USING TIMELINES TO ANSWER SPATIO-TEMPORAL QUESTIONS AT DIFFERENT TEMPORAL GRANULARITIES

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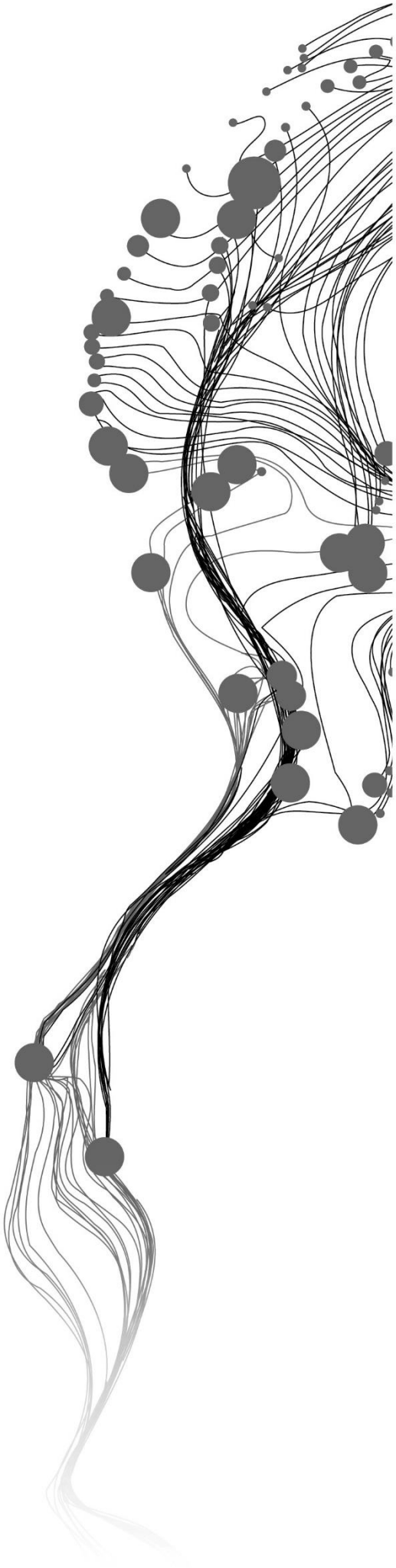

USING TIMELINES TO ANSWER SPATIO-TEMPORAL QUESTIONS AT DIFFERENT TEMPORAL GRANULARITIES

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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.

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ABSTRACT

Nowadays, a large volume of spatio-temporal data have been collected with the development of network technology, but it is difficult to use. Visualisation method can help people to understand and analyse data. Timelines are potentially a good way to visualise spatio-temporal data.

The purpose of this study was to explore how timelines can help users to solve spatio-temporal questions with different temporal granularities. It used user-centred design to do the research. Started from analysing user requirements, a task taxonomy was provided to categorize the spatio-temporal questions. After that, sketches were provided to each question type as answers. Then a visualisation tool was designed to prove that these sketches could answer the questions and could be put into practice. After designing the functions and interface of the visualisation tool, they were implemented as a prototype. Lastly, the research organised focus group and post-experience interview to evaluate this prototype.

From the result in evaluation, the prototype could help users to solve questions. Therefore, the result of this research was that timeline was able to help users to solve spatio-temporal questions, especially at different temporal granularities.

Keywords: timelines, temporal granularity, visualisation, spatio-temporal question

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1. INTRODUCTION

1.1. Motivation and problem statement

With the development of network technology, a large volume of data accompanied by changes in time and space can be acquired. For example, airport records data regarding the specific departure and arrival time, and the real-time location of each flight, which are accompanied by changes in time and space, these data are called spatio-temporal data. Spatio-temporal data is information about the position of individual objects over time Wang and Kraak (2013). It can reveal the information about the positional change over time, which is very valuable to research. Li and Kraak (2008) discussed the importance of spatio-temporal data analysis. Analysing spatio-temporal data helps detect the changes and explore the trends.

On the one hand, detecting changes along with the spatial and temporal information can be used in the disease control field. For example, spatio-temporal data on the spread of infectious diseases can help people to analyse the spread of diseases so that the action can be taken efficiently.

On the other hand, exploring spatio-temporal data is beneficial to discover the regularity of events. Taking the flight data as an example, the airport managers care about the regularity of the passenger flows and flight volumes, which can be achieved by analysing the flight data. However, the spatio-temporal data is messy and complicated to visualise and research. To make data more intuitive and usable, it becomes vital to apply visualisation techniques to it.

Visualisation utilises the techniques and methods of graphic images to help people understand and analyse data. A suitable visualisation method can simplify the representation of spatio-temporal data and make it understandable and accessible to process.

However, which kind of visualisation method is suitable for solving this problem? There are many different visualisation methods, while timelines are potentially a good way to visualise spatio-temporal data. They have been used in various domains such as patient medical records (Bui, Aberle, & Kangarloo, 2007), historical event (Kraak & Kveladze, 2017) and movement data (Kveladze, Kraak, & van. Elzakker, 2015).

Currently, the spatio-temporal data have been shown on timelines and maps, but it is not enough when users want detailed information or manipulate the temporal data to find other trends. Hence, making more interactive data shown on the timeline can achieve user requirements.

Another problem of the timeline is the visualisation of temporal granularity. Time comprises different forms of granularities (e.g. minutes, hours, days, weeks, months and years), so the timeline should show different data or trends at different temporal granularities. Similarly, if the occurrence of an event is not periodic, how to represent this event on the timeline is also a problem to be solved (Aigner, Miksch, Schumann, & Tominski, 2011).

The motivation of this thesis is to investigate how timelines can help to solve spatio-temporal questions, especially at different temporal granularities. Besides, it is essential to find out how to deal with an interactive timeline with different temporal granularities for users to manipulate. This thesis uses flight data from Schiphol airport as a case study. From the perspective of passenger flow, Schiphol airport is the third busiest airport in Europe and the eleventh busiest airport in the world in 2017 ("Preliminary 2017 world airport traffic rankings," 2018), which is typical to study.

1.2. Research objectives and research questions

The main objective is to identify how timelines can help users to solve spatio-temporal questions at different temporal granularities. Users of this timeline are the temporal analysts who have spatio-temporal questions and need to explore spatio-temporal patterns to inform the stakeholder to deal with spatio-temporal questions. Assuming that stakeholder is the manager of the airport who is willing to run airport smoothly at any moment in time, the temporal analyst can use the output to identify the trend of passenger flows in different times, and this result can help the airport managers to make decisions.

There are four sub-objectives and research questions listed below.

Sub-objective 1: Formulating spatio-temporal questions according to the user requirements.

Research questions are:

- Which categories of questions can be involved in timeline visualisation?
- How to formulate questions and reflect the relationship among objects, spatial and temporal information?

Sub-objective 2: Providing the answer of questions on the timeline and designing the conceptual design of the visualisation tool.

Research questions are:

- What kind of timelines exists to match different types of temporal questions and data?
- What functions should the timeline have to help users solving temporal questions?
- How to deal with temporal granularity in these questions?
- How can the timeline inform about a spatial attribute in an environment with changing granularity?

Sub-objective 3: Implementing the conceptual design.

Research questions are:

- What will the interface of timeline look like?
- How to display different temporal granularities?
- When we have different temporal granularities, how to keep the overview and still see the detail related to the question?

Sub-objective 4: Evaluating the implementation.

Research questions are:

- How to evaluate the usability of timelines visualisation tool?

1.3. Innovation

Firstly, this research focuses on formulating questions that users have in spatio-temporal data and its temporal granularity. Also, this research establishes a task taxonomy by studying flight data, which can be applied to more extensive uses in formulating questions related to spatio-temporal data and temporal granularity.

Secondly, this thesis dealt with how the interactive timeline deals with multiple temporal granularities in answering temporal questions. It can visualise different temporal granularities regarding real-time user requirements. When users change the time granularity, the graphs will change correspondingly.

1.4. Thesis structure

This thesis divides into six chapters.

Chapter 1 mainly describes the motivation of this research, the objective and questions that will be solved in this research.

Chapter 2 gives the background of some aspects related to the research.

Chapter 3 describes the data and the methods used to solve research questions in this study.

Chapter 4 discusses the results according to the detailed workflows of achieving each research sub-objective in this research.

Chapter 5 summarises the important findings and limitations of the research.

Chapter 6 gives the conclusions and puts forward recommendations for further research.

1.5. Methodology outline

Figure 1-1 states three steps to achieve the main objective in this research. The first step is analysing problem. It formulates spatio-temporal questions based on user requirements, which aims to solve sub-objective 1. The second step is providing solution for questions in the previous step. It contains two processes, putting forward conceptual design and its implementation. Conceptual design focuses on two aspects, using sketches as answers to solve spatio-temporal questions and designing an interface for visualisation tool. The third step is evaluation. Full details can be found in Chapter 3.

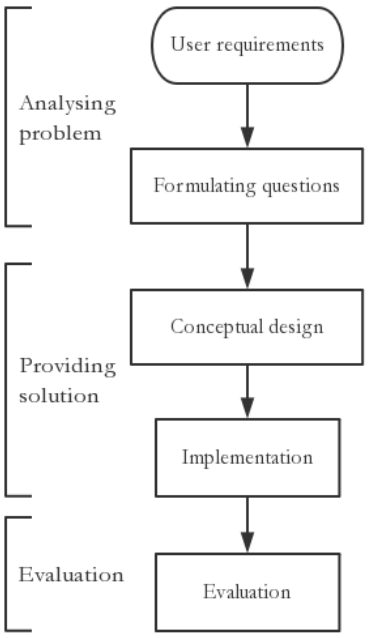

Figure 1-1 Methodology outline

2. BACKGROUND

This chapter contains four sections. Section 2.1 demonstrates the development of spatio-temporal data. Section 2.2 describes the evolution of formulating temporal questions. Section 2.3 introduces the development status of dealing with temporal granularity. Section 2.4 discusses the situation of timelines in recent years.

2.1. Spatio-temporal data

It has generated a large volume of spatio-temporal data, which were difficult to use and visualise, with the development of network technology. But its utilisation can help discover geographic patterns that would otherwise go unnoticed. Until now, researchers have tackled a range of challenges related to processing and visualising spatio-temporal data.

Tominski, Aigner, Miksch and Schumann (2017) viewed the characteristics of time and time-oriented data as the key to design visualisation methods. They analysed and categorised time-oriented data and summarised visualisation methods for each kind of data in the TimeViz Browser designed by themselves. Time-oriented data, as explained in the article, was the data tuples which tied to time primitives. This kind of data built the relation between data and time. Furthermore, if data tuples also related to spatial information, this formulated the spatio-temporal data. After that, this article discussed the visual variables that could be used to visualise time-oriented data.

Based on these principles, fundamental ways of visualising time-oriented data were explained, such as the number of variates and the format of the timeline (linear or cyclic). There were also many examples provided for explaining. Besides, they also developed a TimeViz Browser, which was an interactive survey of visualisation for time-oriented data.

Peuquet (1984) detailedly analysed the structure of spatio-temporal data and divided spatio-temporal data into three aspects: location, attribute and time. Location was related to the spatial attribute in the data. The attribute was about the other attribute of data. Time was the temporal attribute of data. Later, these three aspects were connected to the question type. Location was connected with the "where" question. The attribute was linked with "what" question and time were related to "when" question. This theory was vital for understanding the structure of spatio-temporal data and helpful for formulating spatio-temporal questions.

Li and Kraak (2008) mentioned this theory and further summarised. In their research, they designed Time Wave, a new method for visualising spatio-temporal data. They discussed the relationship and visualisation method among location, space and time (Figure 2-1). From the figure, the combination of location and time can be visualised via space-time cube, the combination of location and attribute can be visualised via map and the combination of attribute and time can be visualised via diagrams.

This theory provided basic visualisation method about spatio-temporal data, which is helpful in this research. Also, this structure helps to formulate spatio-temporal questions in the next step.

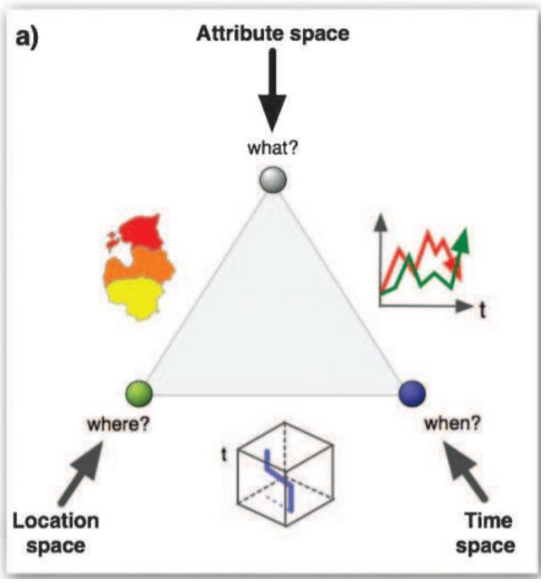

Figure 2-1 A view from location-space, attribute-space and time-space (source: Li and Kraak (2008))

2.2. Temporal questions

Jacques Bertin (1967) distinguished possible questions according to the components of data. "There are as many types of questions as components in the information". He used stock and price as an example to explain this theory. There were two components of questions:

-- On a given date, what is the price of stock x?

-- For a given price, on what date(s) was it attained?

Within each type of question, he divided into three reading levels named elementary, intermediate and overall. This theory was based on the elements of data in each question. If the question focused on a single element, it belonged to the elementary level. If the question focused on a group of data elements as a component, it belonged to the intermediate level. If the question concerned all the data elements, it belonged to the overall level.

This category method relies on the data component, so it had extensive use. Besides, it was easy to classify questions, which formulate a clear structure. Bertin said: "Any question can be defined by its type and level".

Andrienko and Andrienko (2006) amended Bertin's theory and systematically analysed the composition of the question. They thought the difference between intermediate and overall reading level was the range of the dataset. Intermediate level viewed the subset as a whole, while the overall level referred to the whole set. Hence, the three reading levels could be amended into two analytical levels: elementary level, which considered elements, and synoptic level, which considered sets.

Besides, they analysed the composition of the question and systematically described various question types. "Any task (question) implies two parts: a target and constraints". The task was the question that needed to be answered. The target could be viewed as an unknown part of the question, which was needed to find an answer for this part. The constraint was the known condition in the question; answers should be found based on that. For example:

- When were the KLM flights departed from Schiphol airport between 10.00 a.m. and 12.00 a.m.?

In this task, the target is the departed time of flights, while constraints are KLM airline, flight direction (departed from Schiphol airport) and time interval (between 10.00 a.m. and 12.00 a.m.).

As about spatio-temporal data, the constraint, also could be called the "focus", which was mainly concerns about three fundamental components: objects, space and time. Based on the theory of the composition of the question, they put forward a formula to represent questions:

$$f(x) = y$$

Where x is an independent variable, which can be viewed as "constraints" in the question, while y is dependent variable, which represents the "target" in the question. f is a function, which means the correspondence between x and y, that is, each independent variable has a dependent variable corresponding to it.

Combining with the formula, Andrienko and Andrienko further refined the analytical level. The elementary level tasks contained lookup task, comparison task and relation-seeking task. The synoptic level tasks contained pattern definition task, pattern search task, pattern comparison task and relation-seeking task.

Boyandin (2013) discussed various taxonomies of formulating questions for data analysis. On the one hand, some taxonomies which related to formulating spatio-temporal questions were summarised. On the other hand, the author designed a task taxonomy to analyse temporal origin-destination data (OD-data) according to the work from Andrienko and Andrienko (2006). This taxonomy provided all possible combinations among location, attribute and time, and listed them separately in focus and target. Later, some key meanings of formulating elementary and synoptic questions were provided after every combination. Then for each kind of questions, there was one formulated question as an example to describe the type.

This article combined the theoretical development of formulating questions for the OD-data. Besides, the result has a certain inspiration for this research.

2.3. Temporal granularity

Chittaro (2006) proposed six visualisations for recording the patient data (**Error! Reference source not found.**), one common feature of which was the presentation of multiple granularities. All six visualisation had a timeline and zoom buttons to allow users to switch temporal granularity to see the data on a timeline.

In **Error! Reference source not found.**, the granularity part was under the timeline and divided into two levels. The zoom button was on the left of the granularity part. When users chose coarser levels of temporal granularity, the upper part of the timeline and temporal granularity displayed the weeks (or days), while the lower part of temporal granularity showed month or year; when users selected finer temporal granularity, those upper parts showed the hours and the lower showed the date. The level of temporal granularity was chosen by the zoom button.

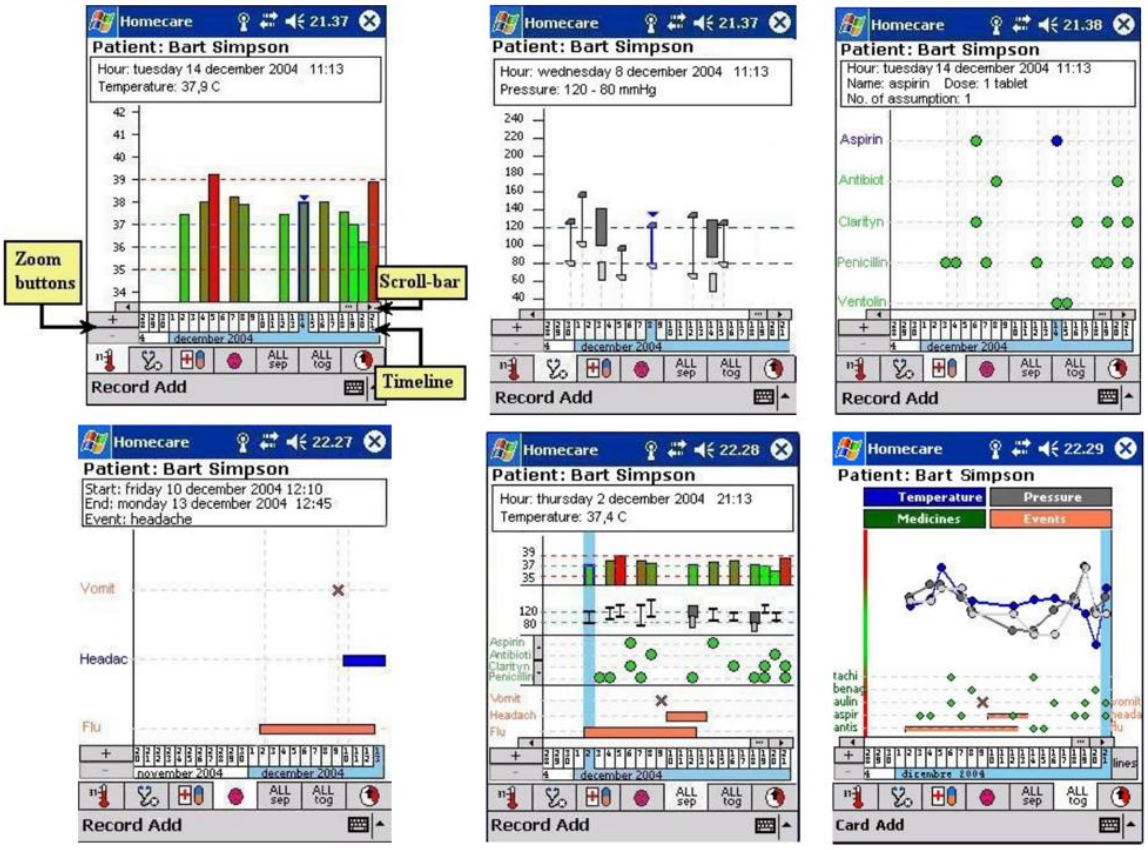

Figure 2-2 Six visualisations for recording patient data (Source: Chittaro (2006))

Jonathan (2018) presented four event lines along with the timeline at the same time. The trend and statics of the event changed when the timeline changed the temporal granularity. Chittaro (2006) proposed one timeline and a granularity part. The timeline changed once users changed the granularity.

