in OD data in reality. Finding out the operating approaches to visualize OD data, helping people get new insights from the data becomes more and more necessary. Four characteristics of OD data: connections, direction as well as quantitative and qualitative attributes need to be noticed. Next, an overview of OD visualization methods is displayed in Figure 2-5.

A chord diagram is a kind of visualization method where radial layout represents locations. Bostock (2012) showed migrations between districts within San Francisco through a chord diagram, the example shows in Figure 2-5 a; Sankey arcs is another method to visualize movements where locations are represented by sequenced nodes. Nagel (2012) visualized movement between bus stops in Singapore by using this approach (Figure 2-5 b); A necklace map is an alteration of chord diagram where an underlying map surrounded by curve (the necklace). Speckmann and Verbeek (2010) shown population and the resettlements between 12 provinces in the Netherlands (Figure 2-5 c); When OD-matrix visualizing OD-data, colour values will be the visual variable to show relative data about OD movements. Rows and columns still represent the origins and destinations. Boyandin (2011) used OD-matrix to show the canton migrations in Switzerland (Figure 2-5 d); For OD-treemap, (Shneiderman & Wattenberg, 2001) shown the origins and destinations in hierarchy, the destinations are children cells while the corresponding origins are parents cells (Figure 2-5 e); The idea of Map^2 comes from Guo (2006), Map^2 uses the same sized rectangles ordered by the correspond geographic placement, uses multiple displays to show separate maps relevant to each origin. An example of the resettlement of US companies between different states was implemented by map^2 is displayed in Figure 2-5 f; OD-map divides the map into cells with a regular grid, which include small maps representing origins. Values represent flow magnitudes. Wood (2010) using OD-map visualized around one million citizens relocated among the US. However, it is impossible to observe the flows within an individual location (Figure 2-5 g); Symbol map uses symbols such as bubbles over a map to show the magnitudes of incoming and outgoing flows. To distinguish different directions, colours are used. Similar to symbol maps, O and D symbol maps distinguish different flows by two individual map views (Figure 2-5 h).

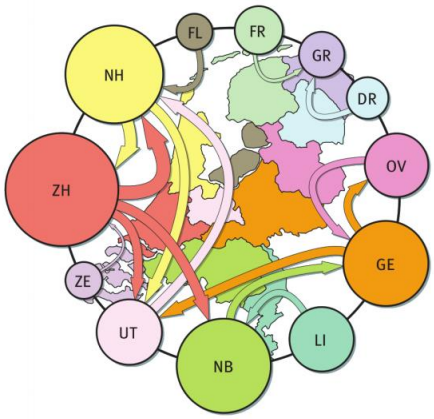
Flowstrates is an interactive visualization method, which is used to explore temporal origin-destination data (Boyandin et al., 2011). OD-data of flows will be visualized in two maps beside, combine with the heat map in the middle to represent the changes over time. However, too many lines and junctions, invisible flows on one map are limitations of flowstrates. Flow map is the most common technique to represent movement data (Boyandin, 2013), which is a node linked graph. Flows represented by lines to connect each pair of locations in a geographic map. Moreover, various representations of lines show the attributes of OD data (Slocum, 2009).



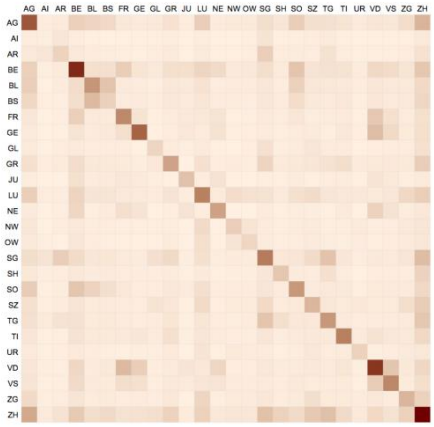
a. Chord diagram (Bostock 2012)



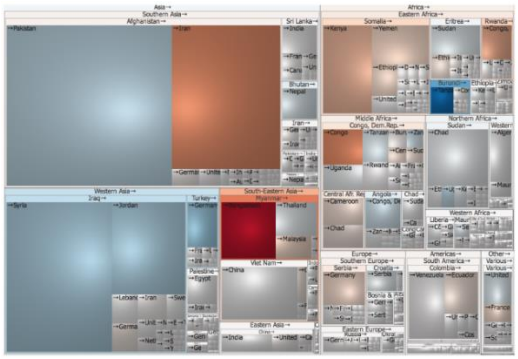
b. Sankey arcs (Nagel 2012)



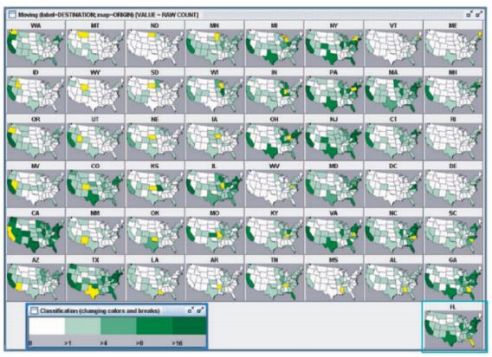
c. Necklace map (Nagel 212)



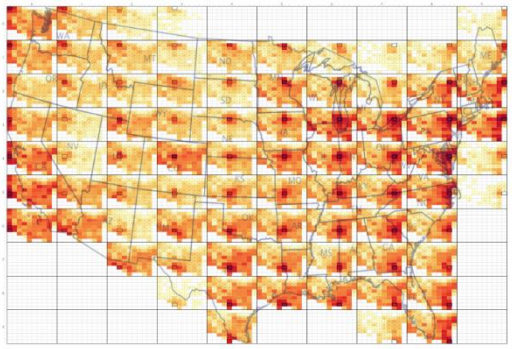
d. OD-matrix (Boyandin 2011)



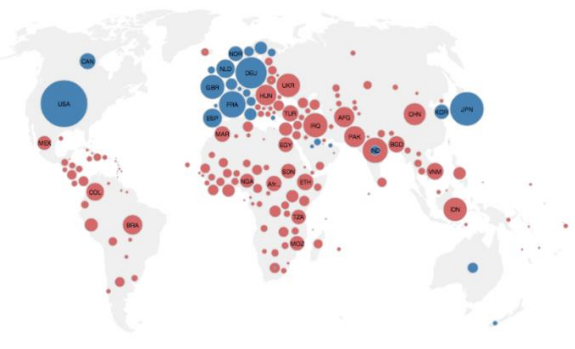
e. OD-tree (Shneiderman & Wattenberg, 2001)



f. Map2 (Guo 2006)



g. OD-map (Wood 2010)



h. Symbol map (Tableau, 2011)

Figure 2-5: Examples of different OD visualization

2.2. Flow map

2.2.1. History of flow map

When geography is involved, OD-data is visualized in flow maps, origin-destination pairs could be shown on the map and flows could represent the corresponding attributes with the use of different visual variable. The flow map is not a novel conception, Henry Harness created the first flow map in 1837, which was made for comparing passengers transported in different directions across Ireland for Railway commissioners (Arthur H. Robinson, 1955a), proportional lines were first used to show the magnitude in this flow map. Figure 2-6 shows a part of the Harness' first flow map.

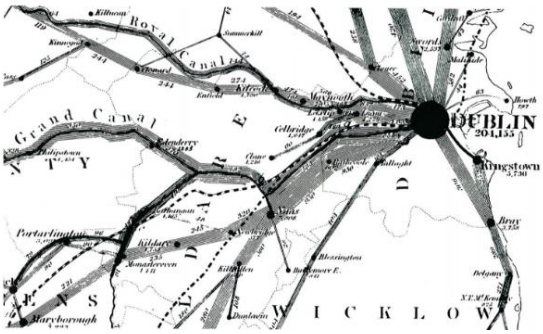


Figure 2-6: Harness' passenger conveyance flow map

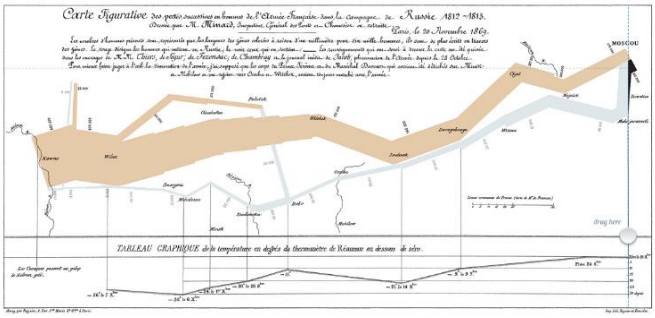


Figure 2-7: Charles Minard's map of Napoleon's disastrous Russian campaign of 1812

Charles Joseph Minard was the pioneer of flow mapping, a well-known diagram was designed by him in order to show the size changes of Napoleon's troops during he concurred Russia from 1812 to 1813. The magnitude of the army, direction, location, marched distance, temperature and time, six attributes in total were designed and depicted in one map. "It may well be the best statistical graphic ever drawn" (Tufte, 1983). It is widely used as an example to explain how to visualize qualitative and quantitative attributes. Minard also created the worldwide migration map in 1862 and the French wine export map in 1864 (Arthur H. Robinson, 1967). Minard's Napoleon's Russian campaign flow map is shown in Figure 2-7
With the development of the computer science, software became a useful and efficient tool in cartography field. Tobler's migration map was one of the first map showing migration flows displayed by software (Waldo R. Tobler, 1987). In this map, directions and magnitudes were depicted by arrows with various line widths.
Nowadays, storage techniques are improving rapidly, data collection devices are widespread, a huge amount of data are recorded in every second. Too much information needed to be visualized in maps. The

big amount of data makes maps crowded and unreadable sometimes, which is called visual clutter (Geoffrey Ellis & Dix, 2007).

2.2.2. Representation of OD data in flow maps

2.2.2.1. Representation of directions

The direction is an important characteristic of flow maps when OD-data is visualized, origins and destinations should be distinguished by map readers. Boyandin (2013) summarized five common designs to depict the flow directions:

- Arrow is the most straightforward and common one. Users could recognize the direction according to the arrow.
- Bending flows in a recognizable way.
- Use the visual variable, varying the H-I-T (hue, intensity, and transparency).
- The thickness of flow line, directions such as from the thin to the thick of flow.
- Animation, particles moving along the flow path to indicate the movement direction.

2.2.2.2. Representation of attributes

The attributes of flow lines could be divided into qualitative and quantitative (Gu, Kraak, & Engelhardt, 2016). Sometimes a flow line contains both qualitative and quantitative attributes.

- The thickness of flow lines is used to represent quantitative attribute (Waldo R. Tobler, 1987a).
- The weighted thickness of arrows can also represent the amount.
- Colours can be used to distinguish the different attributes, both for absolute number and relative data, depending on the colour encoding (hues or values of colour).
- Animated particles themselves also depict attributes. Different size, density and the moving speed of particles which moving along the flow lines can show the quantitative attributes (Holten 2011)(Maleki, 2016).

2.2.3. Classification of flow maps

Parks (1987) grouped flow maps into three types: radial, network, and distributives. There is a main node at the central of a radial flow map, the endpoints of others lines connect to the central node such like branches radiate outwards. Network flow map shows the connections between the nodes in a map, for example, applying the different widths of lines within a city street network to show the number of vehicles passing through each road. When drawing the distributive flow maps, attributes are considered additionally to describe the movement of humans or objects among geographic regions. Attributes of lines between nodes will be shown.

Five kinds of flow map were considered by Slocum (2009) depends on their purpose, two more were added to Parks' work, they are continuous flow map and telecommunications flow map. Continuous flow map illustrates the movement of continuous objectives such as winds and currents. Telecommunications flow maps aim to show the telecommunications technology flows, for instance, the Internet and information connections. Apart from this, Slocum divided distributive flow maps into two sub-class, one attempts to map the actual flow routes at the scale of the whole world, for instance, a world trade flow map. The other focus on the flows within a part of the geographic area, in this case, the mapping area could be a country or continent for example, a national migration maps.

Boyandin (2013) classified the OD representation techniques (flow maps) according to eight aspects: layout, OD, flow, direction, magnitude, distance, OD total and OD degree. The classification is shown below in Figure 2-8.

Technique	Layout	OD	Flow	Direction	Magnitude	Distance	OD total	OD degree
Flow map	geo	same	explicit line	directed line	line thickness	yes[1]	optional[2]	yes
Chord diagram	circular	same	explicit line	directed line	line thickness	no	yes[3]	yes
Arc diagram	linear	same	explicit line	directed line	line thickness	no	optional[4]	yes
Sankey arcs	linear	same	explicit line	directed line	line thickness	no	yes[5]	yes
OD-matrix	linear	matrix	row→column	row→column	cell fill color	no	optional[6]	yes
OD-treemap	fit[7]	nesting	parent→child	parent→child	cell fill color	no	yes[8]	yes
Map[2]	geo	nesting	parent→child	parent→child	area fill color	yes	yes[9]	yes
OD-map	geo	nesting	parent→child	parent→child	cell fill color	yes	yes[10]	yes[11]
Hive plot	linear	separate	explicit line	O-axis→D-axis[12]	line thickness	no	optional[13]	yes
Symbol map	geo	same	on-demand[14]	O-color→D-color	on-demand[15]	yes	yes[16]	on-demand
O and D symbol maps	geo	separate	on-demand	O-map→D-map	on-demand[17]	yes[18]	yes[19]	on-demand

Figure 2-8: Classification of OD-data (flow map) visualization techniques (Boyandin, 2013)

Gu (2016) classified the flow maps according to the different types of flows and origins/destinations. Flows were split into five classes first: flows are not shown, flows are shown without attributes, flows are shown with qualitative attributes, flows are shown with quantitative attributes, flows are shown with both qualitative and quantitative attributes. For the origins and destinations part, the five classes of flows with different kinds of attributes are also the first five classes of origins and destinations, additional, the sixth class is either the origins or the destination is shown without attributes.

2.2.4. Design principles

Here are some essentials that should be followed when designing flow maps.
Small lines should be shown on top of larger lines. If there are both land and water on the charted area, the contrasts of them are necessary Dent (1999). Slocum (2009) claimed that sometimes the interpretation of spatial pattern is more interesting than the exact numerical info. Flow lines are usually curved but symmetrical curved lines are preferred than sharp bends as mentioned by Jenny and his colleagues (2016). For the attributes, Imhof (1972) recommends multiple parallels or icons along the flows to illustrate the different attributes of flow lines. Tobler (1987) claimed the variation of width is preferred than the variation of colour values to show the quantity in his automatic flow mapping research. Similarly, Jenny (2016) found that line width is the popular used method to show the quantitative attributes of flow maps. When showing the directions in flow maps, Dent (1999) thought the use of arrows is essential when directions are vital. Jenny (2016) proved arrowheads are more efficient than tapered lines.

2.2.5. Limitations of flow maps and the existing solutions

There are also some limitations for flow maps. Visual clutter is a common problem when a mass of data and information visualized at the same time in a visualization area which is not big enough. In 3D environment, clutter is called occlusion because of the nearby objects against human perceptual system (Elmqvist & Tsigas, 2007). Graphic perceptual salience is another limitation, according to the geography first law: 'near things are more related than distant things' (Tobler, 1970). Long flows usually take more spaces and attracted more attentions from the users than the shorter flows. Geographic unit is another problem. When different locations are generated into different levels of regions (e.g., continent, country, province), the original geographic will be changes, that caused the distortions.
Some solutions and methods were suggested to improve flow maps. Filters is a solution to sole the first kind of problem, clustering, different attributes such as time, magnitude, direction could all be filtered by the defined filter in different use case. Sampling (G. Ellis & Dix, 2006) (Rae, 2009) hierarchical clustering (Guo, 2009), or interactive queries to choose and show some subsets of the whole dataset are also solutions that have already be applied and proved. Some combinations, such as combine edges to bundles could also solve clustering problem (Cui, Zhou, Qu, Wong, & Li, 2008), in some research it called bundle (W. Q. Wang, Cai, & Zhang, 2016). The use of range slider that could reduce the arrows and Quadratic Bezier curved lines instead of straights lines could avoid cluttered (Ho, Nguyen, & Jern, 2011).

3. INVENTORY OF EXISTING FLOW MAPS

Before we explore the details of flow maps, we need to understand what flow maps are. First of all, what is a map? A map is a graphic representation of our milieu (Arthur Howard Robinson, Petchenik, & Petchenik, 1976). Secondly, what is a flow map? Flow maps are an established cartographic method to depict movements over time and space (Claudel, Nagel, & Ratti, 2016). In my opinion, a flow map is a graphic description that is capable of representing the movements (OD data) in our surroundings.
In order to generate the guidelines for the design of flow maps, an inventory of the existing flow maps is necessary. When assessing these flow maps based on the criteria, representations used for existing flow maps will be given.

3.1. Criteria of flow maps

A set of criteria is necessary to assess the existing flow maps. The following are the six aspects of this criteria: Topic, OD layout, flow line, direction, attributes and time. For each criterion, respective details will be shown. Table 3-1 depicts the criteria of flow maps.

Table 3-1: Criteria of flow maps

1. Topic	What is the subject of the flow map?
	What objects are represented by the flow lines in the flow map; are they discrete or continuous?
2. OD layout	Does the flow map show more information about the origins or about the destinations?
	Are the origins and destinations points or regions?
3. Flow line	Are the flow lines drawn into the flow map?
	What attributes are depicted by the flow lines?
4. Direction	Are the directions indicated?
	Which kind of representations are used to indicate the directions?
5. Attribute	How many attributes are shown in the flow map?
	Which kind of representations are used to show these attributes?
6. Time	Is time depicted in the flow map?
	How is the element of time depicted?

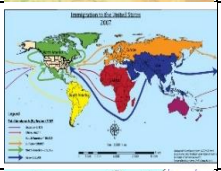
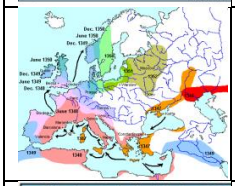
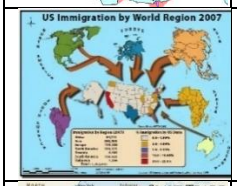
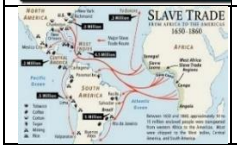
These six aspects of the criteria were chosen based on which kind of information could be depicted in a flow map and how important it is. Topic and OD layout are the first two criteria, since every flow map contains them. These two criteria depict general information about a map. Flow lines are the symbol of a flow map. This characteristic can distinguish flow maps from normal maps directly, however, not all maps include the actual flow lines, Guo(2006) for example, displayed the movement by the use of a matrix sequence. It has been mentioned in Chapter 2 that the data represented in flow maps is: OD data and OD data recording movements. Therefore, the representation of directions is necessary. Mostly, directions are shown based on the flow lines in flow maps. For the Direction criterion, same as the flow line, not all maps describe the directions in the flow map immediately, some of them show the connections (Ricardo

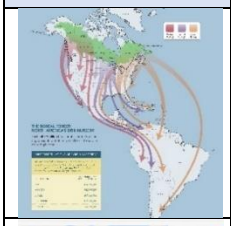
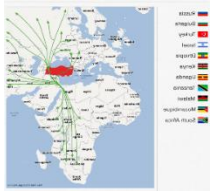
Bion, 2016) or the network (Buczkowski, 2016) instead. Apart from this, Attribute and Time are the most elaborate information which may be displayed in flow maps. Compared with the previous criteria, they are important but not necessary for every map.
Considering the sequence of how to extract the information from a flow map step by step, from Topic to Time, one should know the topic of the map intuitively when reading a flow map: What is the subject of this map and what objects are represented by the flow lines? Subsequently, one should find out information about the origins and destinations: What's the OD layout of this map; are the origins and directions points or regions? The first two steps contain general information. In the next step, one is supposed to focus on the flow lines: Are the flow lines drawn into the map and what information is represented by them? The users of the maps are then expected to recognize the direction of the movements: What are the directions of the movements and which representations are used to depict them? Map users needing more details should figure out the precise information based on the flow lines: What kind of attributes are shown and how, including the representation of the time element?

3.2. Inventory of flow maps

To assess different representations, flow maps from a variety of sources were collected. For the inventory, a total of 183 flow maps were collected and an inventory table of all these revisited flow maps was created. It is the objective to assess, compare and summarize the existing flow maps. Table 3-2 only shows the first 10 flow maps (Map 1 to Map 10) of the inventory, the complete inventory table with all 183 flow maps is attached in Appendix A.

Table 3-2: The first 10 maps of the inventory table

	Topic	Lay out	Flow line	Direction	Attribute	Time	Remarks
	Army Continuous	OD P-P	No-attribute Line	Arrows (front)	No-attribute	Arrow sequence	1.
	Migration Discrete	In R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL-Map colours	No-time	2.
	Disease Continuous	OD R-R	No-attribute Line	Arrows (front)	No-attribute	(1) Arrow sequence (2) Map colours	3.
	Migration Discrete	In R-R	QT Line	Arrows (front)	QT-Line thickness QL-Map colours	No-time	4. Distortion of base map and Drop shadow
	Slave trade Continuous	OD R-P	No-attribute Line	Arrows (front)	QL-Labels	No-time	5.

	Birds migration Discrete	Out R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL-Map colour	No-time	6. Transparent line
	Birds migration Discrete	OD R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	7. Interactive base map
	Migration Discrete	In R-R	QL Line	Arrows (front)	QL-Line colours	No-time	8.
	Migration Discrete	In R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	9.
	World exploration (war) Continuous	OD P-R	QL Line	Arrows (front/ middle)	QL-Labels /line colours/map colours	Arrow sequence /labels	10.

The inventory table is created based on the criteria consisting of the six aspects of how to assess flow maps. There are 8 columns in the table. The first one displays the map whereas the last column shows the remarks which include the number of each map in the inventory. For some flow maps, the design characteristics are also described briefly in this column. The other columns are: Topic, Layout, Flow line, Direction and Attribute, from the second to the sixth column, respectively.

The sources of these 183 flow maps are divided into three categories: Media, School atlas and Web application. Figure 3-1 shows the proportion of inventory flow map sources in a pie chart.

- Media: This is the main source of the revisited flow maps. Static or dynamic flow maps from websites, news reports, academic articles or some personal blogs are all grouped in this category. It aims to show the corresponding information to everyone by using flow maps. 93 out of the 183 flow maps were collected in this part. They take up more than half of all flow maps.
- School atlas: Several school atlases were browsed, 65 flow maps were selected, scanned and added to the inventory. They make up 35% of the inventory. Flow maps from school atlases are usually designed with the most traditional and classic representations compared to the previous two categories. This is to ascertain that the inventory balanced and typical.
- Web applications: 25 web applications were collected in this inventory; They account for 14%. A web application is a complete and independent website in which flow maps are used to show the corresponding networks, directions or attributes. Normally, interactions are necessary for web applications. Users may operate the functions which are provided by the web application, changing the attributes or turning the views of the flow maps for interaction.

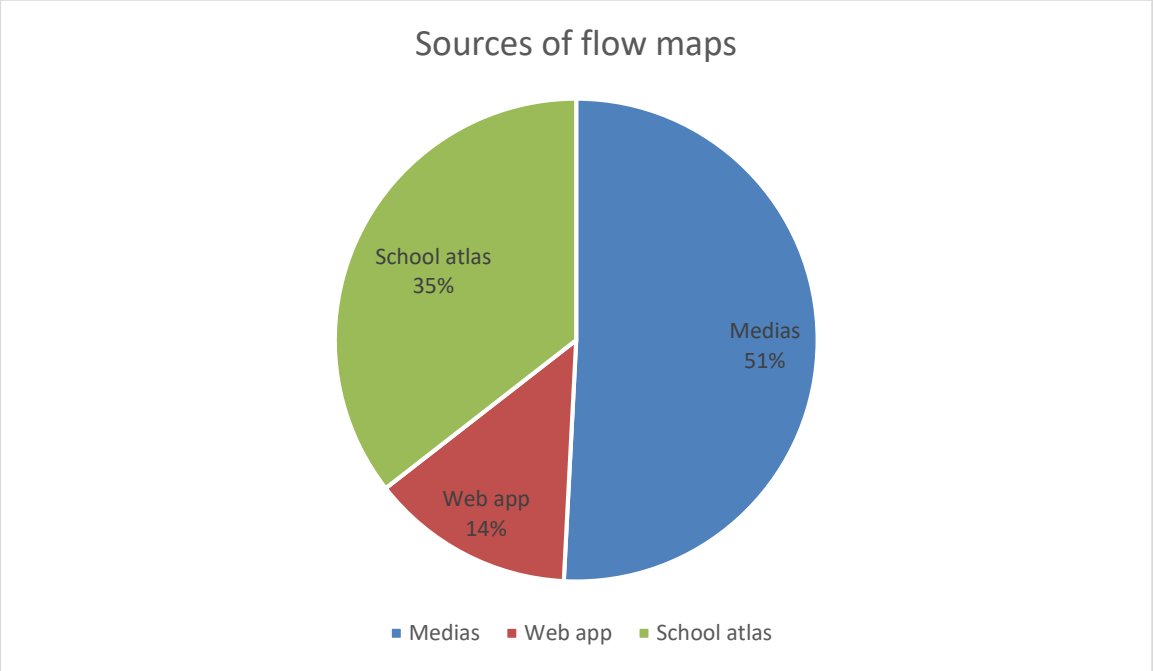


Figure 3-1: The proportion of inventory flow map sources

3.3. Summary of the representation of flow maps

In this part, different representations of flow map will be summarized according to the six criteria. With the number of map, every example mentioned in this Chapter can be found in Appendix A: the inventory of flow maps.

3.3.1. Topic

Topic is the first criterion when assessing a flow map - it refers to the subject. There are two tasks concerning the Topic.

- What is the subject of the flow map?

The most common topic concerns animal movements, which include the migration of humans and animals as well as refugees and commuters. There is a total of 81 flow maps, 44% of which depict the movement of humans and animals. Traffic and trade are also quite common topics. 41 (22%) of the maps describe flight, satellite and shipping movements as well as the flow of goods trading. The 30 flow maps covering wars show the movement of armies and military equipment.
In addition to this, the topics of information transmission, internet connection, digital attack, culture transmission, money and finance and things in nature such as wind and ocean currents, genes, diseases, diastrophism and evolution are all shown in flow maps. Figure 3-2 is a word cloud displaying the topics of flow maps. The size of each word is based on the frequency of the topics.

