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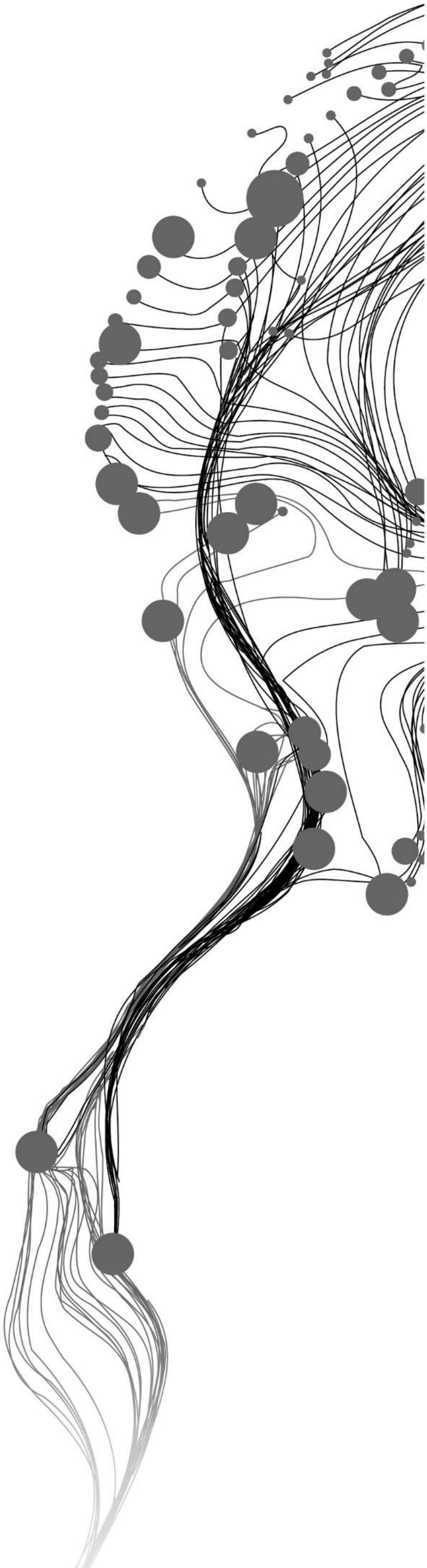

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Enschede, The Netherlands, February, 2017

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

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ABSTRACT

Dashboard is a visual environment that is able to display all kind of data, including origin-destination (OD) data. Most of current dashboards were failed to communicate effectively and efficiently in terms of exploration. An adaptive feature for dashboard was proposed in this research to increase the exploration ability. The adaptive feature enabled a dashboard to change its visualisation according to users' queries. The aim of this study was to design an adaptive dashboard that is able to explore and to get insights on temporal OD data effectively. Peuquet triad framework was used as starting point. Temporal concept framework was used to determine user tasks, data framework, and visualisation framework. Space, attribute, and time components of Schiphol airport were used as data framework. Based on user tasks and data framework, a two-in-one dashboard was designed and constructed. It consists of general non adaptive dashboard and adaptive dashboard with multiple-page approach. The delivered dashboard prototype was evaluated using a combination of task analysis, eye tracking, screen logging, video/sound recording, and interview. The adaptive dashboard prototype was able to perform exploration on temporal OD data. However, after conducting an evaluation to the dashboard, it was discovered that the prototype was not as effective and efficient as it was expected. Adaptive feature using multiple-page approach did not work well in terms of effective and efficient exploration. It is recommended to focus on a single-page approach for future study about adaptive dashboard.

Keywords: dashboard, adaptive, origin-destination, temporal OD data, visualisation, exploration

ACKNOWLEDGEMENTS

First of all I would like to offer my uttermost gratitude to prof. dr. Menno-Jan Kraak, my first supervisor who has tirelessly gave me guidance and support throughout this thesis. I am grateful for his "demanding" nature and out of the box idea during discussions when it comes to spatio-temporal visualisations. My gratitude also goes to Ms. Parya Pasha Zadeh Monajjemi, MSc, my second supervisor whom I can always count on for fruitful and cheerful discussions. I am sincerely grateful for her passionate efforts to raise my confidence on the writing aspect.

I would also like to extend my appreciation to Monday Visualisation meeting participants for such engaging discussions, particularly Yuri von Engelhardt and Ieva Dobraja for their helps on working with Tableau. My gratitude also goes to dr. Corné van Elzakker and Willy Kock for their helps on usability test. Thank you to all test participants as well for your time and feedbacks.

My sincere gratitude is also addressed to Indonesia Endowment Fund for Education (LPDP) for providing fund support during my study in The Netherlands. I am thankful for this splendid experience.

Thank you for all my GFM classmates, it's been up and down and finally we're here at the end of our MSc journey. I will always treasure this experience and memories for the rest of my life.

Also for my Indonesian compatriots, I am happy to know that I can have Indonesian dish whenever we cook together, or travel somewhere whenever time allowed. Thank you for being lovely "brothers and sisters" in this far yet not-so-foreign land. Special thanks goes to mbak Dewi for her patience on proof-reading my documents.

My tribute is also goes to my late father. I am sure you've been watching my journey from up there. Also to my mum, my brother, and my sister.

Last but not least, I would like to extend my utmost appreciations to my better halves Tia and Dipta. Thank you for your supports from half the world away.

Lastly, in the name of miracle, I submitted my thesis. After a period of caffeine overdose, skipping meals, lacking of sunshine, and also having a light lower-back pain, finally I could sleep well. Tabik.

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1. INTRODUCTION

1.1. Motivation and problem statement

Since its first flight in 1914, the airlines industry has served over 65 billion passengers (Oxley & Goodger, 2016). The relatively shorter travel times compared to other transportation methods is one of the reasons air travel became enthused by many. Recently, the declining fares and the development of airports all over the world also has contributed the high increase in number of air travel. Aeroplanes from all over the world come and go to an airport and deliver either people or cargo from their respective origin country. In this schema, the airport plays an important role as a connector between the country it belongs to and the rest of the world.

Origin-destination data is data that shows spatial interaction, or movement of things between places (Boyandin, 2013). The moving objects can be anything; aeroplanes, people, goods, vehicle, or an ideology are few examples. Most of the times, the origins and the destinations of the movements are known, as well as their attributes, but their exact movement routes remain unknown (Boyandin, Bertini, Bak, & Lalanne, 2011).

The flow of aeroplanes coming to and leaving from the airports is a kind of origin-destination movement. The airport of departure and arrival serve as origin and destination respectively. The amount of flights, passengers, or cargo are also known, and they can serve as attribute. The exact movement or track of the flights are also supposedly known. However, to access that kind of data is beyond this research. When presented as time series within a certain period it becomes temporal origin-destination (OD) data. With this kind of data, airlines management can get insight to provide better services and maximise their profit in the future.

It is common for major airlines to perform passenger analysis. For the purpose of this research, communication with staff (Almira Ladimananda of Garuda Indonesia) from the airlines industry has been made. According to her, temporal OD data are being analysed as initial indication to decide when to give promotional tickets or consider new flight routes. As for the tool, for example Garuda Indonesia Airways using dashboard environment to provide analysis tool for their executive direction board.

As defined by Few (2006), a dashboard is a visual display that provides the most notable information at a glance. It is a visual interface to the data. It should be able to allow users to explore their data, not only in terms of spatio-temporal aspect, but also in terms of attribute aspect. The main goal of visualisation is to provide insight, as beneficial knowledge about the data under certain analysis (Boyandin, 2013). By nature, dashboards are specifically used for overview as they provide the most essential information, (usually) including a map, at a glance. This matches with first step of visualisation seeking mantra by Shneiderman (1996), overview, which followed by filter zoom in/out, and details on demand.

Dashboards are able to display all kinds of data (Few, 2006), including OD data. OD data is traditionally visualised in flow maps. Maps have capability to provide insight in geographic patterns and trends since they only present selected feature of the complex real world (Kraak, 2006). However, flow maps have problem when dealing with big data as they might get cluttered and deviate readers from important information (Boyandin, 2013). Traditional approaches such as static maps or Geographic Information Systems do not provide enough distinct graphic representations to overview spatio-temporal data (Andrienko et al., 2010).

A dashboard environment can do that since it can contain various types of graphic representations. It can also perform exploration once spatial, temporal, and attribute are addressed as well (Andrienko, Andrienko, & Gatalsky, 2003). Hence, it is a good option to design a dashboard as exploratory environment of temporal OD data, particularly related to air traffic data in an airport.

However, the problem with most of current dashboards is they fail to communicate effectively and efficiently, hence there is room for improvement in their design (Few, 2006). Some of these focus more on fancy design and neglect the main essence of dashboard, which is to communicate information. The most common mistake of dashboard design according to Tyson (2016) is too strive to look beautiful, mostly by overcompensating with colour, complexity, and perplexing visualisations.

Furthermore, a dashboard needs to be "responsive", or adaptive, in terms of visualising the data. On the technical aspect, many dashboards are already responsive in terms of being able to be displayed in different devices, i.e. mobile and PC. However, adaptive dashboard that adapt to users by changing visualisation based on what questions are asked is also necessary to perform exploration more efficiently.

This research aims to design an adaptive dashboard that visualises temporal OD data of air traffic for an airport based on user queries. It has to be effective and efficient in terms of delivering its messages. Intended user group of this dashboard is reader of Schiphol Airport's annual reports. This dashboard will provide them insight of flight pattern to/from that airport as a consideration to make decision. Proper planning is needed in the design stage to avoid mistakes that might make a dashboard failed to deliver its message.

1.2. Research identification

1.2.1. Research objectives

The overall goal of this thesis is to design an adaptive dashboard to get insight in origin destination data, particularly of air traffic for airports. This research will cover OD data, dashboard, user requirements, and has Schiphol airport as case study. The main objective is split into five sub-objectives.
Sub-Objectives:

1. To understand the basics of OD data.
2. To understand the characteristics of dashboards.
3. To understand the users and their requirements.
4. To develop the conceptual design of the desired dashboard.
5. To implement and evaluate the dashboard.

1.2.2. Research questions

Related to sub-objective 1:

a) What is OD data?
b) How can the spatial, attribute and time component of OD data being visualised?
c) What are the problems with those existing visualisation methods?

Related to sub-objective 2:

a) What is dashboard?
b) What are the problems with existing dashboard?
c) What role could dashboards play in getting insight of OD data?

Related to sub-objective 3:

a) In the context of the application, what kind of question do users have which have to be answered by the dashboard?

Related to sub-objective 4:

a) Based on the previous, what information should be represented on the dashboard to allow users answer their questions?
b) What kind of dashboard design that suits adaptive feature?
c) What kind of graphic representation and functionality are needed?

Related sub-objective 5:

a) How to implement the prototype dashboard?
b) Which methods and techniques can be used to evaluate the dashboard?
c) How to conduct the experiment to evaluate the dashboard?

1.3. Innovation

The novelty of this thesis is about data, design, and adaptive feature of the dashboard. Adaptive feature will allow the dashboard to shapes its contents (in term of visualisation) based on user's questions. This thesis aims at designing a dashboard for temporal OD data related to a certain airport. At the initial stage, user requirements analysis was carried out. The design of the dashboard then evaluated on effective and efficient communication.

1.4. Related work

A number of researches about OD data and its visualisation has been carried out. One technique to represent OD data is the flow map. An example of traditional, static, yet powerful flow map is Charles Minard's map which visualises the casualties of Napoleon's army in the Russian campaign of 1812, as stated by Tufte (2016) on his website. It manages to visualise location, time, and attributes in a single map.

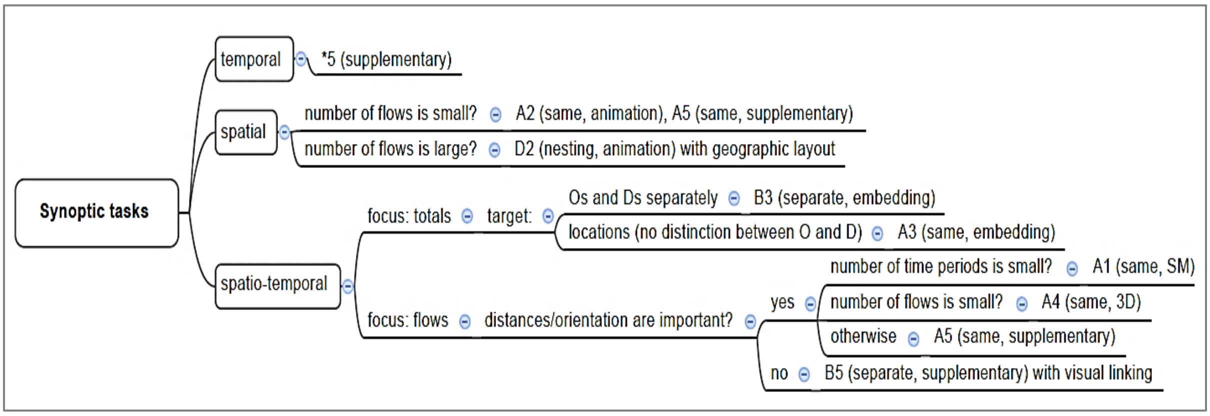


Figure 1-1. Decision tree based on synoptic tasks for choosing temporal OD data visualisation ((Boyandin, 2013)

In his thesis, Boyandin (2013) explained various techniques to visualise OD data, temporal or non-temporal. He also mentioned alternative ways to represent time: small multiples, animation, embedding, 3rd dimension as time, and supplementary view. Visualising temporal OD data proved to be more challenging since it involves time dimension, hence enables further exploration. He recommended a decision tree based on synoptic tasks to visualise temporal OD data (Figure 1-1).

Phan, et al. (2005) proposed a method to automatically generate flow maps based on hierarchical clustering from a set of nodes, positions, and flow attributes. However, Guo (2009) mentioned in his paper that flow map has some limitations: effective only on small dataset, mostly uses default geographic unit, and hard to perceive patterns that involves multiple variables information along with flow structure. Thus, he "developed an integrated approach to visualise multivariate spatial patterns by encoding multivariate clusters (derived with a self-organizing map) with a 2-D colour scheme and then use the colours (which signify multivariate information) to render a multivariate map" (Guo, 2009).

Specific environment is needed to perform exploration, namely by visual analysis. Visual analytics usually based on large data, it incorporates automated analysis techniques with interactive visualisations in order to have effective understanding, reasoning and decision making (Keim et al., 2008). The existing visual analytic strategies have been organised and synthesised by Roth (2012) into a logical framework, resulting in three dominant approaches: (1) objective-based, (2) operator-based, and (3) operand-based. Geovisual analytics are basically visual analytics, in terms of geospatial data. In their paper, Andrienko et al. (2010) concluded that geovisual analytic environment needs to deal with, as well as make use of, characteristics of time and space, while still manage to be visual and exploratory. This environment needs to be responsive, or adaptive, in terms of appearance by user requirements. However, research about responsiveness mainly focused on technology, on how to display web feature on mobile devices (Jiang, Zhang, Zhou, Jiang, & Zhang, 2014) or different platform (Zhu, 2014), (Mohorovicic, 2013).

The use of dashboards in organizations and industry of all sizes is not a strange thing nowadays (Pauwels et al., 2009). Krush, Agnihotri, Trainor, & Nowlin (2013) explain in their paper the use of marketing dashboard has an interactive effect as it highlights the significance of incorporating both sales and marketing operations. The use of dashboard also became prevalent in other fields such as public health (Lechner & Fruhling, 2014), architecture and construction (Guerriero, Zignale, & Halin, 2012), urban development (Scipioni, Mazzi, Mason, & Manzardo, 2009), and education (Maldonado, Kay, Yacef, & Schwendimann, 2012).

Some domains who could also benefited from dashboards still use traditional methods. An example to air traffic data is Schiphol Group (2016), who on their website put annual report which contains "traditional" visualisation of their traffic OD data. Another report related to air traffic OD data also carried out by International Air Transport Association on a monthly basis which contains analysis about air passengers of major airports in the world. This analysis using temporal OD data in table form and mainly talk about trend of passengers in certain country or region (IATA, 2016).