2.4. Timelines

Wang and Kraak (2013) analysed the characteristics of spatio-temporal data and summarised the theories and tools related to the timeline. First, the answer types were categorised to answer the temporal questions. As shown in Figure 2-3, it was divided into three categories, attribute, location and time for one specific object when formulating the temporal questions. Second, they reviewed the existing timelines based on the three criteria including the type, the visual information and the functionality. The analysis of the timeline applications in the paper contributed to this research regarding the conceptual design of the timelines in dealing with different types of temporal questions.

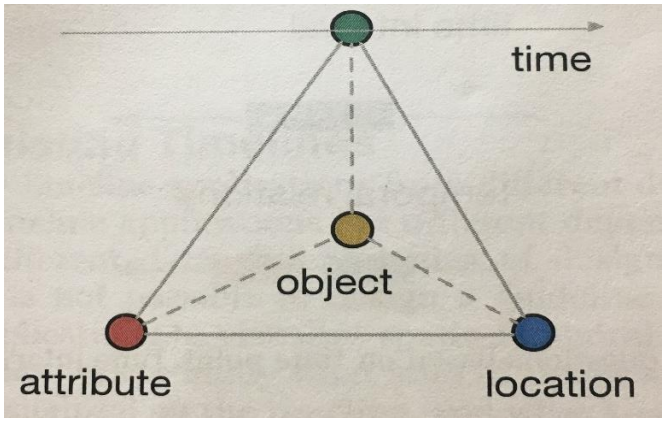

Figure 2-3 Location, attribute and time (source: Wang and Kraak (2013))

Brehmer et al. (2017) presented a design space for storytelling with timelines. They summarised their proposed design space along with three dimensions: representation, scale and layout (Figure 2-4). Also, they provided several choices in each dimension so that the storyteller could make a decision and finally combined them to get a suitable timeline expression.

Representation dimension aimed to provide selection on the display format of the timeline. For example, the timeline could be displayed in a "linear" format, which was very common to visualise time. Besides, the timeline could be depicted as a calendar. In this case, the timeline was better to express the temporal granularities, the format of which was "grid".

Scale dimension focused on the sequence of events. For example, "chronological" scales mainly expressed events according to the order in which the events occurred. "Sequential + interim duration" scale focused on eliminating the different lengths of a gap on the timeline caused by different intervals between events.

Layout dimension considered the relation of events. If events happened at the same time, the format of the layout was "faceted". "Segmented" layout was better to depict events compared by periodic time, such as weekly or monthly.

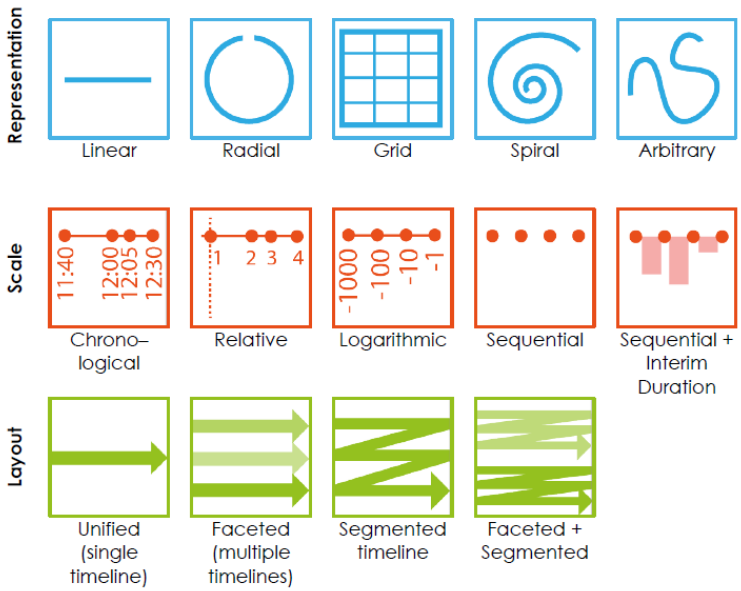

Figure 2-4 The three dimensions of the design space (source: Brehmer et al. (2017))

This article gave a reasonable way of expressing timeline ideas. By thinking about those three aspects and combining the expressions provided by each aspect, designing the most reasonable expression of timeline became very effective. This expression and way of thinking were also used in this research.

Aigner, Miksch, Schumann and Tominski (2011) provided a systematic view of the visualisation of time-oriented data and presented the visualisation. This view was structured along three fundamental questions, time, associated data and user tasks. The aspects of time and associated data described what was being visualised, and user tasks were related to the problem of why something should be visualised. These characteristics and functions determined how the visualisation was to be designed. To support visual exploration, interaction techniques and analytical methods were required as well. The concepts explained in this book were illustrated with numerous examples, such as Space-Time Cube, TimeWheel, and Timeline Trees.

2.5. Evaluation

Zhao, Drucker, Fisher and Brinkman (2012) presented an interactive faceted visualisation, known as TimeSlice, and invited eight volunteers to do the evaluation. The process was prone to qualitative evaluation, which could be a reference to this research.

Rabiee (2004) detailly discussed the process of the focus group, which was one of the qualitative analysis methods. The article introduced the concept of qualitative analysis and the focus group at first; then it described the process of how to design a focus group interview, which could be a reference. Besides, this article summarized the related work objectively and discussed some methods of data analysis.

Kveladze et al. (2015) discussed a detailed process about space-time Cube. They also described the methods of qualitative evaluation. For example, considering the qualitative evaluation, there were some methods such as focus group, post-experience interview, observation and audio recording. In terms of quantitative evaluation, there were some methods like task analysis, questionnaire and eye tracking.

Besides, they listed a lot of case studies as examples of the use and evaluation of space-time Cube, which had great help in understanding these theories.

3. METHODOLOGY

Chapter 2 summarises the previous works on spatio-temporal data, temporal questions, temporal granularity and timelines. This chapter discusses the methodology according to the research questions, which contains five sections. Section 3.1 lists the data used in this research. The concept of user-centred design (Figure 3-3) is carried out throughout the whole research, which will be discussed in section 3.2. Section 3.2 is corresponding to the "analyse requirements" step of user-centred design. Section 3.3 formulated questions based on user requirements. Section 3.4, section 3.5 and section 3.6 are corresponding to the "produce design solutions" step of user-centred design. Section 3.7 is related to the "evaluation designs" step of user-centred design.

3.1. Data

This section contains two parts. 3.1.1 describes the flight data which was primarily used in the research. 3.1.2 introduces the airport's data as the supplement in the implementation.

3.1.1. Flight data

The data was from Schiphol airport. Schiphol airport is located 9 kilometres southwest of the Amsterdam, in Haarlemmermeer, North Holland. It is the main international airport in the Netherlands. The Schiphol flight information is managed by the Central Information System Schiphol (CISS). Part of this flight information was made available via the Rest API Flight Information (API) to developers. The API is a set of clearly defined methods of communication between various components. This website provided several APIs. This topic used the data from "Flight API" in the "Developer centre" of the webpage. The offered flight information relates to passenger flights and cargo flights (scheduled flights and charter flights). The example of data from Schiphol airport shows in Figure 3-1, which was extracted from the link below:

https://www.schiphol.nl/nl/developer-center/pagina/explore-all-schiphols-apis-in-the-developer-center/

The detailed flight information provided were:

- Destinations
- Airlines that operate the flights to and from Schiphol
- Aircraft types operated by the airlines
- Flights data elements
- Flight status

```
{
  "flights": [
    {
      "id": 126119090970030100,
      "flightName": "ZXP041",
      "scheduleDate": "2019-01-20",
      "flightDirection": "D",
      "flightNumber": 41,
      "prefixIATA": null,
      "prefixICAO": "ZXP",
      "scheduleTime": "00:01:00",
      "serviceType": null,
      "mainFlight": "ZXP041",
      "codeshares": null,
      "estimatedLandingTime": null,
      "actualLandingTime": null,
      "publicEstimatedOffBlockTime": null,
      "actualOffBlockTime": "2019-01-20T00:06:00.000+01:00",
      "publicFlightState": {
        "flightStates": [
          "DEP"
        ]
      },
```


Figure 3-1 The data from Schiphol airport

3.1.2. Airports data

Airports data was stored in a text file named "Airports.txt". This data contained information about worldwide airports, including the abbreviation and full name of airports, and the coordinates of airports. Figure 3-2 shows some part of the data. This data was used in a destination part in the section 3.6.3 to give the coordinate of the airport from the abbreviation which selected or typed in from users on the web page.


```
Airports.txt
1  1,"Goroka Airport","Goroka","Papua New Guinea","GKA","AYGA",-6.081689834590001,145.391998291,5282,10,"U","Pacific/
   Port_Moresby","airport","OurAirports"
2  2,"Madang Airport","Madang","Papua New Guinea","MAG","AYMD",-5.20707988739,145.789001465,20,10,"U","Pacific/
   Port_Moresby","airport","OurAirports"
3  3,"Mount Hagen Kagamuga Airport","Mount Hagen","Papua New
   Guinea","HGU","AYMH",-5.826789855957031,144.29600524902344,5388,10,"U","Pacific/Port_Moresby","airport","OurAirports"
4  4,"Nadzab Airport","Nadzab","Papua New Guinea","LAE","AYNZ",-6.569803,146.725977,239,10,"U","Pacific/
   Port_Moresby","airport","OurAirports"
5  5,"Port Moresby Jacksons International Airport","Port Moresby","Papua New
   Guinea","POM","AYPY",-9.443380355834961,147.22000122070312,146,10,"U","Pacific/Port_Moresby","airport","OurAirports"
6  6,"Wewak International Airport","Wewak","Papua New Guinea","WWK","AYWK",-3.58383011818,143.669006348,19,10,"U","Pacific/
   Port_Moresby","airport","OurAirports"
7  7,"Narsarsuaq Airport","Narssarssuaq","Greenland","UAK","BGBW",61.1604995728,-45.4259986877,112,-3,"E","America/
   Godthab","airport","OurAirports"
8  8,"Godthaab / Nuuk Airport","Godthaab","Greenland","GOH","BGGH",64.19090271,-51.6781005859,283,-3,"E","America/
   Godthab","airport","OurAirports"
9  9,"Kangerlussuaq Airport","Sondrestrom","Greenland","SFJ","BGSF",67.0122218992,-50.7116031647,165,-3,"E","America/
   Godthab","airport","OurAirports"
10 10,"Thule Air Base","Thule","Greenland","THU","BGTL",76.5311965942,-68.7032012939,251,-4,"E","America/
   Thule","airport","OurAirports"
11 11,"Akureyri Airport","Akureyri","Iceland","AEY","BIAR",65.66000366210938,-18.07270050048828,6,0,"N","Atlantic/
   Reykjavik","airport","OurAirports"
12 12,"Egilsstaðir Airport","Egilsstadir","Iceland","EGS","BIEG",65.2833023071289,-14.401399612426758,76,0,"N","Atlantic/
   Reykjavik","airport","OurAirports"
13 13,"Hornafjörður Airport","Hofn","Iceland","HFN","BIHN",64.295601,-15.2272,24,0,"N","Atlantic/
   Reykjavik","airport","OurAirports"
14 14,"Húsavík Airport","Husavik","Iceland","HZK","BIHU",65.952301,-17.426001,48,0,"N","Atlantic/
   Reykjavik","airport","OurAirports"
15 15,"Ísafjörður Airport","Isafjordur","Iceland","IFJ","BIIS",66.05809783935547,-23.135299682617188,8,0,"N","Atlantic/
   Reykjavik","airport","OurAirports"
16 16,"Keflavik International Airport","Keflavik","Iceland","KEF","BIKF",63.985000610352,-22.605600357056,171,0,"N","Atlantic/
```


Figure 3-2 Data of airports

3.2. User requirements

Here is an example of user-centred design (Figure 3-3).

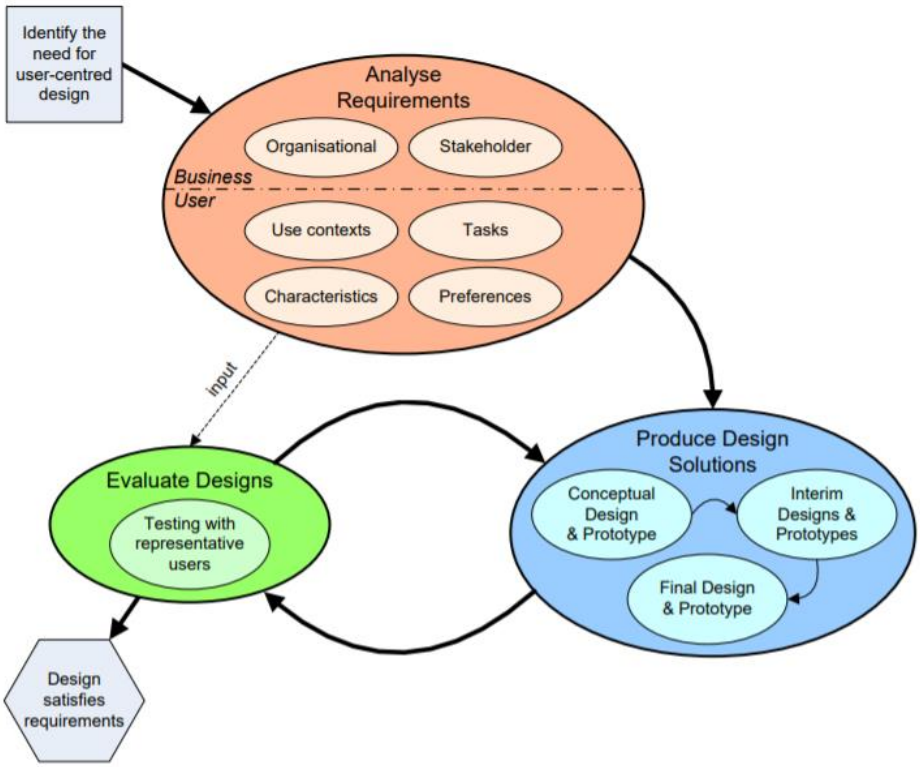

Figure 3-3 User-centred design

From this figure, the first step was to analyse user requirements.

As mentioned above, users were temporal analysts who help solve the spatio-temporal problem in different field. In this research, according to the data source, the stakeholders were the airport managers who had some problems related to the flow of flights, so these problems were related to spatio-temporal patterns. Hence, the purpose of users was to know the answer to those problems and spatio-temporal patterns, so that they needed information about the flow of flights, and this information should depict on the timeline.

3.3. Formulating temporal questions

After knowing the user requirements, the next step was formulating user-centred questions.

Jacques Bertin (1967) distinguished questions into three levels: elementary, intermediate and overall. While Andrienko and Andrienko (2006) amended this theory and systematically analysed the composition of the question, they divided into two levels: elementary and synoptic. The theory of Andrienko and Andrienko (2006) could be referred to this research.

Maceachren (2004) grouped temporal questions into seven categories based on the types of them, these categories include: existence of an object (if), its location in time (when), its duration (how long?), its temporal texture (how often?), its rate of change (how fast?), the sequence of entities (in what order?), and synchronisation (do entities occur together?), which is useful for this research. According to these categories, they can be further separated into analytical levels, which provided question type for each analytical level (Andrienko & Andrienko, 2006). Hence, if and when are in the elementary analytical level, how often, order and synchronisation are grouped in the synoptic analytical level. For question categories "how long" and "how fast", they are not mentioned in this research. For the reasons that in the flight data, there is no related information about the total time of flight.

Also, from Wang and Kraak (2013), there is a new category worth added named "trend", which should be grouped in synoptic level.

However, how to formulate these types of questions? From Li and Kraak (2008), Wang and Kraak (2013), these questions are related to time, location and attribute. In this research, temporal attribute focused on time points, time interval and time relations. Attribute type related to flight-related attribute, for example, airline. Spatial attribute focused on airport location.

Based on these, it is necessary to make a criterion to formulate questions. Wang and Kraak (2013) used to control the variable method to categorise, which was mentioned in section 2.4. This work was helpful for this research in dealing with each aspect in formulating questions. Hence, in the "focus" and "target" of each question types, using this method could list the categories of variables in these two fields. For example, a question like "Did a KLM flight depart at 12.00 a.m.?" because the time point of the answer is 12.00 a.m., so the "focus" is "at 12.00 a.m.". The "target" is "KLM flight", for the reason that it can be viewed as a filter to select the flights.

Therefore, the temporal questions were formulated based on the combination of the previously related taxonomies. But the taxonomy was extended. It included the question of direction called "in" and "out".

Figure 3-4 shows a sketch of "in" and "out" question. In this research if we put the timeline in the center, from this perspective we have questions starting from the timeline with the answer "outside" the timeline (out). The answer might relate to the map or diagram. Band the reverse, we have questions that can find an answer on the timeline (in).

For example, question "Did a KLM flight departed to PEK at 12.00 a.m.?" was under "in" question direction, while question "Where were the destinations of the flights which depicted on the timeline?" was under "out" question direction.