Figure 3-2: The topics of flow maps

- What objects are represented by the flow lines on the map, are they discrete or continuous?

In order to differentiate between discrete or continuous objects, the following must be observed: If objects move from the origin to the destination once in a flow map, then objects are discrete. On the other hand, if the same objects move from one origin to one destination and then move from the previous destination to next destination in a flow map, the objects are continuous. Figure 3-3 compares the flow maps with discrete objects (map on the left) and continuous objects (map on the right). Figure 3-4 shows the proportion of discrete and continuous objects.

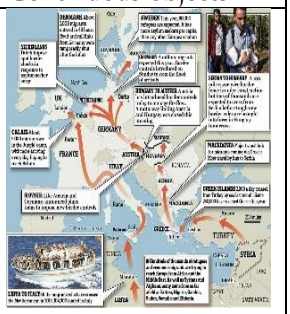
Discrete objects	Continuous objects
	
Map 15	Map 17

Figure 3-3: Maps with discrete objects and continues objectives: Maps15 (left) with discrete objects: military equipment moves from origins to the border; Maps17 (right) with continuous objects: refugees move to one country and continue to the next.

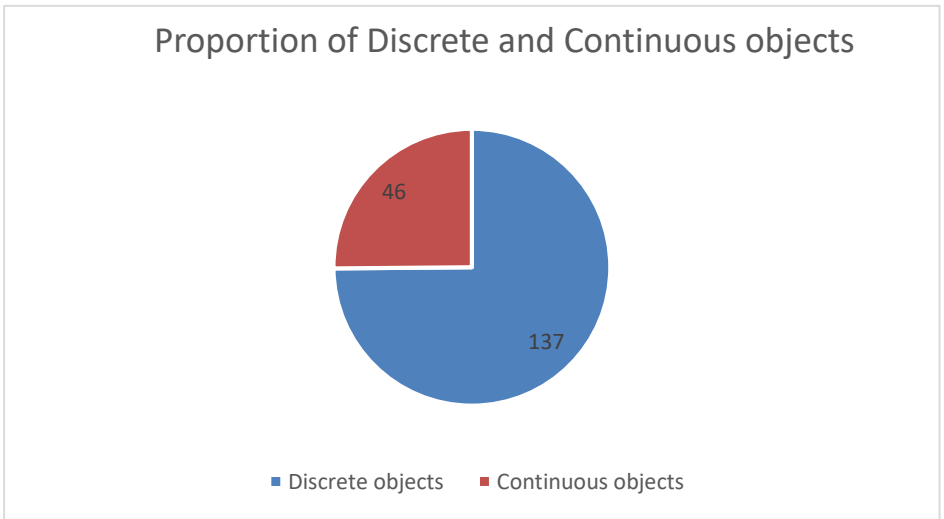


Figure 3-4: Proportion of Discrete and Continuous objects

3.3.2. OD layout

OD layout is the second criterion. There are three questions which refer to this.

- Does the map show more information about the origins or about the destinations?

OD layout shows in which way the origins and destinations are laid out on the screen. It is summarized as three different types: In, Out and O/D.
When flow maps show the incoming flows and focus on the origins portion (In); when flow maps show the outgoing flows and focus on the destinations portion (Out); when flow maps show both the incoming and outgoing flows, as well as the origins and destinations (O/D). In the inventory, 20 maps show the incoming flows, 11 maps show the outgoing flows while 152 maps show both flows. Figure 3-5 shows the proportion of use regarding these three types.

- Are the origins and destinations displayed as points or regions?

Origins/destinations in flow maps are displayed either as points or region. Hence, there are three kinds of origin-destination combinations in flow maps, movements between points (P-P), between regions (R-R) or between points and regions (P-R). The point-region (P-R) movements refer to the origins and destinations which are not on the same level, for example, when an object moves from a city to a country, the city and country are not on the same level in the flow map. 14 of the 183 flow maps in the inventory depict point-region (P-R) movements. 29 maps show the movements between regions (R-R) while 76% (140) of the flow maps in the inventory depict the movements between points (P-P). Figure 3-6 displays the respective proportion of use of these three origin-destination combinations.

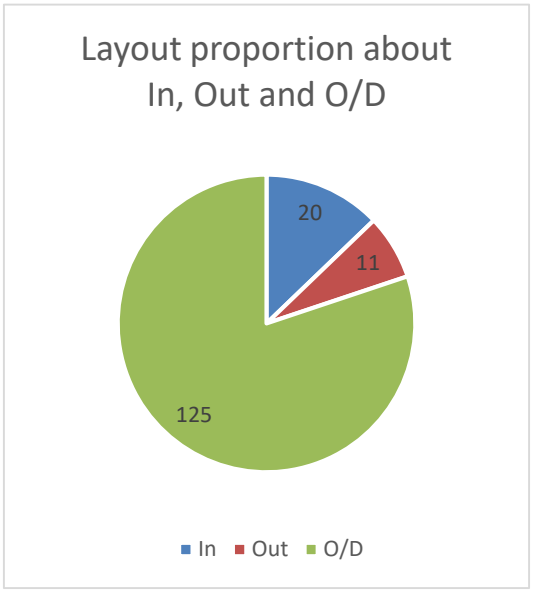


Figure 3-5: Layout proportion about In Out and O/D

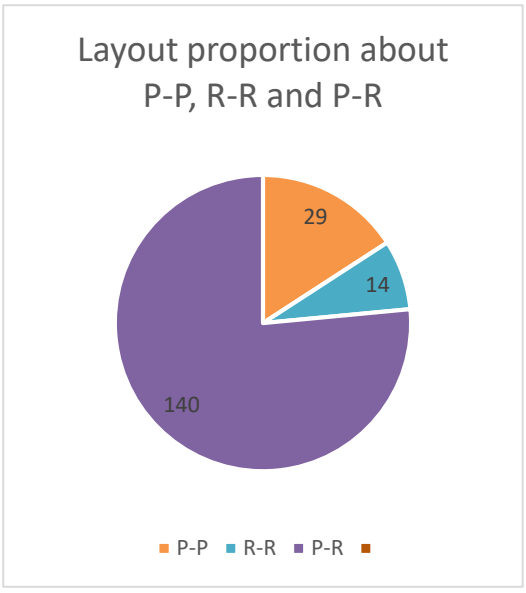


Figure 3-6: Layout proportion about P-P, R-R and P-R

3.3.3. Flow line

Flow lines are the most important elements of flow maps. Flow lines are initially divided into two parts: flows with attributes and flows without attributes.
For the first part, No-Attribute Flows, some flow maps use the matrix sequence (Map 133) or different sizes of symbols at O/D locations (Map 39) to show the movement rather than the actual flows. These kinds of 'flow lines' are recorded as 'No-Line'. Other flow maps only describe the connections or networks of objects and existing flow lines without any attributes (Map 119). This kind of element in a flow map is called a 'Line'.

The attributed flow lines are divided into three subclasses: flow lines with qualitative attributes (QL Line), flow lines with quantitative attributes (QT Line) and flow lines with both qualitative and quantitative attributes (QT-QL Line). Figure 3-7 shows the frequency of the use of all these flow lines in the inventory. Lines can be divided into three types within the three rows of Figure 3-8. The first column illustrates the elementary segments for each type of line. The second and third columns show the examples when lines are used to show one-to-many and many-to-many O/D. The first row shows the line which is only used to represent the O/D connections and networks. The second row shows a thicker line. For these kinds of lines, the thickness varies on the map based on the direction and the attributes of the object. When two or more lines join, the width of the joint lines is not the summation of the width of the previous lines. The third type of line is the typical line. The thickness of each line is the same. When two lines come together that share the same destination, the width of the combined line is the summation of the width of the two previous lines.

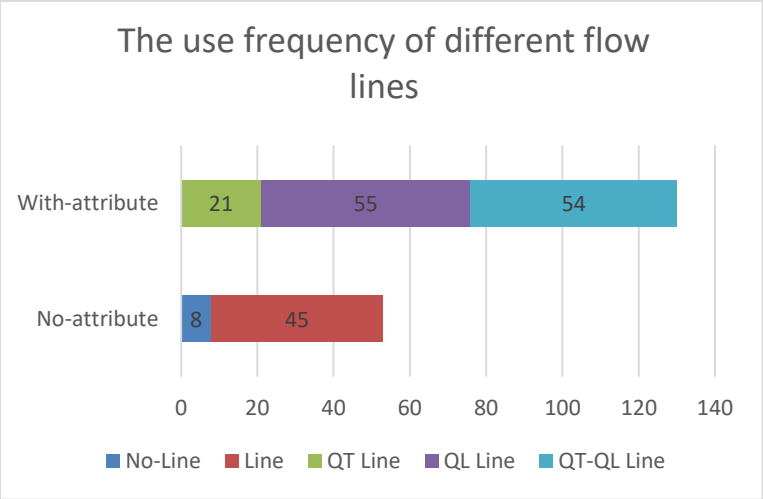


Figure 3-7: The use frequency of different flow lines

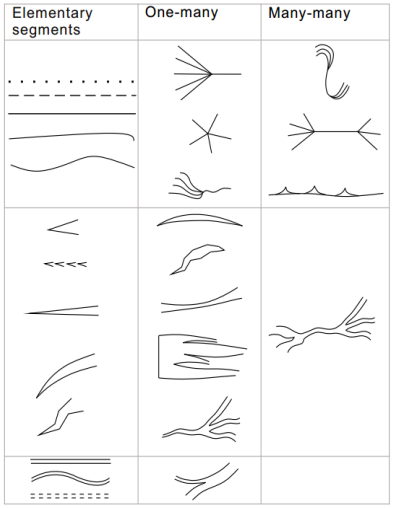


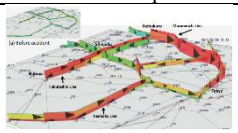
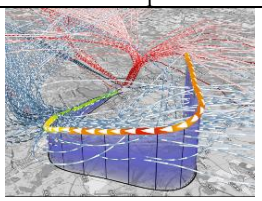
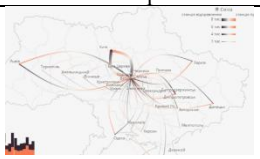
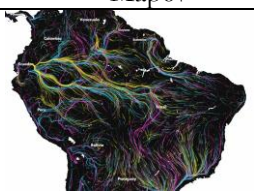
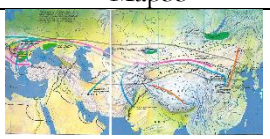
Figure 3-8: Flow lines grouping

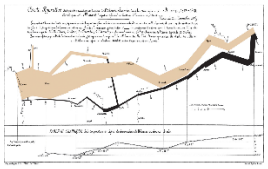
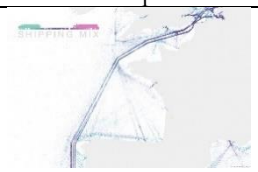
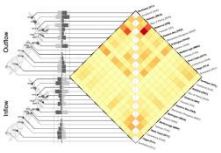
3.3.4. Direction

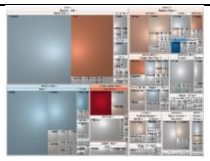
How to depict directions is one of the most important task in this research, Table 3-3 displays the classification of all the direction representations with the corresponding examples. The sequence of each representation depends on the using frequency of these representations in the inventory.

Table 3-3: Representation of time in flow maps

Representation of time in flow maps			
Different representations			Example
Directions of with-line flow maps	Arrow	Front	 Map6

		Middle		 Map26
		Inside		 Map128
		Bi-direction		 Map38
	Colour	Hue	Colures changes	 Map34
			Gradual change	 Map67
		Intensity (value)	Dark→light	 Map33
			Light →dark	 Map97
		Transparency		 Map59

	Tapered	Thick→thin	 Map74
		Thin→thick	 Map121
	Animation	Animated point particle	 Map68
		Animated lines particle	 Map61
	One O/D		 Map129
	Networks		 Map127
Directions of no-line flow maps	Changes of colours		 Map39
	Changes of sizes/density		 Map58
	Sequence	Matrix	 Map132

		Quad-tree	 Map41

With regard to the direction representations of With-Line flow maps, arrow is the most common way to show the direction according to the inventory, which is also proved by Jenny (2016). The use of arrows is often combine with different type of lines that was introduced in Figure 3-8.
Arrows can be placed in the different place of each line: in the front of the lines (Figure 3-9 a), in the middle of the lines (Figure 3-9 b), and inside of the lines (Figure 3-9 c). Apart from this, Tobler divided arrows into single direction arrow and bio-direction arrow (Map 38).

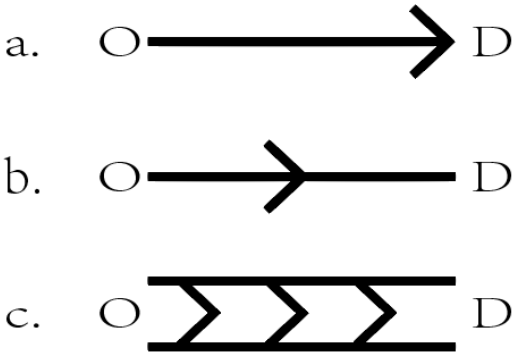


Figure 3-9: Arrows representations: a. Arrows in front of lines b. Arrows in the middle of lines c. Arrows inside of lines

Colour changes is possible to represent the direction of movements. It was classified into Hue, intensity and transparent (H-I-T). For Hue, different flow lines in different colours (Map 34) and one flow line with a gradual colours changing (Map 67) are the two sub-classes. Dark-to-light (Map 33) or light-to-dark (Map 97) are two designs of Intensity. Besides, *Transparent-opaque line* is a familiar representation to indicate directions as well (Map 59). According to the inventory, the ranking of these three colour variables is Hue, Intensity, and Transparency.
Tapered line is another representation, thick-to-thin (Map 74) and thin-to-thick (Map 121) are two alternatives.
As for *Animation*, which is an increasing applied direction representation these days with the development of internet and the popularize of personal mobile devices. The moved point particles (Map 68) and line particles (Map 61) are two feasible designs. However, readers have to browse this kind of flow maps based on the screen, books and paper cannot be the media of this map representation.
There are also some maps which have *only one origin or one destination*. In this way, map readers can recognise the directions of movement by the only one origin or destination which will be informed on the map (Map 129).
The last part of the representation of with-line flow maps is *networks*, these flow maps aim on display the connections between locations instead of a specific direction (Map 127).
In respect to the direction representation of No-Line flow maps, flow maps without actual flow lines or lines only connect the graphs without visualize any attributes are summarized. Directions shown by the changes of symbol colours (Map 39), and the changes of symbol (at O/D locations) sizes (Map 39: from big symbols to small symbols or Map58: from density area to sparse area). Furthermore, the sequence of

reading habits (Map 132, Map41: from top to bottom, left to right) can remind readers to notice the moving directions.

The No-Line flow maps could also be classified as single or multiple displays. Figure 3-10 displays the classification of No-Line flow maps in single or multiple views.

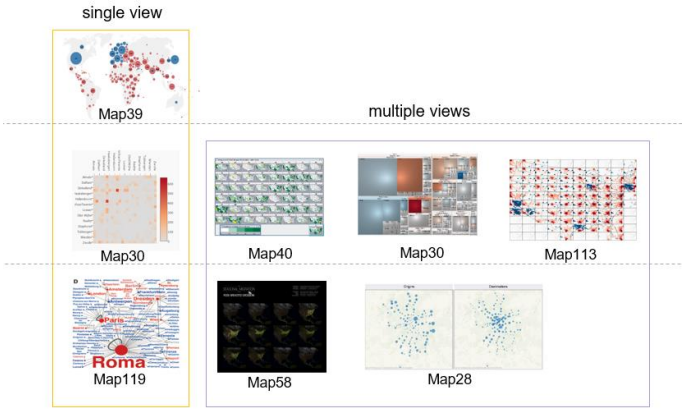


Figure 3-10: Single-multiple views of no-line flow maps

3.3.5. Attribute

Quantitative and qualitative attributes are usually visualized in flow maps, according to the rules of visual variables, size is the best one to describe quantitative data. Colour is optimal for qualitative. The representations about quantitative (QT) attributes and qualitative (QL) attributes are describe in Figure 3-11 and Figure 3-12 respectively.

Line thickness is the most common applied representation of quantitative attributes, 59 (32%) of the flow maps were used in the inventory. Symbol size is followed and 30 maps are adopted. Animated particle which include particle density and moving speed, 18 times were counted in the inventory.

With regards to qualitative attributes, the frequency of line colours and labels are much popular than the others. In 82 (45%) and 83 (45%) maps where qualitative attributes were demonstrated by line colours and labels separately, which also proves the design principle of Imhof (1972).

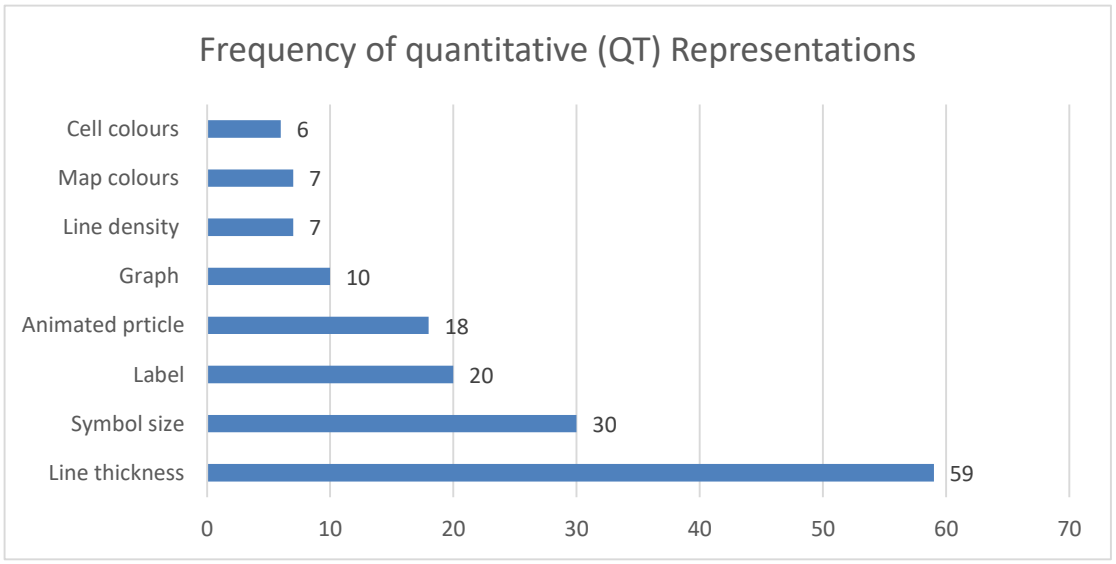


Figure 3-11: Frequency of quantitative (QT) Representations

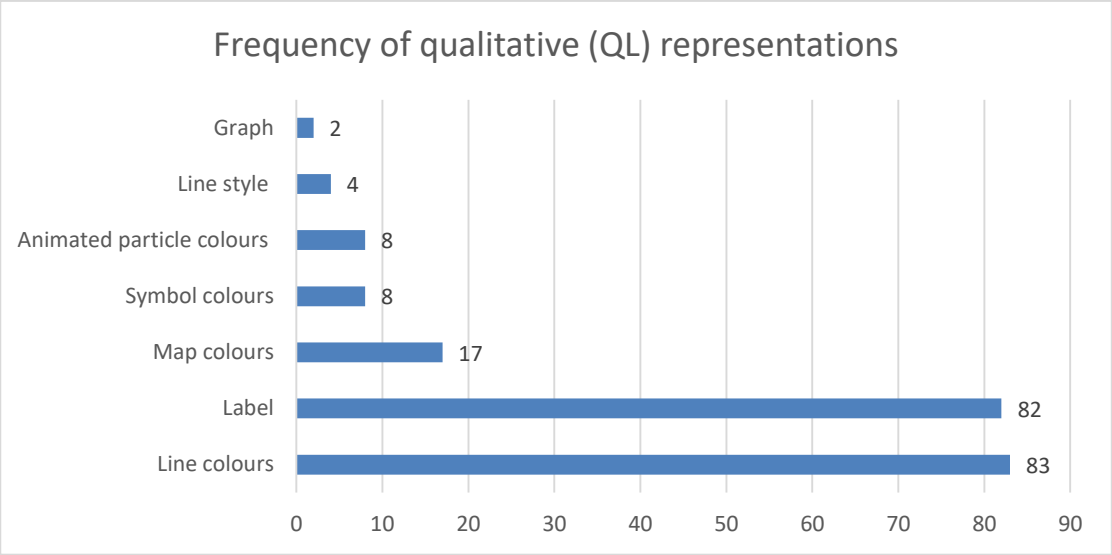


Figure 3-12: Frequency of qualitative (QL) representations

3.3.6. Time

Time element shows the time and objects moving sequence. Although time is inherent to flow maps is not always described in the maps. Table 3-4 shows the summary of time representation and examples from the inventory. With the example numbers, all the maps can be found in the inventory which is attached in Appendix A.

Table 3-4: Representation of time in flow maps

Representation of time in flow maps		
Different representations		Example
Line	Style	Map135
	Colour	Map115
	Contour	Map72
Sequence	Arrow	Map21
	Matrix	Map31
Animated	Line	Map61
	Particle	Map54
Changes of symbol size		Map63
Map colours		Map117
Label		Map139
Multiple views		Map14

Many flow maps show the time element by using the basics flow lines. Lines in different styles (solid lines or dotted lines) and different colours can show the time. Contour line is another kind of representation of flow lines to show the time, Map 72 and Map 73 describe the travel time by the using contour lines.
The sequence of arrows and matrix could also depict time element. When people read a flow map they will follow the flow lines with the indication of arrows one by one, this is often used to describe continuous objects. Usually, people read a matrix from left to right, from top to bottom. When different attribute values are represented in different matrix cell, then it is possible to show the changes. Map 31 shows the different number of refugees in different years' cells in each row.

For the animated flow maps, movements are divided into moved lines and moved points. moving. With the movements of point or line particles, time patterns are depicted.

3.4. General suggestion of flow map design

After the review of the 183 flow maps, some suggestions were summarized as per below:

Web flow maps

- Interactions are necessary for web applications, especially when much information needs to be visualized or the mapping area is small.
- Web applications usually use representations with animation, this is the advantage of web mapping. However, this could also bring some drawbacks since loading animations, effects and interaction functions need time.

Base map:

- Most base maps are typical topographic maps. However, the use of the thematic map (nominal map and choropleth map) could help users easily recognize the origins and destinations areas. Readers could compare the attributes through the base map (choropleth map) which could reduce the clutter of flow maps. However, it can only be used when the origins and destinations are regions rather than points.
- As for flow maps with No-geographical base maps or when locations are represented by symbols, it is unnecessary to distinguish origins and destinations as regions or points.
- The contrast of land and ocean is necessary when the mapping area includes both of them in order to highlight the elements or mapping area.

Line

- The route of flow lines can be represented by some other elements in a map. Map 25 shows the shipping routes by the density of shipping emissions (PM2.5) but the direction cannot be distinguished in this case.
- When drawing the continuous objects into flow maps, segmented flow lines are usually applied. This way, it is easier to demonstrate the direction and attribute changes of objects in different segments of the flow lines.
- Flow maps are the maps which describe movements, however, actual paths do not need to be drawn. A matrix can also describe the movements.

Direction

- Arrows are used in almost all the flow maps to represent directions. Arrows can be combined with the line thickness, transparency or animation. Generally, flow lines include arrows and carry the data
- Arrows can also be symbolized as labels in order to show the attributes. Map 64 uses airplane heads to indicate the direction and the colours to distinguish the qualitative attributes (departure or arrival).
- When representing the directions by an inside-arrow, lines of a proper width are necessary.

Attributes

- Labels (words, pics, symbols) can illustrate both quantitative and qualitative attributes. Labels can be placed at any appropriate place with sufficient space (front, middle, end or along the flow lines).
- The visualization of attributes is not always necessary in flow maps. Some maps only aim to display the connection or network.
- When the range of quantitative data is wide, data classification is required.
- Data representations should follow the Visual Variables Principle in Figure.3-13.

Time

- Due to human reading habits, from left to right, top to bottom, the time element can describe the sequence instead of flow lines, such as a matrix or arrows with segmented flow lines.

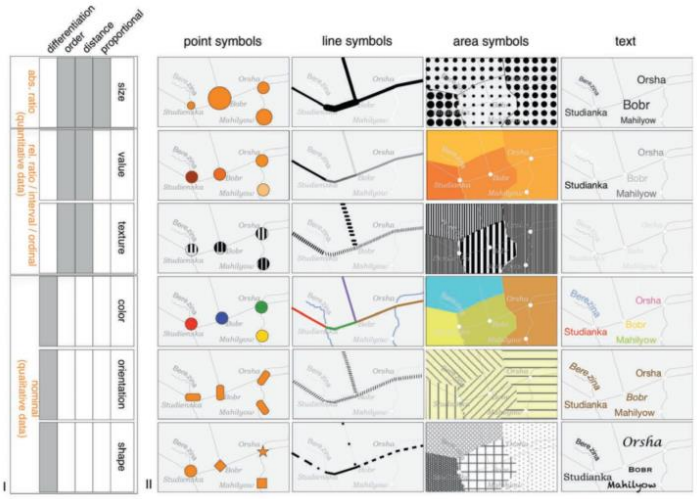


Figure 3-13: Visual varieties (Kraak, 2014)

4. CONCEPTIAL DESIGN AND IMPLEMENTATION OF 2D FLOW MAPS

In order to generate the guidelines for the design of flow maps, the performance of different kinds of representations needs to be tested. In other words, which representation preferences will be evaluated in the next stage.
There are four characteristics of OD data in flow maps: connections, directions as well as quantitative and qualitative attributes. Considering the data characteristics and the criteria of the flow maps which were introduced in Chapter 3.1, four kinds of representations will be described in the following flow maps. Based on the ranking of inventory, the most commonly used representation methods for each group will be visualized in different flow maps using airport data. The summary of the representations of each group are displayed in Table 4-1.