1.5. Methodology

The following methodology has been applied to achieve the objectives of this research:

1. Literature review

   Literatures about temporal OD data, geovisualisation, visual exploration, dashboards, and usability have been reviewed. This review gives big picture about what needed to be done in this research. This stage reviews: a) characteristics of OD data and dashboard, b) visual representation of OD data, as well as problems with existing visualisation method, c) Dashboard characteristics, problem with dashboards, and what role of dashboards to get insight of OD data.

2. Data preparation

   Data that used were obtained from annual Traffic Review (Schiphol Group, 2016) from 2006-2015. They were downloaded from Schiphol Group official website. These data then being reviewed, and based on previous literature review user requirements analysis has performed. Initially, users, problems, and data were being identified. The dashboard as geovisual analytic environment is the product that based on user requirements. During user requirements analysis, several questions that might be asked by the users in the context of application were formulated.

3. Conceptual design

Conceptual design that developed in this stage are based on user requirements analysis. Information that should be represented on the dashboard are determined in this stage, as well as their graphical representation. Functionalities of the dashboard also determined as well, such as whether the dashboard should be able to zoom in/out, perform query, etc.

The dashboard has to be able to address location, attribute, and time. Hence, it should contain map, graphic representative of attribute, and functionality to represent time. The map might be a flow map, or another spatial representation of OD data such as symbol map. Graphical representative of attribute can be line graph, bar graph, or pie graph. Pie graph is more appropriate to show proportion, while line graph and bar graph more suitable for displaying trend. As for representing time, decision tree approach from Boyandin (2013) can be applied (Figure 1-1).

The design of the dashboard is planned to be adaptive, which means it can change its shape according to user's request. For instance, the user wants to know about location then the dashboard's design changed to emphasize the map. When the user wants to know about specific attribute the dashboard will change to accentuate graph representation. The dashboard is oriented from left to right, as it is created in English language. Element on the left should be the most prominent, while additional information are placed on the right.

4. Implementation

   To implement the dashboard, there are at least two platforms that can be used: web-based or stand-alone application. Considering recent technology development, web-based application platform is chosen. This choice also corroborates the selection of available tools since almost all tools to create dashboard are on web-based platform. Appropriate tools are selected based on its functionality and feasibility to meet the user requirements.

   For the purpose of this thesis, there are three possible tools that can be used for implementation: D3 library, CartoDB, and Tableau. CartoDB and D3 library can be combined since CartoDB can generate GeoJSON data format which compatible with D3 library. As for Tableau, it has GUI which relatively more stringent in terms of visual design. However, Tableau has advantages as it's relatively easier to learn and specifically built for creating dashboard.

5. Evaluation

   There are two kind of evaluation method in geospatial data processing and dissemination system: quantitative and qualitative (van Elzakker & Wealands, 2007). Quantitative method can be used to evaluate effectiveness of dashboard. However, van Elzakker & Wealands (2007) argue that qualitative techniques may play important role in user-centred design approaches hence it gained its popularity nowadays. For this research, the evaluation approach to be used is qualitative, which has at least eight techniques: focus group, interviews, observation, thinking aloud, questionnaires, screen logging, eye tracking, and task analysis. One of those methods will be used for this purpose.

1.6. Structure of the thesis

Chapter 1 introduces the background, research objectives, research questions, and methodology of the research.

Chapter 2 introduces basic concepts of OD data and reviews visualisation of OD data in terms of spatial-attribute-time component.

Chapter 3 introduces basic concepts of dashboard, reviews existing dashboard, and explains the role of dashboard in getting insight of OD data.

Chapter 4 designs a conceptual model to represent spatio-temporal OD data. A user task was proposed to find the requirements for such design.

Chapter 5 explains the implementation of the dashboard based on the conceptual model using case study annual report of Schiphol airport from 2006 to 2015.

Chapter 6 explains the evaluation of the designed dashboard. It describes overall process of usability test that has been done to the dashboard.

Chapter 7 draws the conclusion of the research and provides the recommendations for future work.

2. ORIGIN-DESTINATION DATA

2.1. Introducing OD data

2.1.1. Basic concepts

Origin-destination (OD) data is defined as data about movement(s) which connect two or more places. By nature, there are two main components of OD data, space and attribute. Space component comprised of origin and destination which serve as starting point and end of movement respectively. The attributes and trajectories of the movement might be known or unknown. One way that commonly used to represent and store OD data is OD matrix, as shown on Figure 2-1 (Boyandin, 2013).

	ESP	PER	MOZ	DEU	ISR	HUN	ARG
SEN	3.0	3.0	2.0	2.0	2.0	2.0	2.0
CHN	1.0	2.0	2.0	2.0	2.0	2.0	
CHL		7.0	1.0				
ECU	6.0	0.0	8.0	1.0	3.0	0.0	4.0
SRB	8.0	1.0	3.0				
IRQ	8.0	4.0	2.0	5.0	2.0	3.0	6.0
URY	1.0	1.0	1.0		1.0		
...							

Figure 2-1: OD matrix representation of OD data (Boyandin, 2013)

2.1.2. Temporal OD data

When the time dimension is added, OD data became temporal OD data. The time is associated with every movement between each origin and destination (Boyandin, 2013). The time dimension might be aggregated to yearly, monthly, daily, or even hourly. Temporal OD data can also be represented as OD matrix as shown on Figure 2-2: OD matrix for temporal OD data (Boyandin, 2013).

Origin	Dest	Magnitude	Time
SEN	ESP	4.0	2010-01-15 13:43:32
CHN	PER	1.0	2010-01-15 14:05:10
SEN	ESP	4.0	2010-01-16 10:07:31
CHN	PER	1.0	2010-01-16 01:20:32
SEN	ESP	4.0	2010-01-17 03:30:16
CHN	PER	1.0	2010-01-17 22:01:55
IRQ	HUN	1.0	2010-01-17 23:14:07
...			

Figure 2-2: OD matrix for temporal OD data (Boyandin, 2013)

Using proper visualisation, temporal OD data is very powerful to find insight of information it contains. The most common example of insight is trend, as it will be easily seen when the data are placed in ordered time. Another common insight that can be seen is the highest or lowest value of specific attribute in a specific time unit. These examples are shown in Figure 2-4.

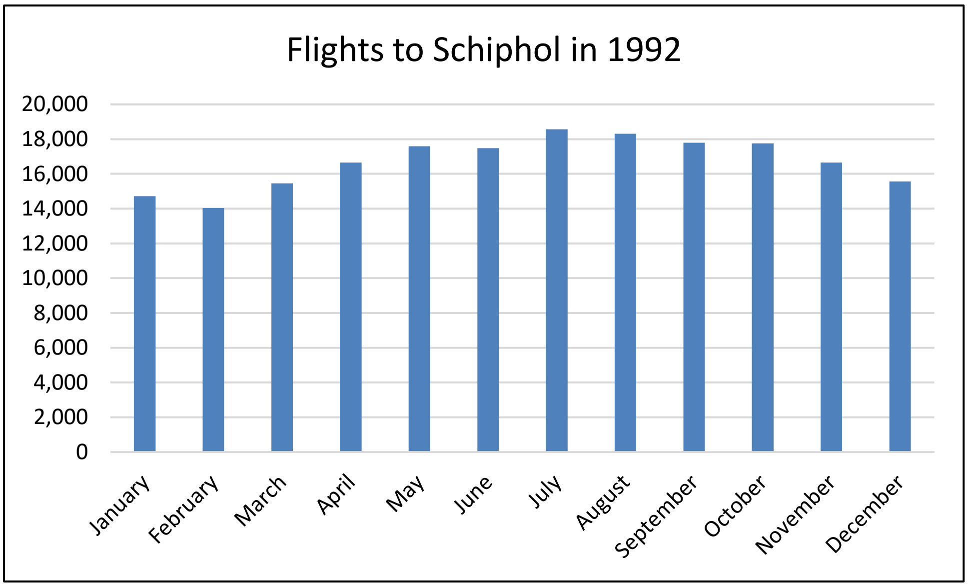


Figure 2-3: Example of getting insight of trend from number of flights to Schiphol Airport in 1992. It is also shown that July has the most flights to Schiphol Airport in 1992

2.2. Visual representation of OD data

2.2.1. Peuquet Triad framework for OD data

While OD data only has two main components in "space/location" (origin-destination) and "attribute", temporal OD data has additional component in "time". Hence, to start with visual representation of temporal OD data, location-attribute-time Triad framework proposed by Peuquet (1994) can be applied. The basic concept of the Triad framework is posing basic kind of questions related to where (what + when), what (where + when), and when (what + where). Components of temporal OD data in this thesis can be represented in the Triad representational framework as shown in Figure 2-4: Example of getting insight of trend from series of temporal data

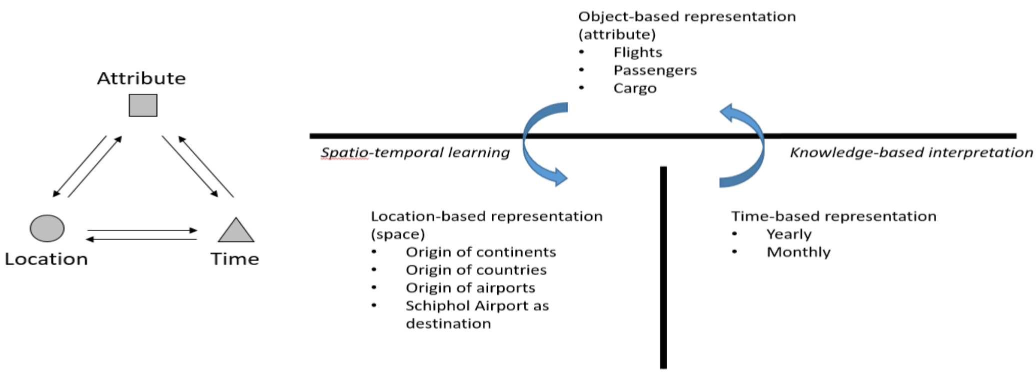


Figure 2-4: The Triad representational framework of temporal OD data of Schiphol Airport, modified from Peuquet (1994)

2.2.2. Temporal visualisation concept for OD data

OD data can be visualised with or without spatial component. However, non-spatial approach (not including map) is more suitable with simple representation and usually focus on attribute aspect. Moreover, it is only effective if users are already familiar with the geography in the data. Hence, OD data visualisation according the spatial approach is used in this research. In line with Peuquet Triad, an approach from each component has been proposed by Li & Kraak (2010). According to them, location, attribute, and time are focussing on the spatial distribution, distribution of the variables, and the temporal distribution respectively. Each of those components should be connected in the manner of coordinated multiple views (CMV), which will be covered more in the next chapter. Furthermore, to deal with temporal visualisation concept an environment which consists of temporal representations and temporal interactive tools can be developed. Categorisation of methods to visualise temporal data are based on their time characteristics: linear time vs cyclic time, time points vs time interval, and ordered time vs branching time vs multiple perspectives (Andrienko et al., 2010).

2.2.3. Temporal OD data representation techniques

Currently there are several techniques to represent OD data. In his thesis, Boyandin (2013) provided summary of existing techniques to represent non-temporal OD data (Figure 2-5). Those techniques then can be classified based on the following aspects: Layout, OD, Flow, Direction, Magnitude, Distance, OD total, and OD degree.

However, it becomes more complicated when the time dimension is added. In addition to non-temporal, Boyandin (2013) also provided summary of approaches to visualise temporal OD data, namely: small multiples, animation, embedding, 3rd dimension as time, and supplementary view. The review of aforementioned approaches and the possibility of using them in relation of representing the airport's annual report data are in the following:

a. Small multiples
   This approach consists of sequence of static maps where each map represents a certain time period of the data. It has limitation in terms of amount of data it can contain, since the size of the map will decrease when the amount time unit increase.
b. Animation
   Animation can show different states of the image in different time dynamically. It is very suitable to visualise change between specific moments in time. Interactive animation (that has forward and rewind functionality) such as time slider will be more effective in depicting change than static animation.
c. Embedding
   This technique embeds temporal information into graphical non-temporal representation. Like small multiples, it also has limitation with respect to amount of temporal data.
d. 3rd dimension as time
   In general this method puts time as z coordinate, while two other axis represent condition in that specific time.
e. Supplementary view
   This approach puts temporal information on the different view which connected to the main view of origin and destination information. In relation with this thesis, this approach is most likely suitable with dashboard environment that will be covered in the next chapter.

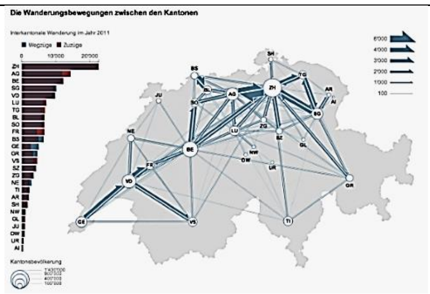
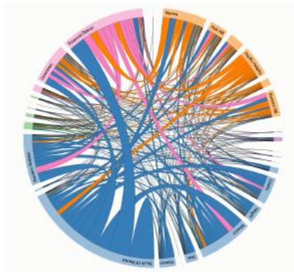
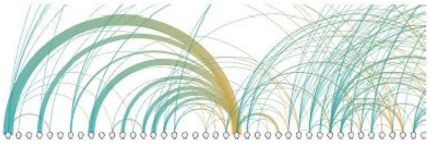
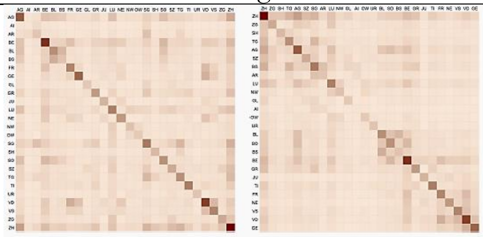
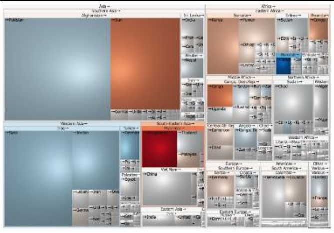
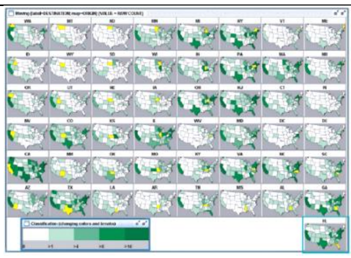
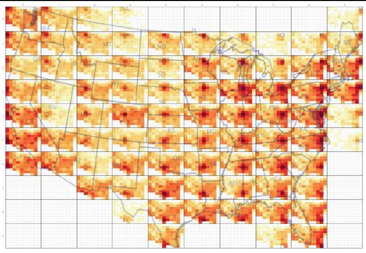
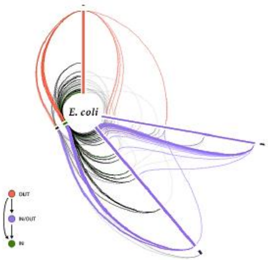
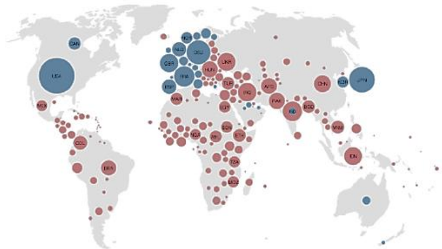
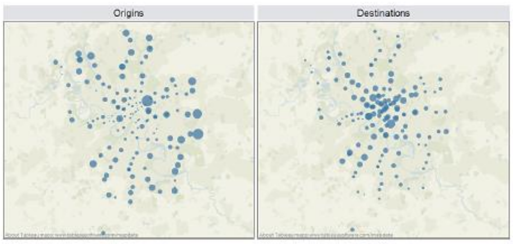
 Flow map	 Chord diagram
 Arc diagram	 Sankey arcs
 OD-matrix	 OD-treemap
 Map²	 OD-map
 Hive plot	 Symbol map
 O and D symbol maps	

Figure 2-5: Various representation techniques of non-temporal OD data as summarised by Boyandin (2013)

2.3. Summary

This chapter reviewed the characteristics and existing visualisation approaches of OD (non-temporal and temporal) data. The chapter started with introducing OD data and its basic characteristics. When it comes to visual representation techniques, Pequet Triad framework was incorporated in line with temporal visualisation concept to determine what kind of environment that suitable. In accordance with those frameworks, various visual representation techniques of OD data were reviewed.