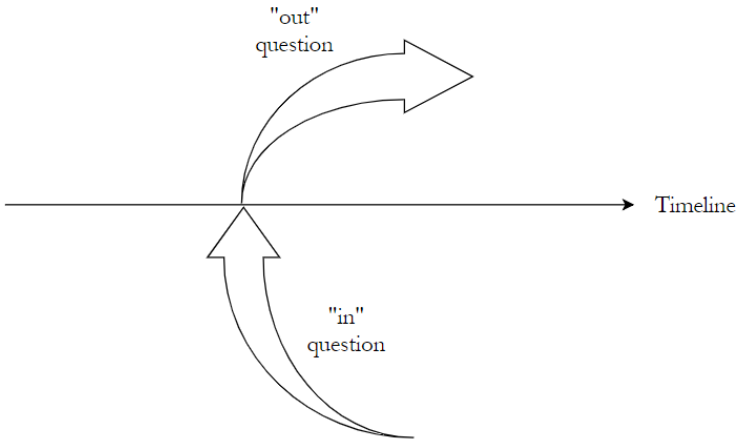

Figure 3-4 Sketch of "in" question and "out" question

In conclusion, the task taxonomy in this research is shown in Figure 3-5. It could be first divided into question directions "in" and "out". Under each question direction, it was further divided into two analytical levels, elementary and synoptic. According to the specific question types, they were categorised in detail. Under the elementary level of "in", there were "if "and "when". Under synoptic level of "in", there were "how often", "order", "synchronization" and "trend". Under elementary level of "out", there were "which", "what", "when" and "where". Under synoptic level of "out", there were "what" and "where".

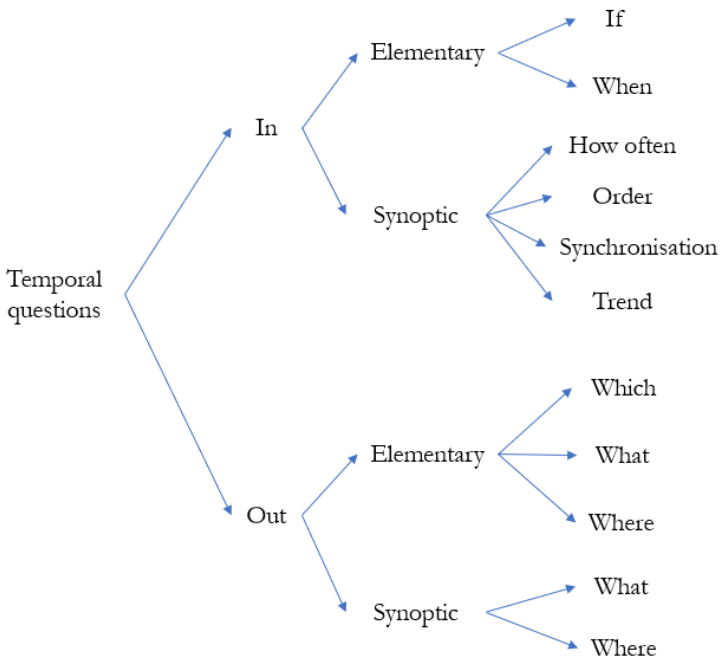

Figure 3-5 Task taxonomy in this research

3.4. Providing answers to temporal questions

This section introduces the process of providing answers to those questions listed in the previous step. The design of these answers was based on the six visual variables from Bertin (1967). Figure 3-6 discussed the perceptual properties of visual expression combining with six visual variables and three symbols, as well as their utilization on depicting qualitative and quantitative data. The design of these answers was referred to this work.

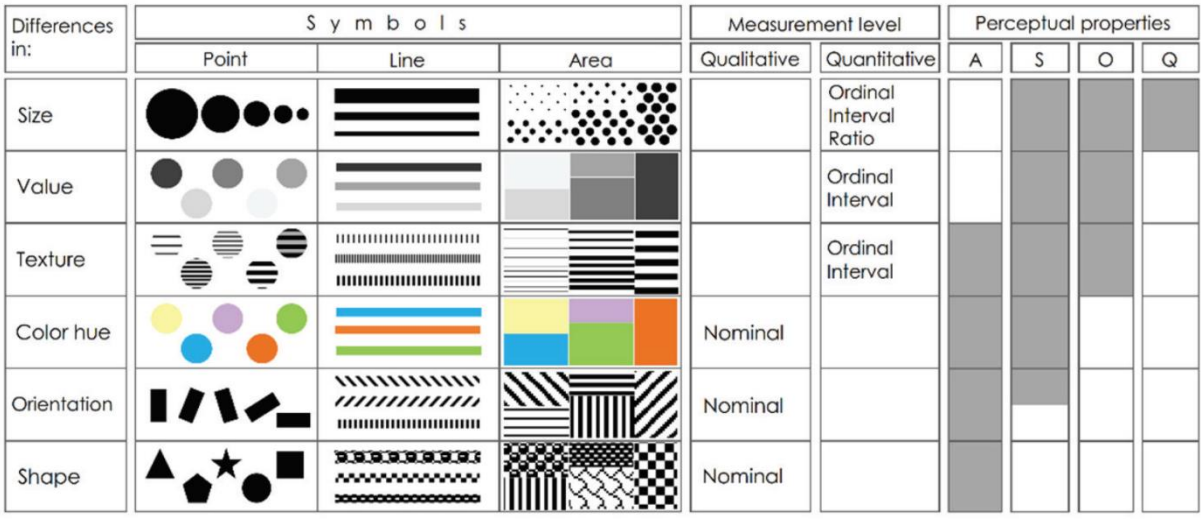

Figure 3-6 Visual variables and their perceptual properties linked to the measurement levels of the data. Perceptual properties: A - associative, S - selective, O - ordered, and Q – quantitative (Source: Bertin (1967))

This part describes in the order of question types in Figure 3-5.

1. Answers of question types under "in" direction describe below.

Firstly, the answer of "if" question type is yes or no, so the answer focuses on whether there is a flight on timeline. For example, Figure 3-7 uses a blue circle to depict flight on timeline, and it can answer question like: If there was a flight between 11 and 12 a.m. on Jan 20, 2019.

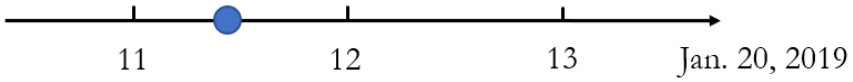

Figure 3-7 Sketch to answer "if" question type

Secondly, the answer of "when" is related to time, so it is important to depict time on the timeline.

Thirdly, when analysing "how often" question type solution, the answer is the number. Therefore, the flights should be depicted with a number on the timeline. Figure 3-8 is a sketch to answer this kind of question. Users can check the number of flights within time interval. If the number of flights improves, Figure 3-9 may be a better visualise method. It combines flights into a rectangle and embeds a counted number to represent the number of flights within time interval.

Figure 3-8 Sketch to answer "how often" question type

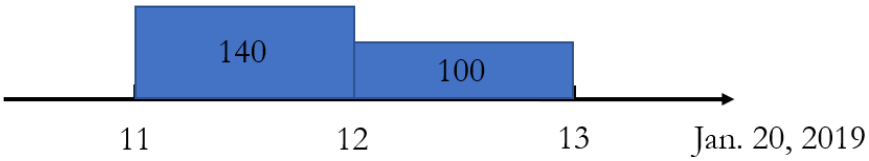

Figure 3-9 Sketch to answer "how often" question type if the number of flights improves

Fourthly, the answer of "order" question type should be a series, so a series of flights should depict on the timeline. Figure 3-10 is an example of answering this question type. This sketch uses different shapes to distinguish flights.

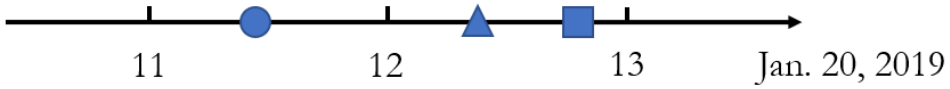

Figure 3-10 Sketch to answer "order" question type

Fifthly, when analysing "synchronisation" question type, the answer should contain the names of the flights. Figure 3-11 uses different shapes to distinguish flights. Each flight depicts on one timeline, users can get answers by checking flights with same locations on timeline.

Figure 3-11 Sketch to answer "synchronisation" question type

Lastly, the answer to "trend" should contain a general description on the timeline. Figure 3-12 provides a sketch to answer this kind of question. There is a line showing the trend of flight flows within five days.

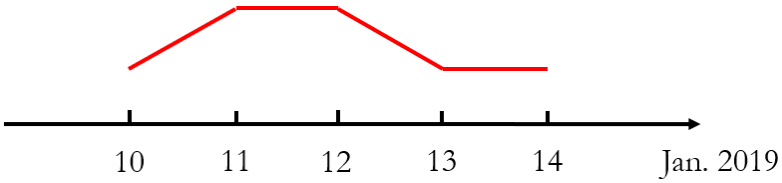

Figure 3-12 Sketch to answer "trend" question type

2. Answers of question types under "out" direction describe below.

First is to discuss "which" question type. Under the "elementary" analytical level, the answer is the name of the flight, so the format of this question type is best to show as a list.

Then it turns to "what". Under the "elementary" analytical level, the answer is detailed information of the selected flights, so the answer is better to show in a list. Under the "synoptic" level, the object is a series of flights, so the answer of these flights may be shown by a diagram with the statistics by some attributes.

Finally, the analytical under "where" question type. Under the "elementary" analytical level, the answers are the destinations of the flights, so it better to show in a map. Under the "synoptic" analytical level, the answer is shown as a statistic of the destinations, which can be depicted in a diagram.

3.5. Conceptual design of the visualisation tool

After describing how to answer temporal questions, the next process was combining these answers into a visualisation tool for users to use. The purpose of this step is to prove that these sketches could answer the questions and could be put into practice. This section described the step of designing the visualisation tool. This process involved three steps, including the main functions the visualisation tool should contained, designing the interface of the visualisation tool, and achieving these functions in a web environment.

The first step was considering functions that the visualisation tool should have. First of all, users could interact with visualisation tool, including depicting extracted data based on users' selection. However, how to achieve this function? It could start by analysing the task taxonomy (Figure 3-5). If users started from choosing question direction "in" and "out", it was hard for users to understand because they were not familiar with the theory.

Task taxonomy was specially designed for distinguishing the relationships among the temporal, spatial and attribute. However, it could be better for users to directly choose among temporal, spatial and attribute. From section 3.4, temporal information could show on the timeline; spatial information could show on the map and attribute information could show on the list or diagram. Besides, it is easier for users to select the question type rather than considering the "question direction". Therefore, this visualisation tool should consider how to distinguish "in" and "out" questions.

For questions under "in" direction, a question list could provided for users to choose. For example, Figure 3-13 was an example list. Besides, map or some lists should also provide to other attributes to help users to formulate a question. Figure 3-14 was an example of this process. Timeline would show on after users selected values in attribute lists and destinations in map. Using a question as an example. An "if" question: "Did a KLM flight departed to PEK at 12.00 a.m.?", users should select question type "if" in Figure 3-13, and select airline value "KLM" in one of the attribute lists, then select location of PEK on map. After that, the timeline would depict the extracted data.

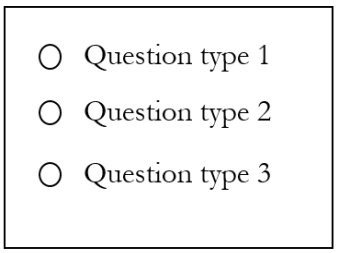

Figure 3-13 List of question types

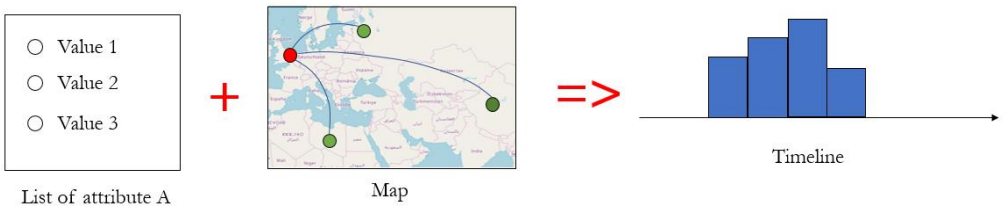

Figure 3-14 Example of user selection about "in" question direction

For questions under "out" direction, some functions could be designed in the timeline. Here, an initialised timeline was needed. For example, user could select a time interval on the initialised timeline, then the map would show on the corresponding spatial information as answer for "where" question type, and the list and diagram would show on detailed information and depict statistics of the data based on the selected time interval as answer for "which" and "what" respectively. For example, an "which" question: "What were the statistics of destinations between 10.00 a.m. 12.00 a.m.". Users selected a time interval from 10.00 a.m. to 12.00 a.m. at first, then the map would depict locations on map, as well as a statistic chart in terms of destinations would depict in the diagram part. Users could check the detailed information in the list part when they hovered on the element in these parts.

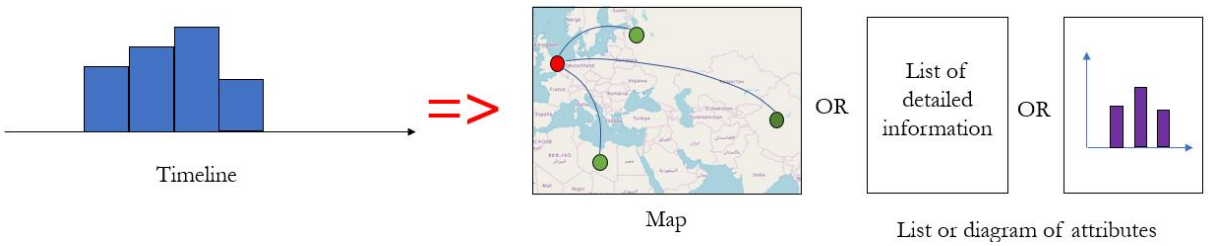

Figure 3-15 Example of user selection about "out" question direction

Secondly, this tool should able to extract and visualise the data based on the selection of users.

Thirdly, the visualisation tool should react to the changes of temporal granularity on the timeline. This function needs the timeline to be more interactive, and the corresponding changes could display swiftly when users were changing the temporal granularity.

The second step was designing the interface of the visualisation tool. The interface is going to learn from the conceptual framework of Rahman (2017), which follows a principle, *"A visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance"*, quoted from Dobrāja, Kraak and Engelhardt (2018).

Figure 3-16 showed the conceptual design of the interface. It contained five sub-parts.

There was a selection part at the top of the interface, which corresponded to the first function in the first step. Besides, the timeline part showed in the middle of the interface. It was messy and impossible to put

all information into the timeline, so timeline just displayed the most important information, for example, the flows of flights every day. Some buttons at the right side of the timeline, which were used to change the temporal granularity. Also, a map part aimed to depict a map which could help to display the spatial attribute, and the list part as well as diagram part depicted the statistics in the interface. They were at the bottom of the interface.

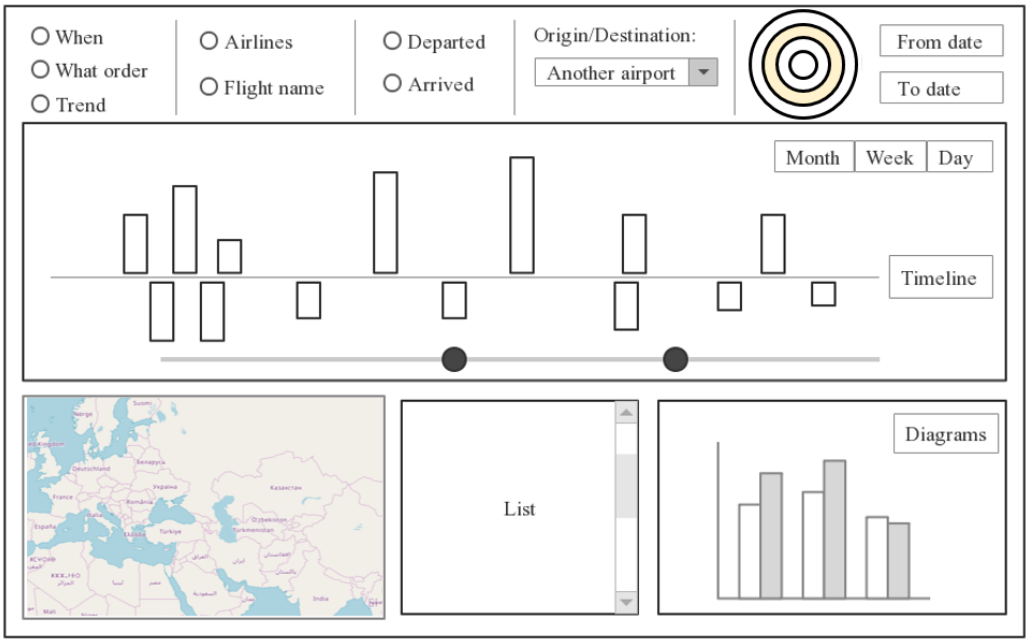

Figure 3-16 The conceptual design of the visualisation tool interface

The third step was achieving these functions online. This research was decided to use a web page. There were three reasons. First of all, the web page has been close to people's work and life, which was easy for users to interact. People interact with web pages every day, for example, a web page can help people in searching on the Internet, translating and shopping online.

Besides, extracting data from the database could be achieved by the script file. After that, this data could depict on a timeline, which could be achieved online. Users selected conditions on the web page, which was called "frontend", then the web page would send these conditions to the script file, which was called "backend". After the "backend" achieving the data extracting, the response could return to the web page for visualisation.

3.6. Implementation

After finishing the conceptual design, the next step was to make the conceptual design come true, which aimed to prove that these conceptual solutions were available. This section demonstrates the introduction, the process of dealing with data, making a web page, including the frontend and backend, the reasons for adopted approaches, the problems encountered and solutions.

3.6.1. Introduction

Before implementation, there were two points needed to be clarified. The first one was the flowchart of the whole process from users' selection to visualisation. The second one was the implementation of conceptual design had limited.

1. The flowchart of the whole process

Figure 3-17 described the whole process from a user selection to visualisation. Firstly, users selected the attribute values on the web page. Next, the web page would send the selections to the backend files. Then the backend files extracted eligible data from the whole data to return to the web page. Lastly, these data would be depicted on the timeline for users to interact. The web page was also called frontend; the backend contained those files of processing data.

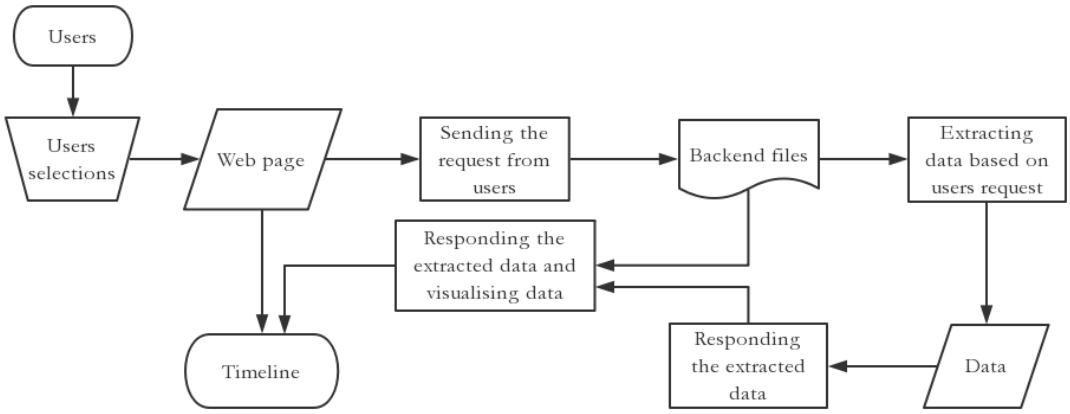

Figure 3-17 Whole process from a user selection to visualisation

2. Implementation of conceptual design had limited

Because of the time limitation, the implementation removed some functions. First of all, the implementation focused on one question type "when". For the reasons that this question type was under "elementary" analytical level, which was a basic question type, but the functions of achieving this question type were similar to others, so that it could satisfy the requirement of implementation. Besides, this implementation considered choosing one value and all values in each attribute type. In principle, users could select one, several and all values in each attribute type.