Table 4-1: The commonly used representations

Group	Representation	
Network	Straight	
	Curved	
Quantitative	Line width	
	Symbol size	
	Line width and symbol size	
Qualitative	Line colour	
	Labels	
Direction	Arrow	Front-arrow
		Mid-arrow
	Colour	Intensity
		Transparency
	Tapered	Thin-thick
		Thick-thin
	Animation	

4.1. Data preparation

The topic of the flow maps in this research is 'flights'. As a practical example, the data of Keflavik International Airport (KEF) and Amsterdam Schiphol Airport (AMS) will be collected and visualized by the use of flow maps in order to test different map representations.
Keflavik International Airport (KEF), Iceland is located between North America and Europe. There are scheduled flights from/to North America and Europe which transferred 4.8 million passengers in 2015 (Flight, Í, Se, Flight, & Jög, 2015). Amsterdam Schiphol Airport (AMS), The Netherlands is one of the busiest airports in Europe. People call it the gate way country of Europe. In 2015, around 58 million passengers travelled via AMS (Schiphol Group, 2015).
The data of this research came from the website Flightradar24 (https://www.flightradar24.com), where the schedules of all the airports are available. The 7-days' data from 25th December 2016 to 1st January 2017 were collected initially, both for Amsterdam Schiphol Airport (AMS), the Netherlands and Keflavik International Airport (KEF), Iceland. However, due to the holidays, the flight information during these

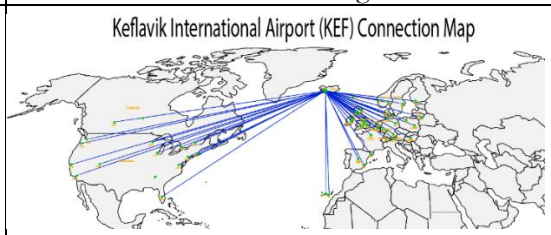
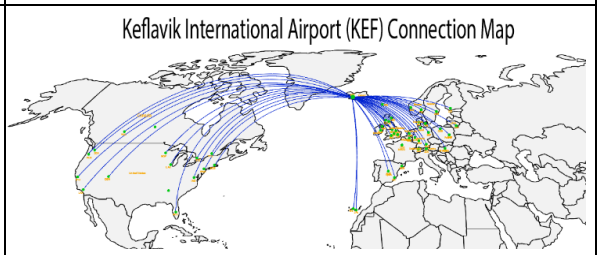
days was not sufficient to show the connections. After a comparison and analysis, the day with the highest number of flights, 30th December 2016, was selected as the dataset for to be used for the flow maps in the next step. The data from the Flightradar24 is all the daily schedules with the details, hence, combining different flights to/from the same cities and classification are necessary.
There are 618 flights arrived at AMS and 619 flights left from AMS, 206 cities connected with Amsterdam on 30th December. As for KEF, 61 flights arrived and 60 flights left, linked with 51 cities directly in one day.

4.2. Implementation

According to the classification of flow lines, the flow lines without attributes will initially be drawn in the flow maps in order to show the connections, the flow lines with quantitative and qualitative attributes are added afterwards. It is different with migration movement. Flight connections between two cities are usually bi-directional, which means the same flight flies between those cities. This is one of the characteristics of flight data. In this case, there is only one origin or destination in each map. Edge crossing doesn't need to be considered. Only the overlaps with the increasing width and density of flow lines should be taken into consideration. Different flow maps will be generated for each representation group. These are Connection, Quantitative, Qualitative, and Direction. The one with the least overlap and which is the least cluttered will be ultimately displayed for user preference testing.

4.2.1. Connections

Initially, this work begins with Keflavik International Airport (KEF), not only because of the amount of flights but also because of its geographical location. Iceland is quite solitary, most of the flights go east and west because of the isolated location. For AMS, air traffic crosses each other a lot.
Considering this group aims to show the airport connections all over the world. All the incoming and outgoing flow lines will be added up. Robinson projection was used as the base map, because the projection is a good compromise between size distortion and shape distortion (Haviland, 2013).
Figure 4-1 displays the KEF and AMS airport connections with straight and curved flow lines used respectively. The curved flow lines drawn rely on the relevant geographic flight path in reality. Due to the shape of the earth, the curvature also increases with the growing latitudes of the corresponding destination/origins. In this step, it is the maps' objectives to compare which style of line is better to show the connections in a flow map. Should a straight line or curved line be used?

Connection flow maps		
	Connection with straight lines	Connection with curved lines
KEF		

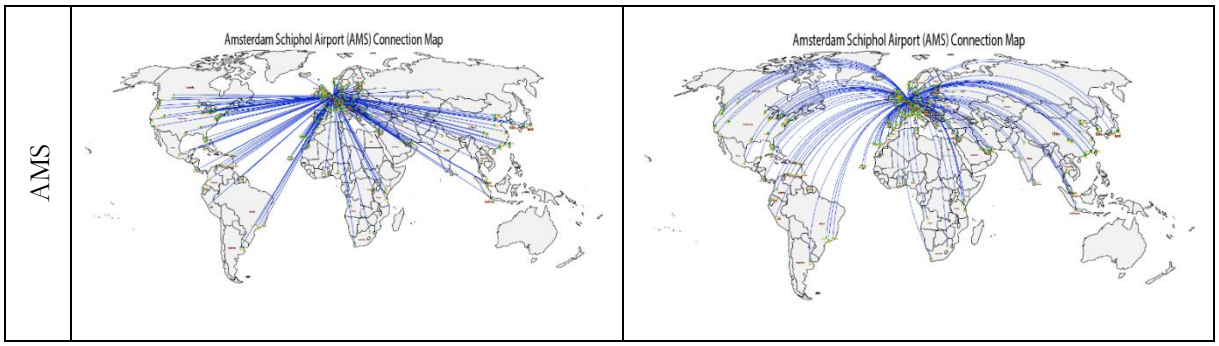
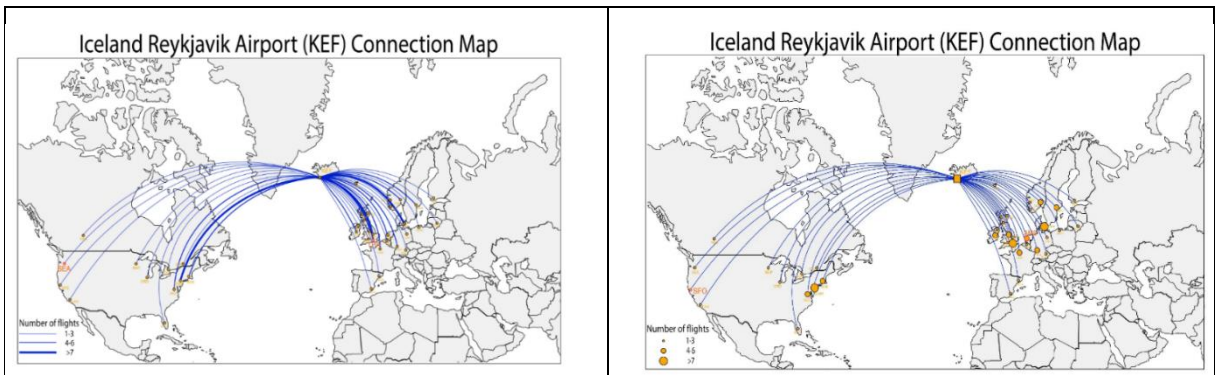


Figure 4-1: Connection flow maps with straight lines and curved lines

After comparing the flow maps in this group, it is noticeable that the data amount of AMS is big. The corresponding flow lines are too crowded to show the details. The next part will focus on Keflavik International Airport (KEF). Since there is more space between curved flow lines than straight ones, details will be drawn based on the curved flow lines from the next step onwards. This is also observed in the inventory: more curved flow lines are used than straight ones.

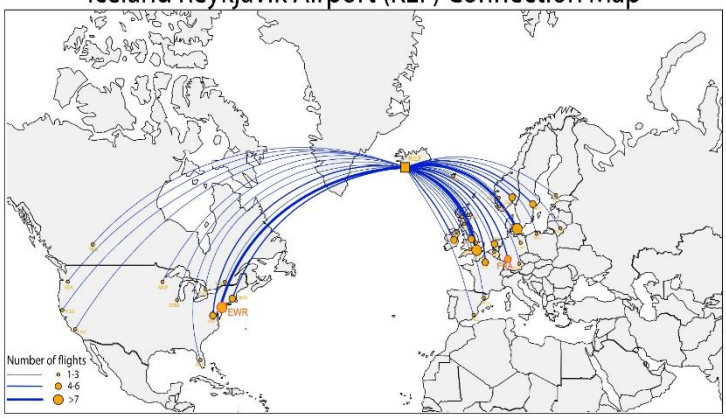
4.2.2. Representation of quantitative attributes

Line thickness and symbol sizes at O/D locations are the most popular used representations of quantitative attributes. Some flow maps use a combination of both of these two representations. In this step, three flow maps with the most popular used representations were drawn in order to figure out which one is easier to be accessed by the readers. Figure 4-2 displays the three representations of quantitative attributes. The quantitative attributes in this case are the number of flights to/from KEF on 30th December 2016. Ten numbers were divided into three classes: 1 to 3 flights, 4 to 6 flights and above 7 flights. The legend at the bottom left corner explains the specific number of different thicknesses and sizes.



a. Flow map with changes in thickness

b. Flow map with changes in symbol sizes



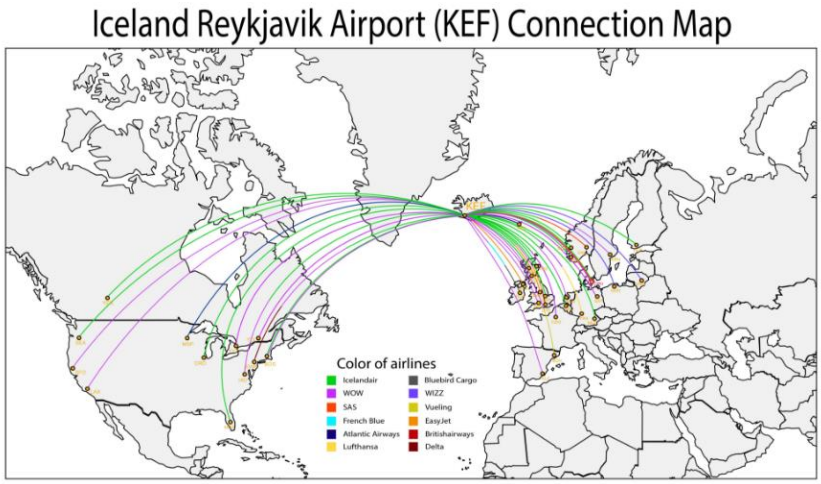
c. Flow map with changes in line thickness and symbol sizes

Figure 4-2: Representations of quantitative attributes

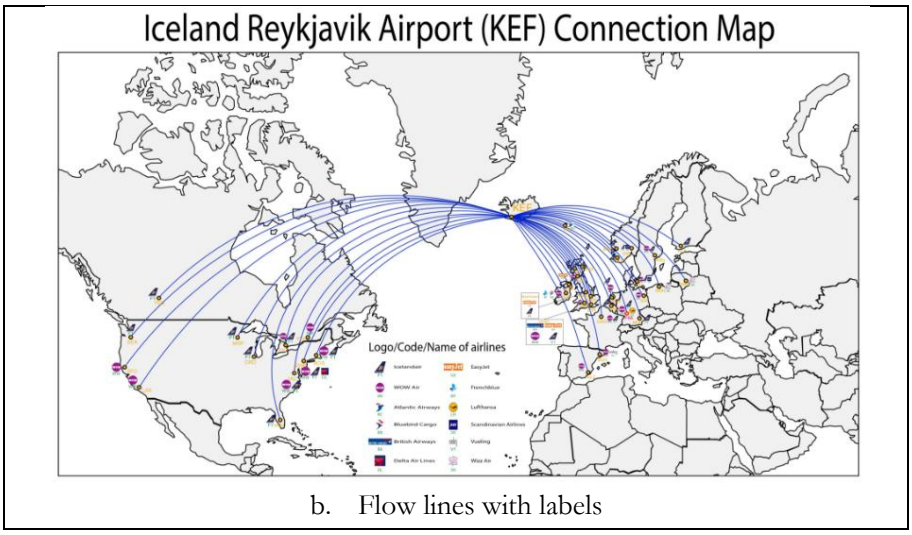
From this stage on, maps begin to use Mercator projection due to the characteristics of preserve angles, which project the world as flat. This is easy to read and to be able to compare the individual flow lines.

4.2.3. Representation of qualitative attributes

Obviously, line colours and labels are the two most popular representations of qualitative attributes. In this step, two flow maps with these two representations will be drawn. The qualitative attributes in this case are the various airline companies which flew to/from KEF on 30th December 2016. It is a question of whether colours or labels are better for the representation of the qualitative attributes.



a. Flow map with coloured lines



b. Flow lines with labels

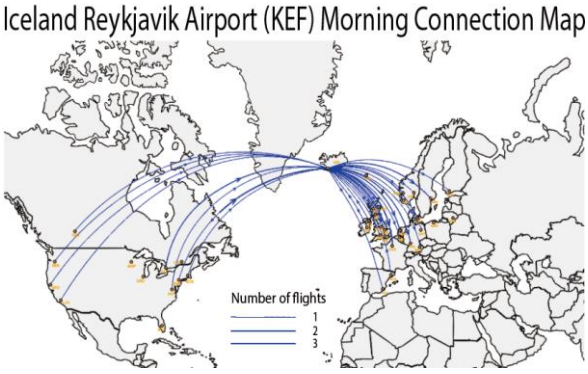
Figure 4-3: Representation of qualitative attributes

On the map with coloured lines, one colour refers to one specific airline, these two maps are displayed in Figure 4-3. Only one line connects each two cities with mixed colours. In reference to the map with labels, different airlines' logos are posted beside the airport symbols. Readers can recognize airlines by different colours or different logos.

4.2.4. Representation of directions

Summarized in Chapter 3.3.4, arrows, colours, tapered lines and animations are the top four used representations of direction. To add more details to these representations, arrows in the front and arrows in the middle; the change of transparency and the change of intensity; the direction from thick-to-thin and from thin-to-thick, can all depict the directions in various ways. As a result of the characteristics of airport data that each flight has two directions, it was decided to only use the data from the morning hours. This way, it is possible to show the direction utilizing airport data. Regarding the location of KEF, the morning patterns are also unusual: Flights from America arrive in the morning, other flights leave to other European countries in the meantime. This is also positive for readers to recognize the flights' directions. Figure 4-4 displays the representations of directions in the case of KEF morning patterns. Data was also classified into three groups: one flight, two flights, and three flights in the morning hours.
For this part, flow maps with commonly used representations of direction were generated in order to figure out which representation makes it simpler for map readers to discern the directions.

a. Flow map with Front-arrow



b. Flow map with Mid-arrow

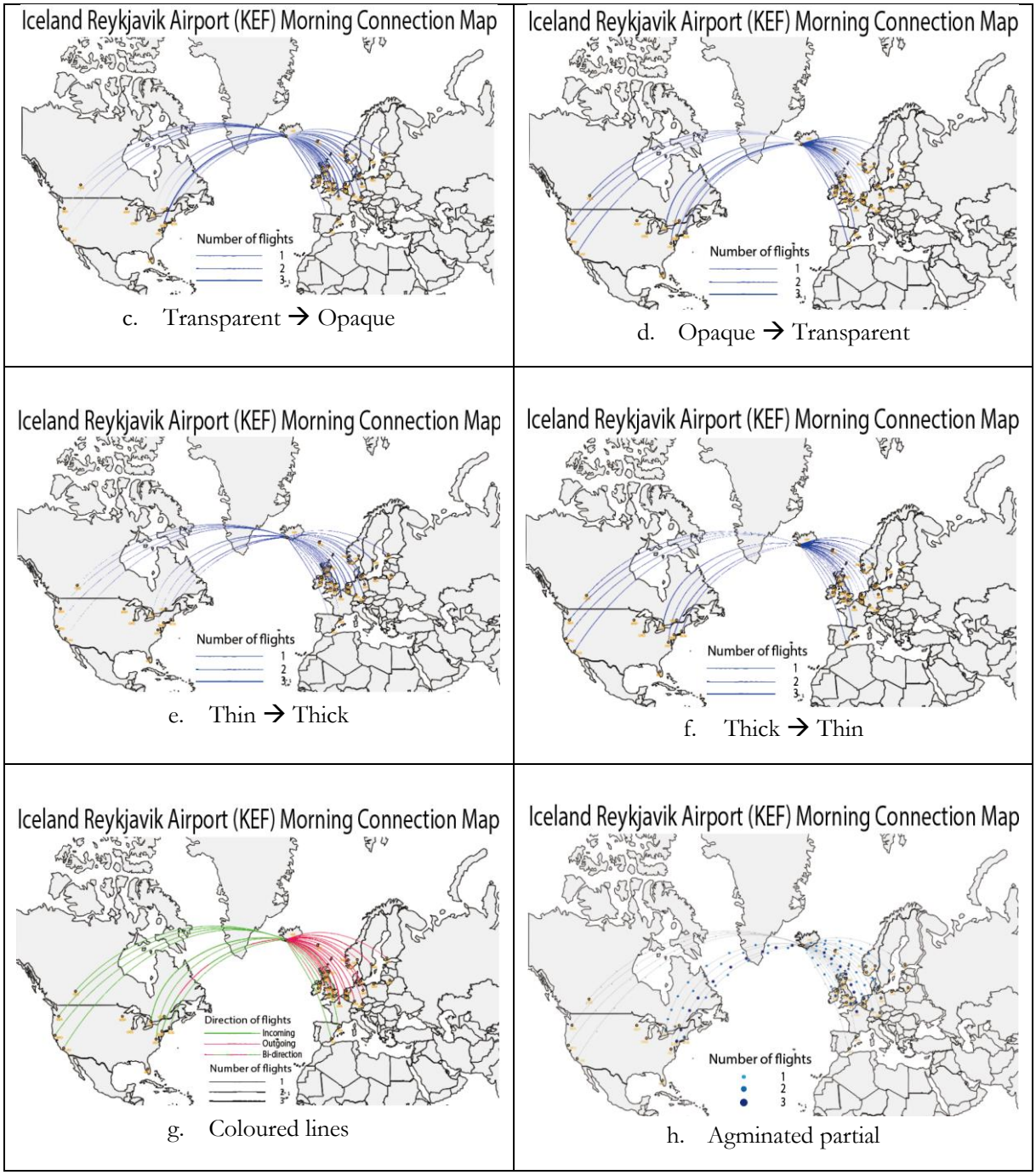


Figure 4-4: Representation of direction

The first two flow maps show directions using arrows, one with a Front-arrow and the other with a Mid-arrow. The second two maps illustrate the directions with transparent-to-opaque lines and opaque-to-transparent lines.

To ensure the readability of the tapered lines, the line width used was stronger than the other maps. For the last two maps, one flow map with colours and another one with animated particles were shown. Different sizes of point particles with different colours refer to the different number of flights come to KEF. Colours only aim to help the readers find out the point particles they don't show any attributes.

5. SURVEY DESIGN AND IMPLEMENTATION

5.1. Introduction

This survey aims to test the usability of the most frequent used graphic representations of OD data in flow maps, in the aspects of the four groups which discussed at the beginning of Chapter 4. They are connections, directions, quantitative, and qualitative attributes. The representations will be applied in the next step which all selected based on the summary ranking of inventory in Chapter 3.3 and discussed at the end of Chapter 4. Both quantitative and qualitative analysis will evaluate to the representation performances.

Five parts constitute the online survey: basic information, connections, quantitative, qualitative and direction. Variables in each group are the different map representations. In the perspective of the sequences of questions, the questions will be asked randomly within each group in order to avoid the influence of the readers' learning. However, a sequence from group 1 to group 4 is fixed. One or two tasks will be given to participants in each part.

In this chapter, the flow maps which generated in Chapter 4 will be tested. A pilot test will be done initially, based on feedback, slightly improved will be done in order to make sure the maps are easy reading.

An online survey will be designed and created by the online software LimeService (https://www.limesurvey.org/), which is possible to records the time consumption for each question and display the animated maps.

5.2. Usability Criteria

The purpose of the test is to know the efficiency, effectiveness, satisfaction of the OD representations, which one works best with visualization of airport data?

The usability criteria are posted:

- Efficiency: how fast can people come with the answer?
- Effectiveness: how good is the answer?
- Satisfaction: does the user like it?

The evaluation part consists of quantitative and qualitative analysis. Median time consumption and accurateness of each task will be recorded for the quantitative analysis which includes efficiency and effectiveness evaluation. Preferred selection and ordered sequence are prepared for the qualitative analysis about the satisfaction of maps readers. In addition, few text feedback or suggestions will also be taken into account. It will explain some questions about 'why'.

5.3. Participant

Participants could be the public, which include the people who have some background or need to work with OD data or have the interests in OD data representation. There are two groups of people will be invited to this survey. The first group is the test group, people will calibrate the survey, provide the feedbacks and suggestions ahead of the official test, which could improve the design and make sure the survey running reasonably and smoothly. The participants who were invited are supervisor, classmates, or friends because the sufficient feedbacks and suggestions can be received easier for closer persons. After the pilot test with 36 participants, the survey was improved in these aspects:

- Used preferred selection replace the use of scales evaluation for Group 1 Question 3, Group 2 Question 4, Group 3 Question 5, and the three questions of Group 4 Question 2.

- Highlighted and increased the size of symbols on destinations which were asked in each question in order to minimize searching time.
- Let participants rank the representations of direction according to readers' preferred from most to least simple instead of asking questions for each map, to decrease the time consuming.
- Set the questions of each group in a random order.

For the second group (the official test), more participants were involved, background information about gender, age, nationality, and education background will be recorded.
To be noticed, the participants for two groups are totally different, people who already attended the survey group will not be invited to the official test.

5.4. Online survey Implementation

There are twenty questions in this survey. Before the investigation starts the first page briefly introduces the purpose, reminds the participants all the destinations mentioned in each question are highlighted on the maps, zoom in on the maps in order to access the detailed information.
The online survey about flow map representation is http://tianyuan.limequery.com/614137?lang=en, the complete survey is attached in Appendix B.

5.4.1. Basic information

The first part of this survey is about basic information. There are four questions about gender, age, nationality, and education background will be asked.

- What's your gender?
- What's your age?
- Where are you from(country)?
- What is your education background?

For the collection of countries, participants are required to fill the country names in order to make sure the data integrity. As for the other questions, options are provided to be selected. There are four options for the age question, from the youngest small than 19 till the oldest above 50. Four kinds education background are also provided, bachelor, master, PhD, and others.

5.4.2. Group 1 Network connection

The purpose of this group is to know which flow line is better to show connectivity, straight or curved?
Thinking about the big number of flights widely connect AMS with all over the worlds, the two AMS flow maps in Figure 4-1: Connection flow maps with straight lines and curved lines which were generated in the previous chapter will be displayed here.

- Group 1 Question 1: How many destinations in East Asia (China, Korea, and Japan) can be reached from Amsterdam Schiphol Airport (AMS)?
- Group 1 Question 2: How many destinations in the USA can be reached from Amsterdam Schiphol Airport (AMS)?
- Group 1 Question 3: Which map do you prefer to show the connections of the Amsterdam Schiphol Airport (AMS)? Please choose one from these two maps.

Three questions will be asked in this group, results of the first two questions will be used to do the quantitative analysis, comparing the efficiency and effectiveness of the straight lines and curved lines. The participants will pick up a preferred map from those two directly for the third questions for the qualitative analysis.
To be noticed, the destinations which were mentioned in the questions, all these dot sizes on the map were increased for the readers to easy counting. The reason the USA and East Asia (China, Korea, and Japan) were asked is only these two areas have the similar territorial area and the number of cities

connected with AMS. Furthermore, the order of the first two questions is random which could avoid the influence of the readers' learning.

5.4.3. Group 2 Representation of quantitative attributes

The purpose of this group is to test which quantitative representation is more appropriate, line thickness, symbol size or the combination? KEF data is visualized with a small scale of view. Three maps of Figure 4-2: Representations of quantitative attributes will be displayed here.

- Group 2 Question 1: How many flights from Reykjavik Airport (KEF) Iceland to London Heathrow Airport (LHR) the UK and Seattle Airport (SEA) the USA?
- Group 2 Question 2: How many flights from Reykjavik Airport (KEF) Iceland to Amsterdam Schiphol Airport (AMS) the Netherlands and San Francisco Airport (SFO) the USA?
- Group 2 Question 3: How many flights from Reykjavik Airport (KEF) Iceland to Newark Airport (EWR) New York the USA and Frankfurt Airport (FRA) Germany?
- Group 2 Question 4: Which representation of quantitative attributes do you prefer most? Please choose one from these three maps.

There are four questions will be asked here, the first three are used to collect quantitative data, the last question will ask participants to select a better reading one based on the experiences of answering the previous questions. The order of the first three questions is also random.
Since there are three levels of numbers are existed after classification (1-3 flights, 4-6 flights, more than 7 flights), every two towns asked in each question has two different numbers, every number was selected twice as the answer. Considering the geography location of the cities on the map, for each task one Europe city and one American city were mentioned, which were also highlight on the map for readers to distinguish.

5.4.4. Group 3 Representation of qualitative attributes

To know the representation performances of coloured line and labels, four maps with five questions will be displayed. There are five tasks in this group, in order to keep balance, the two cities in each question one come from Europe the other come from American.

- Group 3 Question 1: Which airlines fly between Reykjavik Airport (KEF) and Copenhagen Airport (CPH) Denmark?
- Group 3 Question 2: How many destinations can be reached by flying Icelandair in North America (Canada and the USA, the region in light blue)?
- Group 3 Question 3: Which airlines fly between Reykjavik Airport (KEF) and Frankfurt Airport (FRA) Germany?
- Group 3 Question 4: How many destinations can be reached by flying Icelandair in France, Belgium, Netherlands, and Germany (the region in light blue)?
- Group 3 Question 5: Which representation of qualitative attributes do you prefer? Please choose one from these two maps.

The maps Figure 4-3 a, which depicts qualitative attributes by coloured lines will be shown with the first two questions, question 3 and 4 were prepared to Figure 4-3 b. Slightly difference between maps that will be displayed in this step and maps of Figure 4-3 is the referred regions and cities were highlighted on the maps here.
Normally, cities connection with KEF by only one mixed colour line but it is hard to recognise because readers have to look through the whole line to count colours. Then for the selected cities, how many airlines fly, how many different coloured lines they have.