3. DASHBOARD ENVIRONMENT

3.1. Introducing dashboard

Dashboard is a visual interface to the data that combines text and graphics, with an emphasis on graphics, to present information visually (Few, 2006). It is highly graphical since graphical presentation can communicate more effectively given the proper design. This section reviews types of dashboard, dashboard's common pitfalls that should be avoided, and visual perception of the dashboard.

3.1.1. Type of dashboards

There are several ways to categorise dashboards, and a brief taxonomy has been proposed by Few (2006) to categorise dashboard based on different variables. Few (2006) opined that the most common and the most useful way to categorise dashboard is by its role. Based on its role there are three high level categories of dashboard: strategic, analytical, and operational.

a. Strategic
This type is the most general executive dashboard. It has simple display, and strategic in the nature. It provides quick overview of the data along with the notion to make decision or question about that condition. Constantly changing graphic will undermine that purpose. Hence, very simple graphics that only show what is happening without much interactivity work best. It doesn't require real time update, but still need update in regular basis i.e. monthly or weekly.
b. Analytical
Compared to the previous type, this type of dashboard has richer context than just simple overview. It aims to provide analysis by showing trend or pattern that enables further exploration. Like previous type, simple graphics also work best, but with extensive interactivity to allow users (analysts) to explore the data. It doesn't require real time update as well, instead it mostly uses historic data.
c. Operational
This type of dashboard is the most dynamic in term of visualisation compared to the other two types. It aims to monitor situation and act as soon as possible according to the condition. Highly dynamic graphics work best to warn the users when something goes wrong. It requires almost real time data or data with very short time update.

Based on the above explanation, Table 3-1 shows the summary of type of dashboards as modified from Pappas & Whitman (2011). In relation with data that being used, the dashboard designed in this research falls into somewhere between strategic and analytical dashboard type.

Table 3-1: Summary of dashboard types, modified from Pappas & Whitman (2011)

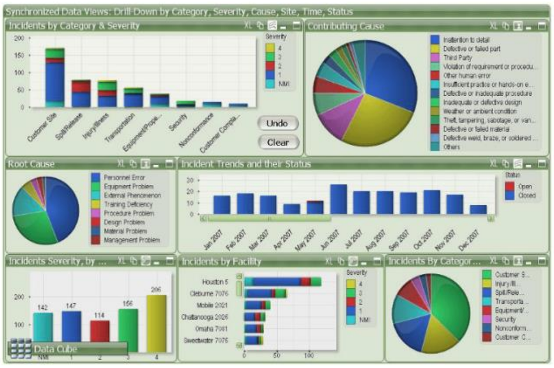
Type	*Purpose*	*Timeframe*	*Graphic presentation*	*Interactivity*	*Update frequency*
Strategic	See and decide or question	Weeks to years	Static	Low	Moderate
Analytical	See and question, explore	Minutes to years	Static	Moderate	Low
Operational	See and act	Minutes to days	Dynamic	High	High

3.1.2. Common pitfalls of dashboard design

As briefly mentioned in Chapter one, many existing dashboards were not properly designed. They didn't incorporate graphical design effectively that makes them failed to deliver information in effective way. There are at least 13 mistakes that commonly happened in dashboard design (Few, 2006), as summarised in Table 3-2. Moreover, some examples of poorly designed dashboards (Tyson, 2016) are shown in Figure 3-1 (a to e) along with Few's pitfalls they fall under. Those pitfalls are to be avoided in designing a dashboard in this research.

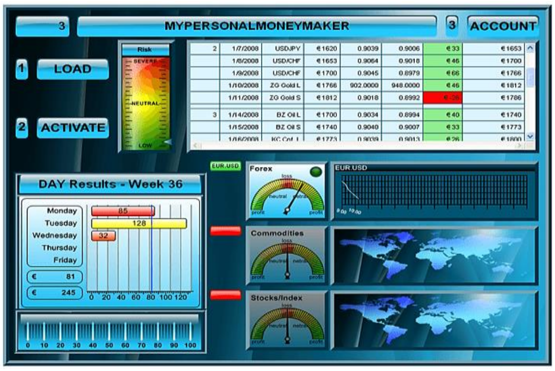
Table 3-2: Thirteen common pitfalls of dashboard design, summarised from Few (2006)

Pitfalls	*Remark*
1. Exceeding the boundaries of a single screen	Too much view. A dashboard should cover all important information in a single display.
2. Supplying inadequate context for the data	Do not have enough comparison or notification whether the current condition is good or bad.
3. Displaying excessive detail	Too much in detail, particularly with quantitative data that showing even until the smallest unit. It's slowing down the users to figure out the situation.
4. Expressing measures indirectly	Using wrong comparison or wrong measuring unit.
5. Choosing inappropriate media of display	Using wrong visual representation, especially for quantitative data.
6. Introducing meaningless variety	Showing many variations of display in the fear of getting user bored with sameness, sacrificing effective display.
7. Using poorly designed display media	Proper (although could be wrong as well) visual representation but with bad symbolisation.
8. Encoding quantitative data inaccurately	Mistake in designing visual representation for quantitative data, still related with previous pitfall.
9. Arranging the data poorly	Organising data in the layout in the way it is hard to read by users.
10. Ineffectively highlighting what's important	Do not highlight important information, or highlight them in the way that confusing users.
11. Cluttering the screen with useless decoration	Put too much glittering decorations that give no (valuable) information to the users
12. Misusing or overusing colour	Do not properly use the colour. Colour should give intended impression to the users (i.e. red for danger, green for safe) and do not distracting them too much.
13. Designing unattractive visual display	Even if the dashboard designed in proper layout with proper visualisation, it is still important to look attractive.



a.

Not glance-able, overuse of colour, use of pie.**(Pitfalls 5, 10, 12)**



b.

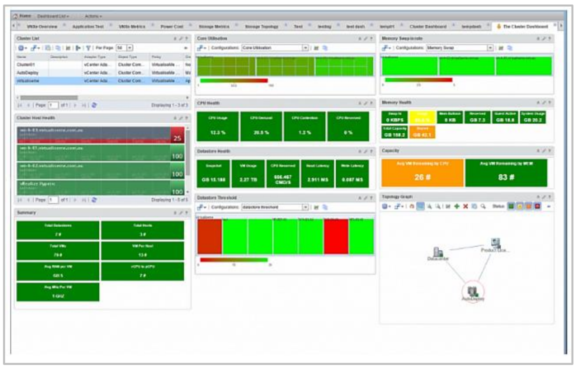
Use of 3D, distracting border (**Pitfalls 6, 11)**

c.

Confusing colours, pie chart (**Pitfalls 5, 12**)

d.

Too much data, variation in font size, metrics hard to interpret (**Pitfalls 3, 4, 5, 7**)



e.

Too much data, too much colours, no clear visualisation (**Pitfalls 3, 6, 12**)

Figure 3-1: Examples of poorly designed dashboard and their mistakes along with Few's pitfalls (Table 3-2) they fall under, modified from Tyson (2016)

3.1.3. Visual perception of dashboard

In his book, Few (2006) argues that to display data in effective way, visual perception plays an important role. This idea was also used by Ware (2012), however he focussed more on the limits of short-term memory, visual encoding for rapid perception, and Gestalt principles to be applied in terms of visual perception for designing a dashboard. The following section covers those aforementioned visual perception areas of focus.

The limits of short-term visual memory

Human's brain process memory in three fundamental types: iconic memory, short-term memory, and long-term memory. Iconic memory is where the images located briefly before being processed, while short-term memory is where the images being actually processed. Short-term memory has a limited space, just like RAM in computer analogy, hence limiting the number of information they can process before they're forgotten or moved into long-term memory. The limits of short-term visual memory is the reason why dashboard should display all important information, particularly the similar ones, at the same time in the same view.

Visual encoding for rapid perception

Rapid perception relates much with pre-attentive processing, where unconsciously human tend to notice specific set of visual characteristic. Proper visual encoding is needed to stimulate users to understand the data quickly. Basically it is similar with visual variables that has been proposed by Bertin (1967), as compared in Table 3-3. The difference is the latter didn't cover line length/width (included in size), enclosure, and motion flicker.

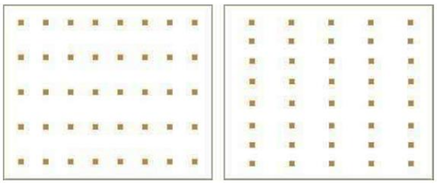
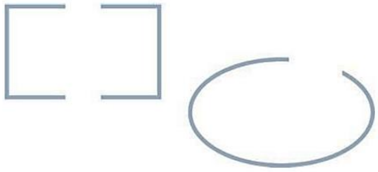
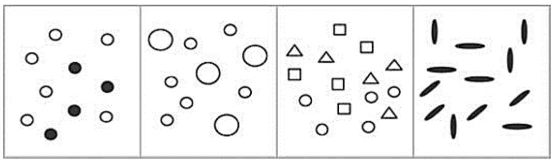
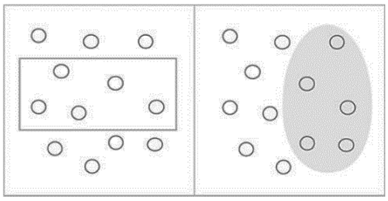
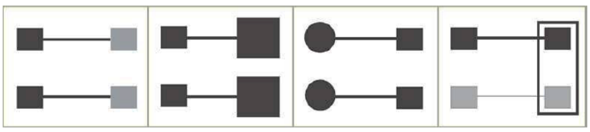
Table 3-3: Comparison of visual encoding by Ware (2012)/Few (2006) and visual variables by Bertin (1967)

Visual encoding (Ware in Few)	*Visual variables (Bertin)*
Colour	Colour, Value
Position	Position
Form	
• Orientation	Orientation
• Line length/width	
• Size	Size
• Shape	Shape
• Added marks	Texture
• Enclosure	
Motion flicker	

Gestalt principles

The term "gestalt" comes from German word that means pattern. It was first applied in visual perception in the 30's and 40's to investigate how human perceive parts of the object and form whole object (Soegaard, 2016). Nowadays it is applied in many design works as it often referred as "law of simplicity". Simplicity is required in order to design effective dashboard. There are at least six Gestalt principles as summarised in Table 3-4.

Table 3-4: Summary of Gestalt principles (Few, 2006)

Principle	*Example*
1. **Proximity** Objects that are closer are easier to detect	
2. **Closure** Object with certain closing pattern are easier to identify	
3. **Similarity** Similar objects are easier to detect	
4. **Continuity** Similar with closure, we tend to follow the pattern to detect object	
5. **Enclosure** Objects that clearly grouped (i.e. by rectangle or ellipse) are easier to be perceived in the same group	
6. **Connection** Similar with enclosure, objects that clearly connected (i.e. by line) are easier to be grouped	

3.2. Role of dashboard

As mentioned in Chapter one, dashboard has a particular characteristic to display all (important) information at a glance. Hence, it gives possibility to get insight based on those displayed information. This section covers the relation of dashboard with coordinated multiple views (CMV) and its role to get insight using effective visualisation.

3.2.1. Dashboard and multiple views

Coordinated multiple views (CMV) is a certain visualisation technique that allows users exploring their data by interacting with it (Roberts, 2007). State of the art about CMV have been proposed by Roberts (2007). He covers fundamental areas of CMV: data processing and preparation, view generation and multiple views, exploration techniques, coordination and control, tools and infrastructure, human interface, and usability and perception. Current condition of aforementioned areas are summarised in Table 3-5. Evaluation about CMV was already researched by Golebiowska, Opach, & Rød (2016). They concluded that integrating various visualisation methods in a CMV environment is more effective than put them in separate way. Accordingly, sufficient interaction techniques becomes crucial with regard to effectiveness of CMV environment.

Table 3-5: Summary of current state of the art of CMV (Roberts, 2007)

Fundamental area	*Current condition*
Data processing and preparation	• Problem increasing with users wish to integrate multiple datasets • Processing temporal data is still a challenge
View generation and multiple views	• There are many methods for generating views • The use of difference views is useful but difficult to implement • Aggregation is needed to create dual views to generate overview
Exploration techniques	• Varied from sliders, brush, to direct manipulation on visualisation displays
Coordination and control	• There are a lot of highly interactive CMV systems but still few highly coordinated systems
Tools and infrastructure	• Start to consider further aspects of interoperability and extensibility
Human interface	• Window management strategies • Exploration control is still basic • Needs better navigation tools that work for large displays and integrate it with smaller handheld devices
Usability and perception	• Effective evaluation is still hard and time consuming, but it is necessary to figure out what aspects, tasks, and solution regarding the CMV

By nature, dashboard is an overview tool and not really an exploratory tool. However, by incorporating CMV in the dashboard environment will give dashboard exploratory function. This exploratory function can be enhanced further by making it adaptive, in essence of changing its visualisation shape. The change of shape adjusting the type of question is implementing Shneiderman (1996) visualisation seeking mantra as we try to go further to provide details on demand. An example of work about dashboard with multiple views are from Lundblad & Jern (2013). They propose storytelling method to improve reader's visual knowledge through reflection of the data. The storytelling mechanism started with classic 4W questions Where, What, When, and Why that being incorporated into separate views with various symbolisations (Figure 3-2).

Figure 3-2: Multiple views dashboard with storytelling panel and questions to answer (Lundblad & Jern, 2013)

3.2.2. Effective dashboard data visualisation

To deliver information effectively, a dashboard should be properly designed, in terms of using the right visualisations. In his book, Few (2006) proposed two fundamental principles to select visualisation in a dashboard: 1) it must be the best means that commonly found, 2) it must be still functional even in small space. Those visualisations then divided into six categories: graphs, images, icons, drawing objects, text, and organisers. Furthermore, Pappas & Whitman (2011) have proposed guidance for choosing the right visualisations for dashboard. Basic key guidance from that paper are covered in the following list:

- ***Strategic and analytic dashboard***
  For strategic and analytic type of dashboards, interactivity is necessary to some extent to let users do further exploration. Filtering, drill-down, tooltips, expand/collapse, or data brushing/highlighting can be used for this purpose.
- ***Comparison***
  Comparing the data is common task that users want to do. For comparison, it is better to use visuals that compare line lengths with common baseline. Line graph, bar chart, or bullet bars are good visualisations to use. Other visualisation for comparison is key performance index (KPI), since it also draws attention on area that users may need to act. Needless to say that consistent colour coding are required for different KPI to avoid distraction from users.
- ***Things to be avoided***
  It is better to avoid visuals that show comparison based on angles, area, volume, or colour. Pie charts, speedometers, or dials are the examples, they are inefficient in using space (consuming more space) and difficult to compare (angle based). Pictures or background image are also better to be avoided since they draw attention away from the data without adding any value as much as data visualisations. Looping animation and too many/bright colours also distracting hence they are better to be avoided as well.

3.3. Summary

This chapter reviewed dashboard environment. It started with introducing dashboard which includes types/categories, common pitfalls, and visual perception of dashboard. As dashboard contains various visualisations, it has role in getting insight of the data when visualised properly. As multiple views, dashboard can be designed to be adaptive in accordance with Pequet Triad type of questions that asked by user. Based on the review in the last two chapters, the next chapter will determine user requirements and design a conceptual framework for a dashboard as exploratory tool for OD data of certain airport.

4. CONCEPTUAL DESIGN

4.1. Introduction

These days, everyone is spatio-temporal analyst, all society can be potential users, the challenges are to learn and understand the users (Andrienko et al., 2010). To understand the users, common starting point has to be placed in the beginning of the process. As mentioned in Chapter two, starting point approach to solve problem of visualisations by Li & Kraak (2010) is used in this research. Using this approach, there are three components that involved in this process: user tasks, data framework, and visualisation framework (see Figure 4-1). This chapter covers briefly about data framework, and extensively depict user tasks and visualisation framework in this thesis. Those overall process are summarised as conceptual design.