Secondly, the list part and diagram part in the conceptual design were skipped in the implementation. In terms of the programming, plotting diagram was similar to the timeline, both of which were bar chart. With the limitation of time, there was no need to implement this part. The function of list part was to "print" extracted information, so it was not valuable to achieve this function in a limited time.

However, the implementation also made an improvement based on the conceptual design. In the implementation, the method of changing the temporal granularity of the timeline changed from zoom function into buttons. These buttons were at the right top of the timeline part; each button represented for one granularity. If users clicked on one button, the timeline would change to that granularity.

3.6.2. Data processing

First of all, it should start to understand the data source. Schiphol airport provided API and Uniform Resource Locator (URL) for requesting data. People can request data via the parameters of the URL. The format of data showed in pages. In the header of the response, there was a parameter telling the last number of pages, which was used to request all the data in the programming.

Secondly, it was necessary to request the data. The reason was that this step could save time of extracting data using users' selection. Because the format of data was in pages, and the data of one day was about 500 pages, it would spend users more time on requesting data based on their selections from Schiphol airport database. Therefore, this research downloaded data in advance so that the web page could directly dealing with data extraction. Besides, this research downloaded data in two-week period from Schiphol airport to

do the implementation, which were from 01 Jan. 2019 to 14 Jan. 2019. In addition, requesting the data from Schiphol airport could be achieved in a function in Python language.

The third stage was extracting the data for initialised timeline. Extracting the scheduled date and flight direction of each data and store them to another file, then use this file to draw the initial timeline, which would show when the web page loaded. The data was in a large volume, which would cost a lot of time if the code directly links to it. So, it was time-saving to extract the needed element and used it to depict the timeline.

3.6.3. Selection part

Figure 3-18 shows the interface of the prototype. The first part was the selection part, the first row at the top of the prototype. There were six subparts divided by thin lines arranged in a row. From left to right, they were questioning type part, attribute type part, flight direction part, destination part, time interval part as well as submission and reset part. The sequence of these sub-parts was based on the question structure. For example, if users had a question: "What time did the KLM flights depart with the destination of PEK between 13.00 and 20.00 on 14 Jan. 2019?", they would like to select the values based on the sequences of the different elements in one question.

The detailed descriptions of these sub-parts are in section 4.3.2.

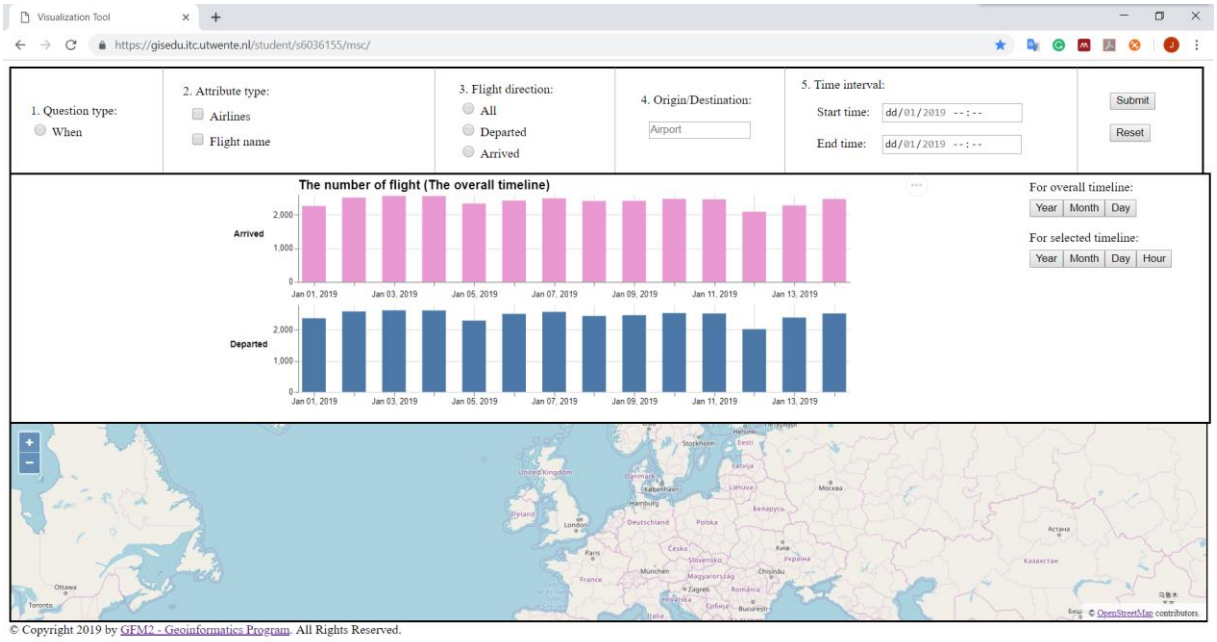

Figure 3-18 Interface of the prototype

3.6.4. Timeline part

The second part was the timeline part. This part should achieve three functions. First of all, this part should depict an initial timeline when users loading the web page. The initial timeline depicted flow of flights in two-week period. The purpose of this timeline was to give users a brief overview of the trend. Secondly, this part should depict the timeline for extracted data from users' selections. Thirdly, the timeline should be able to adapt the temporal granularity. This function could be achieved by adding some buttons. Each button represented for one temporal granularity, for example, day, month and year. When users clicked on one button, the temporal granularity of the timeline could be transformed into the selection.

3.6.5. Map part

This part was used to depict the location of airports. The map should be triggered when users input an airport in the destination sub-part of the selection part. Besides, when users deleted or changed the value, the map should respond to these changes.

3.6.6. Footer part

The last part was the footer part. It was located at the bottom of the web page, which clarified the copyright information. There is a link in the footer when users hover the mouse over it; it will turn to the page: https://www.itc.nl/education/studyfinder/geo-information-science-earth-observation/specialization/geoinformatics/

3.7. Evaluation

After finishing the prototype of the conceptual design, this section discusses the evaluation. The purpose of this step was to test the usability of the web page. Focus group and post-experience interview were adopted to analyse the users' feedback qualitatively. The questionnaire was adopted to measure the users' satisfaction (Appendix 2). It was issued to the participants during the focus group and the post-experience interviews with experts.

The purpose was to know the effectiveness, efficiency and satisfaction of the web page (www.iso.org, 1998). Effectiveness and efficiency were to test the accuracy and completeness of the web page, while satisfaction was to test the overall design of the web page. Five-point Likert Scale was used in this research because it was efficient enough to reflect users' thoughts (Likert, 1932). The response category shows below (Table 3-1).

Table 3-1 Likert Scale category

Likert Scale	1	2	3	4	5
Category	Very poor	Poor	Neutral	Good	Very good

1. Participant

There were six participants joined in the evaluation. All of them are working/studying at Faculty for Geo-Information Science and Earth Observation, University of Twente. Four students formulated the focus group, and they all had bachelor background in geographic information system. The post-interview additionally invited a PhD student and a Geoscientist.

2. Focus group

Focus group could provide a synergy of the group interaction thus offer abundant information on ideas and feelings the participants have towards one specific issue (Rabiee, 2004). Therefore, it could help to improve the web page. For simple research, it may necessarily contain three or four participants (Burrows & Kendall, 1997). One focus group with four participants was organised. The focus group was audio-recorded to memorise for detailed analysis (Kveladze et al., 2015).

The process was in two steps. The first step was reading the information sheet and answering questions. The purpose of this step was to let participants getting familiar with the web page. The second step was to do the post-experience interview. The purpose of this step was to allow participants to think aloud and discuss sensitive issues.

This evaluation was held in Globe of ITC Hotel on 16 January 2019. Focus group, observation, task analysis, questionnaire and interviews were used to evaluate the web page. The combination of these

methods could judge the effectiveness of the accuracy and completeness of the web page, as well as the satisfaction of the web page.

This research assumed users were the temporal analysts who had temporal questions and needs to explore spatio-temporal patterns. Hence, this evaluation selected people who had experience in operating the web page and could finish the test. To minimise the bias, the procedure to all participants had to be similar. Therefore, an information sheet was prepared (Appendix 2). It contained a description of the background information was given to the participants before the evaluation.

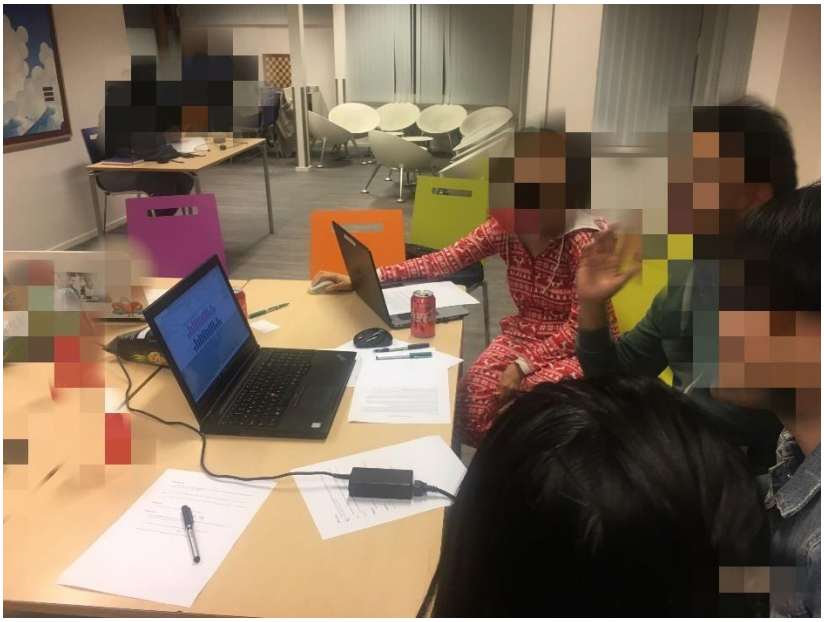

Figure 3-19 Focus group

3. Post-experience interview

Post-experience Interview with professionals could gain in-depth information (Rabiee, 2004). The post-experience interview was mainly held for PhD student and a Geoscientist separately. The purpose was to acquire the feedback in terms of the design and function of the web page. These questions were asked during the interview.

- How is your impression of the interface design?
- How to evaluate the web page functions?
- How to evaluate the visualisation? Which part is difficult to understand?
- What is your suggestion for the web page?

4. RESULTS

This chapter contains four sections, which are corresponding to the sub-objectives in section 1.2. Section 4.1 discussed the result of the sub-objective 1 and part of the result of sub-objective 2 to clearly clarify the result.

4.1. Formulating spatio-temporal questions and providing the answer of questions on the timeline

The result of this step is shown as a table in Appendix 1, which is described here. Each part of Appendix 1 contained sub-tables to clarify the questions, as well as figures to describe the answer in each question types.

In these sub-tables, the related attributes were painted in different colours and used the abbreviations in the table to make the description. The temporal attribute was represented by "T" and shows in green, spatial attributes were represented by "L" showed in blue, and attribute type was represented by "A" showed in orange. The object was represented by "O" and showed in yellow. These tables showed these attribute types in single attribute value to simplify the question structure except Table 4-3, which were substituted by several values in the question.

In these figures, flights could be either departed from or arrived at Schiphol airport, so it was better to depict them separately. Therefore, when designing the timeline, the part above the timeline was used to depict flights departed from Schiphol airport and the part below the timeline was used to depict flights arrived at Schiphol airport.

Besides, questions under the "in" direction level meant that these questions could be answered by the timeline while questions under "out" direction level meant that these questions should be answered by using other auxiliary tools (for example map, diagram, list).

One the one hand, the questions under the "in" direction level show in below.

Firstly, the questions under "elementary" analytical level show in below.

There were two question types in the "elementary" analytical level: "if" and "when", which shows in below.

a. "If":

i. Questions

Error! Reference source not found. describes the question structure and types under the "if" question type. The second and third column were "focus" and "target" respectively. The "target" could be viewed as an unknown part of the question, which was needed to find an answer for this part. The "focus" was the known condition in the question; answers should be found based on that.

This question type belonged to "in" direction, so the "focus" in this question type was corresponding to the temporal attributes, which showed as a green "T". The "target" was the other aspects. Because either spatial or temporal attributes belonged to the objects, so the unknown spatial attribute could also view it as unknown objects with exact spatial attributes.

The fourth column named "general description", which aimed to further explain the relationship between the "focus" and "target" into a general question sentence.

The fifth column listed questions formulated based on this research. The formulation of these questions was processed according to the question type and the attributes which could be found in the flight data.

Table 4-1 Questions under "if" question types level

Question type	Focus	Target	General description	Example question
If	T	O	Is there an Object departed/arrived at Time?	Is there a flight departed at 12.00 a.m. today?
	T	A (A, O; The number of attribute value can be one or several)	Is there an Object which Attribute was * departed/arrived at Time?	Did a KLM flight departed at 12.00 a.m. today?
	T	L (L, O)	Is there an Object which departed from/arrived at Location at Time?	Did a flight depart with destination of PEK at 12.00 a.m. today?
	T	A, L	Is there an Object which departed from/arrived at Location and Attribute was * at Time?	Did a KLM flight departed to PEK at 12.00 a.m.?

ii. Answer

The answer to this question type was yes or no, so it was important for the users to check whether there was flight(s) within a given time interval or not. Figure 4-1 shows the answer to "if" question type. The temporal granularity was hour. There was a bar which illustrated the extracted flights on the timeline, and the answer used the "colour" visual variable to distinguish flights. These colours could represent the airline of the flight. The height of the bar represented the number of flights.

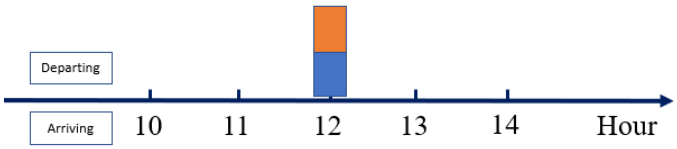

Figure 4-1 Solution of "if" question type

b. "When"

i. Questions

Table 4-2 describes the question structure and contents under the "when" question type. The principle of formulating this table was similar to **Error! Reference source not found.**.

Table 4-2 Questions under "when" question type level

Question type	Focus	Target	General description	Example question
When	T	O	When was the Object departed/arrived within Time?	When was the flight departed between 10.00 a.m. and 12.00 a.m.?
	T	A (A, O; The number of attribute value can be one or several)	When was the Object which Attribute was * departed/arrived within Time?	When were the KLM flights departed between 10.00 a.m. and 12.00 a.m.?

	T	L (L, O)	When was the Object which the destination was * departed/arrived within Time?	When were the flights which the destination was PEK airport departed between 10.00 a.m. and 12.00 a.m.?
	T	A, L	When were the Object which Attribute was * and the destination was * departed/arrived within Time?	When were the KLM flights departed which the destination was PEK airport between 10.00 a.m. and 12.00 a.m.?

ii. Answers

Figure 4-2, Figure 4-3 and Figure 4-4 depict as answers under "when" question type. Answers to this type of question considered the influence of the number of flights, so it was necessary to decide different depicting method according to the different number of flights and temporal granularities.

For example, if flights could be directly depicted on the timeline without causing visual clutter, then they could be viewed as points on timelines like in Figure 4-2. However, if the number of flights increased, the timeline would become cluttered, and this method might not be able to give users an intuitive expression. For example, Figure 4-5 depicts the drawback of the first answer because of the large number of flights.

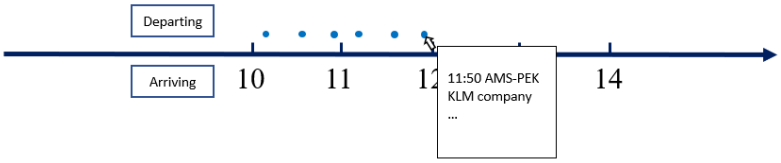

Figure 4-2 answer of "when" question type in less flight number

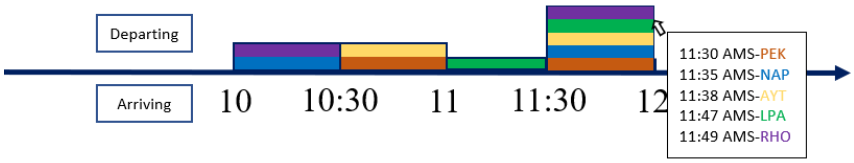

Figure 4-3 Answer of "when" question type in the large flight number

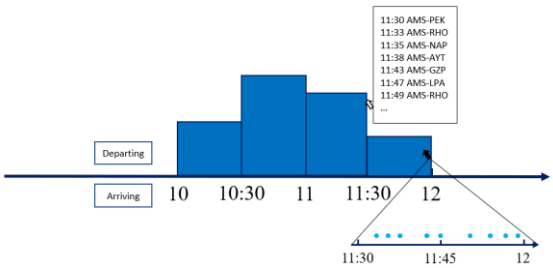

Figure 4-4 Answer of "when" question type in the larger flight number

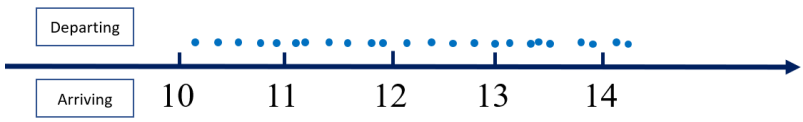

Figure 4-5 Drawback of the first answer when extracted a large number of flights

To solve this drawback, one of the answers was to grouped these flights based on temporal granularity. Figure 4-3 merged the number of flights in every 15 minutes (or another time interval, depending on the need of the user). Each flight was depicted on the timeline by using different colours.

However, the colour shade could also depict a group of flights during this interval. For example, in Figure 4-6, all the flights which belonged to KLM airline could be grouped and depicted as a blue bar on the timeline. However, the light blue and dark blue blocks depicted flights departed in the morning and afternoon respectively.