5.4.5. Group 4 Representation of directions

About direction, it is quite difficult to ask the participants to finish the tasks of each five representations one by one. Hence, quantitative analysis is replaced by qualitative analysis. It is designed to let the members read the five flow maps with five representations of direction. There are two tasks in this group,

- Group 4 Question 1: Arrange the direction according to your preferred order of simplicity ranking from most to least simple.
- For more details about each representation, select a preferred one.

Initially, the KEF morning pattern will be described, five maps with different representations will be posted on the page, participants will arrange the order based on their understanding. According to the inventory, the top five direction representations are arrow(front), coloured line, transparent line (transparent to opaque), tapered line (thin to thick) and animation. The maps of Figure 4-4 a, c, e, g, h will be exhibited on the survey in sequence.

For more details about the representation of directions by arrow (Group 4 Question 21), transparent line (Group 4 Question 22) and tapered line (Group 4 Question 23), there are alternatives also need to be compared. For the second task of this group, three pairs of maps will be displays (Map Figure 4-4a and b, c and d, e and f). For each group, two maps beside each other with same representation in a different way, describing the same direction with the same data. Participants will select the preferred one for each representation.

6. RESULT ANALYSIS

There are 103 participants involves in this survey in total, among whom 64 people finished all the questions while 39 people did not. For compare analysis, median time consumption will be calculated, since median shows the 'middle of the data'.

6.1. Result about users

There are 50 males and 36 females participating did this survey, and Figure 6-1 displays the gender distribution of the participants. 55 people are at the age of 20-29 years old, which accounts for the majority. The number of participants aged below 19, 30-39 and 40-49 is 2, 21 and 8, respectively. However, no one older than 50 participated this survey, and the age distribution is also described in Figure 6-2.

For the nationality, 38 people from China have occupied the largest proportion, and individuals coming from America, Australia, Austria, Brazil, Germany, India, Indonesia, Iran, Kenya, Malaysia, Netherlands and Uganda also attend this survey.

The participants include 46 masters, 25 bachelors, and 11 PhDs, with the education background information shown in Figure 6-3.

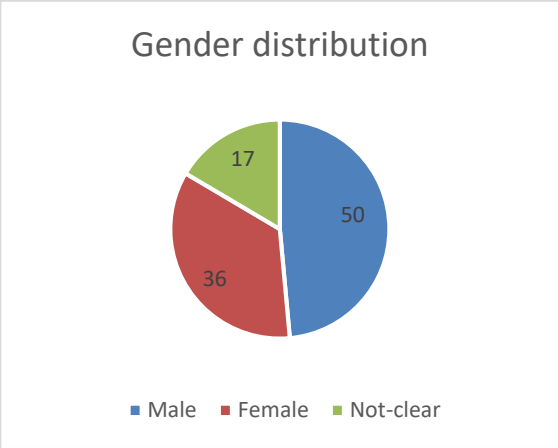


Figure 6-1: Gender distribution

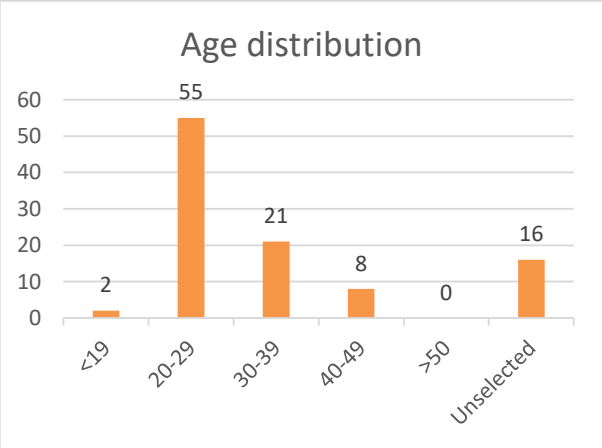


Figure 6-2: Age distribution

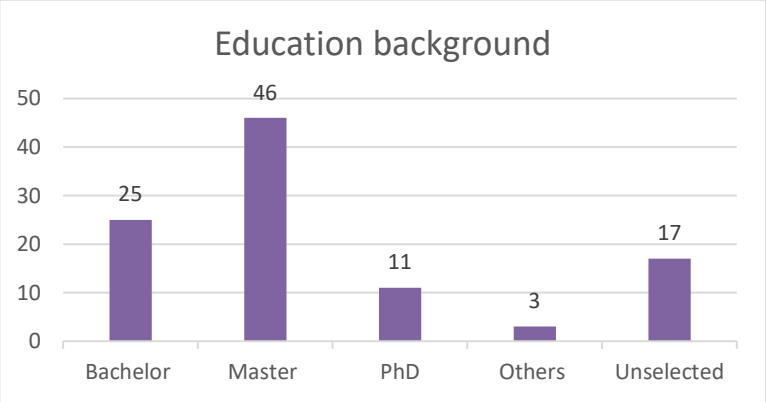


Figure 6-3: Education background

6.2. Network connection

For Group1 Question 1 the connection map with straight lines, 53 out of 103 are correct with the accuracy of 51%; median time consumption is 48.595s, and 16 participants preferred. For the accuracy of 53% with 53.21s median time consumption, 52 people curved lines have a better performance for connection map. Table 6-1 displays the three parameters about Group1 connections.

Table 6-1: The result of Group 1 connections

	Median time consumption (s)	Accuracy	Preferred selection
Connection with straight lines	48.59	51%	16
Connection with curved lines	53.21	53%	52

The result shows that when it comes to depicting the flow map connections, the flow maps with straight lines are more efficient (around 5 seconds quicker). However, the map with the curved line has been preferred by most people, with a slightly 2% better accuracy.
The reason that a high time consumption map with a significant advantage for preferred selection is that the destinations asked for the first map are harder to find out than the second map.
According to the feedback from participants, that straight flow lines don't consider the relative positions, but curved lines do. When the maps only show the connections, the straight lines are more efficient since readers only need to notice the origins and destinations on the map. However, when attributes are depicted by flow lines, curved lines will be used more often. This is because the space between flow lines are necessary to show the attributes, otherwise it will cause the overlap.

6.3. Representation of quantitative attributes

The median time consumption of the three maps is similar, they are 44.4, 45.04 and 44.85 respectively. The accuracy of the map with both line thickness and symbol size at O/D location is 53% higher than the other two maps, with the accuracies being 47% and 46% respectively. However, 35 people like using symbol size to show quantitative attributes, 26 participants prefer the one with lines thickness and symbol size, and only 7 people consider line thickness to present quantitative data. The result of representation of quantitative attributes is displayed in Table 6-2.

Table 6-2: The result of Group 2 representation of quantitative (QT) attributes

	Median time consumption (s)	Accuracy	Preferred selection
QT with line thickness	44.40	47%	7
QT with symbol size	45.04	46%	35
QT with lines thickness and symbol size	44.85	53%	26

For the representation of quantitative attributes, the flow map with different symbol sizes got the greatest efficiency but the lowest accuracy. The third map with both lines thickness and symbol size has the highest accuracy, and the gaps between the other two maps are 6% and 7% respectively. 26 people voted this as the preference. Nevertheless, the popular one is the map with only the symbol size at O/D locations to represent quantitative attributes.
From the feedback, people suggested using varying kinds of symbols (square, triangle, circle) to show that different levels of quantitative number, however, shape is not a variable to display quantities. It is also suggested the choropleth map to describe the number, but it is not appropriate for absolute numbers. This

may prove that exacting numerical info in less attractive than interpretation of spatial pattern Slocum (2009).

6.4. Representation of qualitative attributes

In this group there are two multiple choices, and three options are correct for each, which counts for right only when the participants select all the three choices. The median time consumption, an accuracy of each question, and the result of preferred selection are shown in Table 6-3.

Table 6-3: The result of Group 2 representation of qualitative (QL) attributes

		Median time consumption (s)	Accuracy	Preferred selection
QL with line colour	Question1 (multiple choice)	63.06	28%	31
	Question2	53.54	32%	
QL with label	Question3 (multiple choice)	55.01	40%	36
	Question4	54.26	19%	

Four median times consumption the number for Questions 1 is quite larger than the other similar three numbers. The apparent height accuracy 40% comes from the qualitative attributes with label map, and 36 people also preference for the map However, the accuracy of question 4 is only 19%. In this case, it's hard to declare which one is better, but there could be the conclusion that representation of qualitative attributes by labels is more appropriate and popular when visualizing airport data in this case.
However, what makes the accuracy for that question so low? According to the feedback, participants said that the label sizes were small and it was difficult to find out all the correct answers on the map. Most of them only pick one or two correct options but not all. If the label size could be increased, then the accuracy would be increased a lot.
Someone also suggested colouring the whole area instead of the coloured countries outlines, because the former option would be easier for readers to recognise the regions. That suggestion is useful for representation of quantitative attributes by labels. If the whole area coloured in the first map, one more colour needs to be recognized. There are already ten more qualitative colours on the map, which will make the map colour cluttered. Then the coloured outlines are retained to show the areas in the questions.
There is one more important feedback if your readers would involve, then the use of colours to distinguish qualitative attributes would not be considerate, and it's impossible for the colour-blind people to read that kind of maps.

6.5. Representation of directions

In this group, direction representation ranking will be evaluated by qualitative analysis. The selected frequency arranged by participants is shown in Table 6-4.

Table 6-4: Ranking of direction representations

	Animated- particle	Arrow-line	Coloured-line	Transparent-line	Tapered-line
1st	19	4	9	4	7
2nd	10	18	5	7	3
3rd	4	10	14	5	10
4th	6	3	9	16	9

5th	4	7	6	11	15

Times that partitions selected were counted, which were shown in rows in turn. 19 people arranged animated-particle as the first place, and they think animation is the number 1 representation of directions because of the simplicity. Arrow-line was chosen for 18 times as the second preferred representation. The third fourth and fifth come to coloured-line, transparent-line, and tapered-line respectively.
For more details about the representation of directions by Arrows, Front-arrow and Mid-arrow are the two alternatives, and 32 people appreciate Front-arrow to show direction and 34 like Mid-arrow more. Figure 6-4 present the comparisons of the selected number of these two alternatives. Two numbers are quite similar, but we could say Front-arrow is favoured somewhat in the case of visualizing airport data.

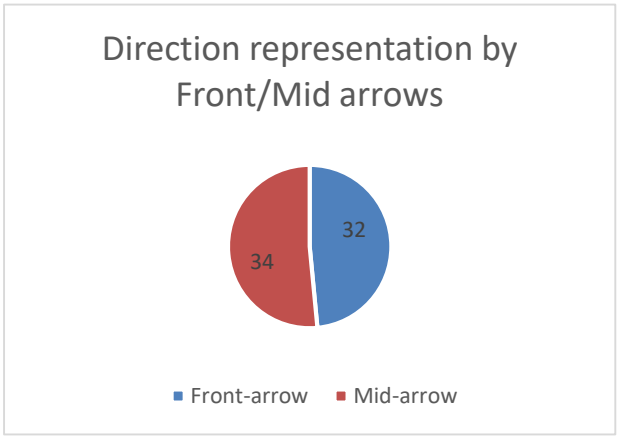


Figure 6-4: Comparison of direction representation by Front/Mid arrows

For more details about the representation of directions by Transparent lines, transparent-to-solid or solid-to-transparent are the two alternatives. Transparent-to-solid is popular, taken by 52 participants, which are dominated. Figure 6-5 shows the comparison of direction representation by transparent-to-solid and solid-to-transparent.
Regarding the tapered line, Thin-to-thick was appreciated by 45 participants, with another 21 supporting thick-to-thin. Figure 6-6 shows the comparison about supporters of these two alternatives.

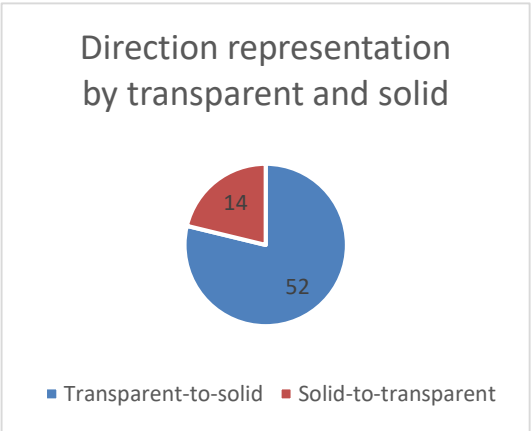


Figure 6-5: Comparison of direction representation by transparent and solid lines

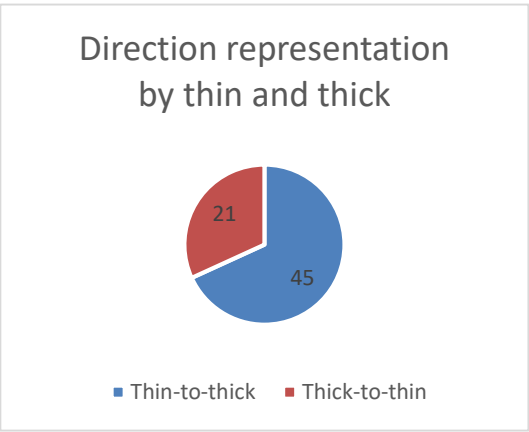


Figure 6-6: Comparison of direction representation by thin and thick

7. CONCLUSION AND REFLECTION

The main objective of this research is to understand flow maps, evaluate the different representations in order to generate the guidelines. First, a set of criteria about how to assess a flow map was generated based on how a reader extracts information from a flow map step by step. Existing flow maps from different sources were collected and analysed as an inventory based on the criteria, which is the basis of this research. Subsequently, different presentations were summarized and classified after the inventory. Considering the criteria in this research and the characteristics of the data in this case, 4 aspects (Network, Quantitative, Qualitative, and Direction) were selected and then displayed by different flow maps with various representations. Following this, an online survey was designed and carried out with more than 100 participants in order to assess the user preferences for each map representation.

When depicting the flow map connections, flow maps with straight lines are more efficient, nevertheless, maps with curved lines are more popular and accurate in relation to answering questions correctly, which is also proven by Jenny (2016). When attributes are depicted by flow lines, curved lines will be used more often by cartographers because the space between the flow lines is required to show the attributes. Overlaps will be caused otherwise.
People prefer to compare quantitative data using symbols of different sizes at O/D location rather than using varying thicknesses of flow lines. However, the quantitative comparison by symbol size and line thickness has a higher accuracy.
The label is a better representation to show the qualitative attributes in a flow map. The explanations made by labels are necessary when the lines are cluttered or not clear enough. In order to be noticeable, the label size should be legible with minimum overlaps.
The ranking of direction preference is: Animated-particle, Arrow-line, Coloured-line, Transparent-line, and Tapered. In this case, Animated-particle is the preferred representation when depicting directions in a flow map. Animation can leave a deep and intuitive impression on readers, which will tell people the direction without any required further input. When it comes to the Arrow-line, there is no clear difference between Front-arrow and mid-arrow. Opinions pointed to the preference that the background colour should be offset by the line colour when using the transparent-line, almost all participants prefer the direction from transparent-to-solid rather than the solid-to-transparent one. For the Tapered-line, it is possible to improve the performance by widening the flow lines from thin-to-thick, as the moving direction is more decipherable instead of in the thick-to-thin direction.

7.1. Answers to research questions

Research questions related to objective one: Understanding flow maps:

Question 1.1 What are flow maps, which kind of data do they present?

Question 1.2 How are different aspects of the data visually represented in a flow map?

Question 1.3 What are the (dis)advantages of flow maps?

Flow maps describe movements over space and time. It is a graphic description that is capable of representing the movements in our surroundings. OD-data is visualized in flow maps, origin-destination pairs are shown on the map and flows represent the attributes of movement with the use of different visual variables. It is possible to visualize the connections, directions, quantitative and qualitative attributes of OD movements in flow maps. The corresponding and specific representations are summarized in Chapter 3.3. Visual clutter, graphic perceptual salience and improper representations are the common limitations of flow maps.

Research questions related to objective two: Understanding user requirements in application context:

Question 2.1 What questions do the users have in relation to the data?

Users in this case are the general public, such as newspaper readers or the people who are willing to make movements visible to the public by using flow maps. They want to extract information from flow maps to see the spatial patterns and recognize the movement attributers. Since the application context is about the visualization of airport data, they will ask questions about the four OD data characteristics: How many destinations can be reached from an airport? (Connection); How many flights fly between two towns per day? (Quantitative); Which airlines fly between two airports? (Qualitative); In which direction do the airplane fly? (Direction). In general, they will ask which representation is the easiest to understand. The questions ask participants to search, identify and count.

Research questions related to objective three: Formulation:

Question 3.1 What is the specific character of the implementation?

Question 3.2 Which of the design solutions can be found in the inventory to answer user questions?

Question 3.3 Are the found solutions sufficient to solve the problems?

Question 3.4 How are sample flow maps created for data visualization?

The implementation of this research consists of two parts: map generation and survey implementation. Multiple representations which were summarized after the inventory in Chapter 3 can be used to answer each of the user's questions. The common ones were evaluated in this research. More participants can be reached and processed via the online survey than interviews. LimeService was selected because it is possible to record the time consumption of each question, and it also can supply a random order for questions within each group.

Visualization also has two parts: design and implementation. Sample flow maps are designed based on the criteria and the data characteristics in this case. Adobe Illustrator and Photoshop were the main tools used to generate the flow maps.

Research questions related to objective four: Usability test and improvement:

Question 4.1 Which of the qualitative and/or quantitative evaluation methods are suitable to test the example flow maps?

Question 4.2 How is the evaluation set-up and executed?

The efficiency, effectiveness and satisfaction of each representation is evaluated in this research. For quantitative analysis, median time consumption and accuracy were calculated for each question in the survey. Preferred selection is compared for qualitative analysis. In addition, text feedback or suggestions were taken into account. For the first three groups in the survey (Group 1 Connection, Group 2 Quantitative and Group 3 Qualitative), median time consumption, accuracy and preferred selection were all be taken into account. As for the test of Group 4 (Direction), only Qualitative analysis was used.

7.2. Reflection

For the inventory: 183 flow maps were studied in this research, 14% of which are based on the web applications. Web-based applications are becoming more common these days. In due time, the proportion of web-based flow maps and the results of the inventory will certainly increase, making animation more common.
For the criteria: The first criterion 'Topic' is not really decisive regarding how to draw a flow map but it is significant for reading and understanding a flow map.
For the tools: Flow maps in the research are mostly static without interaction because of the limitation of the tool I used. If the interaction functions are combined, it will be easier for the readers to discover the information.
For the Projection: Only Mercator projection was mainly used in this research. Considering the geographical location of Iceland, the maps can be drawn with a projection that puts Iceland in the centre. Visualizing data in this case probably causes different results.

For the survey: Since the survey method used only allowed static maps, one can wonder if an interactive environment would have had different and maybe better results
Only about 62% of the participants finished the complete survey. Too many questions could be the reason for this. If different representations were tested separately, maybe participants would be more willing to finish all questions.
Some questioned destinations in the survey are easy to find on the map, some are difficult. Even though all the mentioned cities were highlighted, some of the surroundings could also have negative influence on the readers.

For the users: The devices used by the respondents may have had influence on the answer time.
Most participants in this research are people who study or work in ITC with a solid knowledge of geography. If this survey widely invites participants with different backgrounds, the result could be slightly different.
The age distribution could influence the result. In this research, most participants are 20-29 years old. If older participants with more experience regarding maps constitute the majority, the result could be different.

For the analysis: The statistics significance test could be helpful for the analysis of the result, however, since there are around one hundred participants, the numbers were compared directly.
Quantitative analysis was compared only by median consumption. If mode or mean was the standard, the results could be slightly different.

For the design: compared with some beautiful and fancy designs in the inventory of existing flow maps, the maps in this research have few lines with small arrows. Actually, generating the maps with dense flow lines is possible with AMS data, however, this could cause clutters and overlaps when depicting the attributes. For example, the AMS Connection Map (Figure 4-1) has already caused trouble for readers when recognizing the connections within Europe. Due to this, some improvements such as bundles are needed. The nature of the data is also a reason a pattern with different directions is necessary in the map. Data must be filtered to decrease the amount. Apart from this, the purpose of this research is to basically test the most commonly used map representations. Fancy designs are not necessary and it is not certain whether these designs are suitable in the context of many lines coming from/going to one point. Try to keep the maps easy and clear in order to control the variables and to exclude the influences by other aspects such as bundles. That is also the reason why more maps were generated with KEF. However, it is

not excluded that beautiful maps with large mapping areas designed by artists or designers with same the data could influence the result.

From the result, we can briefly recognize which representation is the 'better design' for each group. However, there is not a significant difference between these numbers. A few of them are quite similar and some are almost even equal. Two reasons for this can be summarized: the design and the nature of the data affect each other. The reviewed results will be discussed in the following paragraph with regard to the four groups in the survey,
Group 1 Connection: the user preference of this group is very clear. Curved lines are preferred three times more often than straight lines. The quantitative part is quite similar. However, as mentioned in Chapter 6.2, participants in the survey considered finding the destinations via straight line in Asia easier than finding destinations in the US using the curved line. The readers of the curved line maps tend to include Canadian cities as US cities despite a differentiation in symbol size which takes more time.
Group 2 Quantitative representation: In this part, people do not like the maps with Line-thickness. Perhaps this is due to the fact that the lines are too close and it is difficult to distinguish the different thickness which represent various numbers of flights.
For symbols as well. However bigger symbols or wide lines cause overlaps, especially for European cities.
Group 3 Qualitative representation: Maps with labels are the 'winner' with regard to the qualitative representation in this research. The reasons for this could be that the thin lines with colours are difficult for readers to distinguish. Apart from this, explanations of labels are needed. Some suggested to increase the width of the coloured lines, but in order to control the variable I left the line thickness the same size for all maps. Besides this, the wide lines could also cause the KEF map to become messy since all the flow lines come from several points to one location. Probably, if all lines went into separate directions, the result would be different. What's more, if the colours are tested with only a few wide lines (maybe only three lines) and few colours with a small data set, the result could be different as well.
Group 4 Directions: for the first part, we can find the user preferences by the ranking of different representations. The animation is the favourite one maybe because it is a fancy design compared with the previous maps. It will leave a deep impression since I put it at the end of the survey. If I displayed this in the beginning, the result could be slightly different.
When it comes to the second part, alternatives for three representations (Arrows, Transparent-line, Tapered-line), we can see the superiority of the last two representations, however, the difference between Front-arrow and Mid-arrow is slight. The reasons may be that the small arrow design and thin flow line design are similar. If there is an obvious difference between two designs the result would be different. Same as before, the reasons the designs are similar is to control the variable (using the same width, same arrow). Only vary the arrow position from the front to the middle and try to keep the maps simple to avoid the clutter and mess. What is more, considering the characteristics of data, lines come from or go to the same location (KEF). If the directions totally vary by the use of another data set, the result could be different.

Jenny (2016) also generated some design principles for origin-destination flow maps. In some aspects, our conclusions are similar. Definitely, there are also differences.
Jenny identified the design principle by analysis 97 flow maps, these 97 origin-destination flow maps are not including: flow maps with branching or merging flows; flow lines follow the geographic path; maps use symbols to show orientations; 3D and animated flow maps; flow lines produced with algorithms. Compare with my purpose, generate the guidelines of different representations. Flow maps were collected and accessed in the inventory table as long as it describes the movement even for some maps without actual flow lines (Map 30: OD map). In his summary, arrowhead is the only design for representing direction, however, there are various ones in my summary.

The maps which used in Jenny's test were visualized with the movements of humans, traffics, funds, and trades. However, it is only focus on the movement of flights in my study. The data are all about movement but the characteristics are far from the same, the significant difference is the numbers of origins and destinations. Movements in his maps are dispersive with many origins and destinations but my flights in maps are come from/go to one origin or destination (AMS or KEF).
In addition, Jenny generates the principle that arrow is more effective than tapered line widths. While I tested the five commonly used representations (Arrow-line, Coloured-line, Transparent-line, Tapered-line, and Animated-particle), for more details, the alternative designs of Arrow-line, Transparent-line, and Tapered-line were also studied.

7.3. Further work

Now we know that animation is the preferred representation of flights directions in this research, flow maps with animations and interactions are more and more used these days, this work could be extending to the guidelines of animated flow maps.
Enlarge the amount of inventory, increase the proportion of online flow maps. More detailed representations will be summarized, and the guidelines could be extending.
For some questions such as the comparison of Front-arrow and Mid-arrow is still not clear enough, more participants can be invited in to know which performs well.
Considering the characteristics of the data characteristics in this research, most connections were drawn with only one direction. In the further study, the representations of bi-direction could be summarized in detail and tested for user preferences.
There are four aspects were tested in this research with the airport data, if different data sets would be applied to generate flow maps, maybe there are more aspects could be studied as well. Then more of representations principles will be added to the guidelines.
The performances of solutions which could reduce the flow map cluttered such as sampling and binding could be tested.