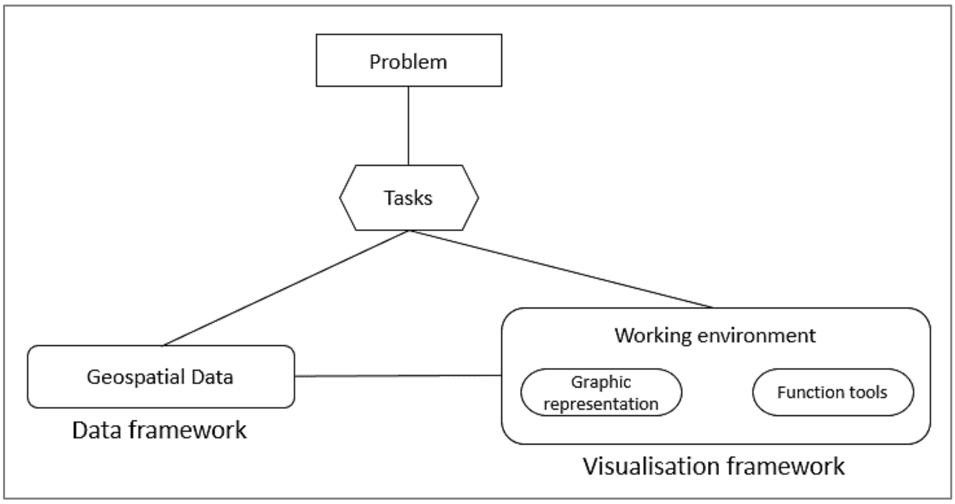


Figure 4-1: An approach to solve problem of visualisation which includes user tasks, data, and visualisation framework (Li & Kraak, 2010)

Before going further, it has to be noted that this research designed a dashboard whose type falls into somewhere between strategic and analytical, as briefly mentioned in Chapter three. The dashboard also has adaptive feature, in terms of changing its visualisation based on users' queries related to space time attribute components. With that notion, the dashboard that designed here is a "two-in-one" dashboard, a general (strategic) dashboard and an adaptive (analytical) dashboard. The general dashboard is following the idea of single page dashboard, while adaptive dashboard follows multiple pages dashboard idea. The following sections discuss about how such dashboard was designed in this research.

4.2. Data framework

As briefly introduced in Chapter one, data that used for this research is from Schiphol Airport annual report. It contains amount of flights, passengers, and cargo that came into Schiphol from all over the world during 2006-2015. However, the data are aggregated into top 20 for each year, meaning that not all countries are included in the list. Hence, the insights that can be extracted from it are also limited. To get more insights more detailed granularity of time is needed, which means another data needs to be added as well. Monthly data from monthly traffic report of Schiphol and arrival/departure flights of the day are used for this purpose. They are obtained from Schiphol Airport website and www.flightradar24.com respectively. The information that can be extracted from the data based on actual origin-destination and time granularity properties are listed in Table 4-1.

Table 4-1: Information that can be extracted from data sources in relation with time attribute space components.

Time	Attribute							Space
	Flights (amount)	Passengers (amount)	Cargo (amount)	Airlines	Aircraft size	Aircraft type/model	Flight no.	Actual OD
Year	Yes	Yes	Yes	No	No	No	No	Yes
Month	Yes	Yes	Yes	No	No	No	No	No
Day	Yes	No	No	Yes	Yes	Yes	Yes	Yes

4.3. User tasks design framework

Users of this dashboard are the readers of Schiphol airport annual report. Those readers might be someone from an airline company or a simple passenger who wants to get insight from flights, passengers, and cargo data. Communication with airlines staff has been made, and according to her top managers of airlines rarely read annual report of airports. However, she insists that it is still necessary to read those kind of reports to determine new routes or adding new flights slot. Generally speaking, user of this dashboard is quite general. This section covers the user tasks design that will be used for user requirements analysis in relation with spatial time attribute components.

Initially, this research would only use data from Schiphol Airport annual report. However, to exploit "adaptiveness" of the dashboard, more detailed granularity of time is needed. Hence, as mentioned in previous section, a monthly data and a one day data have been added. Based on that data, possible questions that might be posed by users are then formulated. These questions are grouped into three reading levels: elementary, intermediate, and overall (Bertin, 1983). This approach is in line with typology of queries proposed by Peuquet (1994), which categorises questions not only into what, where, and when, but also the changes. Peuquet's approach is even considered as practical use of Bertin's approach in terms of spatio-temporal data (Boyandin, 2013). Some examples of the addressed questions along with type of Peuquet's questions are listed in the following:

Elementary questions:

- How many flights to Schiphol from country x in the year 20xx? **(what)**
- How many passengers arrived from country x in the year 20xx? **(what)**
- How many flights of airlines x from Schiphol in 17 December 2016? **(what)**
- How much cargo arrived from airport x in the year 20xx? **(what)**

Intermediate questions

- Which continent/region/country has the most/least flights to Schiphol in the year 20xx? **(where)**
- Which continent/region/country has the most/least passengers arriving at Schiphol in the year 20xx? **(where)**
- Which continent/region/country has the most/least cargo arriving at Schiphol in the year 20xx? **(where)**
- Which airport has the most/least passengers flying to Schiphol in 17 December 2016? **(where)**

Overall questions

- What is the trend of flights from country x in 2005-2015? **(change)**
- In which year did the highest number of passengers from country x arrive? **(when)**
- In which hour did most flights from Asia arrive in Schiphol in 17 December 2016? **(when)**
- In which year did most cargo arrive from airport x? **(when)**
- What is the monthly pattern of flights/passengers in 20xx? **(change)**

In summary, visual representation that used in this dashboard should be able to address the aforementioned questions. Since there are different time granularities, conventional single CMV dashboard is not sufficient. Hence, there will be several dashboards that linked to each other (multiple pages dashboard). Each dashboard provides different visualisation with respect to characteristics of the data it bears. Structure of the envisaged dashboard are shown in Figure 4-2, while type of visualisations are covered in the following section.

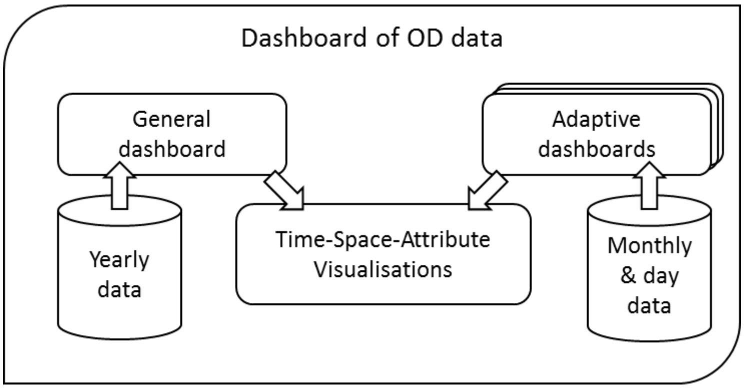


Figure 4-2: Structure of the dashboard that contains adaptive features from data with different time granularities

4.4. Visualisation framework

4.4.1. Dashboard layout (working environment)

As explained in previous section, in this research there are two kind of dashboards: general and adaptive. The general non-adaptive dashboard only consists of three single pages which acts as CMV (Figure 4-3). General dashboard uses yearly data since it's simpler in terms of variation of data that can be spatialized. It has at least three different visualisations for space, attribute, time, or combination between those three. On the other hand, adaptive dashboard has three different views which are connected by mutual buttons. Each view consists of visual representations of space (Figure 4-4a), attribute (Figure 4-4b), and time (Figure 4-4c) respectively with which users can choose to answer the questions.

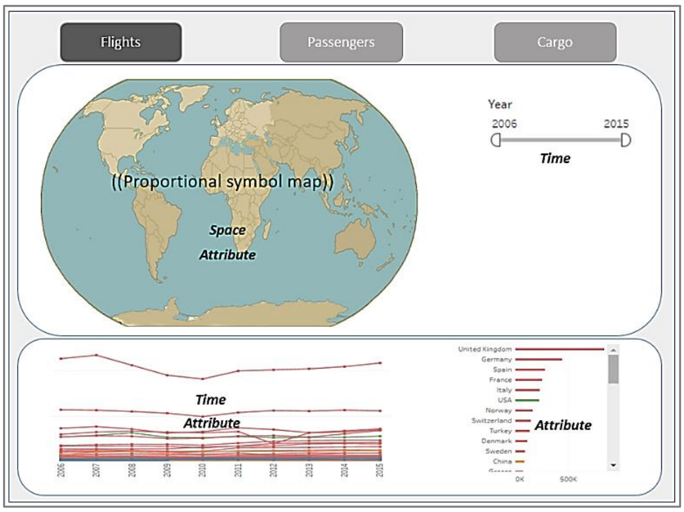


Figure 4-3: Layout design of general non-adaptive dashboard

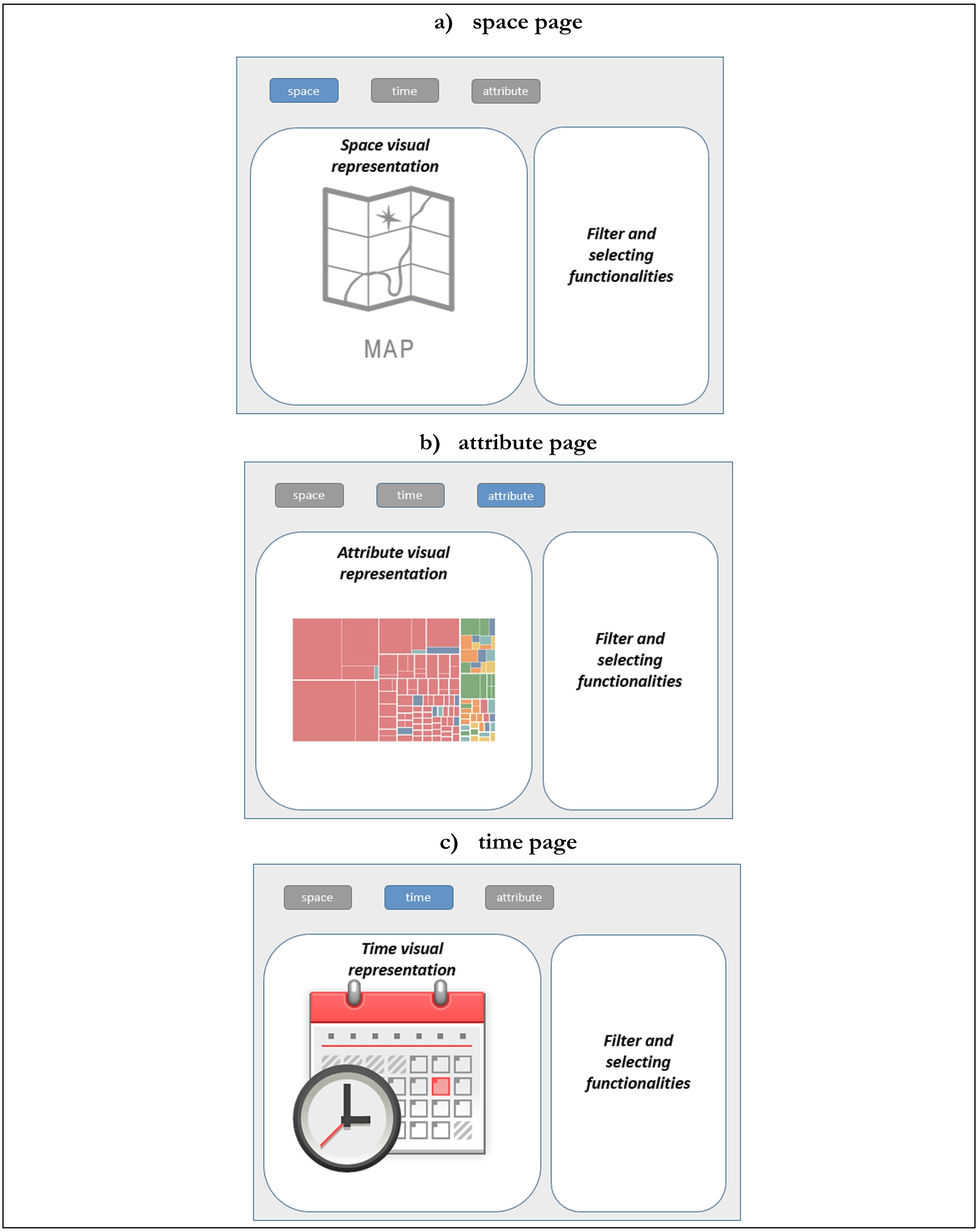


Figure 4-4: Layout design pages for adaptive dashboard

4.4.2. Graphic representations

There are sundry ways to represent space, time, and attribute, as explained in Chapter two. This section elaborates more on the choice of visual representations that used in this dashboard, considering what has been covered in Chapter three.

Space

The wonted way to represent space is map. It can easily answers "where" questions that related to space. Spatial aspects of the data in this dashboard are country and airport of origin/destination, since indeed this is an OD data. With that in notion, flow map is a sensible way to be used with the flow connecting between origin and destination (Figure 4-5). The departure and arrival flights are distinguished by colour coding. Another visualisation could be incorporated as well to represent number of attribute (number of flights, passengers, or cargo) in space, namely proportional point symbol map (Figure 4-6). Point symbols that drawn on the map are indicating location of the origin country/airport, while their size represent number of respected attribute. Colours of symbol are representing region of origin.

Figure 4-5: Flow map of flights to and from Schiphol Airport in 17 December 2016, as visual representation of movements in space

Figure 4-6: Proportional point symbol map of flights to Schiphol 2006-2015, as visual representation of number attribute in space

Time

Time is all about change. Even if the condition or attribute remains unchanged, the time is still ticking and no longer same. Representing time means representing changes over time. There are sundry ways to visualise time. One classic way to represent changes over time is line graph, using x axis to represent time and y axis as amount of attributes. As shown in Figure 4-7, x axis is representing year as time dimension, while y axis represents number of flights. For addressing clutter, highlight functionality is applied in this graph.

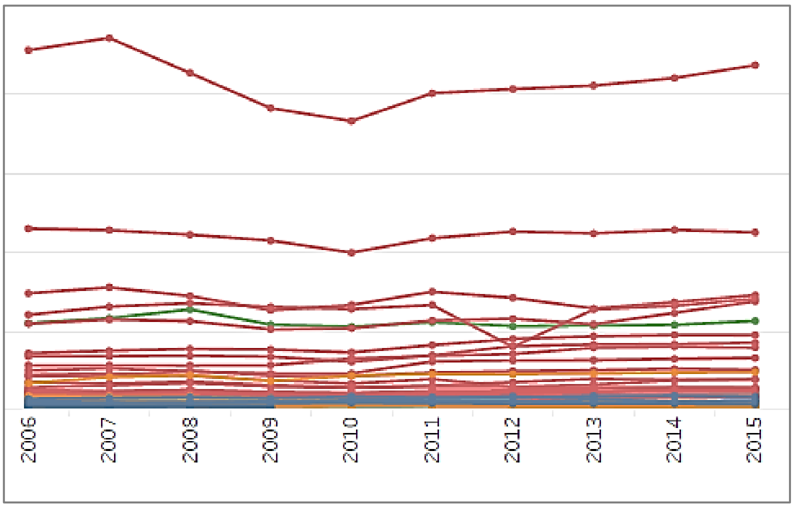


Figure 4-7: Line graph of number of flights to Schiphol 2006-2015, as visual representation of changes over time. Each line represents country of origin, while colour represents region of origin

Another common way to represent changes over time is time slider. It is a very forthright method as one can simply "slide" the slider to see the data in specific time. This dashboard uses double time slider, a variation of time slider. It provides more than just one moment of time, but also one period of time (Figure 4-8).

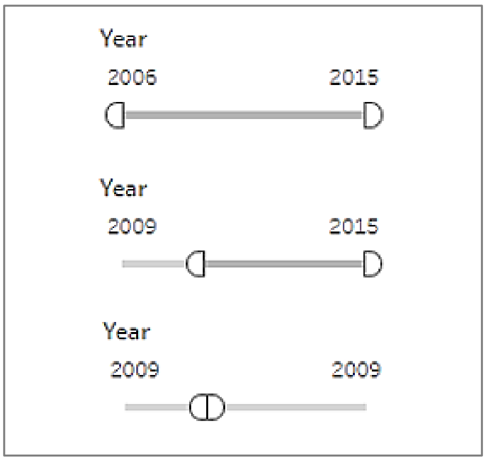


Figure 4-8: Double time slider that can shows not only one moment of time (one year) but also a period of time (multiple years), as visual representation of changes over time

There are also unorthodox –yet simple– ways to visualise time incorporated in this dashboard. One of them is heat map table as shown in Figure 4-9, which used to represent monthly data. It is somehow a simplified combination between OD matrix and OD map that were mentioned in Chapter two. Both column and row are representing time dimension with different granularity, columns for month and rows for year. Colour coding is used to represent "magnitude" (Boyandin, 2013), in this case a percentile of a single cell to total value of its row. It is set as gradation therefore it is easier to compare amongst months. Since the colour of one row doesn't necessarily related to other rows, the comparison is only amongst cells in the same row (monthly period), and the comparison between rows (yearly period) is only relative.