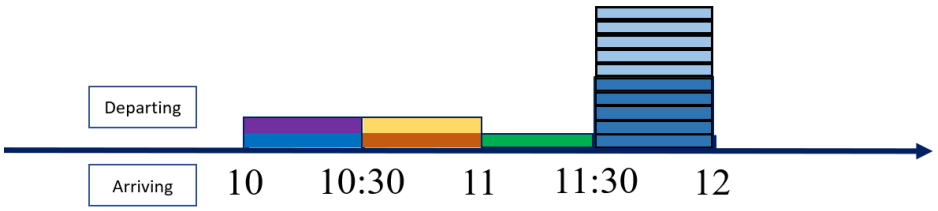

Figure 4-6 Using colour hue and shade to depict flights

If the total number of flights become even larger than these in the previous two scenarios, then the answer in Figure 4-4 was used. In the timeline, flights were merged, and the bar described the total number of flights which departed in the time interval. If the user hovered on the timeline, this would show the departed time and airline of each flight. If the user clicked one bar, then a smaller timeline would show information in detail in this time interval. So that this answer could either keep the overall trend of the flow of flights or show details.

Secondly, the questions under the "synoptic" analytical level show in below.

There are four question types in the "synoptic" analytical level: "how often", "order", "synchronisation" and "trend", which show in below.

a. "How often"

i. Questions

The formulation principle was similar to **Error! Reference source not found.** (Appendix 1).

ii. Answers

Figure 4-7 shows the answer to "how often" question type. The answer to this type of question was number, so number was the most important element to show on the timeline. There was a bar which merged flights based on the time interval in the question on the timeline. If the temporal granularity in the question was "day", the time unit of the timeline would group the flights every day. Besides, a number, which was the answer to the question, was written on the bar for intuitive representation.

There was a detailed timeline show the flights in finer time unit on timeline if users clicked on the bar. In Figure 4-7, there were two timelines, the main timeline, temporal granularity was the day, and the finer timeline, whose temporal granularity was an hour. There was a slider at the bottom of the finer timeline for users to slide and explore. With these two timelines, users could either see the answer to this type of question directly or check the detailed information they need. The adjustment of the temporal granularity on the main timeline relied on the zooming in and out function or external button. The temporal granularity on the finer timeline was always used the next level of the main timeline. For example, if the main timeline adopted the granularity of day, the finer timeline adopted the granularity of hour.

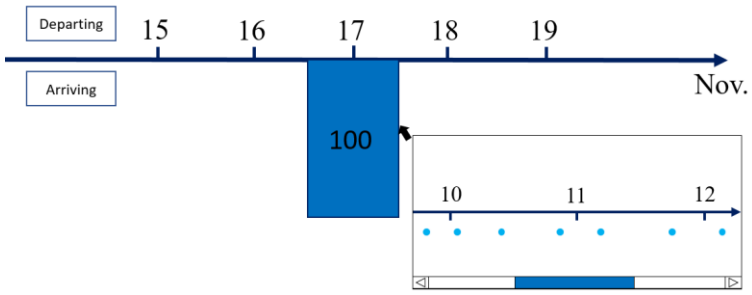

Figure 4-7 Answer of "how often" question type

b. "Order"

i. Questions

When considering the question structure in the "order" question type in Table 4-3, there was a difference compared with other question types. The "order" aimed to make the comparison, which could be done either among flights with the same attributes or with the different attributes. Because of the different structure of question types, it was necessary to list all the combinations of these attributes and each of which with one and several attribute values. For example, the second, third, fifth and seventh rows of Table 4-3 showed these attribute types all with a single value; the fourth and sixth rows showed the single attribute types with multiple values. The eighth and ninth rows showed the two attribute types and one of them with a single value and another with multiple values. The last row of the table showed the two attribute types, and both of them had multiple attribute values.

Table 4-3 Questions under "order" question type level

Question type	Focus	Target	General description	Example question
Order	T	O	What order did Objects depart/arrived within Time?	What order did flights depart between 10.00 a.m. and 11.00 a.m.?
	T	A (A, O; The number of attribute value can be one or several)	What order did Objects which Attribute was * departed/arrived within Time?	What order did the KLM flights which departed from Schiphol airport 15 minutes ago?
	T	As (As, Os; means that there were several attribute values to select the flights)	What order did Objects which Attribute was * and the flight which Attribute was ** departed/arrived within Time?	What order did the KLM and TRA flights depart between 11.00 a.m. and 12.00 a.m.?
	T	L (L, O)	What order did Objects which the destination was * departed from Schiphol airport within Time?	What order did flights which the destination was PEK airport departed from Schiphol airport between 11.00 a.m. and 12.00 a.m.?
	T	Ls (Ls, Os; means that there were several location values to select the flights)	What order did Objects which the destination was * and the flight which the destination was ** departed from/arrived at Schiphol airport within Time?	What order did the flight which the destinations were PEK airport, AGP airport and BJV airport departed from Schiphol airport 15minutes ago?

	T	A, L	What order did Objects which Attribute was * and Location was * departed from/arrived at Schiphol airport within Time?	What order did the KLM flights which the destination was PEK airport departed from Schiphol airport 15minutes ago?
	T	As, L (means that there were several attribute values and one location value to select flights)	What order did Objects which Attribute were * and ** and Location was * departed from/arrived at Schiphol airport within Time?	What order did the KLM and TRA flights which the destination was PEK airport departed from Schiphol airport 15minutes ago?
	T	A, Ls (means that there were several location values and one attribute value to select flights)	What order did Objects which Attribute was * and Location were * and ** departed from/arrived at Schiphol airport within Time?	What order did the KLM flights which destination were PEK airport and AGP airport departed from Schiphol airport between 10.00 a.m. and 12.00 a.m. today?
	T	As, Ls (means that there were several attribute values and several location values to select flights)	What order did Objects which Attribute were * and ** and Location were * and ** departed from/arrived at Schiphol airport within Time?	What order did the KLM and TRA flights which destination were PEK airport and AGP airport departed from Schiphol airport between 10.00 a.m. and 12.00 a.m. today?

ii. Answer

Figure 4-8 displays the answer of "order" question type. The answer to this type of question was a series of flights in time order. To distinguish these flights, shape was used to depict them on the timeline. And the selection of temporal granularity relied on the question. Users could later adjust the temporal granularity of the timeline by zooming in and out function or external button.

Figure 4-8 Answer of "order" question type

c. "Synchronization"

i. Questions

The formulation principle was mostly similar to **Error! Reference source not found.** (Appendix 1).

ii. Answer

Figure 4-9 is the answer of "synchronisation" question type. The answer to this type of question was the departed or arrived time, and flight names. Here, lines were used to depict flights departed at the time point, and the colour of lines was used to show different flights. If users hovered on the timeline, detailed information would appear, such as flight names and destinations.

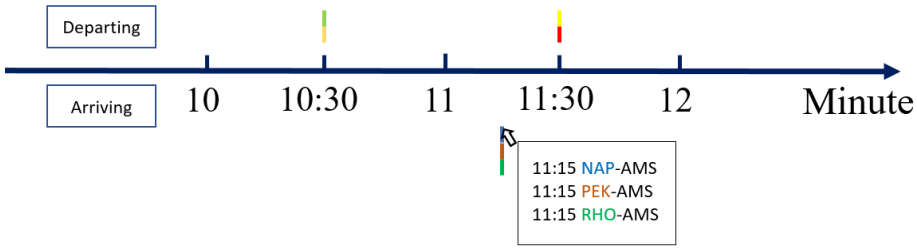

Figure 4-9 Answer of "synchronisation" question type

d. "Trend"

i. Questions

The formulation principle was mostly similar to **Error! Reference source not found.** (Appendix 1).

Table 4-4 Questions under "trend" question type level

Question type	Focus	Target	General description	Example question
Trend	T	O	What was the trend of departed/arrived Object within Time?	What was the trend of the departed flight this week?
	T	A (A, O; The number of attribute value can be one or several)	What was the trend of departed/arrived Object which Attribute was * within Time?	What was the trend of the KLM departed flight in this week?
	T	L (L, O)	What was the trend of Object which Location was * within Time?	What was the trend of departed flights which destination was PEK airport this week?
	T	A, L	What was the trend of Object which Attribute was * and Location was * within Time?	What was the trend of KLM departed flights which destination was PEK airport this week?

ii. Answer

Figure 4-10 shows the solution to "trend" question type. The answer of this type of question was a trend, so in the figure, there was a line depicting the change of every day, and a red line was the average number of flights during this time interval. The temporal granularity could be changed according to the question. Users could hover on the line and check the detailed information, for example, the number of flights.

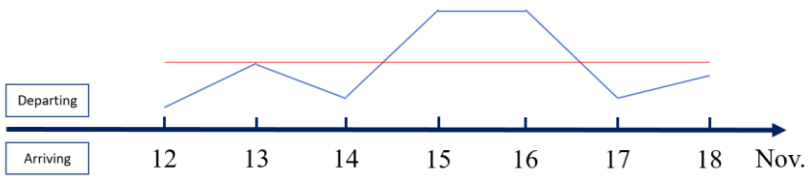

Figure 4-10 Answer of "trend" question type

One the other hand, questions under the "out" direction level show in below.

These questions should be answered by using other auxiliary tools (for example map, diagram, list). From Figure 2-3, question should be formulated to ask about spatial information, attribute information and the object, which corresponding to question type where, what and which.

First of all, questions under "elementary" analytical level show in below.

i. Questions

Table 4-5 describes the question structures and types under the "elementary" analytical level.

Table 4-5 Questions under "elementary" analytical level

Question type	Focus	Target	General description	Example question
Which	O	Flights depicted on the timeline	How many Objects happened within/at Time?	How many flights departed at 12.00 a.m.?
What	A	Flights depicted on the timeline	What was the Attribute value of these Objects within/at Time?	What was the detailed information of these flights which are depicting on the timeline?
Where	L	Flights depicted on the timeline	Where was the Location of these Objects within/at Time?	Where were the destinations of the flights which depicted on the timeline?

ii. Answers

The solutions show in Figure 4-11 and Figure 4-12. In Figure 4-11, it displayed detailed information in a list, which was necessary for answering "which" and "what" question. Hover function was designed to show detailed information depicting on the timeline (such as exact departed/arrived time of every flight, airlines, etc).

For example, when users hovered on a merging bar, detailed information would show in the related part, as shown in Figure 4-11.

Figure 4-11 Answer of "which" and "what" under "elementary" analytical level

When users were curious about the destinations of the flights depicted on the timeline, they used the mouse to hover the flight or the bar on the timeline; then an interactive map would depict the destinations of these flights in the interactive map part in Figure 4-12.

Also, when users hovered on the map, corresponding detailed information would appear.

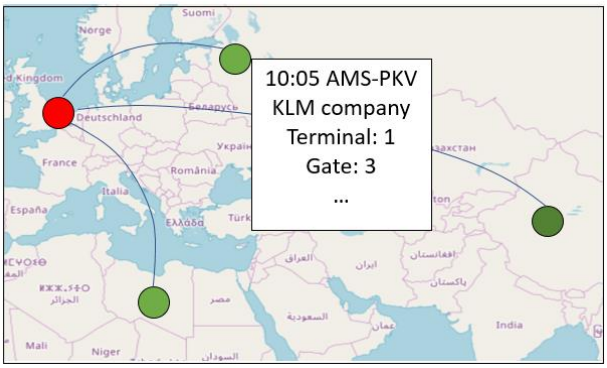

Figure 4-12 Answer of "where" under "elementary" analytical level

Secondly, questions under the "synoptic" analytical level show in below.

i. Questions

Table 4-6 describes the question structures and contents under the "synoptic" analytical level. Because this analytical level focused on grouping data as a subset or a whole to analyse, the results of formulating these questions were prone to statistics. Therefore, flights could be grouped by either attribute types or spatial information.

Table 4-6 Questions under "elementary" analytical level

Question type	Focus	Target	General description	Example question
What	A	Flights depicted on the timeline	What are the statistics of the Attribute on the timeline?	What are the statistics of the airline on the timeline?
Where	L	Flights depicted on the timeline	Where were the statistics of Location of these Objects within/at Time?	Where were the statistics of destinations of the flights which depicted on the timeline?

ii. Answers

Secondly, solutions under the "synoptic" analytical level are shown in Figure 4-13 and Figure 4-14. These bar charts will show in the last part in the later conceptual design. They were interactive. When the user hovered on the bar, detailed information would appear.

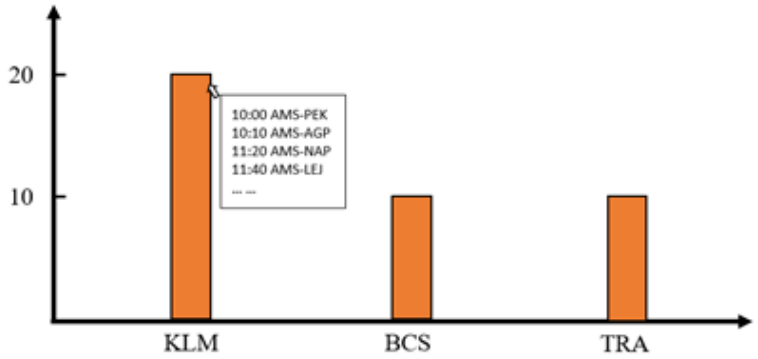

Figure 4-13 Answer of "what" under "synoptic" analytical level

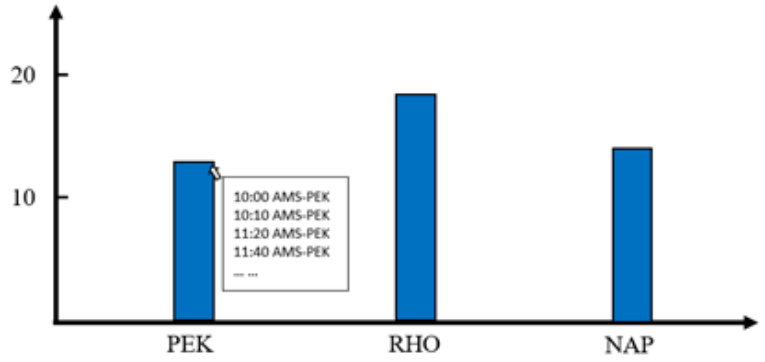

Figure 4-14 Answer of "where" under "synoptic" analytical level

4.2. The conceptual design of the visualisation tool

The designing interface shows below (Figure 4-16). It contained four parts.

The first part was a list of selections at the above of the interface. The sequence of listed attributes was based on the structure of them in the question. For example, a question like When were the KLM flights departed with the destination being PEK airport between 10.00 a.m. and 12.00 a.m. today? In this question, the first element was the question type, so the question type was put at first. Then it was the attributes of the flight, the flight direction, the origin or destination of the flight and the time interval, which were corresponding to the example question. Users could select or type in the needed information in this subpart in the order of their expression habits; then the corresponding timeline would show in the second part.

In addition, there were several circles in the sub-part of choosing a time interval. These circles were designed for changing the temporal granularity. Figure 4-15 is an example of this part. When selecting the "day" circle, the colour of will change, and typing boxes on the right side will shift to the date for users to type in.

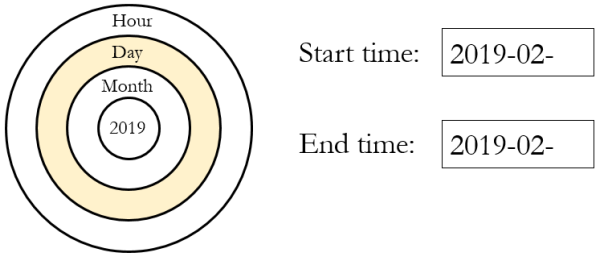

Figure 4-15 Selecting temporal granularity when typing in the date

The second part was an interactive timeline part. It showed the information according to the questions. This part supported users when they used the mouse on the data to check detailed information. It also provided two sliders on the timeline for users to change the start time and end time, which also could be viewed as "boundary" for the detailed information. Besides, this timeline could depict different temporal granularities if users clicked on the button at the right-top of the timeline part.

The third part was an interactive map part. When users selected another airport, which was viewed as the origin or the destination of the flight, the corresponding location of the airport will display on the map. If users hovered over the location or the flow of flight, it would give some useful information about this flight.

The last part aimed to display more detailed information. It was impossible to show all the information on the timeline, so this part was used to show detailed information or statics from the selection of users in the second part. Users could choose what content to display according to the preference (e.g., the delay minutes of the flight and the distance of the flight in an exact time interval).

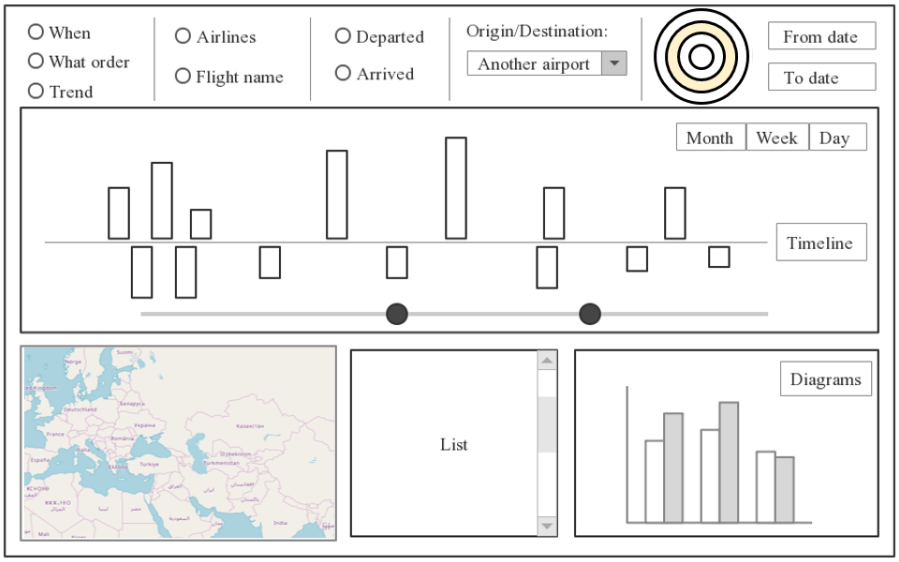

Figure 4-16 The conceptual design of the visualisation tool interface

4.3. Implementing the conceptual design

The implementation was accomplished via four programming languages: python, HyperText Markup Language (HTML), JavaScript (JS) and Cascading Style Sheets (CSS). Python was used to programme in PyCharm software and the file suffix was ".py". HTML, JS and CSS were tested through Google Chrome and edited by Sublime, and the file suffixes were ".html", ".js" and ".css" respectively. Besides, some data files which suffixes were ".txt" were also edited by Sublime.

4.3.1. Data processing

This section contains three parts.