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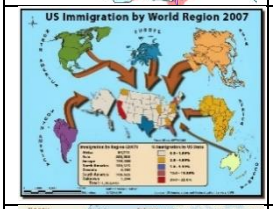
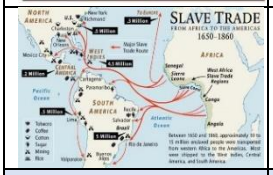
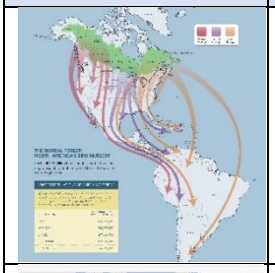
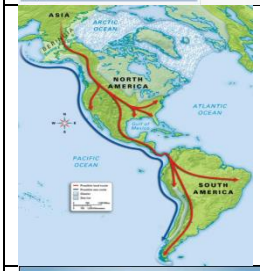
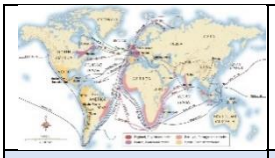
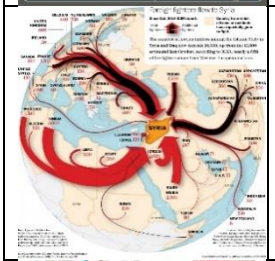
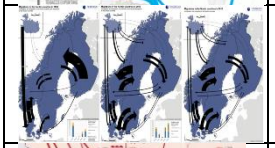
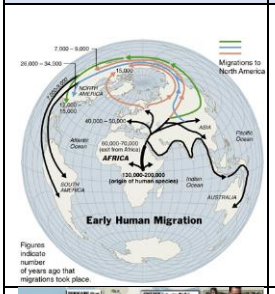
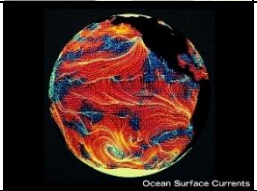
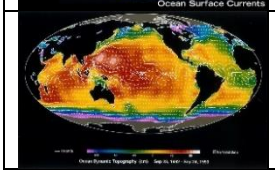
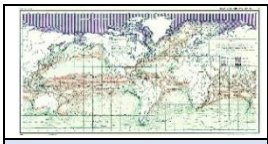
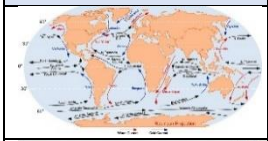
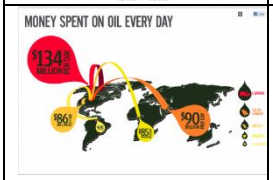
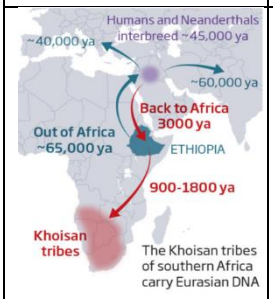
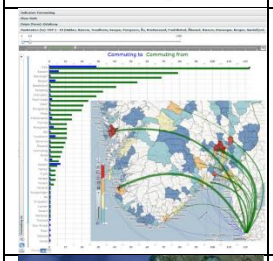
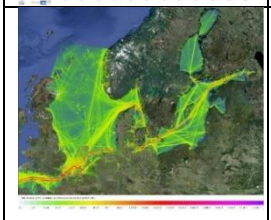
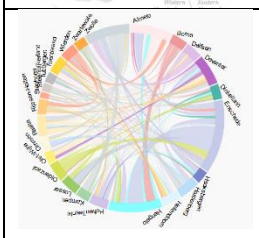
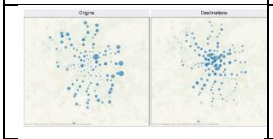
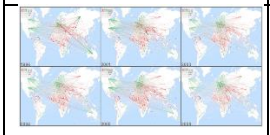
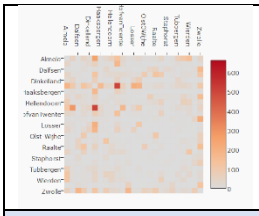
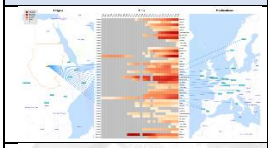
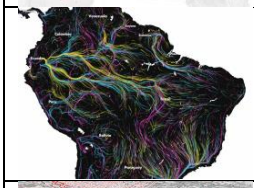
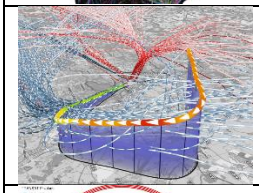
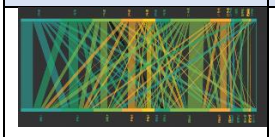
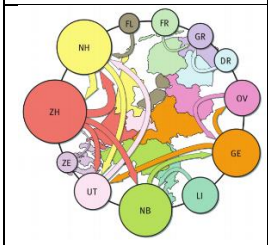
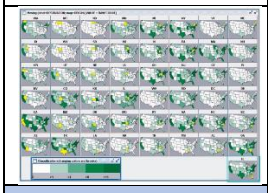
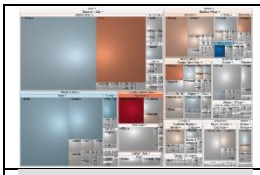
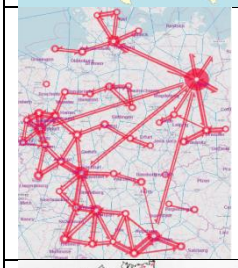
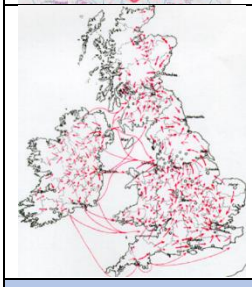
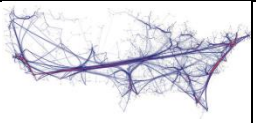
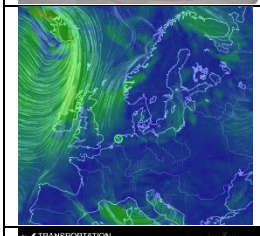
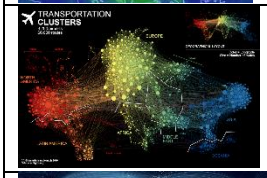
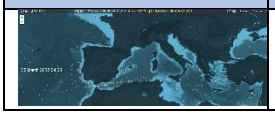
Appendix A: Inventory of flow maps

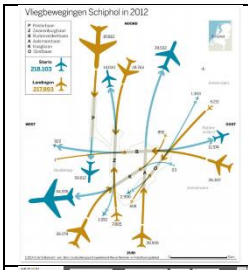
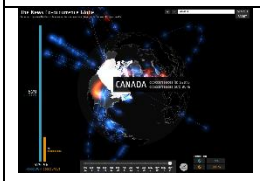
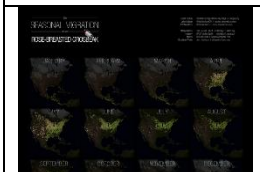
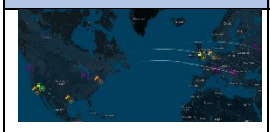
	Topic	Lay out	Flow line	Direction	Attribute	Time	Remarks
	Army Continuous	OD P-P	No-attribute Line	Arrows (front)	No-attribute	Arrow sequence	1.
	Migration Discrete	In R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL-Map colours	No-time	2.
	Disease Continuous	OD R-R	No-attribute Line	Arrows (front)	No-attribute	(1) Arrow sequence (2) Map colours	3.
	Migration Discrete	In R-R	QT Line	Arrows (front)	QT-Line thickness QL-Map colours	No-time	4. (1)Distortion of base map (2) Drop shadow
	Slave trade Continuous	OD R-P	No-attribute Line	Arrows (front)	QL-Labels	No-time	5.
	Birds migration Discrete	Out R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL-Map colour	No-time	6. Transparent line
	Birds migration Discrete	OD R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	7. Interactive base map
	Migration Discrete	In R-R	QL Line	Arrows (front)	QL-Line colours	No-time	8.
	Migration Discrete	In R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	9.

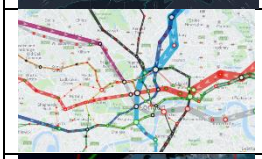
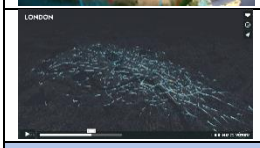
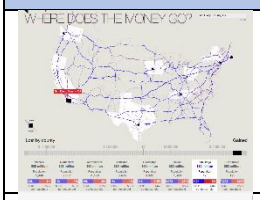
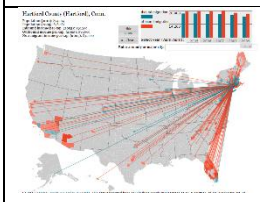
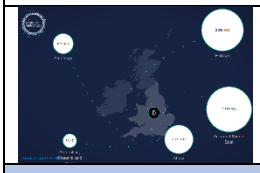
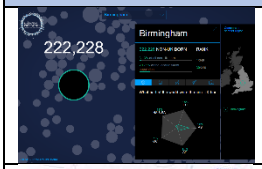
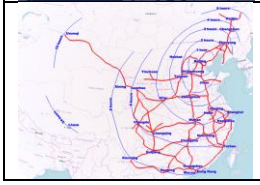
	World exploration (war) Continuous	OD P-R	QL Line	Arrows (front/ middle)	QL-Labels /line colours/map colours	Arrow sequence /labels	10.
	Chromosomes (gene) Continuous	OD R-R	QL Line	Arrows (front)	QL-Labels /line colours	Arrow sequence /line colours	11.
	Human movement Discrete	In R-R	QT-QL Line	Arrows (front)	QT-Line thickness/labels QL- Line colours/labels /map colour	No-time	12. Overlapped colours combine with Sankey lines
	Tobacco trade Discrete	OD R-R	QT-QL Line	Arrows (front)/ line colours	QT-Line thickness/labels QL- Line colours/labels	No-time	13.
	Migration Discrete	OD R-R	QT Line	Arrows (front)	QT-Line thickness/labels/graphs	Multiply views	14. Put Ice land on the top left
	War Discrete	In R-R	QT-QL Line	Arrows (front)/ tapered line	QT-Line thickness/labels QL- Line colours/labels	No-time	15.
	Migration Discrete	OD R-R	QT-QL Line	Arrows (front/ middle)	QT-Line thickness/labels QL- Line colours/labels	Arrow sequence	16.
	Migration Refugee Continuous	In R-R	No-attribute Line	Arrows (front)/transparent line	QL- Labels	Arrow sequence	17. Pictures as labels
	Ocean surface current Continuous	OD R-R	No-attribute Line	Line colours(hue)	QT-Map colours	No-time	18. Using contrast colours of base map
	Ocean current Continuous	OD R-R	No-attribute Line	Arrows (front)	QT- Map colour values	No-time	19.

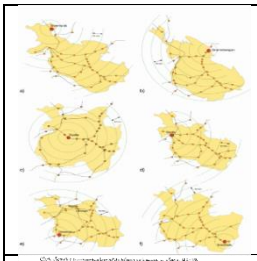
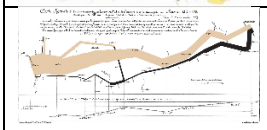
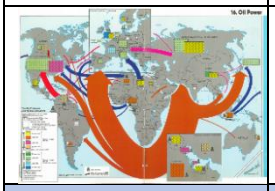
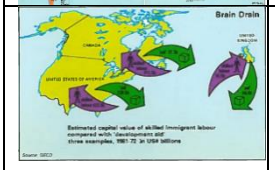
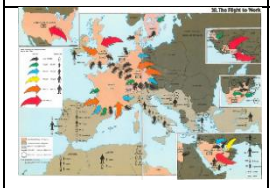
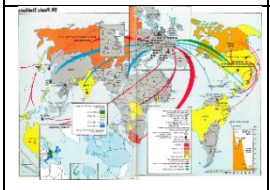
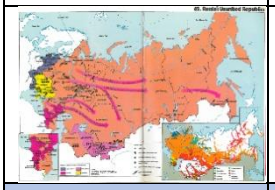
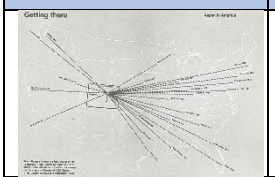
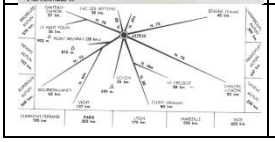
	Ocean current Continuous	OD R-R	No-attribute Line	Arrows (front)	QL- Labels	Arrow sequence	20.
	Ocean current Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Arrow sequence	21.
	Fund Discrete	Out P-R	QT-QL Line	Arrows (front)	QT-Line thickness/labels QL- Line colours/labels	No-time	22. 3D effects
	Gene Discrete	OD R-R	QL Line	Arrows (front)/ tapered line	QL- Line colours/labels /map colours	Arrow sequence/ labels	23.
	Migration Discrete	OD R-R	QT-QL Line	Line colours	QT-Line thickness/ map colours/graph QL- Line colours	No-time	24. Interaction
	Shipping Discrete	OD P-P	QT Line	Network	QT-Line colour values	No-time	25. Using the Intensity of PM2.5 emissions
	Flight lines Discrete	OD P-P	QT Lines	Symbolized arrows (middle)	QL-Line colours	No-time	26. Map projection
	Migration Discrete	OD R-R	QT-QL Line	Line colours	QT-Line thickness QL- Line colours	No-time	27. (1) No geographical map (2) Intercalation
	Commuting Discrete	OD P-P	No-line	Changes of symbol sizes	QT-Symbol sizes	Multiply views	28.
	Migration Discrete	OD R-R	QL Line	Line colours	QT-Line thickness QL- Line colours	Multiply views	29.

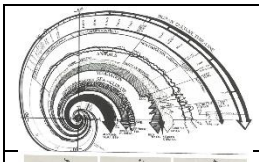
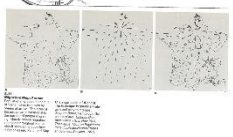
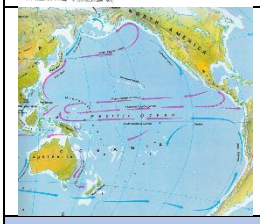
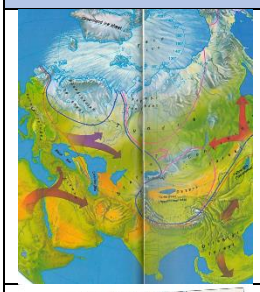
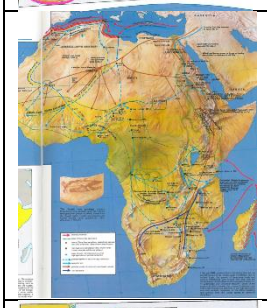
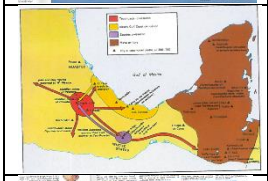
	Migration Discrete	OD R-R	No-Line	Matrix sequence	QT- cell colour values	Matrix sequence	30. No geographical map
	Migration Discrete	OD R-R	No-attribute Line	Matrix sequence	QT-Cell colour values QL- Labels	Matrix sequence	31. Combination wi different views
	Migration Discrete	Out R-R	QT-Line	Tapered line	QT-Line thickness/labels	No-time	32.
	Animal migration Discrete	OD R-R	QL Line	Transparent line/ animated line	QL- Line colours	Animated line	33.
	Flights Discrete	OD P	QL Line	Arrows (inside)	QL- Line colours	No-time	34.
	Migration Discrete	OD P-P	QT-QL Line	Network	QT-Line thickness QL- Line colours	No-time	35. No geographical map
	Commuting Discrete	OD p-p	QT-QL Line	Network	QT-Line thickness QL- Line colours	No-time	36. No geographical map
	Migration Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/ symbol sizes QL-Labels/ coloured (line/ map/ symbols)	No-time	37. Combination wi different views
	Migration Discrete	OD R-R	QT Line	Arrows (front)	QT-Line thickness/symbol sizes/ graph QL- Labels	No-time	38.
	Migration Discrete	OD R-R	No-Line	Symbol colours	QT- Symbol sizes QL- Symbol colours	No-time	39.
	Migration Discrete	OD R-R	No-Line	Matrix sequence	QT-Cell colour values QL- Labels/ cell colours	No-time	40.

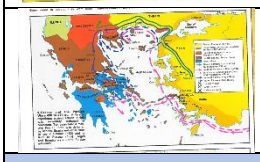
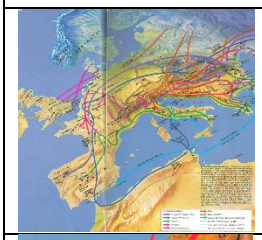
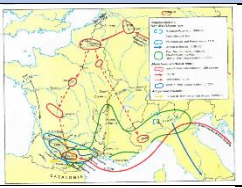
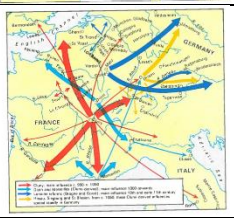
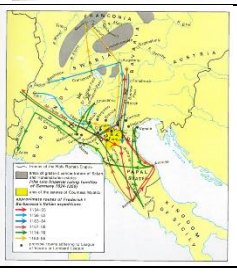
	Migration refugee Discrete	OD R-R	No-Line	Matrix sequence	QT-Cell colour values QL- Labels	No-time	41.
	Migration refugees Discrete	OD R-R	QT Line	Tapered line	QT-Line thickness	No-time	42.
	Migration Discrete	Out R-R	QT Line	One O/D	QT-Line thickness	No-time	43.
	Human movement Discrete	OD R-R	QT Line	Arrows (front)	QT-Line thickness/ symbol sizes	No-time	44.
	Migration Discrete	OD R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	45.
	Migration Discrete	OD R-R	NO-attribute Line	Network	QT- Line colour values	No-time	46.
	Migration Discrete	OD R-R	No-attribute Line	Network	No-attribute	No-time	47.
	Wind Continuous	OD R-R	No-attribute Line	Animated line	No-attribute	Animated line	48.
	Airlines Discrete	OD P-P	QT Line	Network	QT- Symbol sizes QL- Line colour values /labels	No-time	49.
	Human movement Discrete	OD P-P	No-attribute Line	Network	QT- Line density	No-time	50.
	Shipping Continuous	DO R-R	No-attribute Line	Animated line	No-attribute	Animated line	51.

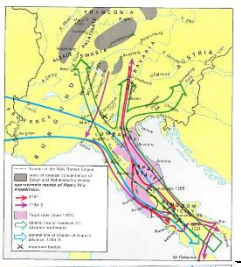
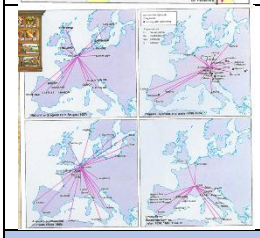
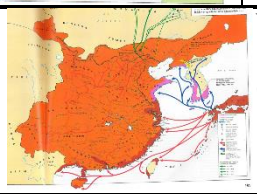
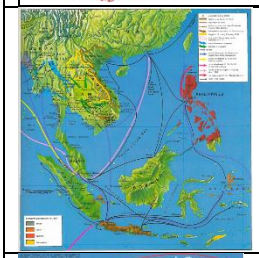
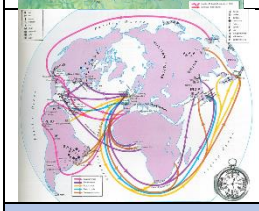
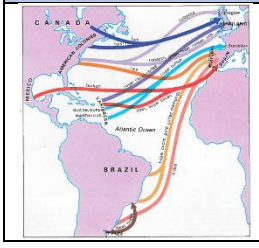
	Airlines Discrete	OD P	QT-QL Line	Symbolized arrow (front)/line colours	QT-Line thickness/labels/symbol sizes QL- Line colours/symbol colours	No-time	52.
	Funds Continuous	OD R-R	No-attribute Line	Arrows (inside)	QL-Labels	Arrow sequence	53. Distorted of base map
	Migration Discrete	OD R-R	QT-QL Line	Animated particle	QT-Particle density/particle speed QL- Particle colours/map colours	Animated particle	54.
	Information meida Discrete	OD R-R	QT-QL Line	Animated line	QT-Particle density/particle speed QL- Particle colours/map colours	Animated particle	55.
	Digital attack Discrete	OD R-R	QT-QL Line	Animated particle	QT-Particle density/particle speed QL- Particle colours/map colours	Animated line	56.
	Human movement Discrete	OD P-P	No-attribute Line	Network	QT- Symbol sizes QL- Symbol colours	No-time	57. Using graphs
	Bird migration Discrete	OD R-R	No-Line	Multiply views	No-attribute	Multiply views	58.
	Air traffic Discrete	OD P-P	QL Line	Animated line/ transparent line	QT-Line density	Animated line	59.
	Trade Discrete	OD P-P	QL Line	Animated line	QT-Line density QL- Line colours	Animated line	60.
	Digital attack Discrete	OD R-R	QL Line	Animated line/ transparent line	QL- Line colours/labels	Animated line	61.

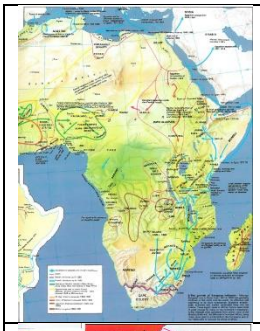
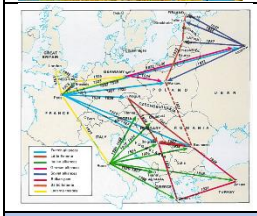
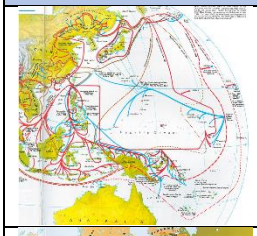
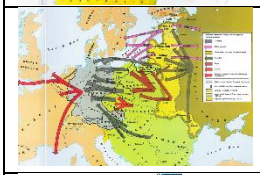
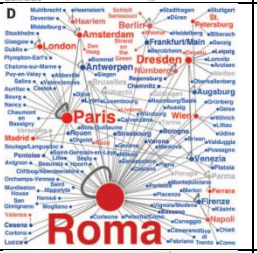
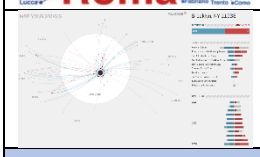
	Migration (refugee) Discrete	In R-R	No-attribute Line	Animated particle/ line / transparent line	QT-Symbol sizes	No-time	62.
	Commuting Discrete	OD R-R	QT-QL Line	Arrows (inside)	QT-Line thickness QL- Line colours	Animation symbol sizes	63.
	Flight Discrete	OD R-R	QL Line	Symbolized arrow (middle) /line colours	QL- Line colours	No-time	64.
	Commuting Discrete	OD R-R	No-attribute Line	Animated line/ transparent line	No-attribute	Animated line	65.
	Fund Discrete	OR R-R	QL-Line	Line colours	QT-Graph/ symbol sizes QL- Line colours/labels /map colours	No-time	66.
	Commuting Discrete	OD R-R	QT-QL Line	Line colours	QT-Line thickness /graph QL- Line colours	No-time	67. Mixed colours line to show multiply attributers
	Migration Discrete	In R-R	QT-QL Line	Animated particle	QT-Particle density/speed QL-Map colours/particle colours	Animated particle	68.
	Migration Discrete	OD R-R	QT-QL Line	Line colours/ one O/D	QT-Line thickness/graph QL- Line colours/map colours	No-time	69.
	Migration Discrete	In R-P	No-attribute Line	Animated particle	QT-Symbol sizes QL-Labels	Animated particle	70. Symbols represent origins in map
	Migration Discrete	In R-P	No-Line	One O/D	QT-Labels/ symbols sizes QT-Graph	No-time	71.
	Rail network Discrete	OD P-P	No-attribute Line	One O/D	No-attribute	Contour line	72. Contour line shows time

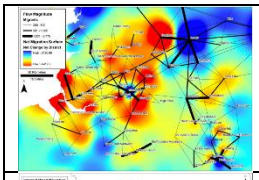
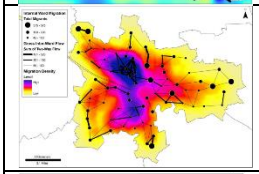
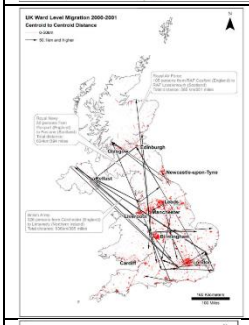
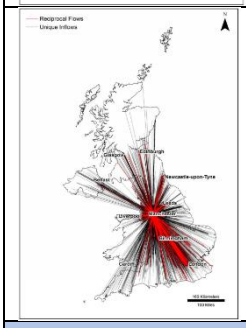
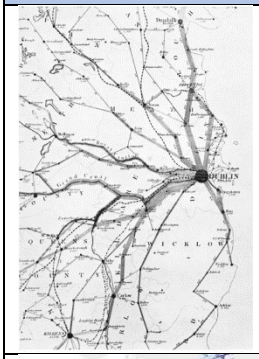
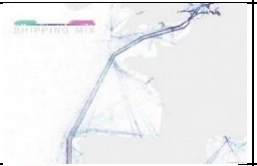
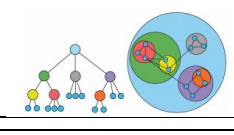
	Rail network Discrete	OD P-P	No-attribute Line	One O/D	No-attribute	Contour line	73. Contour line /map distortion show time
	Army Discrete	OD P-P	QT-QL Line	Tapered line	QT-Line thickness/labels/graph QL- Line colours/labels / graph	Line colours	74. With graph to show multiple attributes
	Trade (Oil) Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/ label sizes QL- Line colours	No-time	75.
	Human movement (refugee) Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Labels QL- Line colours/labels	Labels	76.
	Trade Discrete	OD R-R	QL Line	Arrows (front)	QT-Labels QL- Line colours/labels	No-time	77. Onlu pick up mapping countries as base map
	Human movement Discrete	OD R-R	QT-QL Line	Arrows (front)/tapered line	QT-Line thickness/ label sizes QL- Line colours/labels /map colours	No-time	78.
	War Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/label sizes QL- Line colours/labels /map colours	No-time	79.
	Migration Discrete	OD R-R	QL Line	Arrows (front)	QL- Labels	No-time	80.
	Trade Discrete	In R-R	No-attribute Line	One O/D	QT-Labels QL-Labels	No-time	81.
	Distance Discrete	In R-R	No-attribute Line	One O/D /tapered line	QT-Line thickness/labels/ graph QL-Labels	No-time	82.