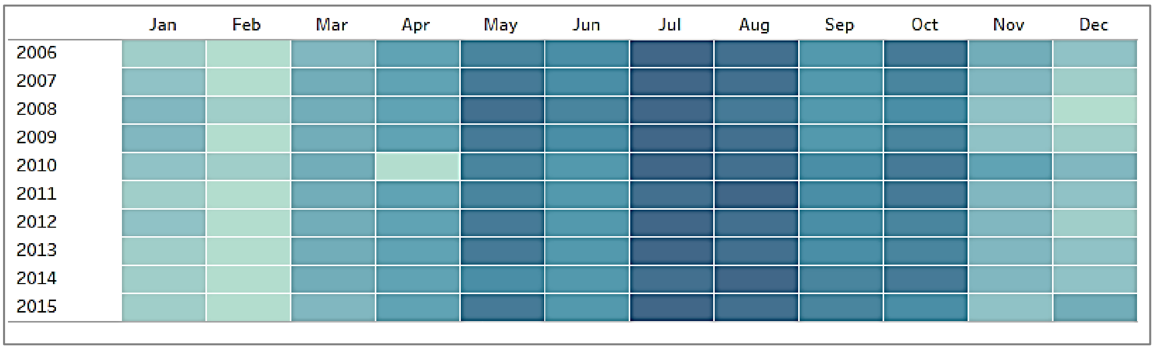


Figure 4-9: Heat map table depicting monthly number of flights to Schiphol 2006-2015, as visual representation of time

The other unorthodox way to visualise time is what called "dot graph" in this thesis (Figure 4-10). It is a modification of Gantt chart, a customary way to display timeline. Each dot represents each flight in one day, and x axis represents hourly time while y axis represents region of origin. Colour coding is used to differentiate flight type between passenger and cargo. However, the order of y axis is determined by number of flights that came or went from/to respected regions. Hence, the uppermost and the lowermost dot series are the most congested and the least congested series respectively.

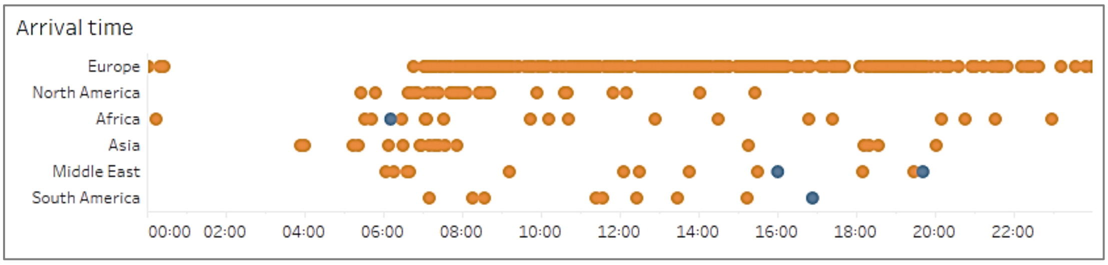


Figure 4-10: "Dot graph" depicting all arrival time of flights to Schiphol on 17 December 2016 from various region, as visual representation of time

Attribute

Attribute is arguably the most comprehensive component compared to space and time. It can contains either quantitative or qualitative values, and can be layered up to many things. When someone speaks about data, most of the time it is about attribute. The most common way to represent attribute is graph, particularly bar graph. Bar graph is very effective in displaying quantitative attribute such as number of flights, passengers, or cargo (Figure 4-11). As mentioned in Chapter three, it is easy to make comparison using bar graph since it has common baseline to compare length. However, it has downside as well since it is unable to display spatial distribution pattern even though it might have spatial components.

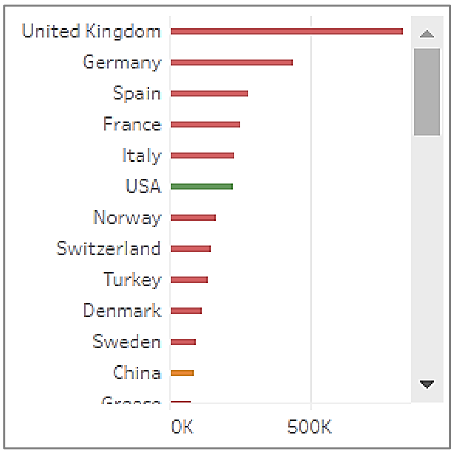


Figure 4-11: Bar graph of number of flights to Schiphol 2006 - 2015, as visual representation of attribute

Another visual representation of attribute that used in this dashboard is tree map. Tree map is one kind of visualisation that depicts large tiered datasets using a space-filling technique (Shneiderman & Wattenberg, 2001). Normally, size comparison visualisation such as pie graph or tree map is not recommended to use in the dashboard. However, for exploration purpose users need to have access to a lot of information in a single view, and tree map is able to do that, provided interactivity in the form of label caption. It is suitable for depicting quantitative attribute, in this case number of flights within a day. The advantage of tree map is it can consists multiple attributes other than number of flights such as aircraft size, airlines, aircraft type/model, flight type, and region of origin/destination (Figure 4-12). The individual boxes represent aircraft model for each airlines in each aircraft size category. The size of the box represents how many flights of that particular aircraft model. The colour represents region of origin/destination.

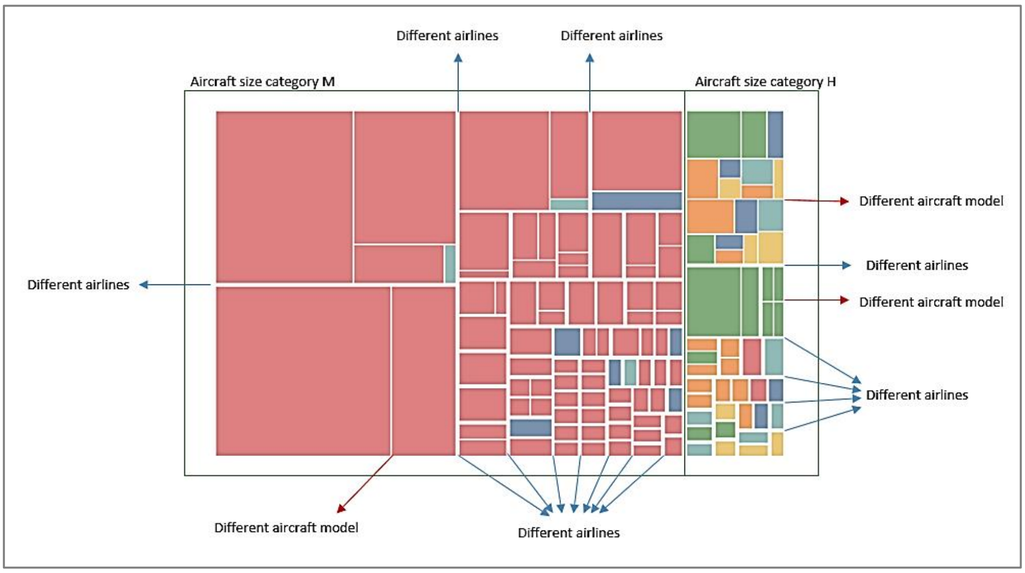
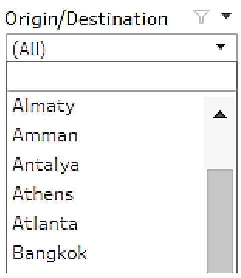


Figure 4-12: Tree map of various attributes of flights in 17 December 2016, as visual representation of attribute

4.4.3. Interactivity

As mentioned in section 3.2.2, interactivity is necessary in strategic and analytic type of dashboard. It lets users to do further exploration. Types of interactivity that used in this dashboard are related to attribute and map interactivity. Attribute interactivity (Figure 4-13a) includes filtering and highlighting, that can be incorporated using drill down box. Map interactivity (Figure 4-13b) includes zoom in/out, pan, and selecting feature on the map. Caption label feature is used as well to display information without cluttering the view.



a. Drill down box to provide filtering and highlighting

b. Zoom in/out, pan, and selection interactivity

Figure 4-13: Types of interactivity that used in this dashboard related to: a. attributes interactivity; b. map interactivity

4.5. Summary

This chapter started with visualisation approach for spatio-temporal data, then built up a conceptual model for dashboard environment. There are two kind of dashboard that has designed based on visualisation style, general with single style visualisation and adaptive with multiple styles of visualisation. Sundry visualisations that used in the dashboard were incorporated based on their characteristics and coherence with space time attribute data. Implementation of the dashboard are covered in the next chapter.

5. IMPLEMENTATION

5.1. Introduction

This chapter explains about how the dashboard being implemented based on conceptual design that has been proposed in Chapter four. It covers the tools, brief data preparation, and the dashboard prototype.

5.2. Tools

As mentioned in Chapter one, there are at least three options of tool to be used for designing dashboard. They are D3.js (Bostock, 2015), Carto (www.carto.com, 2016), and Tableau (www.tableau.com, 2003). This section covers a comparison between aforementioned tools, and reasoning what tool that used in this thesis. Table 5-1 summarised comparison between D3.js, Carto, and Tableau.

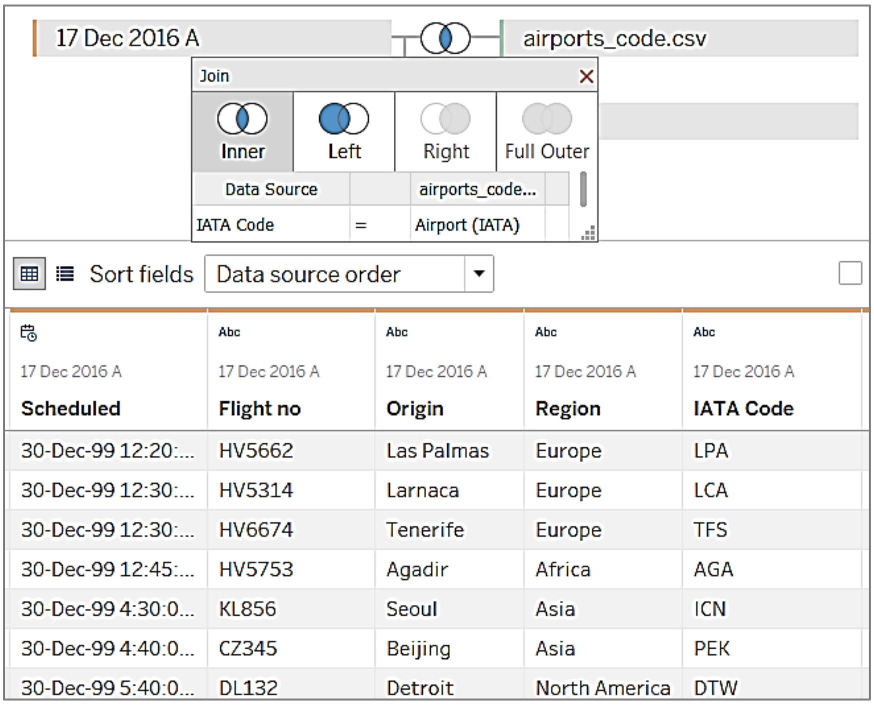
Table 5-1: Comparison between D3.js, Carto, and Tableau

Parameters	D3.js	Carto	Tableau
Platform	Web	Web	Web
Interface	Script code, a library of javascript	Web based GUI	Web and Desktop GUI
Price	Free	Free	Free for public version Free for desktop student version
Visualisation	Flexible	Limited to what available in the package	Limited to what available in the package
Time to learn (relatively)	Long	Short	Short
Resources	Abundant	Moderate	Abundant
Data integration	Broad	Moderate	Moderate

Tableau has advantages in term of time invested to learn and richness of functionalities. It was specifically produced to design dashboard as a business analysis tool, after all. In terms of flexibilities for visual representations, it is still limited compared to D3.js. However, the dashboard that meant for this research does not required much complexities. Resources to learn Tableau also widely available compared to Carto. Based on those considerations, Tableau was chosen in this research.

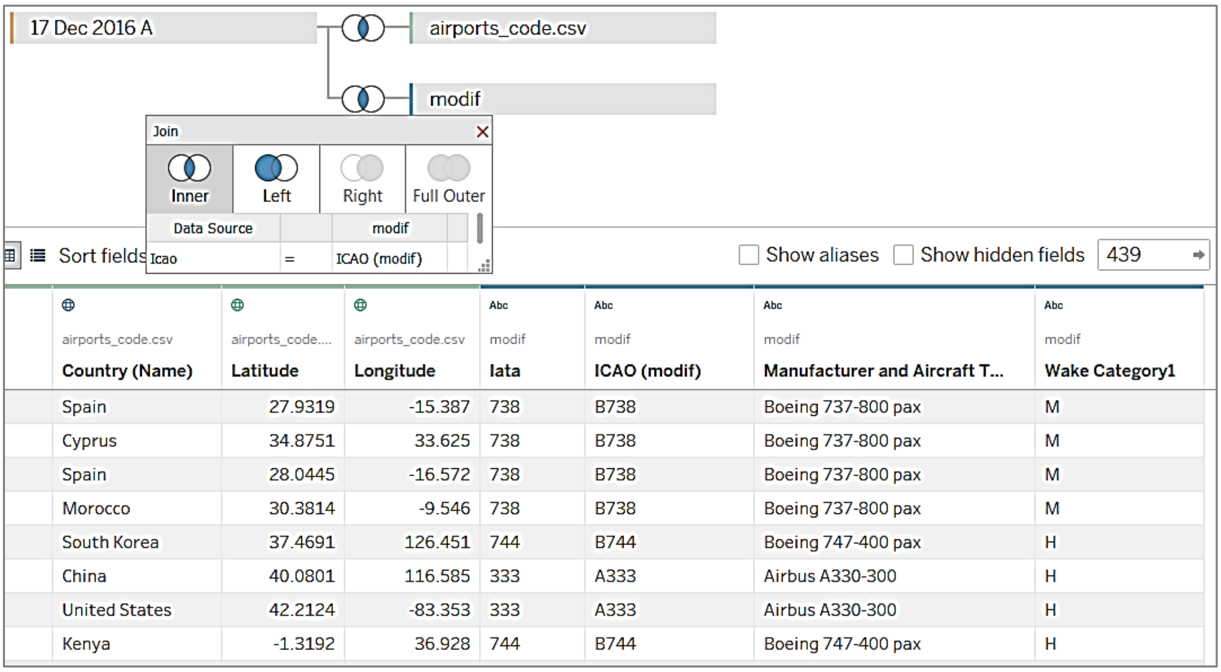
5.3. Data preparation

As briefly explained in chapter four, this thesis uses annual data (flights, passengers, and cargo 2006-2015), monthly data, and one day flights data (17 December 2016). The annual and monthly data were downloaded as PDF, and have to be converted into excel format that compatible with Tableau. Similar treatment also applied to one day data. It was derived by copy and paste from the website into spreadsheet. This process was easy but consumed quite a lot of time for tidying up the spreadsheet format so that it complies with Tableau. Both data from annual report and one day data do not have information of airport's coordinate. They have to be jointed from external data using airport code as joint parameter (Figure 5-1). The one day data has information about aircraft type but only the ICAO code. To get further information such as aircraft type/manufacturer and aircraft size, it has to be jointed as well with external data using ICAO code as joint parameter (Figure 5-2).