Firstly, "GetData.py" file requested and stored data from the Schiphol airport database. The process shows in Figure 4-17. The inputs were the starting date and ending date. They were transformed from string type into date type so that dates could be comparable. Then, a function was defined to acquire the number of the last page with given dates. After that, there was a function to acquire the data. Firstly, the code separated the period into days. Then the code requested the data to the Schiphol airport and created a new file to store data. The data was written and stored in pages in the new file if the database successfully responded and returned the data. The "time.sleep" function served for two purposes, including acquiring data in the iteration of pages and days, respectively. It was used for holding on a few second randomly to keep smooth access to the database. Figure 4-18 shows the acquired data. The result was a data file "2019-01-01-2019-01-14.txt".

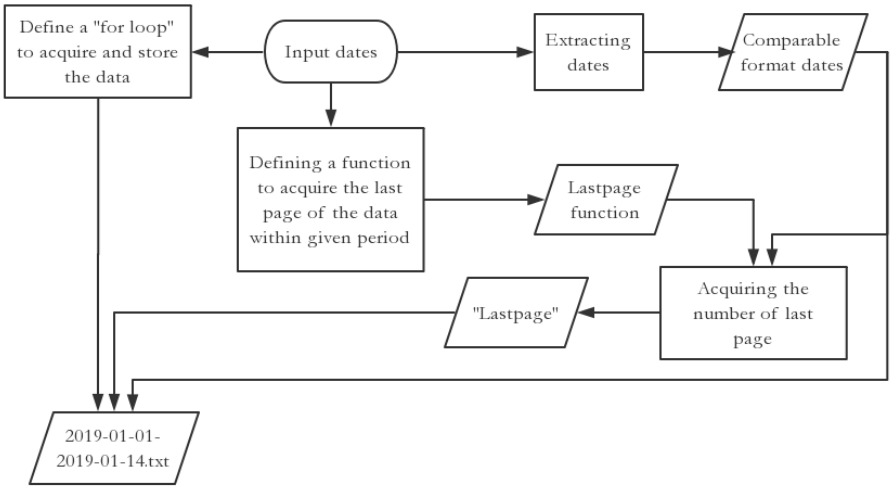

Figure 4-17 The process of request and store data

2019-01-01--2019-01-14.txt


```
1  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "00:05:00", "flightName": "HV5752", "prefixICAO":
   "TRA", "route": {"destinations": ["RAK"]}}
2  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "00:05:00", "flightName": "KL2624", "prefixICAO":
   "KLM", "route": {"destinations": ["RAK"]}}
3  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "00:20:00", "flightName": "KL2690", "prefixICAO":
   "KLM", "route": {"destinations": ["LPA"]}}
4  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "00:20:00", "flightName": "HV5662", "prefixICAO":
   "TRA", "route": {"destinations": ["LPA"]}}
5  {"scheduleDate": "2019-01-01", "flightDirection": "D", "scheduleTime": "00:55:00", "flightName": "PC1256", "prefixICAO":
   "PGT", "route": {"destinations": ["SAW"]}}
6  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "02:15:00", "flightName": "OR554", "prefixICAO":
   "TFL", "route": {"destinations": ["LPA"]}}
7  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "03:54:00", "flightName": "ZXP011", "prefixICAO":
   "ZXP", "route": {"destinations": ["AMS"]}}
8  {"scheduleDate": "2019-01-01", "flightDirection": "D", "scheduleTime": "04:24:00", "flightName": "ZXP011", "prefixICAO":
   "ZXP", "route": {"destinations": ["AMS"]}}
9  {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:30:00", "flightName": "EK9369", "prefixICAO":
   "UAE", "route": {"destinations": ["DWC"]}}
10 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:30:00", "flightName": "KE5925", "prefixICAO":
   "KAL", "route": {"destinations": ["ICN"]}}
11 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:30:00", "flightName": "AF8421", "prefixICAO":
   "AFR", "route": {"destinations": ["ICN"]}}
12 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:30:00", "flightName": "KL0856", "prefixICAO":
   "KLM", "route": {"destinations": ["ICN"]}}
13 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:40:00", "flightName": "KL4302", "prefixICAO":
   "KLM", "route": {"destinations": ["PEK"]}}
14 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:40:00", "flightName": "CZ0345", "prefixICAO":
   "CSN", "route": {"destinations": ["PEK"]}}
15 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "04:40:00", "flightName": "MF9245", "prefixICAO":
   "CXA", "route": {"destinations": ["PEK"]}}
16 {"scheduleDate": "2019-01-01", "flightDirection": "A", "scheduleTime": "05:05:00", "flightName": "MP8372", "prefixICAO":
```


Figure 4-18 Part of the data in "2019-01-01-2019-01-14.txt"

Secondly, "Initial_timeline_data.py" file extracted needed data elements and stored to a new file to plot the initial timeline on the web page.

Lastly, "getCoordinates.py" file extracted the coordinates of an airport based on their abbreviations. When users selected an abbreviation of airport in the destination sub-part of the selection part, the web page would send it to this file, then the file searched in the data file "Airports.txt". After finding the location of the abbreviation, the file will extract the coordinates at the same line and return to the web page.

4.3.2. The result of the selection part

Figure 4-19 is the interface of the web page, the whole page was divided into three parts by thick lines. These thick and thin lines were used to outline different sizes, which allowed users to have a basic understanding of the overall distribution and planning of web pages. From top to bottom were selection part, timeline part and map part.

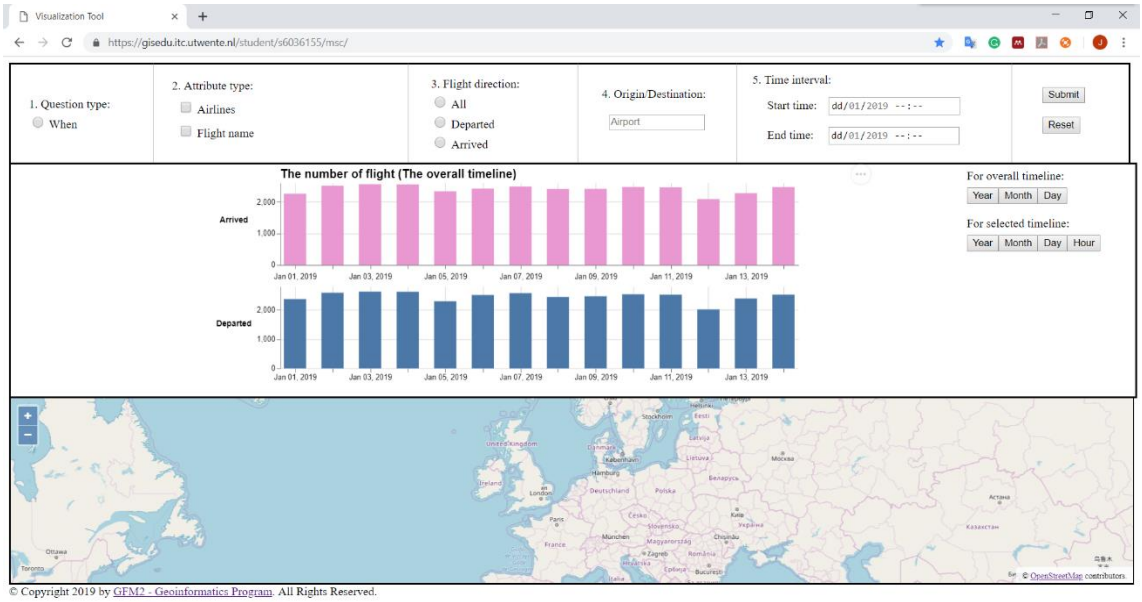

Figure 4-19 Interface of the web page

In the selection part, the first sub-part was used to select question type using "radio button". "Radio button" was one of the input formats in a web page. With the same "name" of these buttons, users could only choose one of them. Besides, a function was provided for users to understand. When users hover the mouse on this question type part, the background colour turned to "Alice Blue", then a sentence "Selecting a question type you have" appears (Figure 4-20). Also, an example question formulated by this question type appeared when users hovered the mouse on each selection button. For example, if users hover the mouse on the first selection button "When", an example question that was "Question like when was the flight departed between 10.00 a.m. and 12.00 a.m.?" would appear (Figure 4-21).

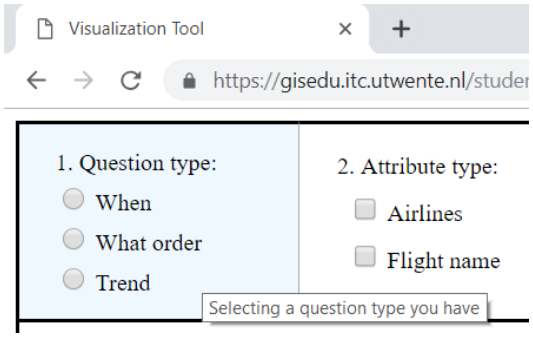

Figure 4-20 Question type sub-part

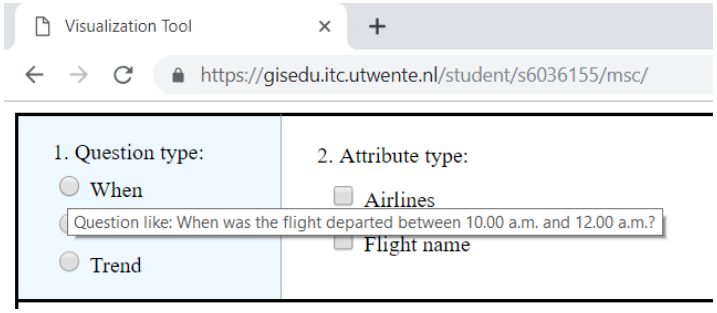

Figure 4-21 Example question of "When"

In the sub-part of attribute type, the achievement of selected attribute type and its value were implemented as follows. Firstly, a hover function was designed to make this subpart more understandable (Figure 4-22). Moreover, there were two attribute types provided as examples for users to choose from. When users hovered the mouse on each attribute type, the corresponding explanation would show on (Figure 4-23). With the help of these explaining sentences, users could easily know the meaning of these subparts and finish the selection.

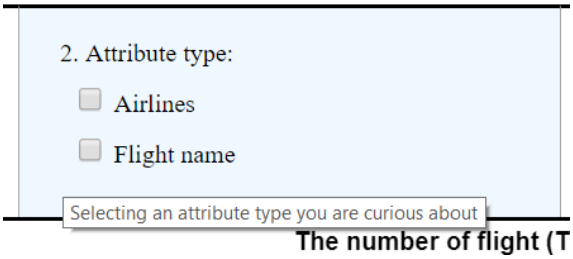

Figure 4-22 Attribute type sub-part

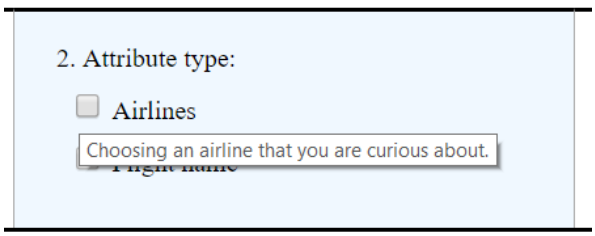

Figure 4-23 Reaction when hovering on "Airlines"

For another, users should choose one or several values in each attribute type for formulating their questions. Because of the time limitation, this web page allowed users to select one and all values here, rather than several values. In this case, the checkbox was taken as a priority. Checkboxes let users select zero or more options of a limited number of choices, which was suitable for this condition. After that,

how to choose the value of the attribute was another visualization problem. Users should either choose or input the value of an attribute. In this way, an input box with a dropdown list was designed for this situation. Users could either directly type in the value or select the value in the dropdown list. Some attribute values were predefined in the list when users click on the input box, and these values were provided to choose. When the input box appeared, "Airlines" was shown in the box until users finished the selection, which aimed to remind users of the attribute type in this box.

Besides, only when users chose this checkbox would the corresponding list of value display. Figure 4-24, as an example, shows the reaction of the web page when selecting the value of the airline. After clicked on the "Airline", an input box showed for users to the input value. A dropdown list which listed the values of airlines appeared if users clicked on the triangle at the right of the input box.

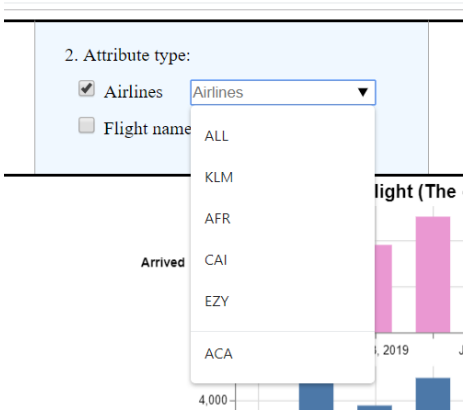

Figure 4-24 Example of selecting the value of airline

In the flight direction sub-part, there were three "radio buttons" designed for users to choose according to the requirement. Similarly, this part also contained some interaction functions to make these selections understandable (Figure 4-25 and Figure 4-26).

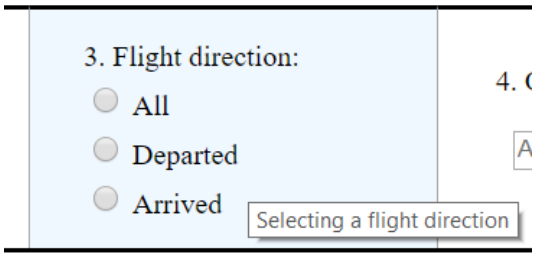

Figure 4-25 Flight direction sub-part

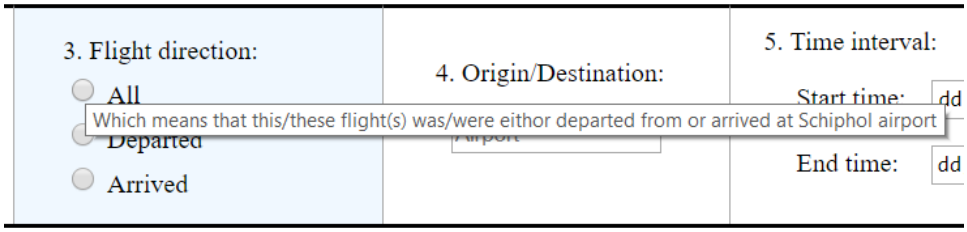

Figure 4-26 Example when hovering on one option

In the destination sub-part, when users hovered with the mouse, the explaining sentence would show, and the background colour would change. Also, an input box with a dropdown list was provided for users to type in or select. Besides, this part also relied on the map to display location information. For example, if users selected "PEK", two red points which corresponding to Schiphol airport and Peking airport, as well

as a line would display on the map to express the location attribute (Figure 4-27). When users changed the value, the corresponding points and line would change.

In this process, when users selected value in the input box, the web page would post the value to the "getCoordinates.py" file and got the response from that file. Then used the predefined function to draw the location of Schiphol airport and the location of the destination, and the line between them. After that, adding these features as new layers to the map. The function of "getCoordinates.py" file was that it got the value from the web page, later search the airport in the "Airports.txt", if the corresponding airport was found, then extracted the coordinates and returned to the web page.

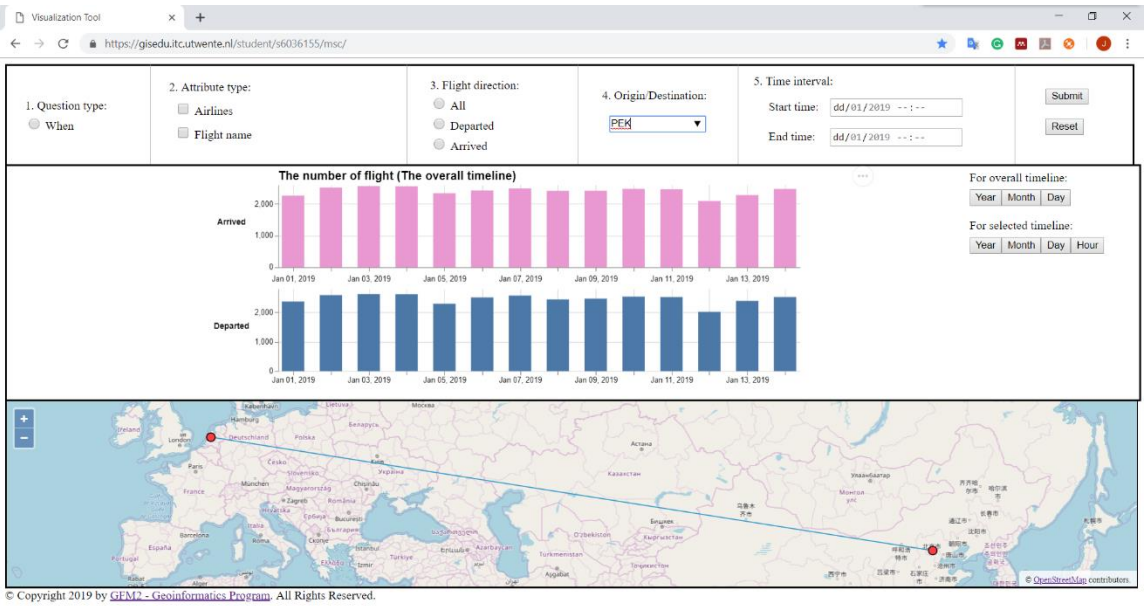

Figure 4-27 The link between the destination part and map part

Time interval sub-part focused on two aspects. To begin with, the interaction functions of this part was the same as other parts (Figure 4-28). Secondly, the implementation of this part used two "date box". There were two input boxes, one for the start date and the other for the end date, users could select the date and time in here. Both dates started from 2019-01-01 and ended before 2019-01-14 (Figure 4-29). Besides, users could skip choosing the time, if so, the code would automatically add "00:00" to the first box and "23:59" to the second box when extracting data.

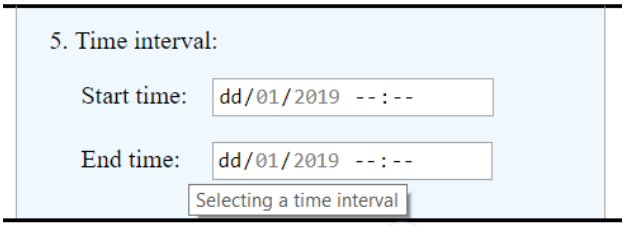

Figure 4-28 Time interval sub-part

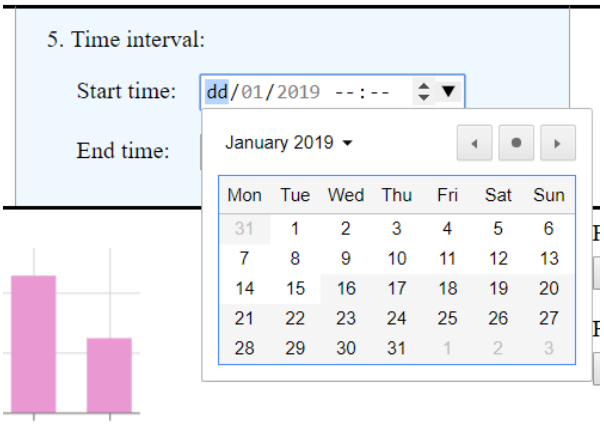

Figure 4-29 Date period

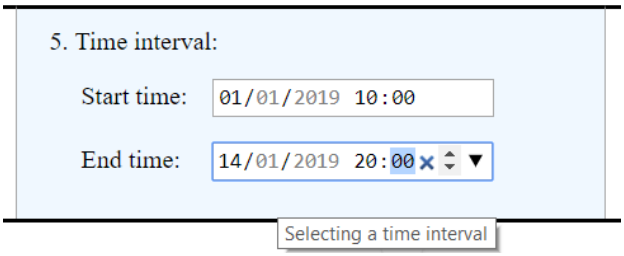

Figure 4-30 Example of selection in time interval sub-part

For the last sub-part, it was a great idea to design two buttons to interact with users from experience and the design of other web pages (Figure 4-31).