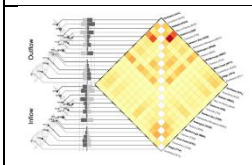
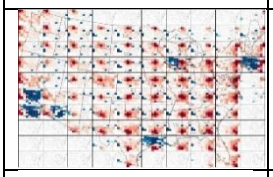
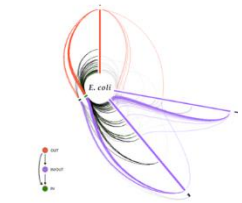
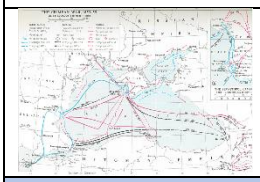
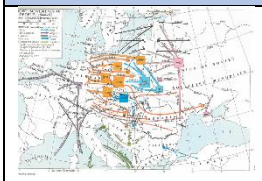
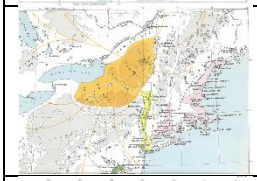
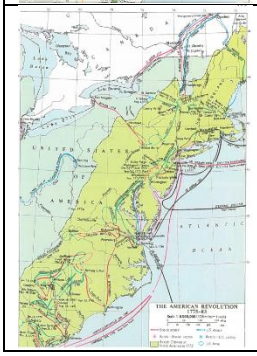
	Evolution Discrete	Out R-R	QL-Line	Arrows (front)/ One O/D	QT-Line thickness/labels QL-Labels	Arrow sequence	83.
	Migration Discrete	OD R-R	No-attribute Line	Arrow(front)/tapered line	No-attribute	No-time	84.
	Ocean current Continuous	OD R-R	QL-Line	Arrow(front)/tapered line	QL-Line colours/ labels	Arrow sequence	85.
	Migration Discrete	OD R-R	QT-QL Line	Arrow(front)/transparent line	QT-Line thickness QL- Line colours	No-time	86.
	Trade Discrete	OD R-R	QL Line	Arrows (front)	QL-Line colours	Line colours	87. Circle the intsrestin g areas
	Migration Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels /line style	No-time	88.
	Migration Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours/ labels/ map colours	No-time	89.
	Migration Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours	No-time	90. Circle the intsrestin g areas
	Army Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours	91.
	Army Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours	92.
	Migration Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours	93.

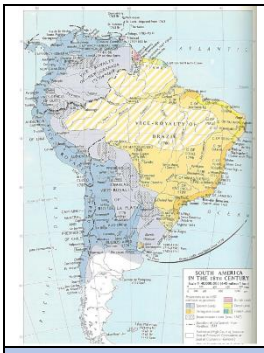
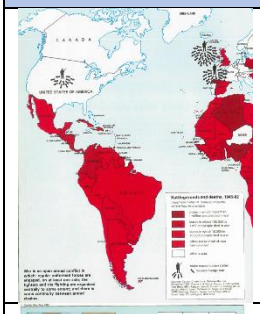
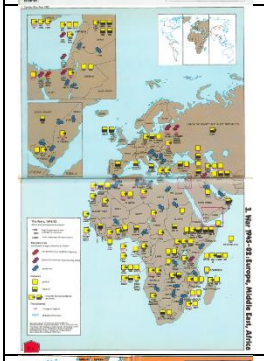
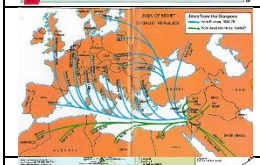
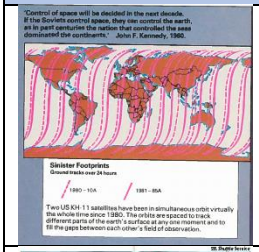
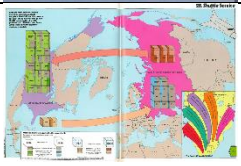
	Trade Discrete	In R-R	QL Line	Arrows (front)	QL- Labels	Labels	94.
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels /map colours	Line colours	95.
	Migration Continuous	OD R-R	QL Line	Arrows (middle)	QL- Line colours/labels /map colours	Line colours	96.
	War Discrete	OD R-R	QL Line	Arrows (front)/ transparent line	QL- Line colours/labels	Line colours	97. Mid-transparency lines
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	No-time	98.
	Migration Continuous	OD R-R	QT- QL Line	Arrows (front)	QT-Line thickness QL- Line colours/labels	Labels	99.
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours	Line colours	100.
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours	101.
	Migration Continuous	Out R-R	QT- QL Line	Arrows (front)	QL- Line colours/labels	Line colours/labels	102.
	War Continuous	OD R-R	QL Line	Arrows (middle)	QL- Line colours/labels	Line colours	103.

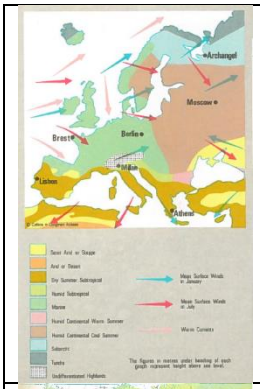
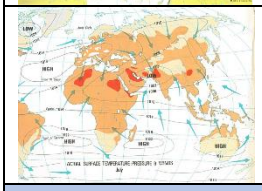
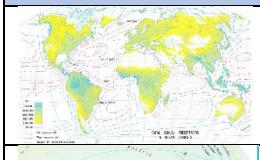
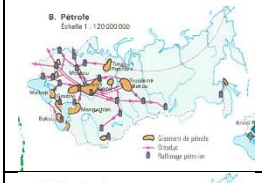
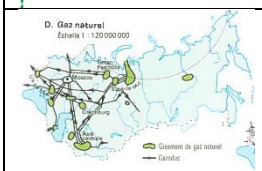
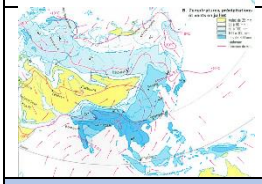
	War Continuous	OD R-R	QT- QL Line	Arrows (front)	QT-Line thickness QL- Line colours/labels	Line colours	104.
	Trade Discrete	In P-P	No-attribute Line	One O/D	QL- Labels	No-time	105.
	Trade Continuous	OD P-P	QL Line	Arrows (front)	QL- Line colours/labels	Arrow sequence	106.
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/map colours	Trade Discrete	Line styles	107.
	War Continuous	OD P-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours	108.
	Trade Continuous	Out R-R	QL Line	Arrows (front)	QL- Labels	No-time	109.
	Trade Continuous	OD R-R	QL Line	Arrows (middle)	QL- Line colours/labels	No-time	110.
	Trade Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	No-time	111.

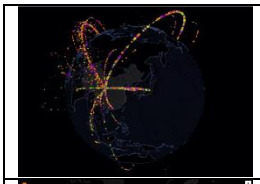
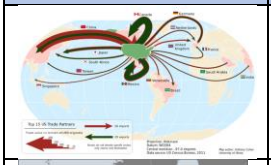
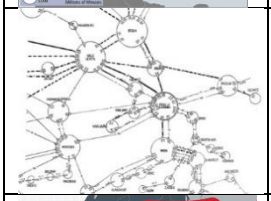
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours	112.
	Migration Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours/labels	113.
	Army Discrete	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	No-time	114.
	War Continuous	OD P-R	QL Line	Arrows (front)	QL- Line colours/labels	Labels	115.
	War Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours/labels	Line colours/labels	116.
	Migration Continuous	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/labels QL- Line colours	Map colours/line colours	117.
	Disease Continuous	OD R-P	QT-QL Line	Arrows (inside)	QT- Line thickness QL- Line colours/labels	No-time	118.
	Clutural Discrete	OD R-R	No-attribute Line	Network	QT-Symbol sizes QL-Labels	No-time	119.
	Migration Discrete	OD R-R	QL Line	Line colours	QT-Graph/ symbol sizes QL-Line colours	No-time	120.
	Migration Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness	No-time	121.

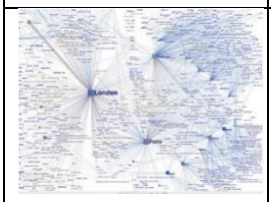
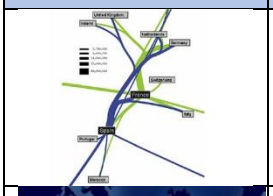
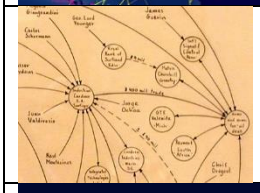
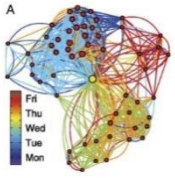
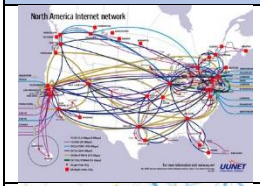
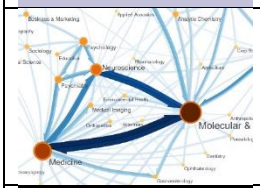
	Migration Discrete	OD R-R	QT-Line	Network	QT-Line thickness/map colours	No-time	122.
	Migration OD R-R Discrete	OD R-R	QT-Line	Network	QT-Line thickness/symbol sizes /map colours	No-time	123.
	Migration Discrete	OD R-R	No-attribute Line	Arrows (front)	QT-Map colours	No-time	124.
	Migration Discrete	In P-P	QT-Line	One O/D	QT-Line density	No-time	125.
	Traffic network Discrete	Out P-P	QT-Line	One O/D	QT-Line thickness	No-time	126.
	Trade (shipping) Discrete	OD R-R	QT-QL Line	Network	QT-line density QL-Line colours	No-time	127.
	Traffic network Continuous	OD P-P	QT-QL Line	Arrows(inside)	QT-Line thickness QL- Line colours	No-time	128.
	Migration Discrete	OD R-R	QT-QL Line	One O/D	QT-Line thickness/symbol sizes QL- Line colours	No-time	129.
	Migration Discrete	OD R-R	No-attribute Line	Arrows (front)	No-attribute	Arrow sequence	130.
	Migration Discrete	Out R-R	No-attribute Line	Sequence(up to down)	QT-Symbol sizes	No-time	131.

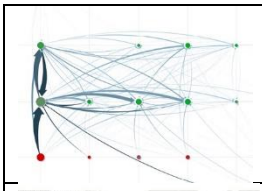
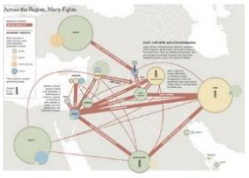
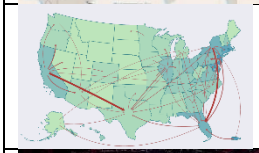
					QL-Symbol colours		
	Migration Discrete	OD R-R	No-attribute Line	Sequence(up to down left to right)	QT-Cell colours/graph QL-Labels	No-time	132. Combine graph and matrix;combine geo and matrix
	Migration Discrete	OD R-R	No-Line	Matric sequence	QT-Cell colours	No-time	133.
	Migration Discrete	OD R-R	QT-QL Line	Line colours	QT-Line thickness QL- Line colours	No-time	134. The layout design
	War Continuous	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL- Line colours/line styles/label	Line styles/labels	135.
	Migration Continuous	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/labels/symbol sizes QL- Line colours/ symbol colours/labels	Line colours/labels	136.
	Migration Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/labels/symbol sizes QL- Line colours/ symbol colours/labels	Line colours	137.
	Migration Discrete	Out R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	138.
	War Continuous	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL- Line colours/labels	Map colours/labesl	139.

	Migration Discrete	OD R-R	QL Line	Arrows (front)	QL-Label	Label	140.
	Army Discrete	Out P-R	No-attribute Line	Arrows (front)	QT-Map colours/line density	No-time	141.
	War Discrete	OD R-R	No-attribute Line	Arrows (front)	QT-Labels QL- Line colours/labels	No-time	142.
	Migration Discrete	In R-P	QL Line	Arrows (front)	QT-Labels QL- Line colours/labels	No-time	143.
	War Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/labels QL- Line colours/labels	No-time	144.
	War Discrete	In R-P	QT-QL Line	Arrows (front) Symbolized	QL- Labels	No-time	145.
	Satellite Continuous	OD R-R	QL Line	Sequence (west to east)	QL- Line style	No-time	146.
	Trade Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/symbol sizes QL- Line colours/labels	No-time	147.

	Migration Continuous	OD R-R	QL Line	Arrows (front)/tapered line	QL- Line colours	Arrow sequence	148.
	War Continuous	In R-R	No-attribute Line	Arrows (front)/ tapered line	No-attribute	Arrow sequence	149.
	Wind Discrete	OD R-R	QL Line	Arrows (front)/ tapered line	No-attribute	No-time	150.
	Ocean current Continuous	OD R-R	QL Line	Arrows (front)	QL- Line colours	Arrow sequence	151.
	Air routes Network Discrete	OD P-P	QL Line	Arrows (front)	QL- Line colours	No-time	152.
	Oil transmission Continuous	OD R-R	No-attribute Line	Arrows (middle)	No-attribute	No-time	153.
	Gas transmission Continuous	OD R-R	No-attribute Line	Arrows (middle)	No-attribute	No-time	154.
	Wind Continuous	OD R-R	No-attribute Line	Arrows (front)	No-attribute	Arrow sequence	155.
	Diastrophism Discrete	OD R-R	No-attribute Line	Arrows (front)	No-attribute	No-time	156.
	Flights network Discrete	OD P-P	No-attribute Line	Network	No-attribute	No-time	157.

	Trade Discrete	OD R-R	QT-QL Line	Animated particle	QT- Particle density/ speed QL- Particle colours	Animated particle	158.
	Migration Discrete	OD R-R	QT-QL Line	Animated particle	QT- Particle density/ speed/symbol sizes QL- Particle colours/ symbol colours	Animated particle	159.
	Trade Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness QL- Line colours/labels	No-time	160.
	Trade Discrete	OD R-R	QT-QL Line	Arrows (front)/line colours	QT-Line thickness QL- Line colours/labels	No-time	161.
	Traffic network Discrete	OD R-R	QT Line	Network	QT-Line thickness/ symbol sizes QL-Labels	No-time	162.
	Flights Discrete	OD R-P	QT Line	Network	QT-Line styles	No-time	163.
	Internet connection Discrete	OD R-R	QT Line	Network	QT-Line thickness/ symbol sizes QL-Labels	No-time	164.
	Traffic Discrete	OD R-P	QT Line	Network	QT-Line thickness/ symbol sizes QL-Labels	No-time	165.
	Internet connection Discrete	OD R-R	QT Line	Network	QT-Line thickness/ symbol sizes QL-Labels	No-time	166.
	Internet connection Discrete	OD P-P	No-attribute Line	Network	No-attribute	No-time	167.
	Internet connection Discrete	OD R-R	QT-QL Line	Network	QT-Labels QL- Line colours/labels	No-time	168.

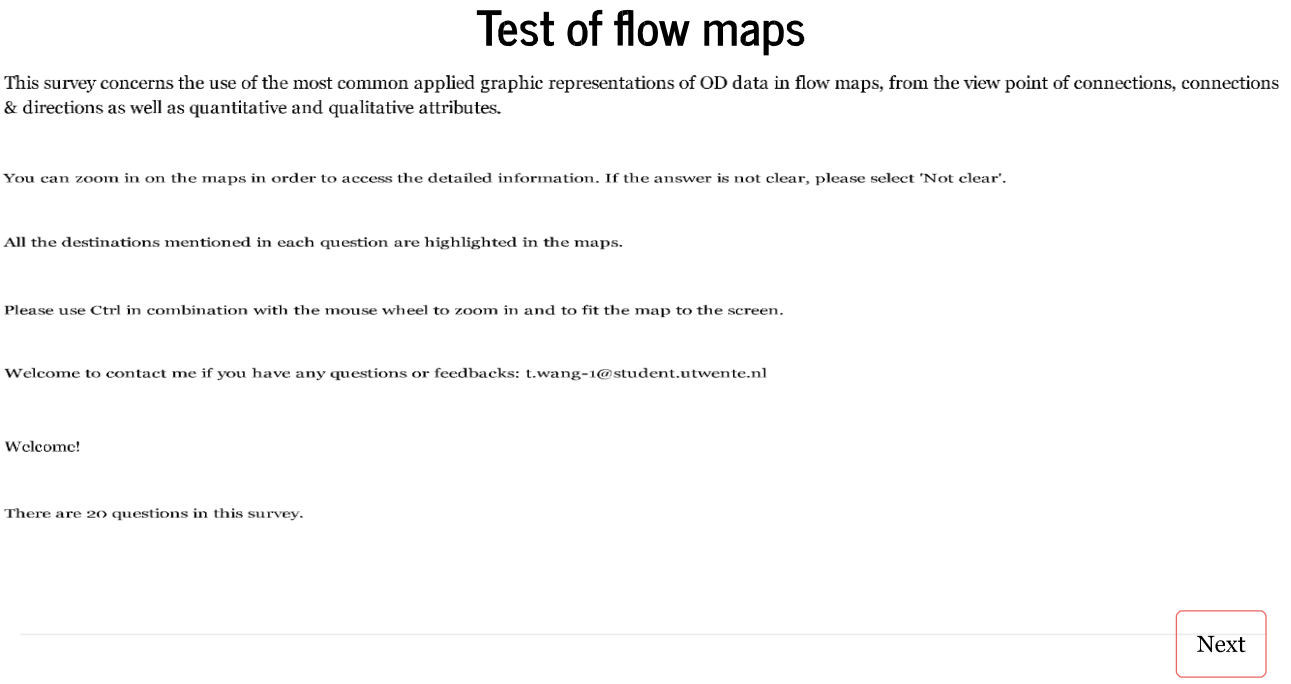
	Human movement Discrete	OD R-P	No-attribute Line	Network	No-attribute	No-time	169.
	Trade connection Discrete	OD P-P	QL Line	Network	QT-Symbols sizes QL-Line colours/symbol colours/ labels	No-time	170.
	Migration Discrete	OD R-R	QT-QL Line	Tapered line	QT-Line thickness QL- Line colours/labels	No-time	171.
	Internet connection Discrete	OD P-P	QT-QL Line	Network	QT-Line thickness	No-time	172.
	Story connection Discrete	OD R-R	QL Line	Arrows (front)	QL- Labels	No-time	173.
	Flights Discrete	OD P-P	No-attribute Line	Network	QT-Line density	No-time	174.
	Commuting Discrete	OD R-R	QL Line	Network	QL-Line colours	No-time	175.
	Internet Network Discrete	OD P-P	QL Line	Network	QT-Symbol sizes QL-Line colours/labels	No-time	176.
	Science connection Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/ symbol sizes QL- Line colours	No-time	177.
	Flights Discrete	OD P-P	No-attribute Line	Network	No-attribute	No-time	178.

	Graph Discrete	OD R-R	QT-QL Line	Arrows (front)	QT-Line thickness/ symbol sizes/ symbol colours	No-time	179.
	War Discrete	OD R-R	QT Line	Arrows (front)	QT-Line thickness/ symbol sizes/ QL-Labels	No-time	180.
	Traffic network Discrete	OD P-P	QT Line	Network	QT-Line thickness	No-time	181.
	Migration Discrete	OD R-R	QT Line	Arrows (front)	QT-Line thickness	No-time	182.
	Migration Discrete	OD P-P	QT-QL Line	Animated line /particle	QT- Particle/ line density /speed QL- Line/ particle colours	Animated line /particle	183.
							184.
							185.

Map sources:
Map1 ("The Dutch War of Independence | Military History Monthly," 2014); Map2 (Rusty Jones, 2010); Map3 (Shirley, 2008); Map4 (Steve Hafner, 2014); Map5 (Neil A. Frankel, 2008); Map6 (Wells et al., 2014); Map7 (University of California Berkeley, 2015); Map8 (Wikispaces, 2005); Map9 (HAROLD CAREY JR, 2012); Map10 World exploration (Sayre, 2013); Map11 (Strong, 2014); Map12 (The Washington Post, 2014); Map13 (Nicolas Rapp, 2013); Map14 (Grunfelder, 2014); Map15 (Gene, 2014); Map16 (Wade, 2003); Map17 (J. Robinson, 2015); Map18, 19 (NASA, n,d,); Map20, 21 (Currents and Tides - MarineBio.org, n.d.); Map23 (Brahic, 2014); Map24 (Ho et al., 2011); Map25 (Johansson et al., 2013); Map27 Choropleth map Image produced by the author of this thesis; Map28-31 (Boyandin, 2013); Map32 (J. Wang et al., 2014); Map33 (Dan Majka, 2016); Map34 (Buschmann & Trapp, 2016); Map35 ("RNA Arc Diagrams - R-chie," n.d.); Map36 (J. Wang et al., 2014); Map37 (Speckmann & Verbeek, 2010); Map38, 39 (Boyandin, 2013); Map40 (Guo et al., 2006); Map41 (Brodbeck & L.Girardin, 2012); Map42 (Boyandin, 2013); Map43 (Verbeek et al., 2011); Map44 (Adrienko & Adrienko, 2011); (Adrienko & Adrienko, 2011) Map45 (W. Tobler, 1995); Map46 (Holten & Van Wijk, 2009); Map47 (Derek, 2015); Map48 (earth.nullschool, 2015); Map49 (Buczkowski, 2016); Map50 (Ricardo Bion, 2016); Map51 (Clark & Houston, 2016); Map52 (Bron, 2012); Map53 (OpenCorporates, 2016); Map54 (Galka, 2016a); Map55 (Gdelt, 2015); Map56 (Arbor Networks, 2013); Map57 (Gross & Sadowski, 2016); Map58 (IDV, 2015); Map59 (NATS, 2014); Map60 (Wikipedia, 2010); Map61 (Ullah & Kraak, 2014); Map62 The flow towards Europe (SAARINEN & OJALA, 2015); Map63 (Oliver O'Brien, 2016); Mpa65 (Till Nagel & Christopher Pietsch, 2016); Map66 (Stamen, 2012); Map67 (Teksty, 2013); Map68 (Galka, 2016b); Map69 (Bruner, 2012); Map70, 71 (Cleverfranke, 2011); Map72 (Yaohua, 2000); Map73 (Ullah & Kraak, 2014); Map74 (Arthur H. Robinson, 1967); Map75-80 The State of the World Atlas (Kidron et al., 1995); Map81-84 Maps : a visual survey and design guide (Michael, Southworth, S. (1982); Map85-117 The Times atlas of world history : historical atlas (Geoffrey, 1979); Map119 (Schich et al., 2014); Map120 (Stefaner, 2010); Map121 (STRAYER, 2016); Map122-125 (Nelson, 2011a); Map126 (Arthur H. Robinson, 1955b); Map127 (Nelson, 2011b); Map128 (Itoh, 2013); Map130 (Chwastyk & Williams, 2015); Map131(Archambault et al., 2008); Map132 (Yang et al., 2017); Map133 (Wood et al., 2010); Map134 (Boyandin,

2013); Map135-140 The New Cambridge Modern History (Darby 1970); Map141-147 The War Atlas (Kidron, 1983); Map148-152 Atlas Four (Collins, 1973); Map153-156 Le petit atlas (Wolters, 1985)

Appendix B: The online survey: Test of flow map



0%

Basic Information

Basic informations of participants.

✱ What's your gender?

♀ Female	♂ Male

✱ What's your age?

Choose one of the following answers

- < 19
- 20 - 29
- 30 - 39
- 40 - 49
- > 50

✱ Where are you from?(Country)

✱ What is your education background?

Choose one of the following answers

- Bachelor
- Master
- PhD
- Others

6%

Group1 Connections Q1

lines.

Test the use of curved and un-curved

✱

How many destinations in east Asia (China, Korea and Japan) can be reached from Amsterdam Schiphol Airport (AMS)?

Choose one of the following answers

- 13 flights
- 14 flights
- 15 flights
- 16 flights

Previous

Next

13%

Group1 Connections Q2

lines.

Test the use of curved and un-curved

✱

How many destinations in the USA can be reached from Amsterdam Schiphol Airport (AMS)?

Choose one of the following answers

- 13 flights
- 14 flights
- 15 flights
- 16 flights

Previous

Next

20%

Group1 Connections Q3

line.

Test the use of curved and un-curved

✱

Which map do you prefer to show the connections of the Amsterdam Schiphol Airport (AMS)?

Please choose one from these two maps.

Choose one of the following answers

- ○ The map with straight lines(left)
- ○ The map with curved lines(right)

Next

Previous

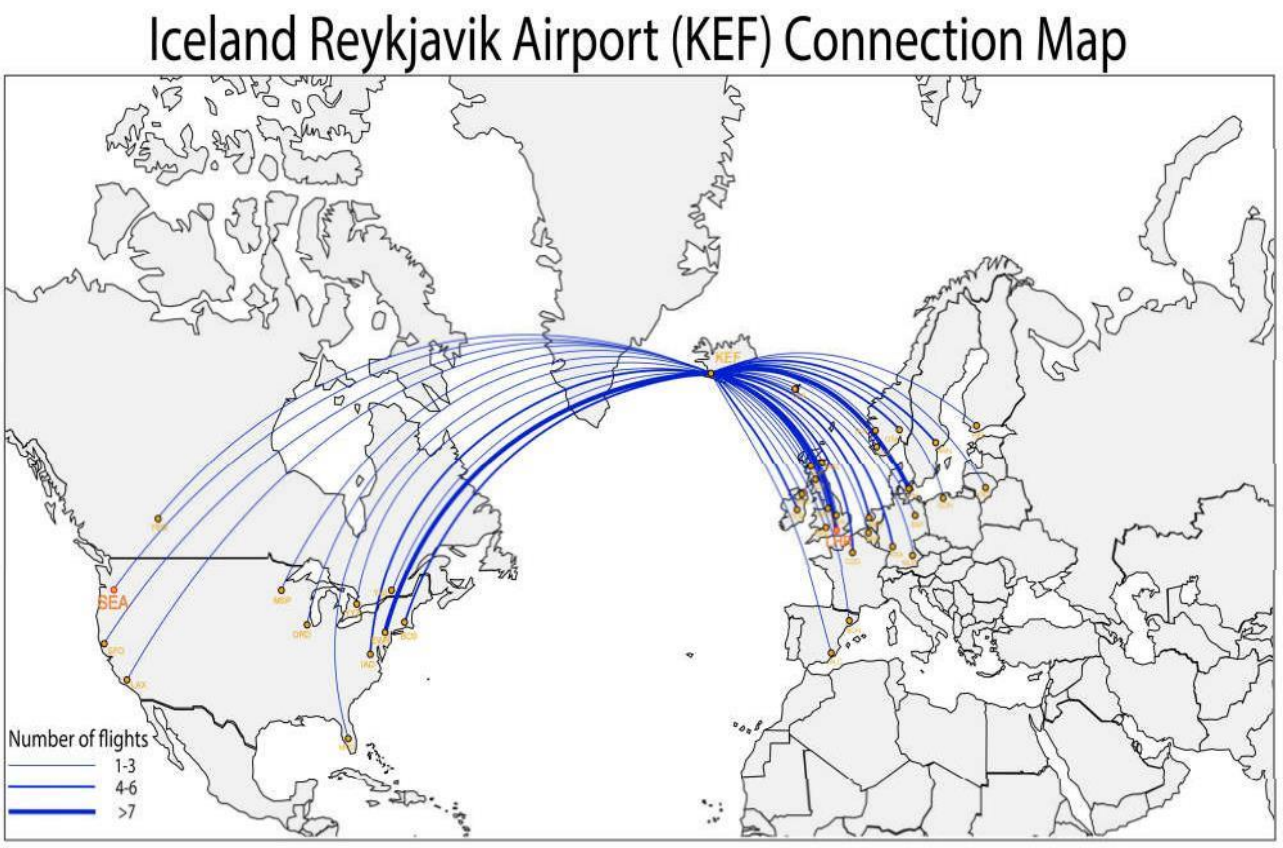
40%

Group2 Quantitative Q1

The representations of quantitative attributes.