17 Dec 2016 A Scheduled	17 Dec 2016 A Flight no	17 Dec 2016 A Origin	17 Dec 2016 A Region	17 Dec 2016 A IATA Code
30-Dec-99 12:20:...	HV5662	Las Palmas	Europe	LPA
30-Dec-99 12:30:...	HV5314	Larnaca	Europe	LCA
30-Dec-99 12:30:...	HV6674	Tenerife	Europe	TFS
30-Dec-99 12:45:...	HV5753	Agadir	Africa	AGA
30-Dec-99 4:30:0...	KL856	Seoul	Asia	ICN
30-Dec-99 4:40:0...	CZ345	Beijing	Asia	PEK
30-Dec-99 5:40:0...	DL132	Detroit	North America	DTW

Figure 5-1: Joint operation between one day data (17Dec2016A) and airport data (airports_code.csv) to get coordinate information using IATA code as joint parameter



airports_code.csv Country (Name)	airports_code.... Latitude	airports_code.csv Longitude	modif Iata	modif ICAO (modif)	modif Manufacturer and Aircraft T...	modif Wake Category1
Spain	27.9319	-15.387	738	B738	Boeing 737-800 pax	M
Cyprus	34.8751	33.625	738	B738	Boeing 737-800 pax	M
Spain	28.0445	-16.572	738	B738	Boeing 737-800 pax	M
Morocco	30.3814	-9.546	738	B738	Boeing 737-800 pax	M
South Korea	37.4691	126.451	744	B744	Boeing 747-400 pax	H
China	40.0801	116.585	333	A333	Airbus A330-300	H
United States	42.2124	-83.353	333	A333	Airbus A330-300	H
Kenya	-1.3192	36.928	744	B744	Boeing 747-400 pax	H

Figure 5-2: Joint operation between one day data (17Dec2016A) and aircraft information (modif) data to get aircraft size and aircraft type information using ICAO code as joint parameter

5.4. Prototype of the dashboard

After the data being prepared in previous section, this section explained about the prototype of the dashboard. In general, this dashboard is designed to get insights from Schiphol Airport data. It contains representation of various types of data such as number of flights, number of passengers, and amount of cargo (in tonnes) to Schiphol within the period of ten years. To add more details, monthly data and daily data are also added with their own specific attribute characteristics. This dashboard has a feature with which the user can browse a different visual representation depending on the nature of a questions s/he has. This is done by choosing from space, time, or attribute buttons. This thesis opined such feature as being "adaptive".

5.4.1. Sitemap of the dashboard

The first step to be done was designing a sitemap of the dashboard. It shows structure of the dashboard and connectivity of each page. As structured in Chapter four (Figure 4-2), it was decided that there are seven interconnected pages in this dashboard. The connection of those pages are shown in Figure 5-3. The general dashboard has three data to visualise: flight, passengers, and cargo. Flights was chosen as the landing page or Home page of the dashboard based on argument "if there are no flights then there will be no passengers or cargo". From all general dashboard pages users can access to adaptive dashboard pages. However, from adaptive dashboard pages users can only access home page.

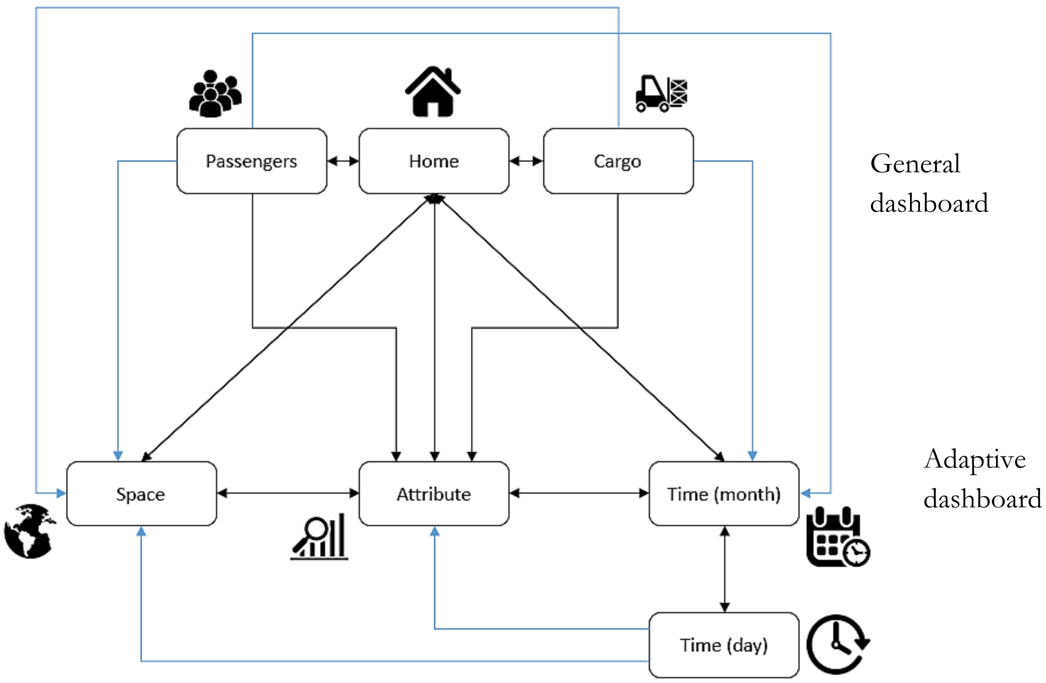


Figure 5-3: Sitemap of the dashboard to depict interconnectivity of the pages

5.4.2. List of buttons and pages

As mentioned before, this dashboard has general and adaptive feature with respect to space time attribute questions. General dashboard has three pages of different data with similar visualisations, while adaptive dashboard has three pages of similar data with different visualisations. Overall, this dashboard has seven dashboard pages and one information credit page. The icons of the buttons were obtained from www.flaticon.com under Creative Commons License (creativecommons.org, 2017). The list of buttons and pages of the dashboard is summarised in Table 5-2.

Table 5-2: List of buttons and pages along with explanation of their role

Button and Page		Explanation
		Data category button (data from Annual Report), general dashboard
	Home	Navigate to main dashboard with data about flights to Schiphol 2006-2015 Visualisation: proportional point symbol map, line graph, bar graph Serves as home/landing page
	Passengers	Navigate to dashboard with data about passengers to Schiphol 2006-2015 Proportional point symbol map, line graph, bar graph
	Cargo	Navigate to dashboard with data about cargo to Schiphol 2006-2015 Visualisation: proportional point symbol map, line graph, bar graph
		Questions related button (additional data monthly and hourly), adaptive dashboard
	Space	Navigate to dashboard with spatial related questions (where), flights from/to Schiphol, and connected **airports** on 17 December 2016 Visualisation: **flow map**
	Attribute	Navigate to dashboard with attribute related questions (what), dig further to **airlines, aircraft model/type and aircraft size** Visualisation: tree map
	Time (monthly)	Navigate to dashboard with time related questions (when), **monthly data of number of flights and passengers from 2006-2015** Visualisation: heat map table
	Time (hourly)	Navigate to dashboard with further granularity of time related questions (when), all **exact time** of flights to/from Schiphol on 17 December 2016 Also featured **airlines, origin/destination, flight's no.** Visualisation: dot graph *Only appear in Time (monthly) page*
		Other buttons
	Info	Navigate to information page, credit of the data and icons used in this dashboard

5.4.3. Working environment

The dashboard was built in Tableau Desktop environment. The version that was used is Tableau 10.0 student edition. In this environment, a dashboard is a collection of one or several visualisation(s). Related visualisations were created with respect to their data. The flow of designing dashboard is shown in Figure 5-4. Although limited, visualisation options that available in Tableau are surprisingly attractive. The choices of visualisation as conceptually designed in chapter four were being implemented. Those visualisations then grouped into dashboard page as explained in the previous section. Home page (flights) (Figure 5-5), Passengers page (Figure 5-6), and Cargo page (Figure 5-7) are part of general dashboard. Space page (Figure 5-8), Attribute page (Figure 5-9), and Time (monthly, see Figure 5-10; hourly, see Figure 5-11) pages are adaptive feature of the dashboard.

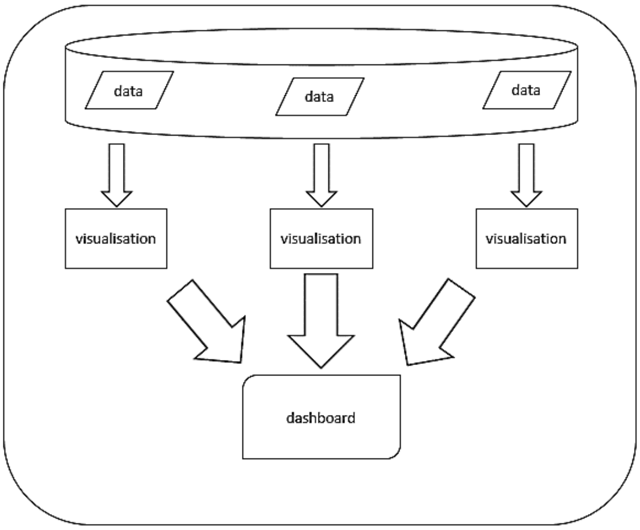


Figure 5-4: Flow of designing dashboard in Tableau

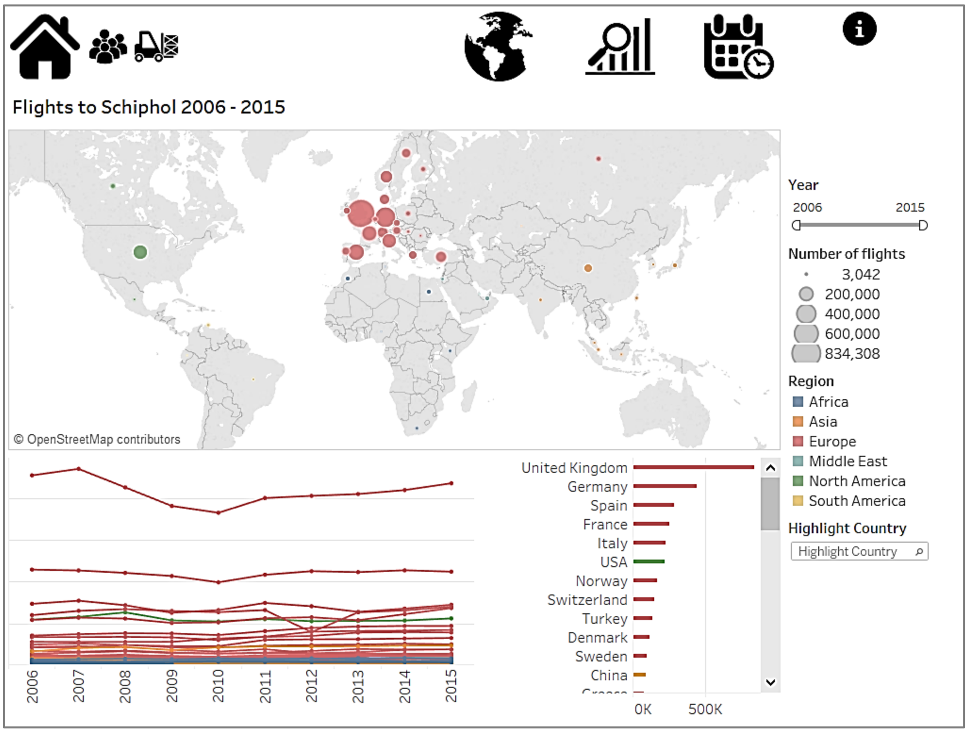


Figure 5-5: Home page of the dashboard, shows flights to Schiphol 2006-2015 data, part of general dashboard

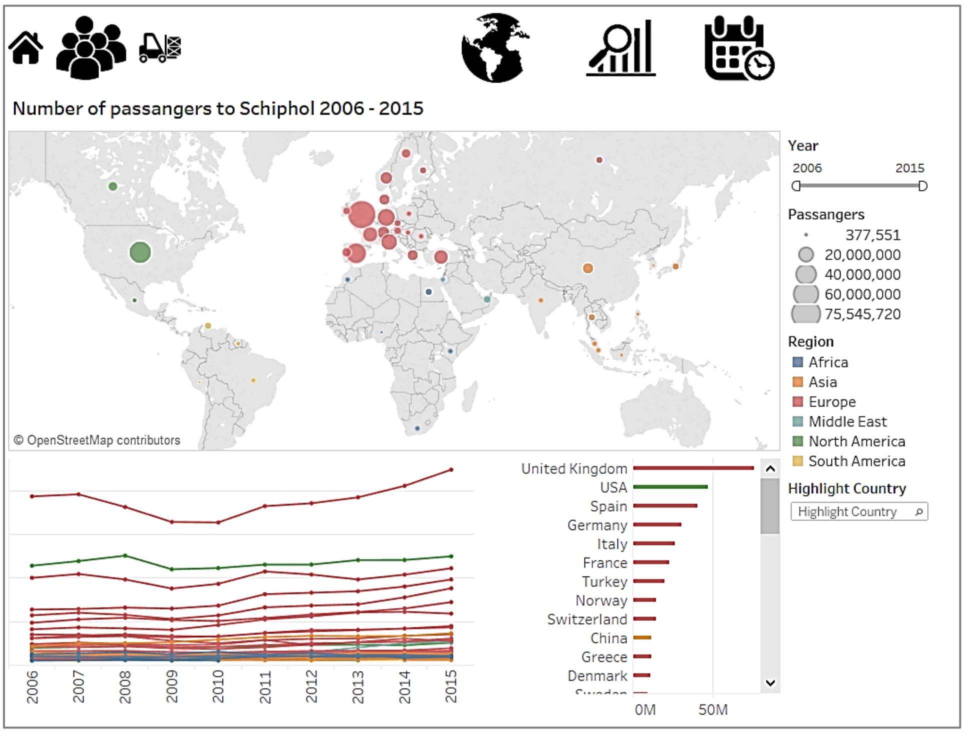


Figure 5-6: Passengers page, shows passengers to Schiphol 2006-2015 data, part of general dashboard

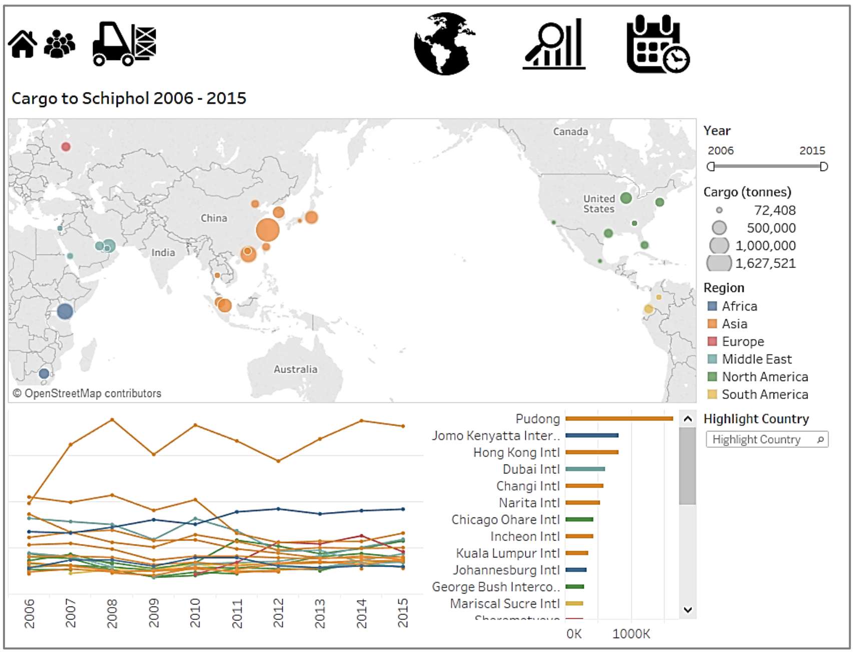


Figure 5-7: Cargo page, shows cargo to Schiphol 2006-2015 data, part of general dashboard