Figure 4-31 Submission and reset button

The first button was used to achieve the submission function, which should be able to post the values selected by users in the previous parts to the backend file. There was an input type named "submit" to match this function. But when testing the effect of this button, a drawback was that the selection part would be cleared after submitting these selections. Hence, this research defined a new function rather than used the "submit" type button. This function contained four parts: acquiring the value for each selection, sending them to the backend file, getting the response, and depicting the timeline. First of all, after users clicked on this button, the web page popped up a window, which aimed to tell users that the web page was started to work and said: "The selections have submitted, and it may take a few minutes, please wait for the response. Click OK to start" (Figure 4-32).

Then the web page started to use the "name" or "id" of those selection boxes to acquire their values and stored them to new variables. After that, these variables were added to the URL and used "XMLHttpRequest" to send those values to the backend python file. Besides, there was a judgment statement to acquiring the response of the backend if the status of the response was correct. If the code

successfully extracted data, the web page would pop up a window and said: "The result has successfully depicted!". If data were not successfully extracted, the web page would pop up a window and said: "There is no such data in the database. Please try another one". After that, a variable was defined as depicting the timeline. Finally, there was a code to depict this variable to the timeline part.

The second button was used to achieve the reset function. This could be solved by setting the type of button into "reset".

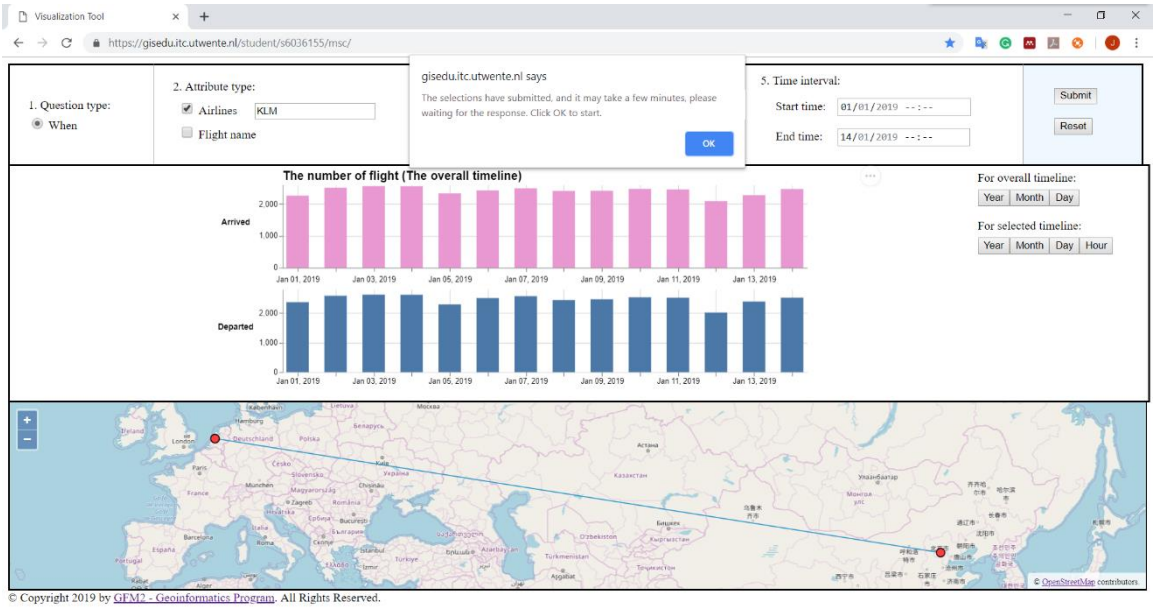

Figure 4-32 the reaction after clicked on the "submit" button

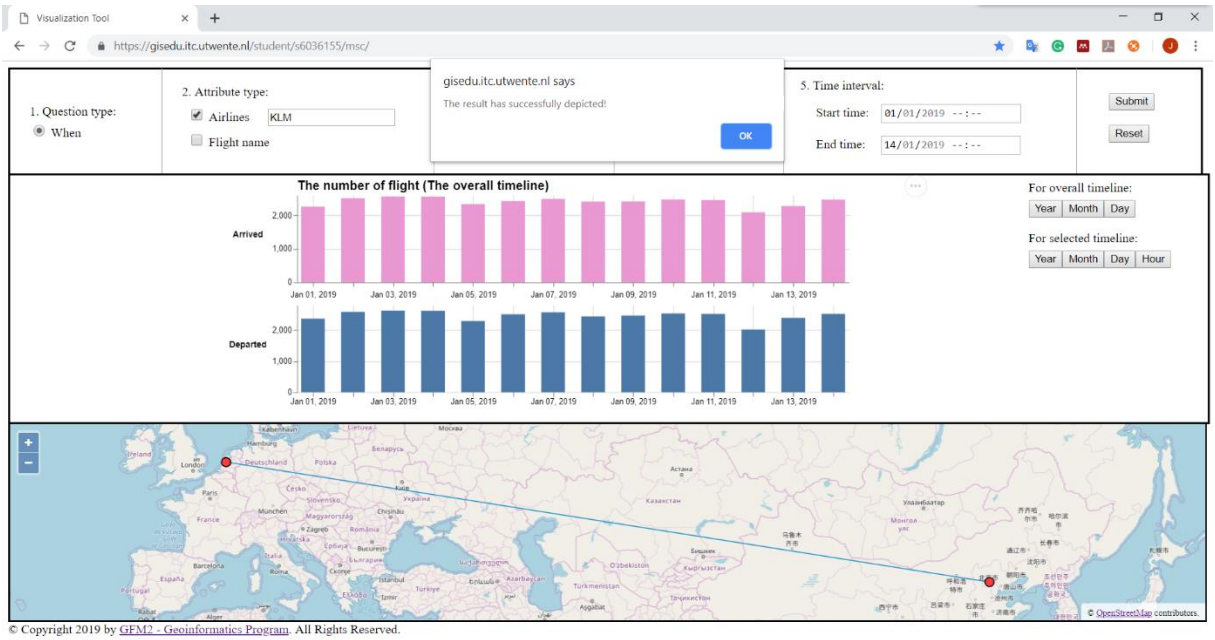

Figure 4-33 The successful reaction from the web page

4.3.3. The result of the timeline part

In this part, timelines were made by "Vega-Lite", a high-level grammar of interactive graphics. It provides a concise JSON syntax for rapidly generating visualizations to support analysis.

Firstly, the initial timeline showed the total number of flights in these two weeks (Figure 4-34). This timeline was divided into two parts; the upper part depicted the flights which arrived at Schiphol airport, while another part depicted the flights which departed from Schiphol airport. They were distinguished by "colour".

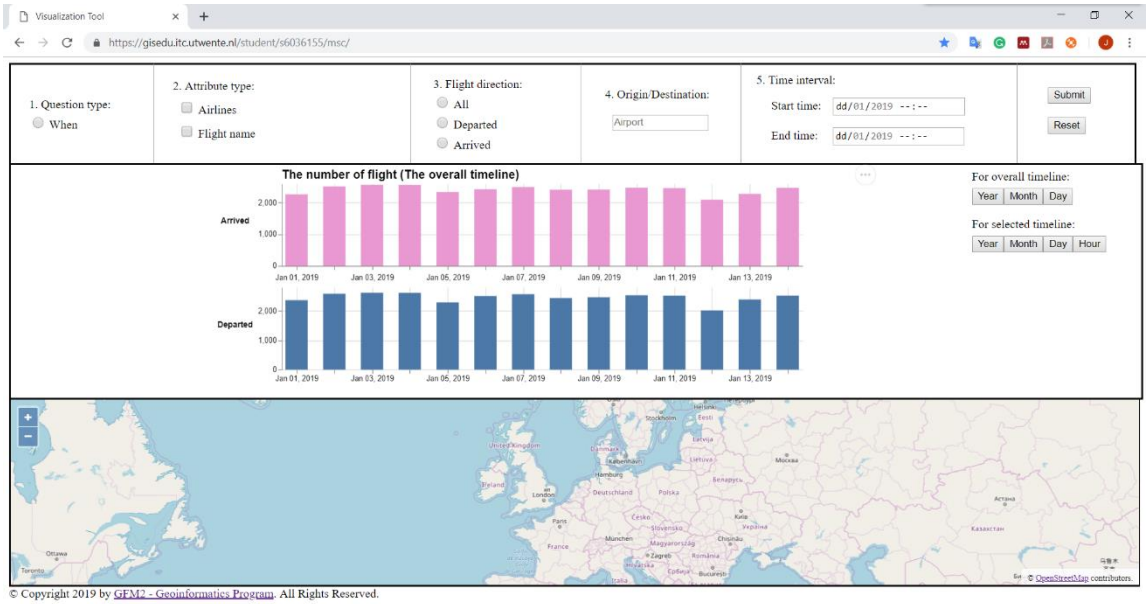

Figure 4-34 The initial timeline

Besides, if users hovered on one of the bars on the timeline, the corresponding date and the total number of flights would appear (Figure 4-35).

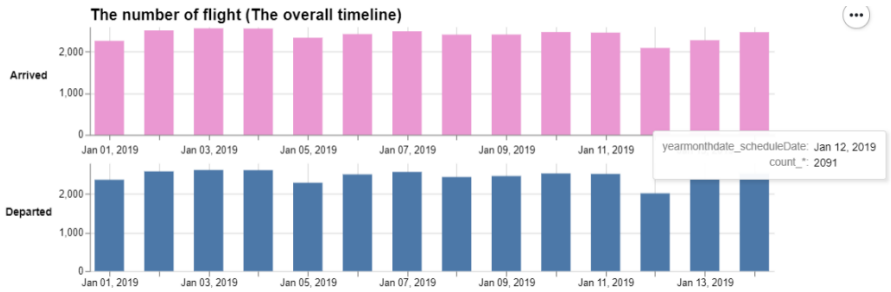

Figure 4-35 The hover function of the timeline

Secondly, this part was used to show the timeline based on the users' selection. Figure 4-36, as an example, depicts timeline after users' selection. Bars on timeline were distinguished by colour based on different flight name if users selected an airline name (Figure 4-36). Otherwise, the bars would be coloured by airlines (Figure 4-37).

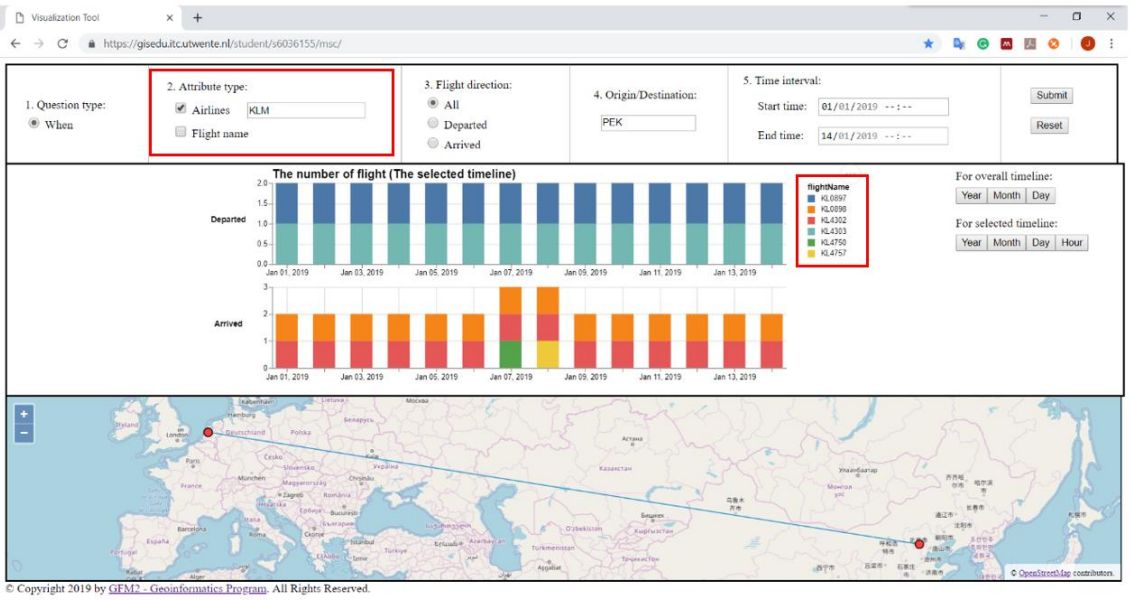

Figure 4-36 One example of the web page, the timeline was coloured by flight name

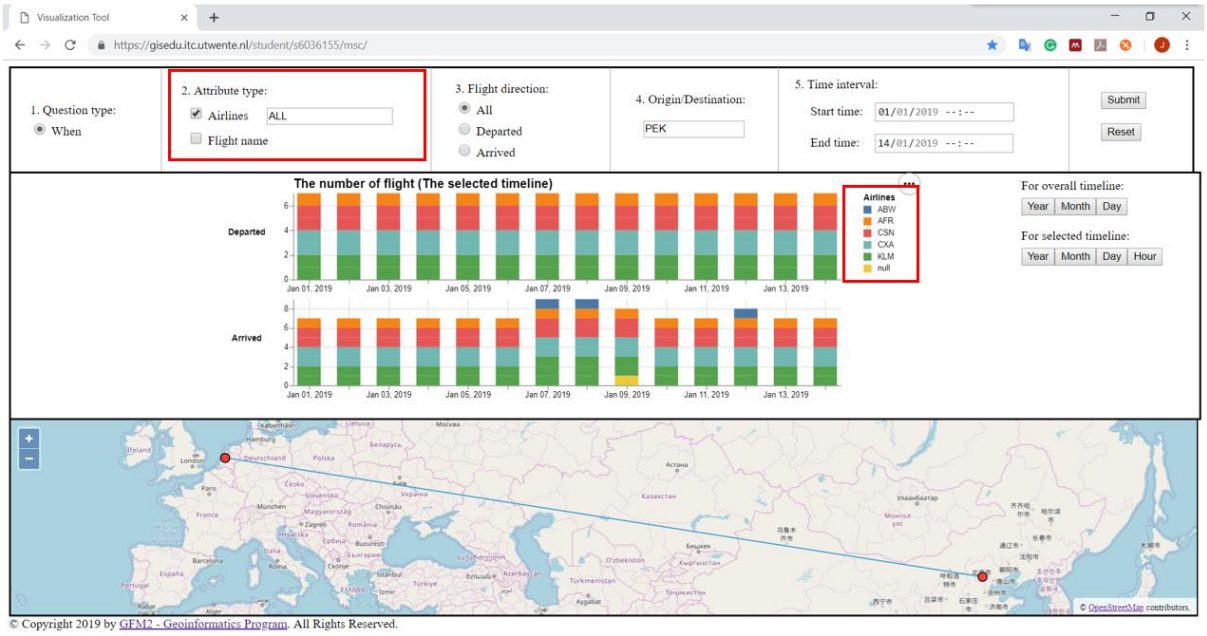

Figure 4-37 One example of the web page, the timeline was coloured by airlines

Thirdly, there were some buttons on the right side of the timeline part, which were used to change the temporal granularity of the timeline (Figure 4-38). In the first row, buttons were used to shift the temporal granularity on the initial timeline, while buttons in the second row were used to shift the temporal granularity on the selected timeline, which depicted the extracted data based on users' selection.

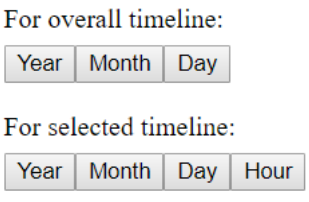

Figure 4-38 Buttons used to change the temporal granularity

4.3.4. The result of the Map part

The map part used to show the spatial attribute of the airports. It was triggered when users select the origin/destination in the selection part.

Initially, a worldwide map should show on this part. But this cannot achieve without an external map database. A map source called "OpenLayers" was used in the implementation. Firstly, "OpenLayers" should be included in the webpage by adding two links in the <head> of HTML file. They contain the library and its style file. After that, the script is allowed to use it as a source. Secondly, it was starting to build the map. The first step is declaring a tile layer with an OSM source which is in the "Openlayers". The second step is to make a base map in this part. There are three elements of this base map needed to be specified. The first one is the "layers" element. This element means that containing the layers to show on this map. The second one is the "target" element. This element means to specify where the map is displayed. The third one is "view" element. This element sets the displayed area, where "center" is the centre of the area selected for display, the default value was the coordinates of Schiphol airport. Besides, "zoom" is used to manage the zoomed-out range. Figure 4-19 shows this worldwide map.

Secondly, it should be an auxiliary tool for helping users to select location attribute in the selection part. When users selected value in the input box of the destination sub-part, the web page would send it to the "getCoordinates.py" file. After getting the response from the file, the map would create a layer to plot the coordinates of the airport and Schiphol airport, as well as a linking line. Then the map embedded this layer and changed the extent of the showing to contain the objects of this layer. If users change the value, the map would clear the previous layer and repeat the step. Figure 4-27 shows the reaction of the map when users input a destination. Figure 4-39 shows the reaction of the map if users deleted the value in the destination input box. There was a red pot left.