*

How many flights from Reykjavik Airport (KEF) Iceland to London Heathrow Airport (LHR) the UK and Seattle Airport (SEA) the USA?



Choose one of the following answers

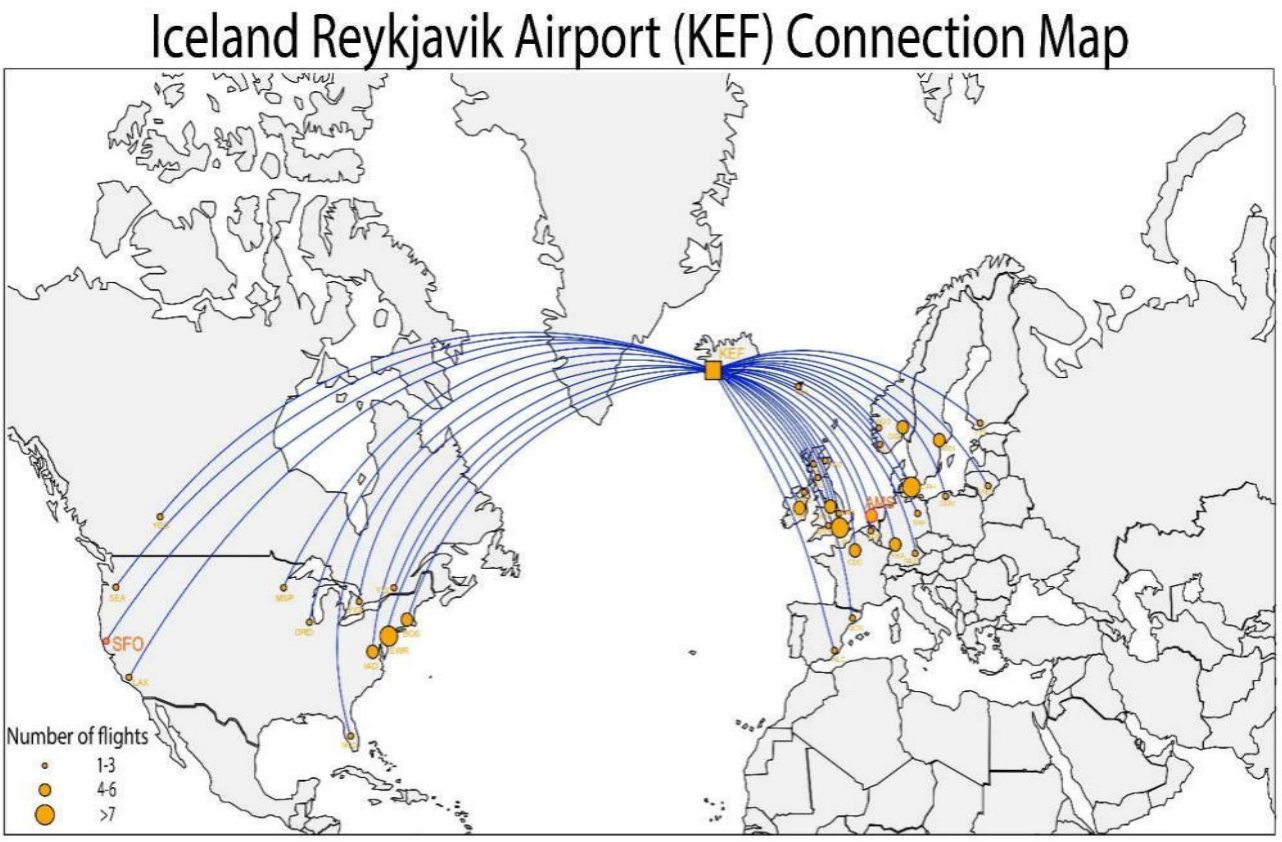
- > 7 flights ; 4 - 6 flights
- > 7 flights ; 1 - 3 flights
- 4 - 6 flights ; 1 - 3 flights

26%

Group2 Quantitative Q2

The representations of quantitative attributes.

✱
How many flights from Reykjavik Airport (KEF) Iceland to Amsterdam Schiphol Airport (AMS) the Netherlands and San Francisco Airport (SFO) the USA?



Choose one of the following answers

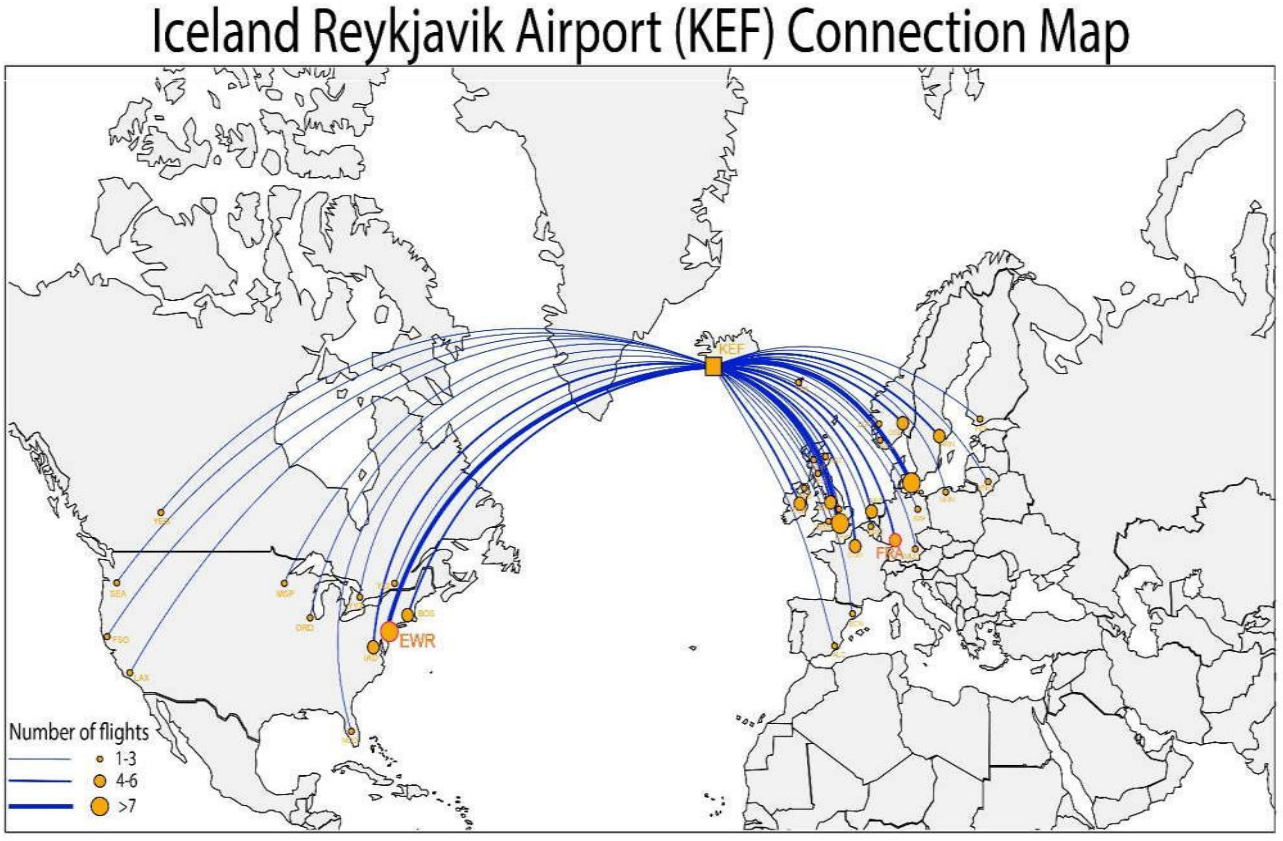
- > 7 flights ; 4 - 6 flights
- > 7 flights ; 1 - 3 flights
- 4 - 6 flights ; 1 - 3 flights

33%

Group2 Quantitative Q3

The representations of quantitative attributes.

✱
How many flights from Reykjavik Airport (KEF) Iceland to Newark Airport (EWR) New York the USA and Frankfurt Airport (FRA) Germany?



❶ **Choose one of the following answers**

- > 7 flights ; 4 - 6 flights
- > 7 flights ; 1 - 3 flights
- 4 - 6 flights ; 1 - 3 flights

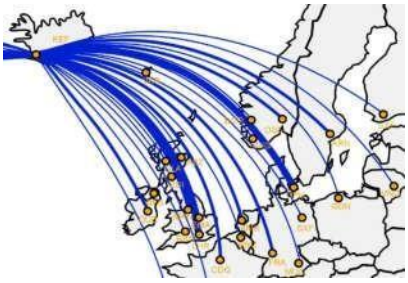
46%

Group2 Quantitative Q4

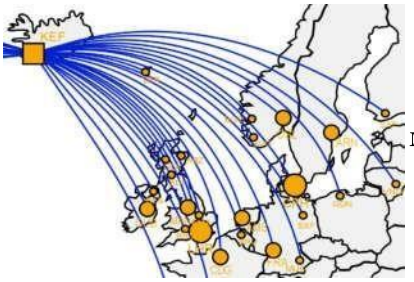
The representations of quantitative attributes.

✱
Which representation of quantitative attributes do you prefer most?

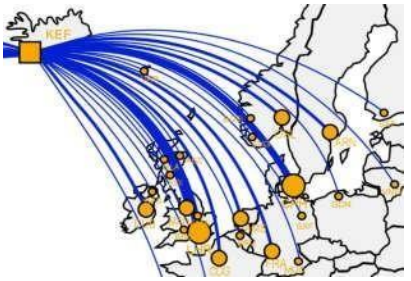
Plesase choose one from these three maps.



Map1



Map2



Map3

Choose one of the following answers

- Map1: Different width of lines
- Map2: Different size of symbols
- Map3: Different width of lines AND different size of symbols

Next

Previous

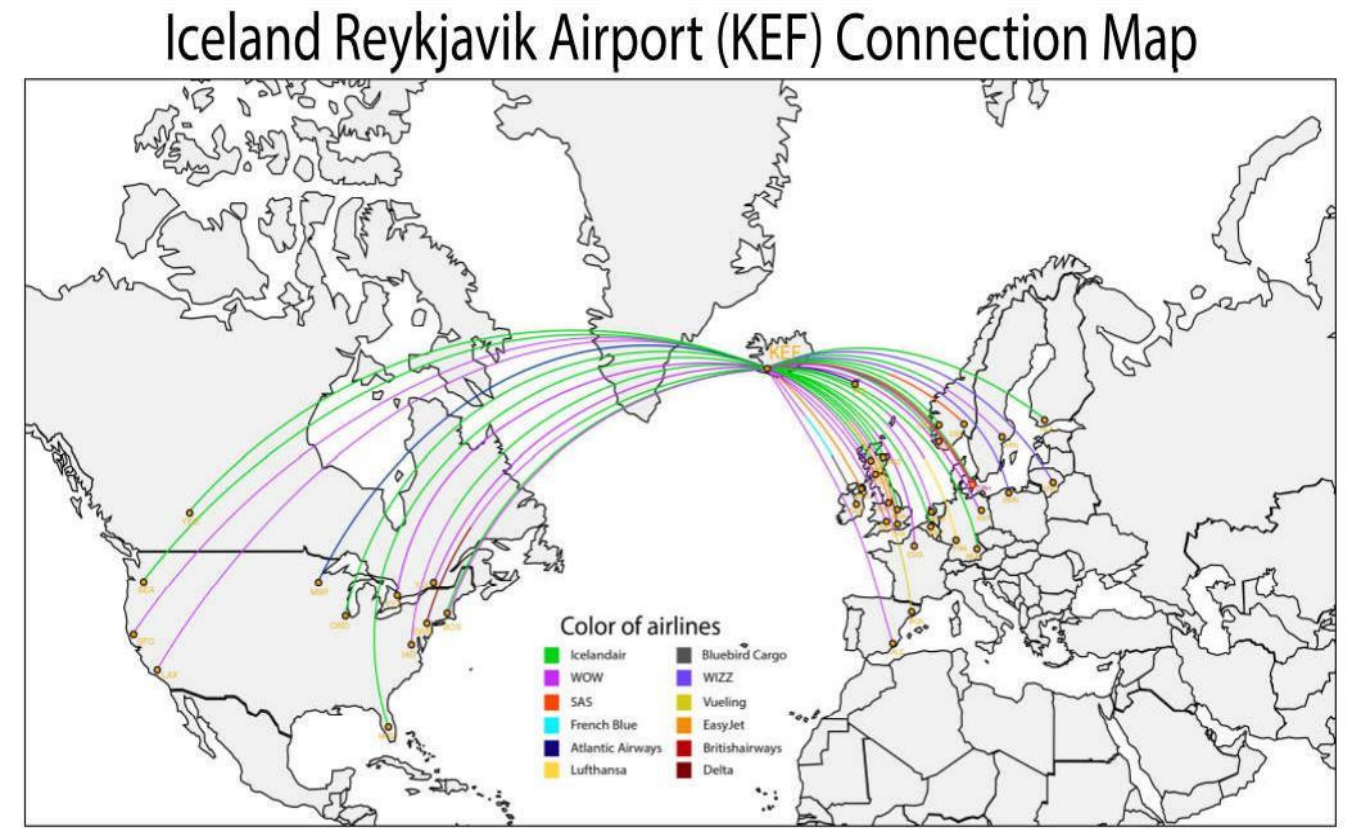
66%

Group3 Qualitative Q1

The representations of qualitative attributes.

✱
Which airlines fly between Reykjavik Airport (KEF) and Copenhagen Airport (CPH) Denmark?

Please select all of them.



Check all that apply

- [ ] Icelandair
- [ ] WOW air
- [ ] Atlantic Airways
- [ ] Bluebird Cargo
- [ ] British Airways
- [ ] Delta Air Lines
- [ ] EasyJet
- [ ] Frenchblue
- [ ] Lufthansa
- [ ] SAS Scandinavian Airlines
- [ ] Vueling

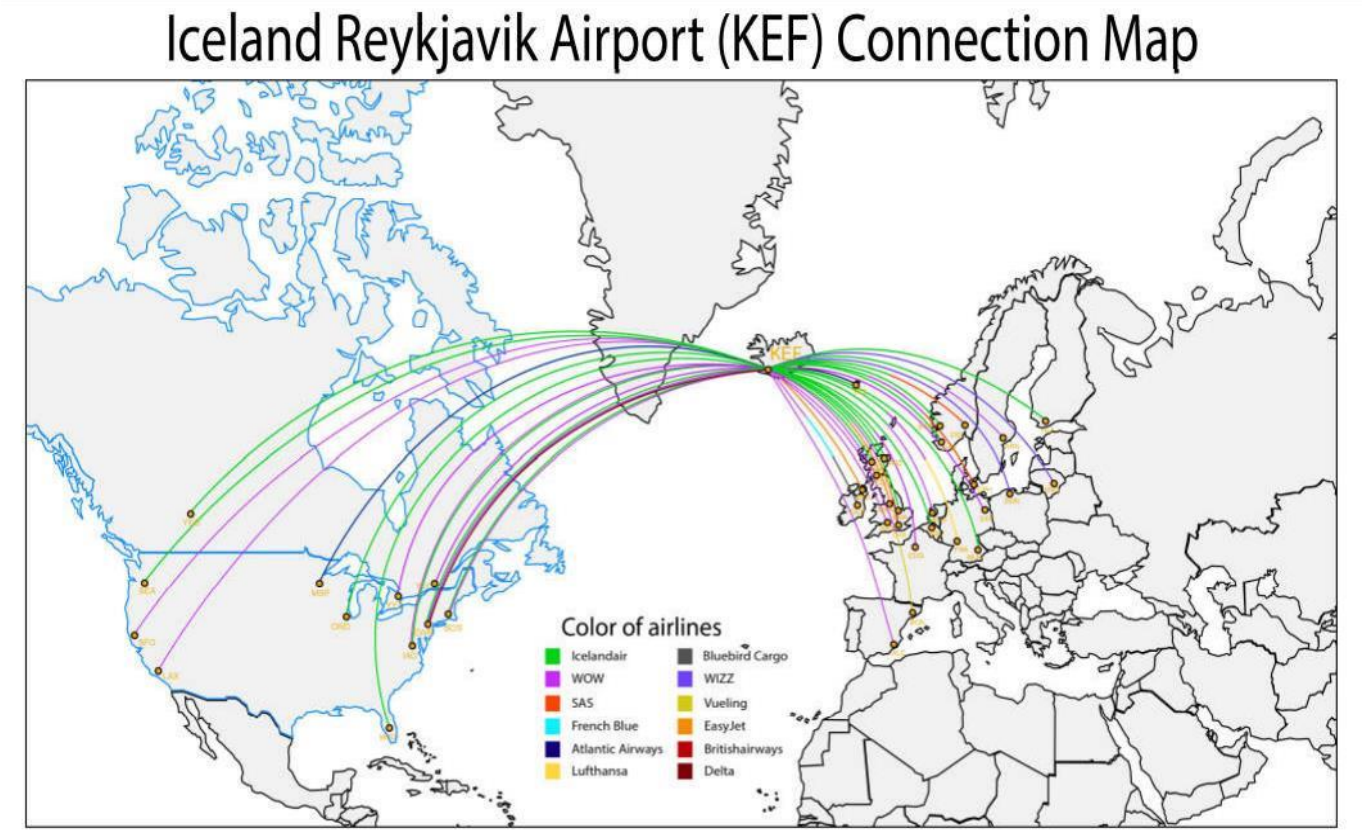
73%

Group3 Qualitative Q2

The representations of qualitative attributes.

✱
How many destinations can be reached by flying Icelandair in North America (Canada and the USA, the region in light blue)?

Please select all of them.



Choose one of the following answers

- 6
- 7
- 8
- 9

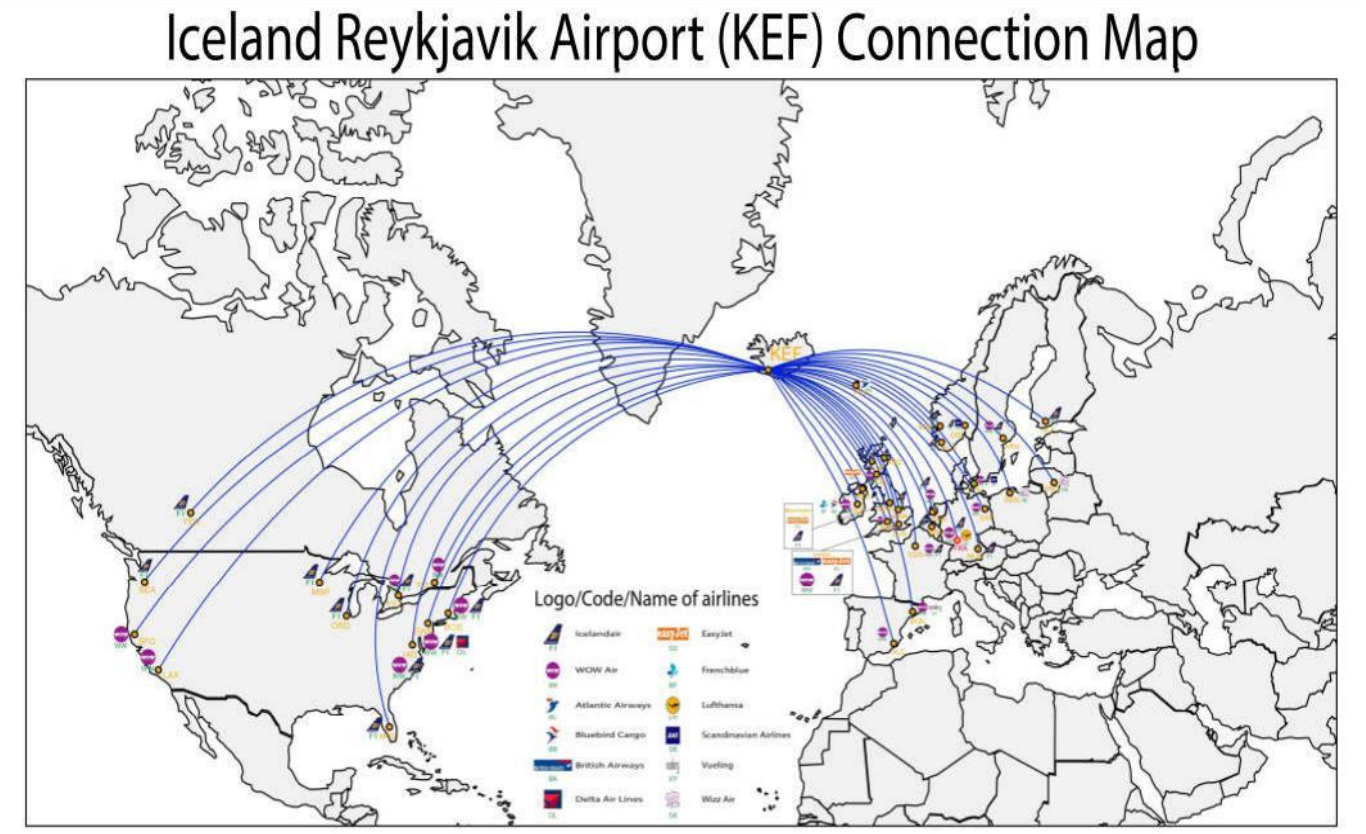
53%

Group3 Qualitative Q3

The representations of qualitative attributes.

*

Which airlines fly between Reykjavik Airport (KEF) and Frankfurt Airport (FRA) Germany?



Check all that apply

- [ ] Icelandair
- [ ] WOW air
- [ ] Atlantic Airways
- [ ] Bluebird Cargo
- [ ] British Airways
- [ ] Delta Air Lines
- [ ] EasyJet
- [ ] Frenchblue
- [ ] Lufthansa

- [ ] SAS Scandinavian Airlines
- [ ] Vueling
- [ ] Wizz Air

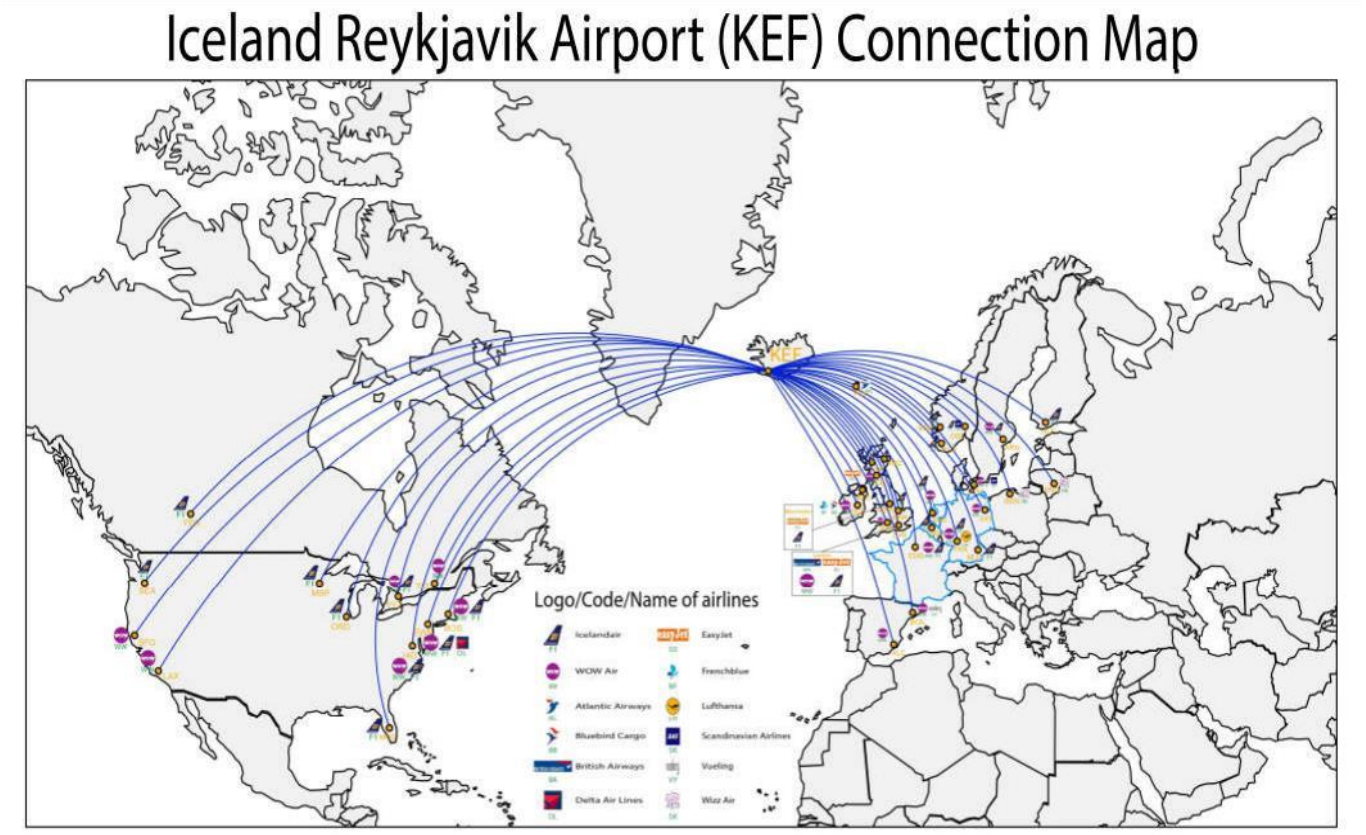
60%

Group3 Qualitative Q4

The representations of qualitative attributes.

*

How many destinations can be reached by flying Iceland air in France, Belgium, Netherlands and Germany (the region in light blue)?