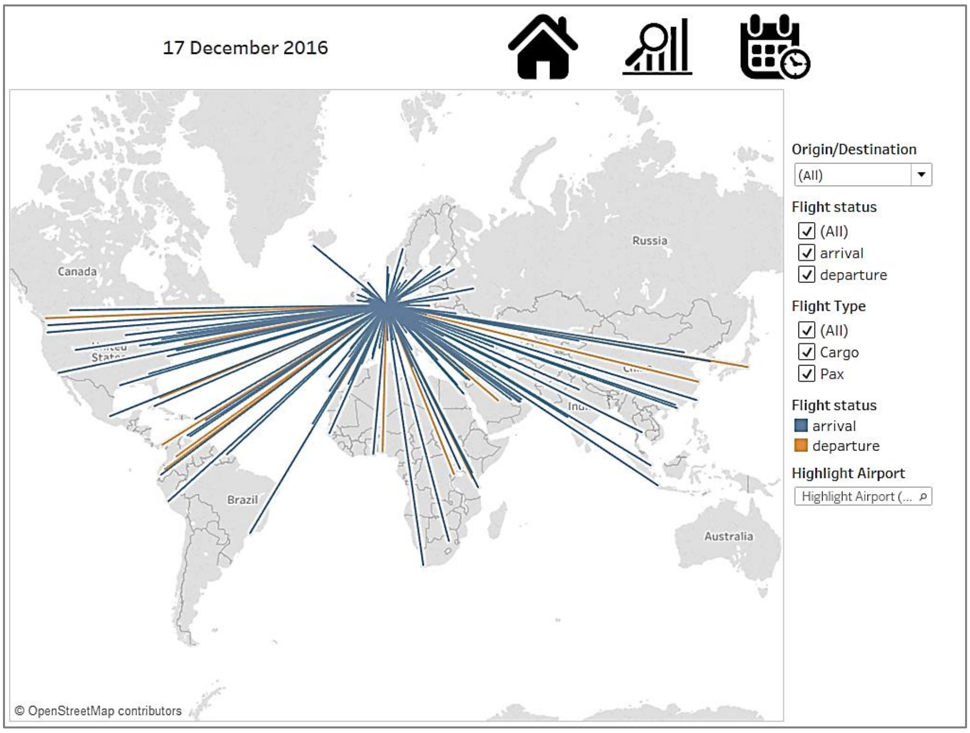


Figure 5-8: Space page, shows route of flights to/from Schiphol on 17 December 2016, adaptive dashboard related to WHERE questions

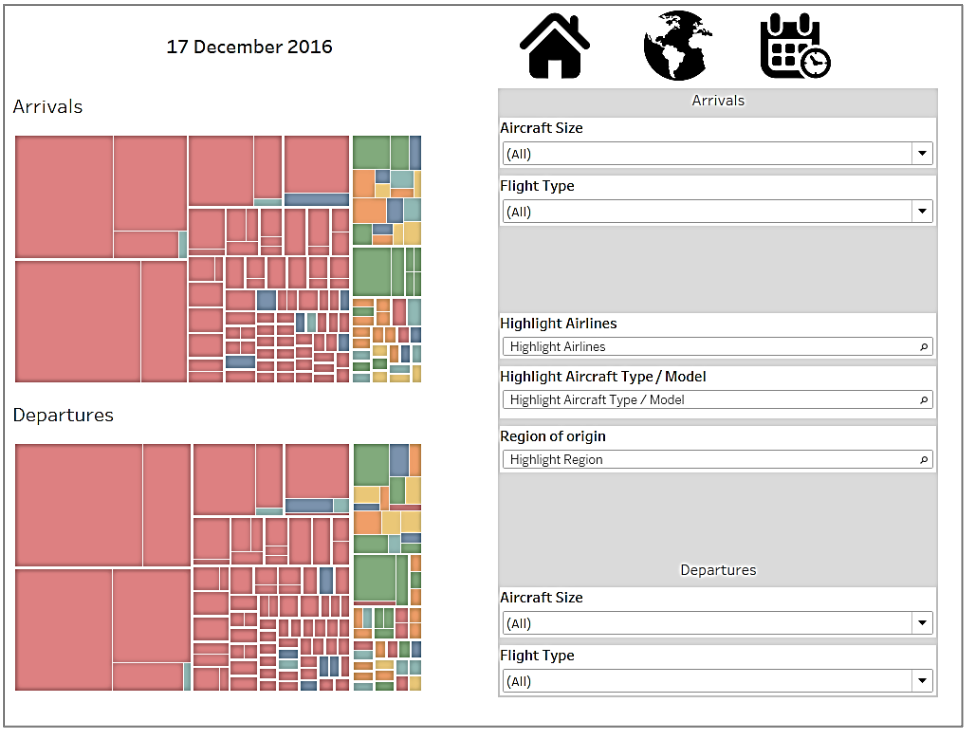


Figure 5-9: Attribute page, shows various information of flights to/from Schiphol on 17 December 2016, adaptive dashboard related to WHAT questions

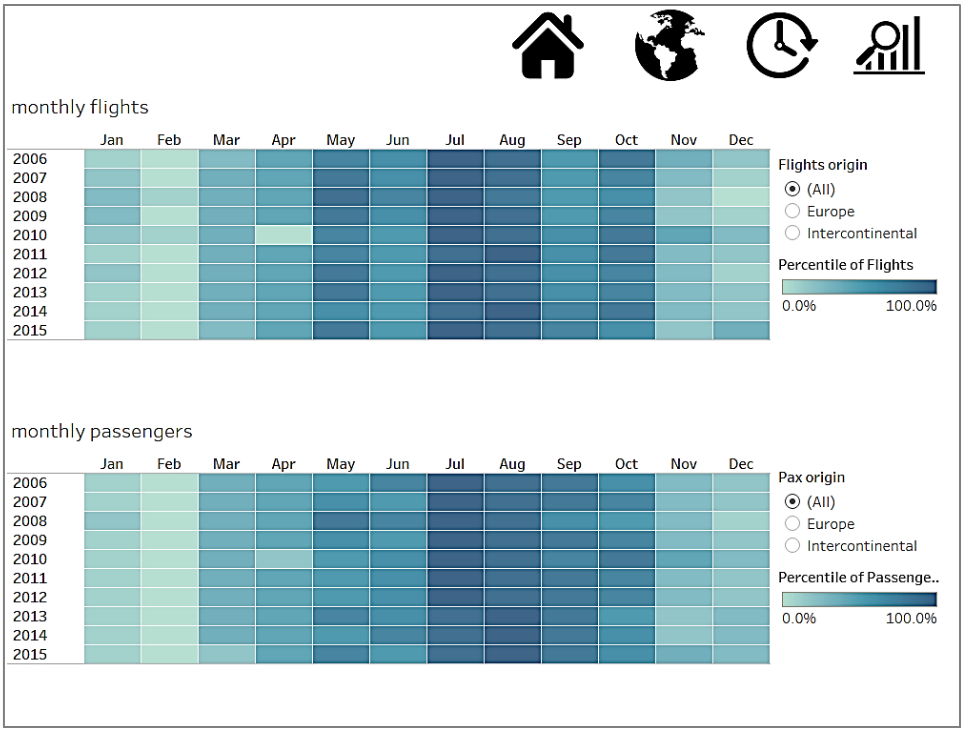


Figure 5-10: Time (monthly) page, shows number of flights and passengers to Schiphol on a monthly basis from 2006 to 2015, adaptive dashboard related to WHEN questions

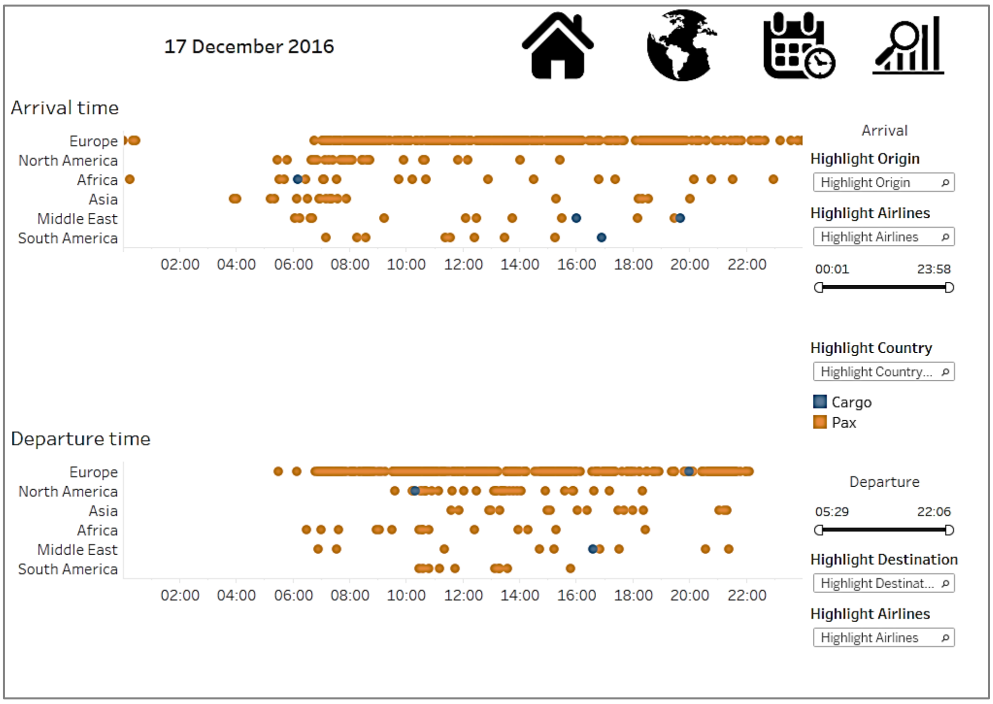
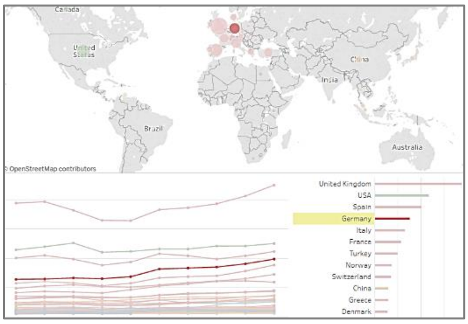
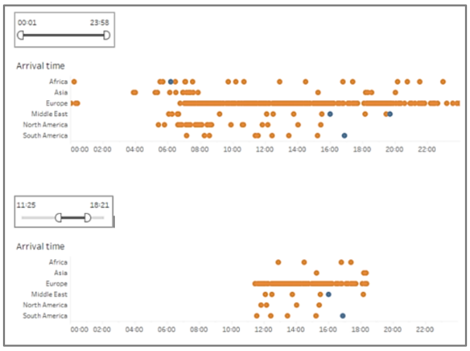


Figure 5-11: Time (hourly) page, shows time of arrival/departure of all flights to/from Schiphol on 17 December 2016, adaptive dashboard related to WHEN questions

5.4.4. Functionalities

Several functionalities are implemented in this dashboard to reduce clutter and provide easier way to understand the data. They also add interactivity to some degree as it is a common feature in digital interface nowadays. Interactivity is also needed to let users exploring the dashboard further as explained in Chapter four. Those functionalities are summarised in the following Table 5-3:

Table 5-3: Summary of functionalities that used in the dashboard

Functionality		What it does
Label caption		When mouse pointer hover on the symbol it displays a popup caption with relevant information
Highlighting		Brushing and linking functionality, when one symbol is selected another linked symbols are also selected
Filtering		Users can select certain information to be displayed and omit others that they don't want

5.5. Summary

This chapter explains how conceptual design from Chapter four being implemented using the chosen tool. The schema of creating dashboard using this tool was also explained. Specific visualisations were created and then combined to create a dashboard page. Those dashboard pages then interconnected each other as such to provide adaptive feature of the dashboard. Functionalities were implemented as well to provide interactivity. The evaluation of the dashboard prototype is discussed in the next chapter.

6. EVALUATION

6.1. Introduction

This chapter explains about usability test to evaluate the dashboard prototype that has been designed in chapter four and instigated in chapter five. The main aspects of the dashboard that were evaluated are effectiveness, efficiency, and satisfaction (www.iso.org, 1998). The effectiveness and efficiency aspects are related to adaptive feature of the dashboard, while satisfaction related more to dashboard's overall design.

6.2. Setup of evaluation

As mentioned in Chapter one, qualitative method was used to evaluate the dashboard. Several techniques of qualitative evaluation are focus group, interviews, observation, thinking aloud, questionnaires, screen log recording, eye tracking, and task analysis. Qualitative analysis can be performed by combining aforementioned techniques. In her thesis, Kveladze (2015) combined think aloud, eye tracking, screen action, video/audio recording, and user interview to analyse Space-Time-Cube visualisation. This method was applied in this thesis as well, with some modifications. Another reason for using qualitative method was also due to time limitation constraint in this research. The evaluation using eye tracking device only used for gaze recording method, which is generally qualitative. Other metric features such as area of interest, gaze plot, and heat map were not generated. This, however, corroborates the argument by Pernice & Nielsen (2009) who stated that heat map often misleading when used for dynamic pages, as this dashboard prototype is. Nevertheless, if the full-fledged eye tracking analysis device is available, as well as time allocation and other resources, Pernice & Nielsen (2009) were in favour of using both quantitative and qualitative analysis.

The test was held in Usability Laboratory of GIP Department (room 1066 of ITC) on 26 and 30 January 2017. Eye tracking, task analysis, screen logging, thinking aloud, observation, and interviews were used to evaluate the dashboard. The advantage of this combination is it can be used to find out effectiveness and efficiency of adaptive feature, as well as find satisfaction of the dashboard. By recording gaze, screen action (screen logging), and video/audio recording (observation), effectiveness and efficiency of the adaptive feature can be evaluated. Satisfaction can be discovered by observation and open interview afterwards.

To minimise bias, the procedure to all test participant (TP) has to be similar. Hence, a scenario about how the test will be done was prepared (Appendix 1). Invitation emails (Appendix 2) were also sent to potential TPs, mostly PhD student/staff at Faculty for Geo-Information Science and Earth Observation, University of Twente. In total there were eight test participants. This was sufficient as optimum number of TP for qualitative eye tracking analysis (gaze recording) is six (Pernice & Nielsen, 2009). Two other TP's test results served as contingency plan in case something wrong with other results. Thus, there are eight different sessions of task analysis with eight test participants. On recording the task analysis process, the code names given to participants are TP01 to TP08.

6.2.1. Profile of test participants

As mentioned earlier, there were eight test participants for this test. All of them are PhD student/staff at Faculty for Geo-Information Science and Earth Observation, University of Twente. Since the intended users of this dashboard are readers of annual report, in general everyone is eligible for this test. However, having PhD students as test participants is an advantage since they are more exposed to research and accustomed to give critical opinion. Out of eight TPs, six of them have master degree in Geography or Geo-Information Science. One of them has degree in Cartography and another one in Climate Science and Policy. Four TPs have never worked with dashboard environment before, two TPs have, and the other two were not sure. In the past five years, three TPs have travelled by plane more than ten times, and the other four have travelled five to ten times. One TP have travelled by plane less than five times in the past five years.

6.2.2. Task analysis

Task analysis is the method where participant asked to do several tasks regarding the object of the test, in this case the dashboard, while his/her behaviour being recorded and/or observed. Prior performing the task analysis, participants were asked to fill their information details (Appendix 3). That information is used for making profile of participant that later incorporated as one of factors to determine the result. Introduction documents (Appendix 4) and additional guidance (Appendix 5) of the dashboard were also provided in print. Participants need to familiarise themselves with the dashboard. This was done by doing several guided tasks that intended to give participants the notion of what to be expected from the dashboard. They were given a specific role that related with temporal OD-data of Schiphol Airport in order to be more engaged with the tasks (Appendix 6). In this case, they were asked to be a student whose uncle is a stock holder in Schiphol Airport and interested into getting insights for his shares. As participant getting familiar with the dashboard, he/she went further to do the actual tasks that meant to get insights from the data. This whole process was recorded using eye tracking device and video/sound recorder (Figure 6-1). During this process participants were asked to speak out loud when they find something peculiar, either good or bad.