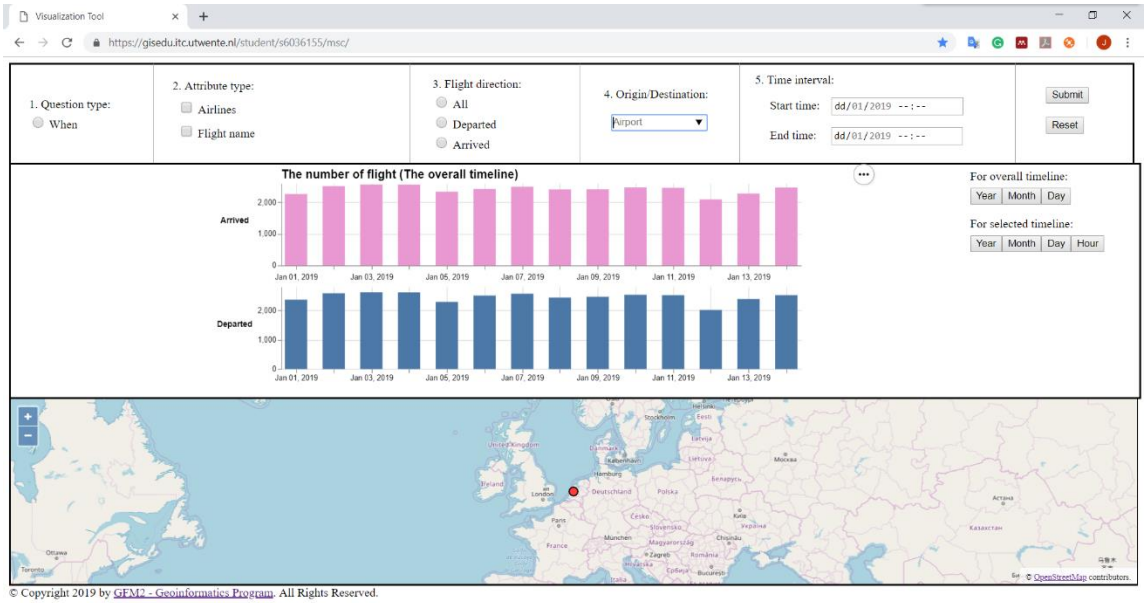

Figure 4-39 Reaction when users clear the value in the destination input box

4.3.5. The result of the footer part

The footer part contained the sentence "Copyright 2019 by GFM2 - Geoinformatics Program. All Rights Reserved." And link "https://www.itc.nl/geoinformatics".

4.4. Evaluating the implementation

The result of the evaluation would describe in focus group and post-experience interview. The six participants were numbered from P1 to P6.

1. Focus group result

The whole process spent approximately one hour. In the first step, all participants read the information sheet and answered questions carefully. Besides, they also showed enough curiosity to the web page. From the questionnaire, they all found the answer to the first two questions, which means that the web page could answer the questions under "when" type.

When observation participants' actions of operating the web page, two participants preferred not to select the value of attribute types in the sequence from left to right. After reading questions, they first input the location and found the spatial attribute on the map; then they input the other attribute values. Besides, some participants got confused about the changing temporal granularity function, because they ignored the title of the timeline and manipulated the button.

The result of the Likert Scale shows below. The average Likert Scale was 3, which means the web page was acceptable.

Table 4-7 Likert Scale from participants

Participants	Likert Scale
P1	4
P2	3
P3	3
P4	3

In the second step, participants discussed the web page in three aspects. First of all, some participants thought the use of the map was not enough. They would not check the spatial attribute of the airport if they selected quickly. Secondly, the test environment of the web page needed to improve. One participant used Linux to operate the web page, and the web page interface showed the difference. Thirdly, some participants suggested adding an example of the selection in selecting the time interval and destination.

2. Post-interview result

The Likert Scale of two participants showed below. The result was neutral on average, which meant that this web page could answer their temporal questions. However, they gave some comments about the web page, which focused on four aspects. First of all, the visual variable on the timeline was not variable. Colour was the most used visual variable on the timeline, which could be substituted by texture or value somewhere. Secondly, each input boxes should provide a default value in the selection part. People might ignore or misunderstand the explaining sentence in each input box, so providing a default value was a better idea. Thirdly, the outlier on timeline should depict at the top of the bar. Outliers should be more prominent so that users could see more intuitively. Lastly, there should be a title like "Exploring for flights to & from Amsterdam between Jan 01-Jan 14".

Participants	Likert Scale

P5	2
P6	3

5. DISCUSSIONS

5.1. Reflection of results

This research aimed to identify how timelines could help users to solve spatio-temporal questions at different temporal granularities. While there existed some problems in terms of effectiveness and satisfaction. The reflection of results showed below.

1. Data

Data processing was vital in this research. The source of the flight data was stored in a database and could be accessed using URL. Because of some limitations about the database request, this research downloaded and stored data in two-week period at a time for researching. The completeness of the flight data was good, and it was enough for the research. To keep the efficiency of the web page, this research kept the necessary data and deleted redundant data.

2. Formulating spatio-temporal questions

Combing with the previous work, this research put forward a new task taxonomy. In every question type of this task taxonomy, it also illustrated the relationship among spatial attributes, temporal attributes and other attributes in details. This result could be utilised in other related fields, having demand to explore spatio-temporal data (e.g., the shipping data).

Besides, this research used the flight data as a case study and formulated example questions to the task taxonomy. These questions were related to the temporal granularity. The purpose was to validate the applicability of the task taxonomy.

3. Providing answers for spatio-temporal questions

Considering the timeline and temporal granularity, this research provided sketches as answers to each question type. Besides, some necessary functions were described in each stretch to fulfil the design. These stretches could answer the questions, while they should be considered using more visual variables so that users could find answers more intuitively.

4. Conceptual design of the visualisation tool

A visualisation tool was designed to prove that these sketches could answer the questions and could be put into practice. The interface considered all the functions mentioned before, as well as the interaction with users. This research put the most important part of the visualisation tool into implementation, which was provided to be feasible through evaluation. It did not make further consideration on the whole part, such as the interaction among these parts in the interface, and the conversion of these parts when responding to different question type answers.

5. Implementation

To prove that the conceptual design was applicable, a prototype was implemented. Considering the limitation of time, the web page, which was the result of the implementation, had some differences with the interface. The web page could be improved in providing more selections for users to choose. For example, how to let users select several values in an attribute type.

6. Evaluation

This research mainly used focus group and post-experience interview to evaluate the web page. From the result, the web page was able to help users to answer questions, while it could be improved by considering

more about the users' operation. For example, if users' operation was not expected, how should the web page respond?

5.2. Limitations

1. The question types were incomplete

Maceachren (2004) grouped temporal questions into seven categories, and Wang and Kraak (2013) added another categories: "trend", while this research focused on six of them. These question types in the research were selected according to the content of data, so other question types could not be analysed in this research. For example, question type "how long" was not analysed in this research, because its result was a time interval, which needed the scheduled time and ending time. However, it was not supported in the data.

2. The data volume was not large

This research extracted data in two-week period to do the implementation. But when the data volume becomes larger, it might cause other problems which were not discussed in the research. For example, it may extend the time of data access, thus cause problems regarding code and database.

3. The limitation of the evaluation

First, there should be more focus groups and expert interviews if time permitted; second, the evaluation contexts could cover more question types to let users test to improve the evaluation comprehensiveness; lastly, it may exist bias of the nationality in the sampling design of the focus group because the author applied the snowball sampling principle.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The main objective of this research was to identify how timelines can help users to solve spatio-temporal questions at different temporal granularities. To achieve the main objective, four sub-objectives were proposed. Each sub-objective contained several research questions. This section summarizes the thesis and answers research questions to achieve sub-objectives and the main objective.

1. Sub-objective 1: Formulating spatio-temporal questions according to the user requirements

Research questions are:

- Which categories of questions can be involved in timeline visualisation?
- How to formulate questions and reflect the relationship among objects, spatial and temporal information?

This research summarized question categories as a task taxonomy in Figure 3-5. Grouped by the "question direction" and "analytical level", temporal questions were divided into several question types. These question types could be involved in timeline visualisation, which included "if", "when", "how often", "order", "synchronisation", "trend", "which", "what" and "where".

This research used "question direction" to describe different relationships among spatial attribute, temporal attribute and other attributes. Questions under the "in" direction level meant that these questions could be answered by the timeline while questions under "out" direction level meant that these questions should be answered by using other auxiliary tools (for example map, diagram, list).

Besides, this research discussed the relationships among spatial attribute, temporal attribute and other attributes based on Figure 2-3 in each question type. The question types were further divided into several categories, which were formulated based on three structures: spatial attribute impacted on the temporal attribute, other attribute impacted on the temporal attribute, as well as the combination of spatial and other attributes impacted on the temporal attribute. The single or plural of each attribute in the structure also influenced the division.

2. Sub-objective 2: Providing the answer to questions on the timeline and designing the conceptual design of the visualisation tool

Research questions are:

- What kind of timelines exists to match different types of temporal questions and data?
- What functions should the timeline have to help users solving temporal questions?
- How to deal with temporal granularity in these questions?
- How can the timeline inform about a spatial attribute in an environment with changing granularity?

This part focused on the timeline and designed different stretches to deal with different temporal questions. In each question type, there was a sketch provided as an answer to it. Besides, some question types contained more answers considering the influence of different temporal granularities.

Users could interact with timelines. Timeline depicted extracted data from users' selections, after that, hover function was designed for users to check detailed information and helped them to solved temporal

questions. Besides, when users clicked on a bar on the timeline, timeline in a finer scale showed to help users to check the details. This was also an idea to deal with different temporal granularities.

Also, zooming function was designed to manipulate the temporal granularity on the timeline. Users could use the scroll wheel to zoom in and out to change the temporal granularity of the timeline.

The timeline could rely on a map to inform the spatial attribute. There was a map at the bottom of the timeline. When the temporal granularity changed, the map could keep the spatial attribute.

3. Sub-objective 3: Implementing the conceptual design

Research questions are:

- What will the interface of timeline look like?
- How to display different temporal granularities?
- When we have different temporal granularities, how to keep the overview and still see the detail related to the question?

Figure 4-19 shows the interface of the web page, which could change based on the question type. The implementation focused on question type "when" because of the limitation of time.

In the implementation, changing temporal granularities was achieved by designing buttons. Figure 4-34 showed the timeline at the beginning. At the right side of the timeline, there were some buttons designed for changing temporal granularities. Each button represented one temporal granularity, for example, year, month, day and so on. When users clicked on one button, it would shift to the selected temporal granularity.

Figure 4-4 describes the solution to keep both the overview and the details in the answers. But this function was not achieved because of the limitation of time. However, users could change the temporal granularity to see the overview trend and the details.

4. Sub-objective 4: Evaluating the implementation

Research questions are:

- How to evaluate the usability of timelines visualisation tool?

This research evaluated the web page by organising focus group and doing the post-experience interview to experts.

Overall, it could be concluded that providing a visualisation tool with an interactive timeline could help users to solve the spatio-temporal questions at different temporal granularities.

6.2. Recommendations

Firstly, when formulating spatio-temporal questions according to user requirements, the question types are limited by the data source. However, there are more question types on other aspects, for example, "how long" and "how fast", which can be further studied.

Secondly, the choice of tools. In the web page, timelines are made by "Vega-Lite". However, using "D3" can give access to a whole suite of usable graphics. Besides, the web page focuses on one question type of the task taxonomy, and it can be better if other question types are implemented.

Lastly, this research studies data in two-week period, which is enough to achieve some functions related to temporal granularity. But the data volume could be extended in further wo

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APPENDIX 1 SPATIAL-TEMPORAL QUESTIONS

Question direction	Analytical levels	Question type	Focus	Target	General description	Example question
In	Elementary	If	T	O	Is there an Object departed/arrived at Time?	Is there a flight departed at 12.00 a.m. today?
			T	A (A, O; The number of an attribute value can be one or several)	Is there an Object which Attribute was * departed/arrived at Time?	Did a KLM flight departed at 12.00 a.m. today?
			T	L (L, O)	Is there an Object which departed from/arrived at Location at Time?	Did a flight depart with destination of PEK at 12.00 a.m. today?
			T	A, L	Is there an Object which departed from/arrived at Location and Attribute was * at Time?	Did a KLM flight departed to PEK at 12.00 a.m.?
		When	T	O	When was the Object departed/arrived within Time?	When was the flight departed between 10.00 a.m. and 12.00 a.m.?
			T	A (A, O; The number of an attribute value can be one or several)	When was the Object which Attribute was * departed/arrived within Time?	When were the KLM flights departed between 10.00 a.m. and 12.00 a.m.?
			T	L (L, O)	When was the Object which the destination was * departed/arrived within Time?	When were the flights departed which the destination was PEK airport between 10.00 a.m. and 12.00 a.m.?

			T	A, L	When were the Object which Attribute was * and the destination was * departed/arrived within Time?	What time did the KLM flights depart with the destination of PEK between 13.00 and 20.00 on 14 Jan. 2019?
	Synoptic	How often	T	O	How often did the Object depart/arrive within Time?	How often did the flight arrive today?
			T	A (A, O; The number of an attribute value can be one or several)	How often did the Object which Attribute was * departed/arrived within Time?	How often did the KLM flight arrive today?
			T	L (L, O)	How often did the Object which the destination was * departed from/arrived at Schiphol airport within Time?	How often did the flight which the destination was PEK airport arrived at Schiphol airport today?
			T	A, L	How often did the Object which Attribute was * and the destination was * departed from/arrived at Schiphol airport within Time?	How often did the KLM flight which the destination was PEK airport arrived at Schiphol airport today?
		Order	T	O	What order did Objects depart/arrive within Time?	What order did flights depart between 10.00 a.m. and 11.00 a.m.?
			T	A (A, O; The number of an attribute value can be one or several)	What order did Objects which Attribute was * departed/arrived within Time?	What order did the KLM flights which departed from Schiphol airport 15 minutes ago?

			T	As (As, Os; means that there were several attribute values to select the flights)	What order did Objects which Attribute was * and the flight which Attribute was ** departed/arrived within Time?	What order did the KLM and TRA flights depart between 11.00 a.m. and 12.00 a.m.?
			T	L (L, O)	What order did Objects which the destination was * departed from Schiphol airport within Time?	What order did flights which the destination was PEK airport departed from Schiphol airport between 11.00 a.m. and 12.00 a.m.?
			T	Ls (Ls, Os; means that there were several location values to select the flights)	What order did Objects which the destination was * and the flight which the destination was ** departed from/arrived at Schiphol airport within Time?	What order did the flight which the destinations were PEK airport, AGP airport and BJV airport departed from Schiphol airport 15minutes ago?
			T	A, L	What order did Objects which Attribute was * and Location was * departed from/arrived at Schiphol airport within Time?	What order did the KLM flights which the destination was PEK airport departed from Schiphol airport 15minutes ago?
			T	As, L (means that there were several attribute values and one location value to select flights)	What order did Objects which Attribute were * and ** and Location was * departed from/arrived at Schiphol airport within Time?	What order did the KLM and TRA flights which the destination was PEK airport departed from Schiphol airport 15minutes ago?
			T	A, Ls (means that there were several location values and one attribute value to select flights)	What order did Objects which Attribute was * and Location were * and ** departed from/arrived at Schiphol airport within Time?	What order did the KLM flights which destination were PEK airport and AGP airport departed from Schiphol airport between 10.00 a.m. and 12.00 a.m. today?

		T	As, Ls (means that there were several attribute values and several location values to select flights)	What order did Objects which Attribute were * and ** and Location were * and ** departed from/arrived at Schiphol airport within Time?	What order did the KLM and TRA flights which destination were PEK airport and AGP airport departed from Schiphol airport between 10.00 a.m. and 12.00 a.m. today?
	Synchronisation	T	O	Which Objects were departed/arrived together within Time?	Which flights were departed or arrived at the same time between 10.00 a.m. and 12.00 a.m.?
		T	A (A, O; The number of an attribute value can be one or several)	Which Objects that Attribute was * were departed/arrived together within Time?	Which KLM flights were departed or arrived at the same time between 10.00 a.m. and 12.00 a.m.?
		T	L (L, O)	Which Objects that Location was * were departed together within Time?	Which flights that destination was PEK airport were departed or arrived at the same time between 10.00 a.m. and 12.00 a.m.?
		T	A, L	Which Objects that Attribute was * and Location was * were departed at the same time within Time?	Which flights that had the same aircraft type and the destination was PEK airport were departed or arrived at the same time between 10.00 a.m. and 12.00 a.m.?
	Trend	T	O	What was the trend of departed/arrived Object within Time?	What was the trend of the departed flight this week?
		T	A (A, O; The number of an attribute value can be one or several)	What was the trend of departed/arrived Object which Attribute was * within Time?	What was the trend of the KLM departed flight this week?
		T	L (L, O)	What was the trend of Object which Location	What was the trend of departed flights which destination was

					was * within Time?	PEK airport this week?
			T	A, L	What was the trend of Object which Attribute was * and Location was * within Time?	What was the trend of KLM departed flights which destination was PEK airport this week?
Question direction	Analysis levels	Question type	Focus	Target	General description	Example question
Out	Elementary	Which	O	Flights depicted on the timeline	How many Objects happened within/at Time?	How many flights departed at 12.00 a.m.?
		What	A	Flights depicted on the timeline	What was the Attribute value of these Objects within/at Time?	What was the detailed information of these flights which are depicting on the timeline?
		Where	L	Flights depicted on the timeline	Where was the Location of these Objects within/at Time?	Where were the destinations of the flights which depicted on the timeline?
	Synoptic	What	A	Flights depicted on the timeline	What are the statistics of the Attribute on the timeline?	What are the statistics of the airline on the timeline?
		Where	L	Flights depicted on the timeline	Where were the statistics of Location of these Objects within/at Time?	Where were the statistics of destinations of the flights which depicted on the timeline?

APPENDIX 2 QUESTIONNAIRE

Information sheet

Dear Sir/Madam,

This evaluation of the web page aims to accomplish the objective of assessment of whether the web page could achieve the functions from the conceptual design. It was under my MSc research titled "Using timelines to answer spatio-temporal questions at different temporal granularities". The evaluation lasts approximately 10 minutes. Please try to evaluate the web page by answering some questions listed on the next page. Using Google Chrome to open the evaluation object, which is the web page: https://gisedu.itc.utwente.nl/student/s6036155/msc/

Before doing the evaluation, please read the background information below.

This web page was an implementation of the conceptual design in the thesis. The target users of the conceptual design were temporal analysts, who had some questions and would like to use this web page to solve their questions. Because of the limited time, the web page simplified the conceptual design and contained some basic functions.

You were assumed to be one of the temporal analysts hired by Schiphol airport managers. They posted some problems during the management of airport operations. You converted these problems into some temporal questions at first; then you would use the web page to solve these temporal questions. After that, you would summarise the result and give it to the manager.

This evaluation tests the steps you need to answer these temporal questions by using this web page.

Thank you for your participation. Your personal information will be kept confidential, and the results of the evaluation will be only used for research purposes.

If you have any questions, please contact j.wang-6@student.utwente.nl. My name is Jiahe Wang.

What time did the KLM flights depart with the destination of PEK between 13.00 and 20.00 on 14 Jan. 2019? Can you acquire the detail information of these flights?

And how many flights departed AMS on Jan. 14th, 2019?

Are you satisfied with the interface of the web page? Please give a score to the design, from 1 to 5 (1- very poor, 2- poor, 3-neutral, 4- good, 5- very good).

Could you please give some suggestions about the web page? Or putting forward one part that needs to improve a lot.