Choose one of the following answers

- 4
- 5
- 6
- 7

80%

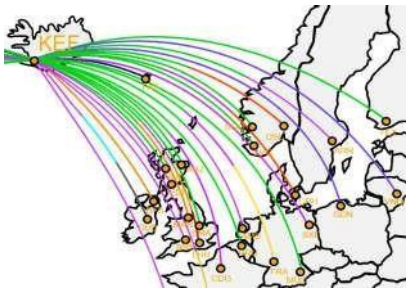
Group3 Qualitative Q5

The representations of qualitative attributes.

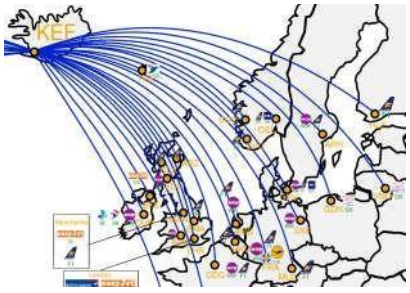
✱
Which representation of qualitative attributes do you prefer?

Plesase choose one from these two maps.

Choose one of the following answers



The map with colored lines



The map with labels

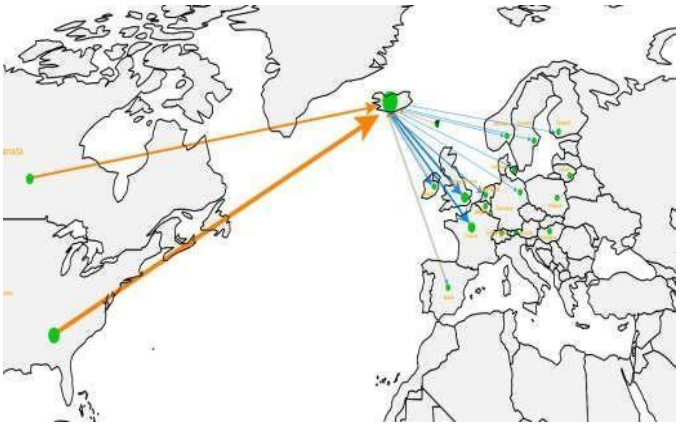
Previous

Next

-6%

Group4 DIrectIon Q1

In the morning, there are flights come from North America (the USA and Canada) to Iceland. In the meantime, other flights leave Iceland for other EU countries. This is the moring flights patteren of Reykjavik Airport (KEF) Iceland. The illustration shows the morning pattern.

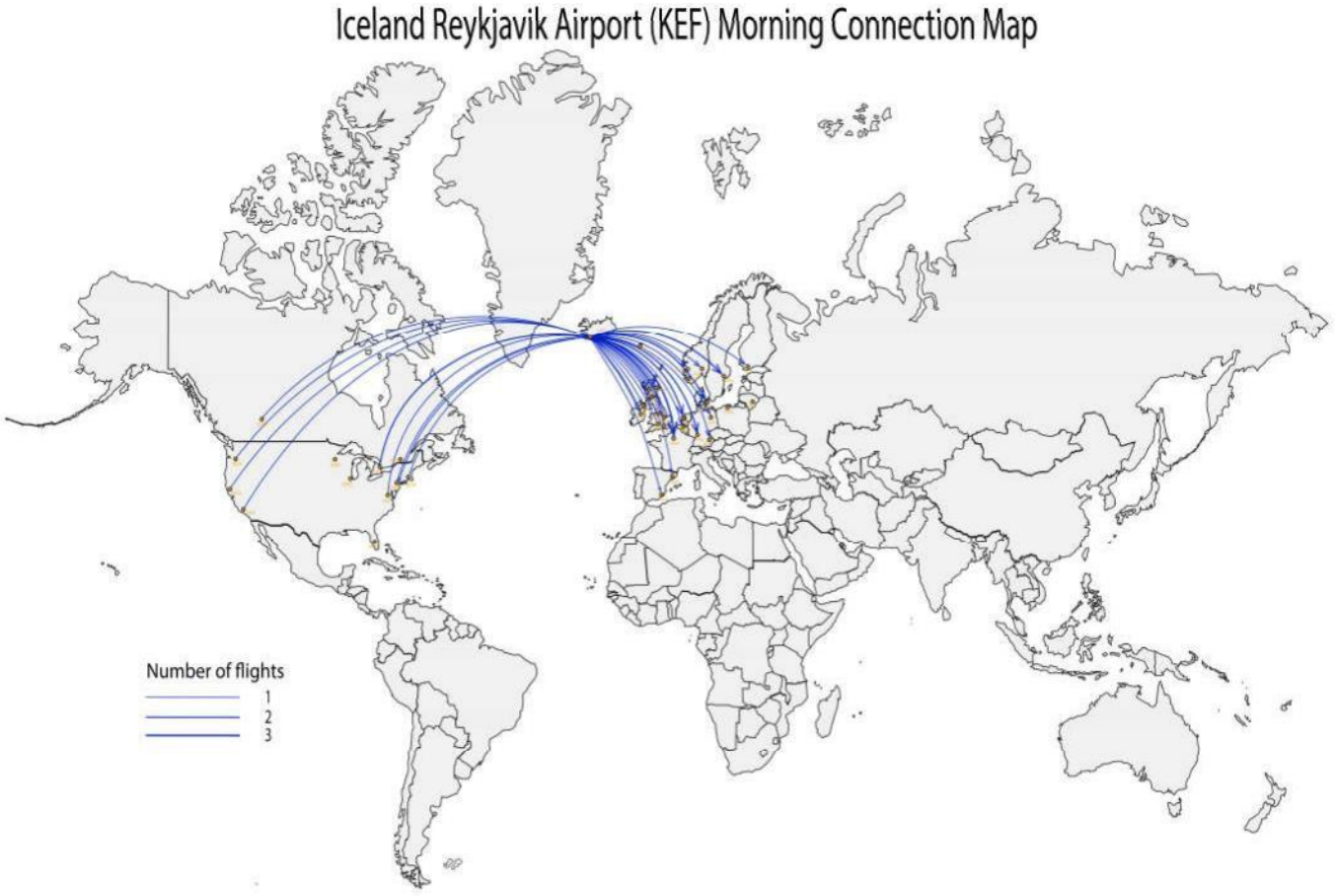


There are some maps with different representations of **Direction**. Are they clear enough to recognize the directions?

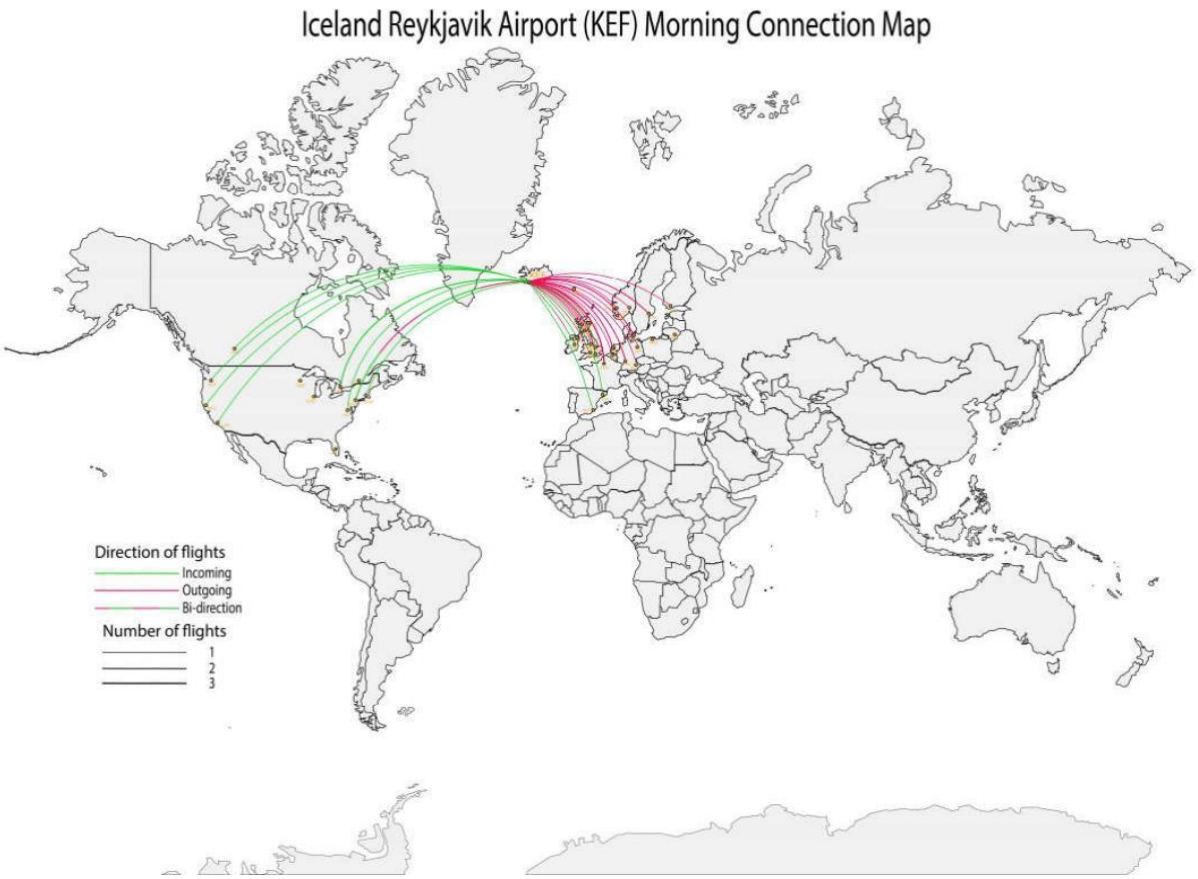
order of **Simplicity** ranking from **most** to **least** simple.

Please arrange the depicted direction according to your preferrec

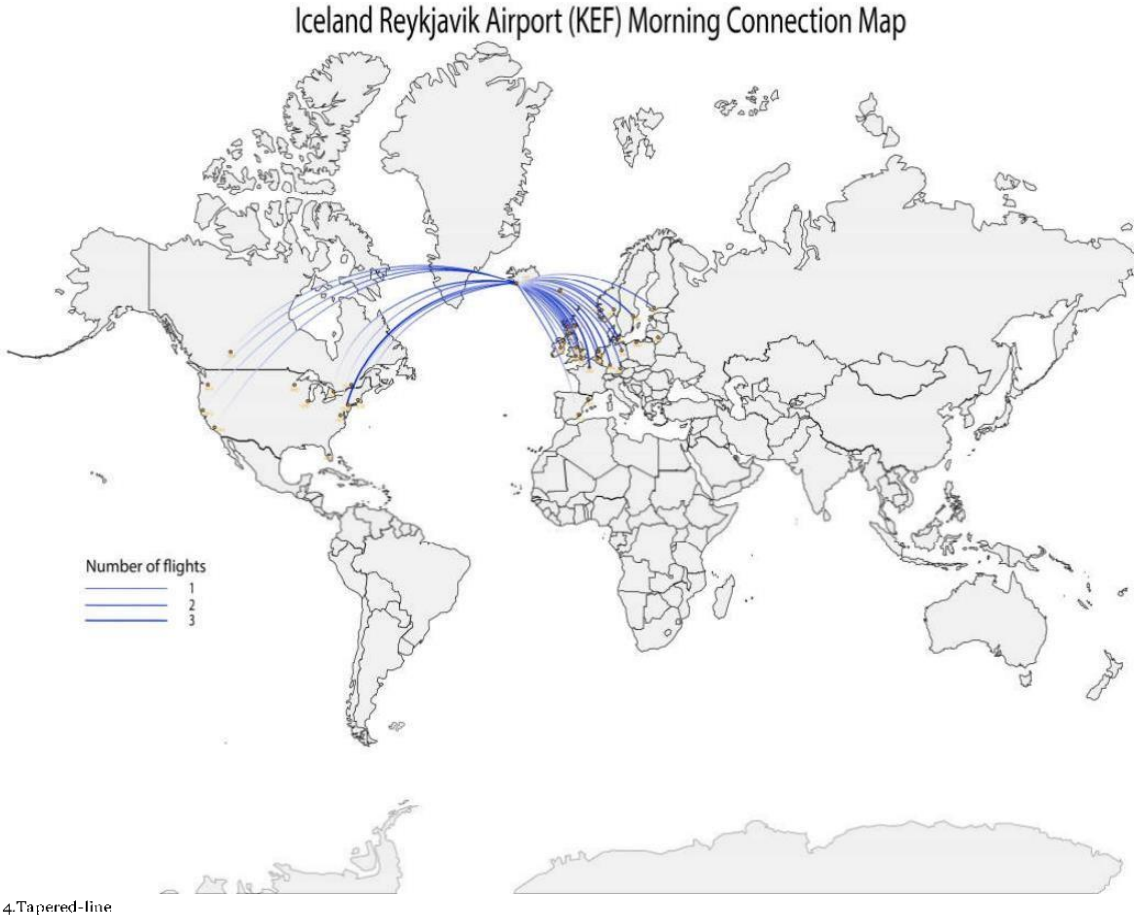
1.Arrow-line



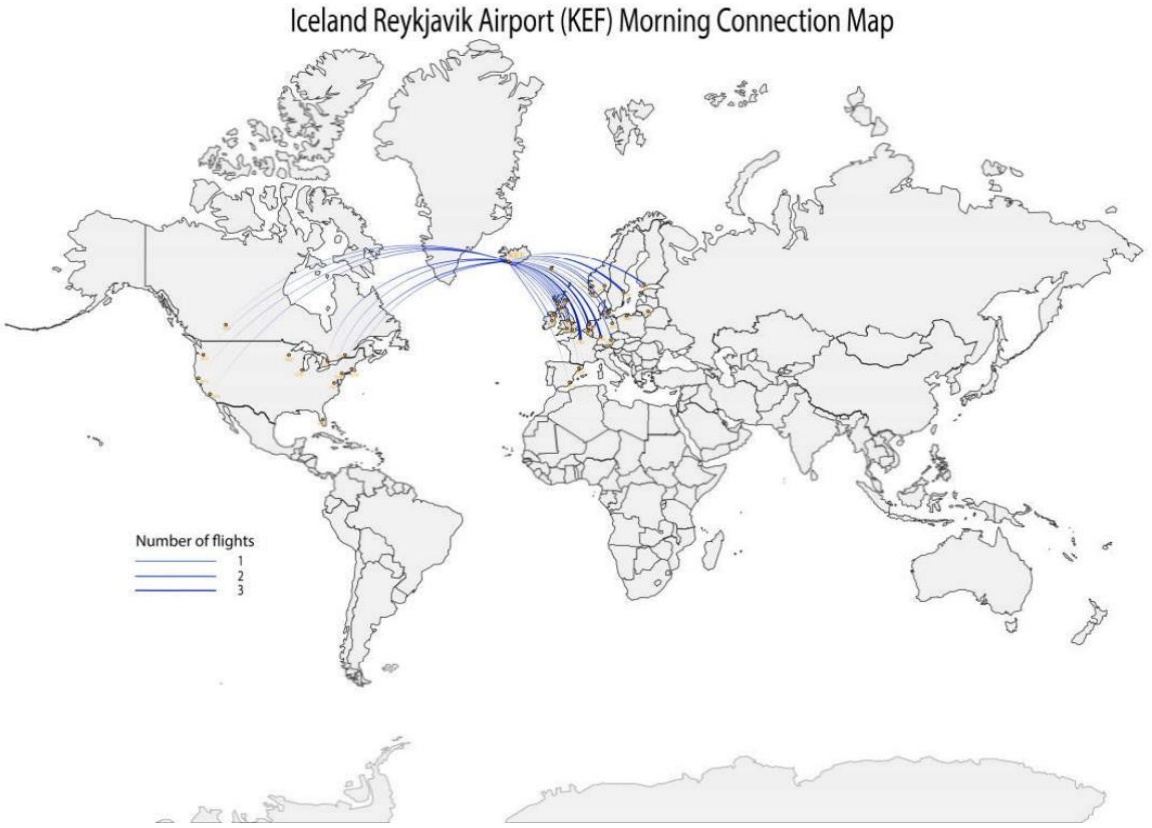
2.Colored-line



3.Transparent-line



4.Tapered-line

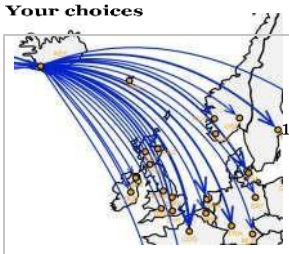


5.Animated-particle

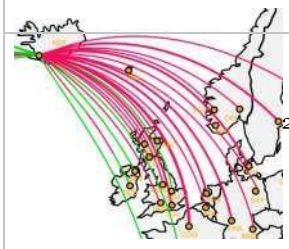
Double-click or drag-and-drop items in the left list to move them to the right - your highest ranking item should be on the top right, moving through to your lowest ranking item.

Your choices

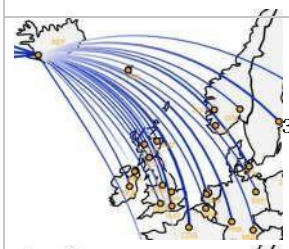
Your ranking



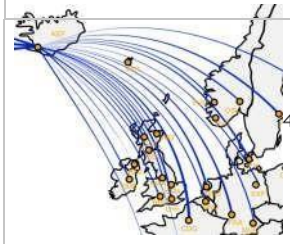
1 A w l



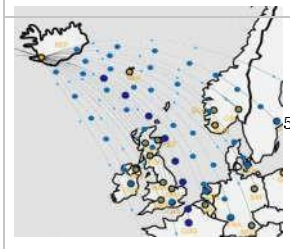
2 C l i l



3 T



4.Tapered-line



5.Animated-particle

93%

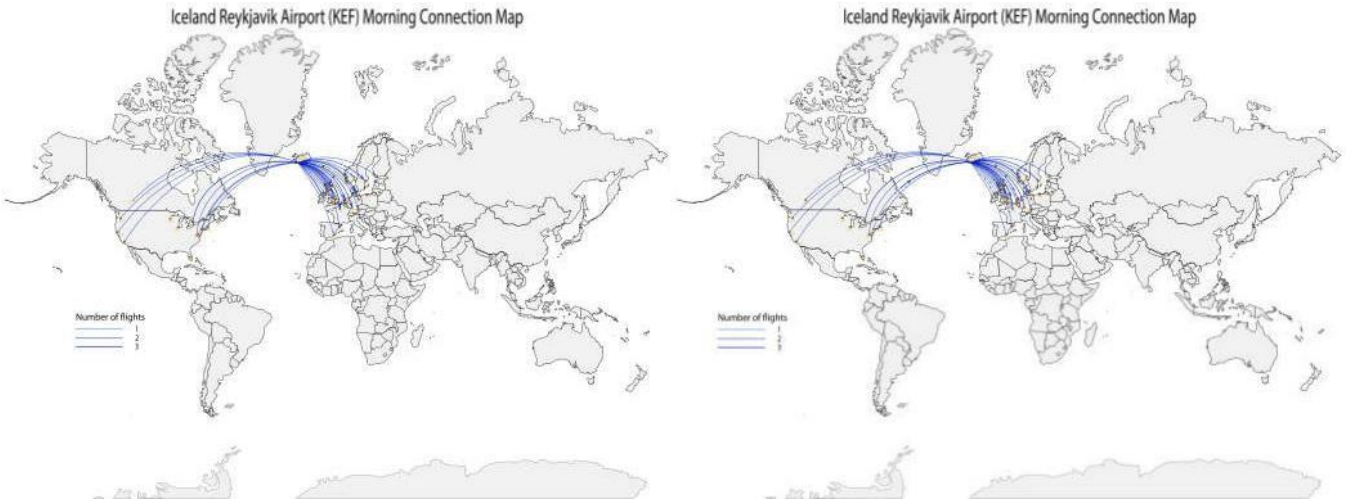
Group4 Direction Q2

The representations of direction.

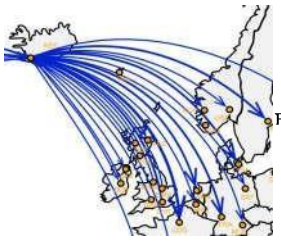
*

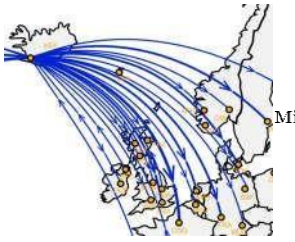
For more details about the representation of directions by **Arrows**, Front-arrow and Mid-arrow are the two alternatives, which one do you prefer?

Plesase choose one from these two maps.



Choose one of the following answers

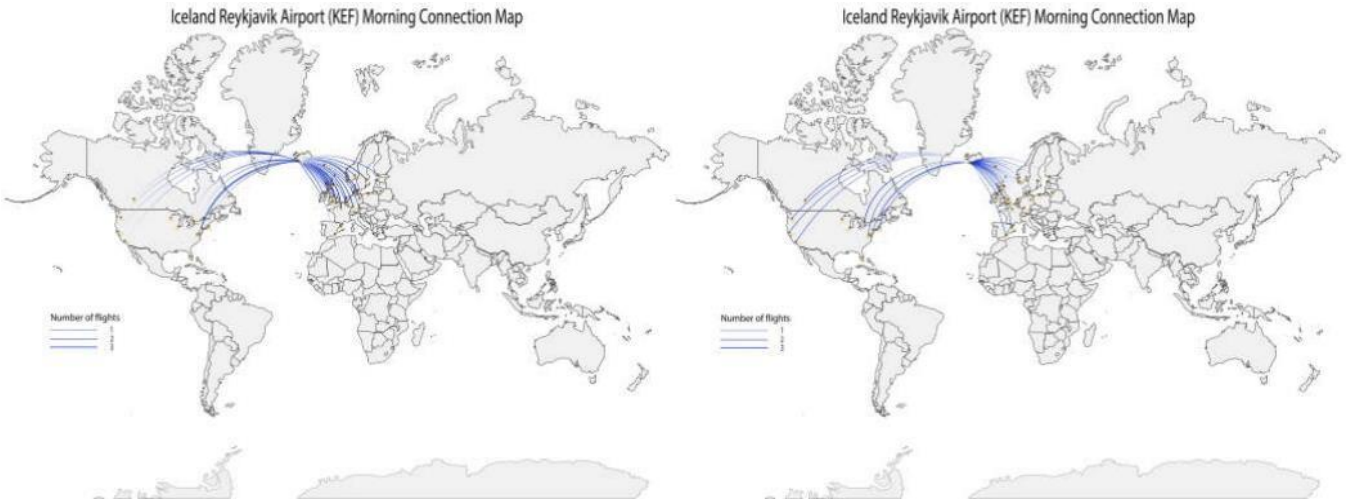

Front-arrow (left)


Mid-arrow (right)

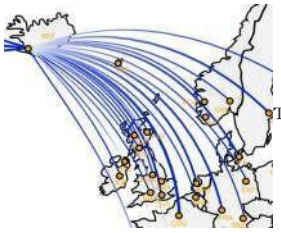
For more details about the representation of directions by **Transparent lines**, transparent to solid OR solid to transparent are the two alternatives.Which one do you prefer?

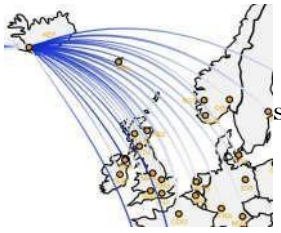
*

Plesase choose one from these two maps.



Choose one of the following answers

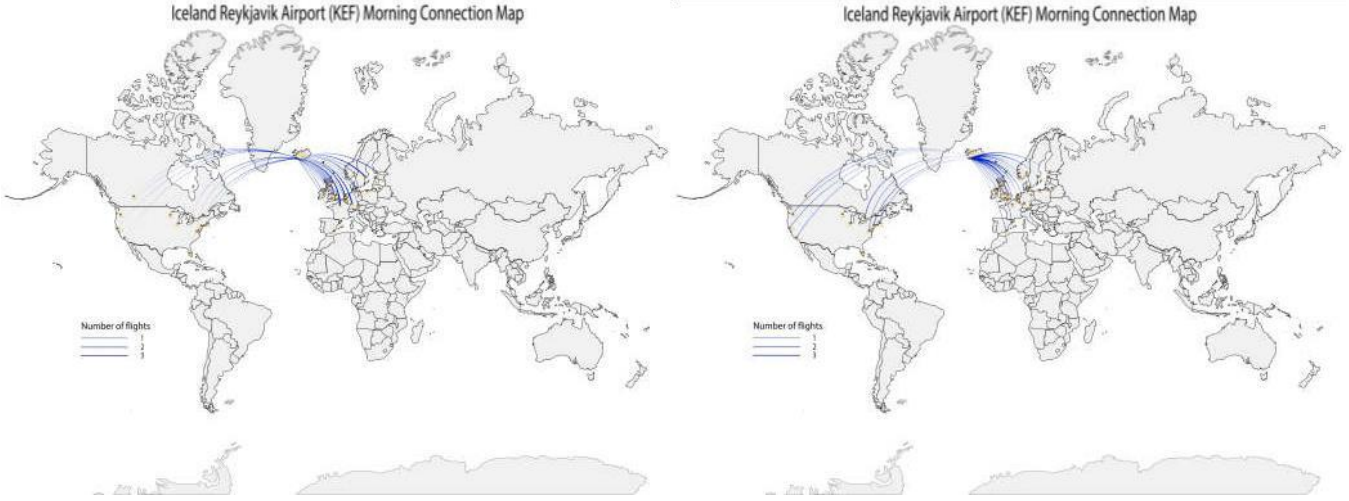

Transparent to solid(left)


Solid to transparent(right)

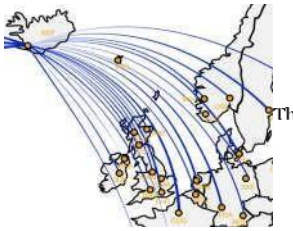
*

For more details about the representation of directions by **Tapered lines**, thin to thck OR thck to thin are the two alternatives. Which one do you prefer?

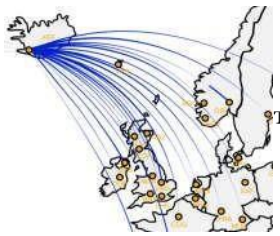
Plesase choose one from these two maps.



Choose one of the following answers



Thin to thick(left)



Thick to thin(right)

Previous

Submit