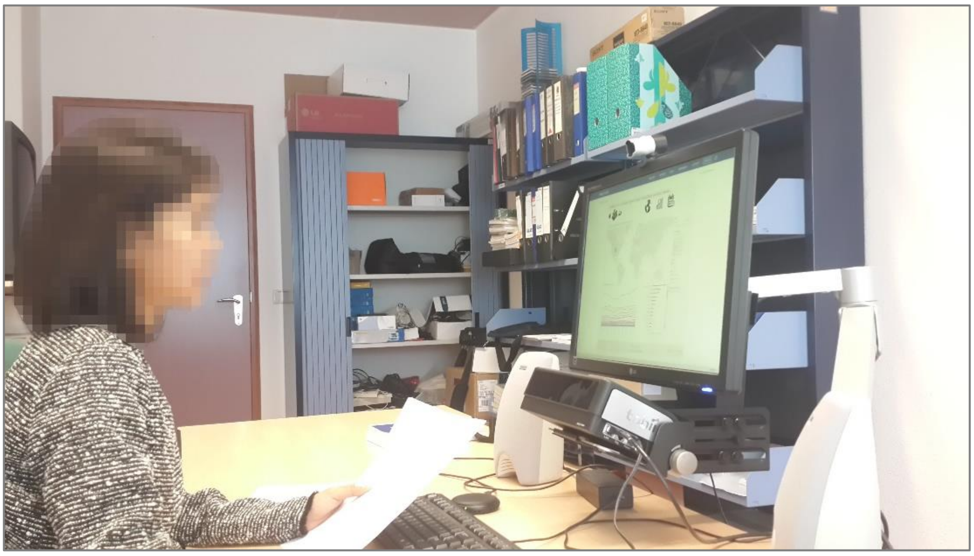


Figure 6-1: TP02 during task analysis session being recorded using eye tracking device, camera, microphone, and screen logging

Initially the task questions were grouped into the same category (space with space, time with tine, and attribute with attribute). However, since the purpose of this analysis is to find out whether user could answer spatio-temporal questions effectively and efficiently or not, the order of questions was then randomised. There are 12 actual tasks to be done by participants for this analysis which related to spatial attribute time (SAT) type of questions as listed in Table 6-1.

Table 6-1: List of spatial attribute time questions that used during task analysis with their respective intended page to solve

No	Tasks	Related SAT questions	Intended page	Expected way(s) to solve
1	How many flights to Schiphol from USA in 2009?	What: Attribute	Home	Point symbol map Line graph
2	How much cargo from Narita Intl Airport (in Japan) was transported in 2015?	What: Attribute	Cargo	Point symbol map Line graph
3	Where do you think the farthest route of cargo flight from Amsterdam in the example day?	Where: Space	Space	Flow map
4	After 18:30, is there any British Airways flights depart from Schiphol? If yes, how many?	When, Whether: Time	Time (hourly)	Dot graph
5	How many passengers arrived at Schiphol from Germany in 2010?	What: Attribute	Passengers	Point symbol map Line graph
6	Looking at monthly flights pattern to Schiphol, could you guess the holiday season in The Netherlands?	When: Time	Time (monthly)	Heat map table
7	At what time do the majority of flights from Asia arrive to Schiphol? (morning, afternoon, or evening)	When: Time	Time (hourly)	Dot graph
8	How many flight routes between London and Amsterdam?	What, Where: Space	Space	Flow map
9	Which month has the highest number of flights in 2010?	When: Time	Time (monthly)	Heat map table
10	How many Vueling flights departed from Schiphol in the example day?	What: Attribute	Attribute	Tree map
11	Is there any flight from Asia or Americas that has Aircraft Size category M (medium)?	Whether: Attribute	Attribute	Tree map
12	How many Fokker 70 aircraft type arrived in Schiphol in the example day?	What: Attribute	Attribute	Tree map

6.2.3. Open interview

After participants finished with the tasks, they were asked regarding their experience with the dashboard in an open interview. This is a structured interview as the same pre-determined questions were asked in the same order. The advantage of structured interviews is comparability of data is more guaranteed due to its repetitiveness (van Elzakker & Wealands, 2007). The list of interview questions is the following:

a) How's your impression of the dashboard?
b) Which task that most difficult to do according to you? Why?
c) Could you easily determine where (which page) to find the answer for each task?
d) Which visualisation that you think easy to understand, which one that is difficult?
e) What's your suggestion for this dashboard?

These sessions were recorded as well, and participants could mention and point out some part of the dashboard that was notable for them. Their answers were used to determine satisfaction with the dashboard, such as which feature should be improved, which symbolisation they like most, which symbolisation that hard to decipher, etc. Using this procedure, this interview provides a lot of feedback regarding design and functionalities of the dashboard.

6.3. Results

How the test situation was going are somewhat mixed. Although supplementary documents were provided, some test participants preferred not to read the introduction document or make use of additional guidance. Similar thing also happened with thinking aloud. Participants were asked to speak out their thought only when they find the answer or something noticeable, while thinking aloud for the whole process is optional. However, some test participants feel comfortable with thinking aloud and took initiative to do that, while others just simply think aloud when finding an answer. The behaviour of all test participants during the test are summarised in Table 6-2.

Table 6-2: Summary of test participants' behaviour during the test regarding think aloud and use of additional documents

Test participants	Think aloud performance	Use additional guidance since the beginning
TP01	Moderately, mostly when find the answer	Yes
TP02	Rarely, only when find the answer or confused	Yes
TP03	Rarely, only when find the answer or confused	Yes
TP04	Rarely, only when find the answer	No
TP05	Almost all the time	No
TP06	Almost all the time	No
TP07	Almost all the time	No
TP08	Rarely, only when find the answer	No

6.3.1. Task analysis result

During the test, several parameters were taken into note as well: correctness of the answers, time spent to finish the tasks, and whether TPs went to intended page or used expected way to find the answers. Those parameters were double-checked by watching the screen and video recording after the test. Correctness of the answers is related to the effectiveness, while time spent to do the tasks is related to efficiency. Intended page where TPs go is related to adaptive feature. It was used to determine whether space time attribute type of questions are helping user to explore further (see Figure 5-3 and Table 6-1). The expected way of users to find the answers was used to consider whether the related visualisations were effective or not to display spatio-temporal data. If TP went directly to the intended page, or at least finally reached there, and find the answer using the expected way there, it is assumed that the adaptive feature is working.

Effectiveness

Effectiveness related to whether the dashboard is useful as it was intended or not. By looking at dashboard sitemap in Figure 5-3, users were expected to go to page Space, Attribute, or Time (yearly/hourly) when asked questions related to space, attribute, or time respectively. Table 6-3 summarises the result of task analysis that have been conducted in this stage. Out of 12 tasks, task 3 and task 10 did not get any parameters that reach 100%. The majority of TPs even did not start at their respective intended pages. This might be because of the question that was asked a bit vague, i.e. in task 3 "*Where do you think the farthest route of cargo flight from Amsterdam in the example day?*" it includes "cargo" that made TPs went to "Cargo page" instead of "Space page". Another space related task is task 8 "*How many flight routes between London and Amsterdam?*" which in the contrary has 100% for all aspects. TPs were naturally "directed" to Space page by the word "flight routes" (Figure 6-2). Hence it seems the problem was in the wording of the questions after all. However, task 10 "*How many Vueling flights departed from Schiphol in the example day?*" has the lowest percentage for all parameters and only 1 TP who managed to go to intended page immediately. It seems because airlines attribute (i.e. Vueling) was also available in another page, in this case Time (hourly). Hence, this situation made TPs tend to go to that page. There were only three TPs who found the answer as expected using tree map, others went to Time (hourly) page and ended up using dot graph to do task 10 (Figure 6-3).

Table 6-3: Summary of task analysis result regarding to effectiveness of the dashboard

Task	Related SAT questions	Percentage of TP who				Visualisation(s)
		found correct answers	started in intended page	ended in intended page	used expected way	
1	What: Attribute	87.5	37.5	100	100	Proportional point symbol map, line graph, bar graph, timeline
2	What: Attribute	87.5	100	100	100	Proportional point symbol map, line graph, bar graph, timeline
3	Where: Space	75	25	75	62.5	Flow map
4	When, Whether: Time	100	50	100	100	Dot graph
5	What: Attribute	87.5	25	100	100	Proportional point symbol map, line graph, bar graph, timeline
6	When: Time	100	87.5	100	100	Heat map table
7	When: Time	100	87.5	100	100	Dot graph
8	What, Where: Space	100	100	100	100	Flow map
9	When: Time	100	75	100	100	Heat map table
10	What: Attribute	62.5	12.5	37.5	37.5	Tree map
11	Whether: Attribute	100	87.5	100	100	Tree map
12	What: Attribute	87.5	75	100	100	Tree map

Regarding with whether TP start in intended page, average percentage for all tasks (general and adaptive dashboard) is 63.54% and for adaptive feature dashboard pages is 66.67%. This low percentage might be because users hardly remember which button refers to which page since they are not always available in the top menu. TP05 pointed it out during the test, said "*It's a bit complicated to access these (pages), I mean the hierarchy of the levels. You have so many 'views', so to say, why don't you put all of them in the home?*" which somehow explains the situation. However, as shown in percentage of TPs ended in intended page, majority of the TPs knew which page they should go, they just temporarily didn't remember how to get there. As for effectiveness of visualisations, almost all of them are properly incorporated as average percentage of TPs used expected way is 91.67%.

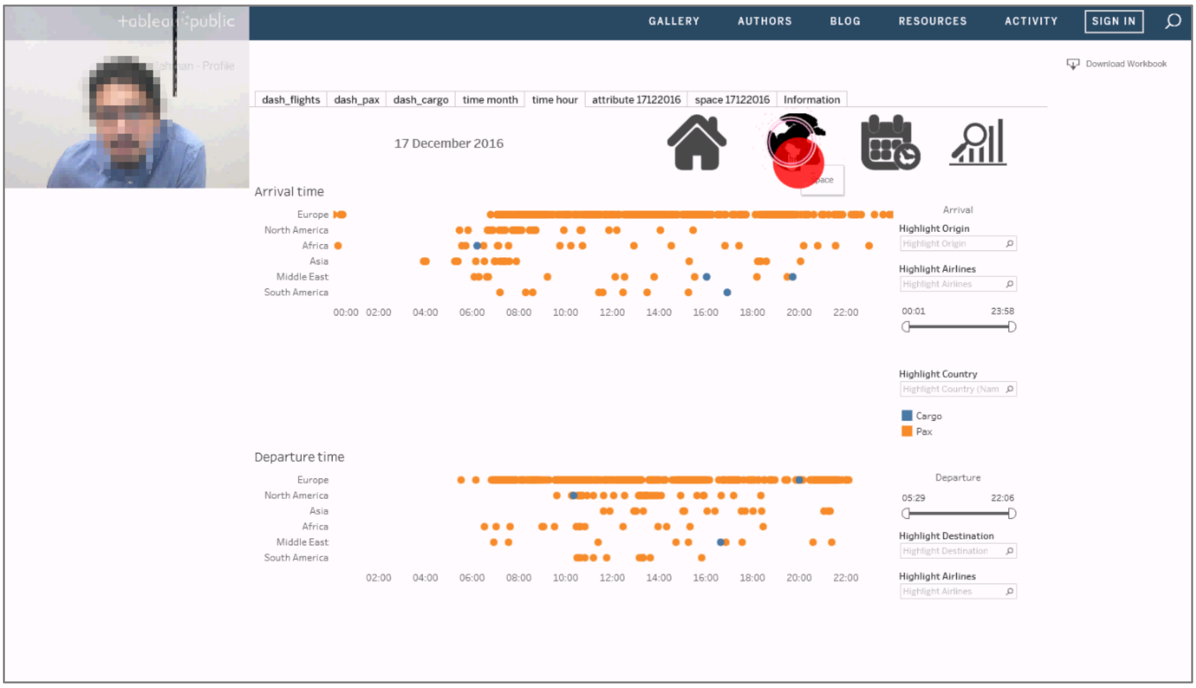


Figure 6-2: TP08 spotted Space page (have eye gazing indicator, the red circle, on the Space page icon) to finish task 8

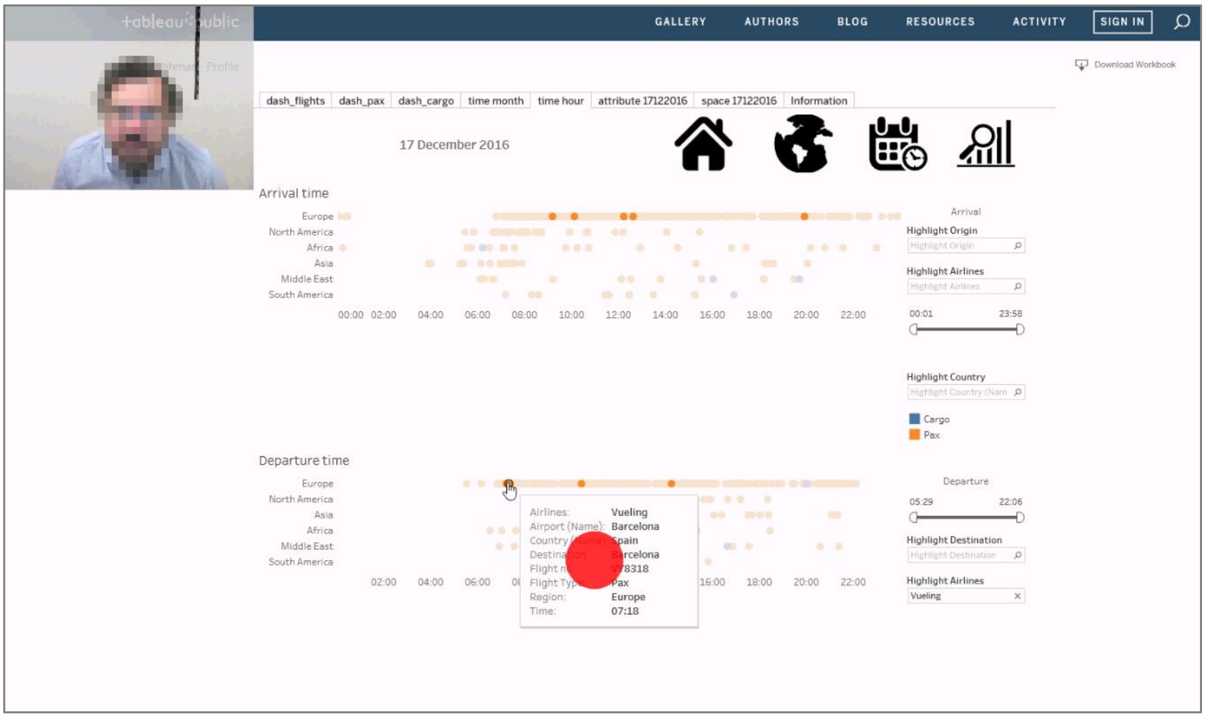


Figure 6-3: TP06 using dot graph to find the answer for task 10, which was unexpected

Efficiency

Efficiency related to "cost" to do certain task. In this context, time that spent to do the tasks. As shown in the Table 6-4, task 2, task 6, and task 9 are relatively quick to finish (under one minute). Since two of them involving heat map table, it can be assumed that heat map is quite efficient in visualising time. Task 5 appears to be the least efficient since in average it took more than three minutes to finish. However, looking back for each TP's time, it is shown that TP03 and TP07 were taking extremely longer time compared to other TPs (more than six minutes). It seems both of them were confused about the data in that page.

Table 6-4: Summary of time spent by TPs to finish the tasks, along with their average values

Task	Related SAT questions	Time spent by TPs (second)								Average time spent (second)	Visualisation(s)
		01	02	03	04	05	06	07	08		
1	What: Attribute	186	295	71	227	27	58	279	62	150.625	Proportional point symbol map, line graph, bar graph, timeline
2	What: Attribute	85	24	50	41	29	38	70	62	49.875	Proportional point symbol map, line graph, bar graph, timeline
3	Where: Space	311	147	96	64	86	203	299	225	178.875	Flow map
4	When, Whether: Time	42	237	109	112	84	35	214	340	146.625	Dot graph
5	What: Attribute	83	41	504	212	92	93	415	69	188.625	Proportional point symbol map, line graph, bar graph, timeline
6	When: Time	20	17	22	31	63	21	138	48	45	Heat map table
7	When: Time	68	97	55	200	44	83	215	122	110.5	Dot graph
8	What, Where: Space	201	72	83	63	47	44	106	64	85	Flow map
9	When: Time	42	23	77	31	52	23	108	42	49.75	Heat map table
10	What: Attribute	328	51	101	75	50	60	280	97	130.25	Tree map
11	Whether: Attribute	182	27	54	45	62	101	85	273	103.625	Tree map
12	What: Attribute	41	58	26	70	19	65	108	190	72.125	Tree map

Other visualisations like dot graph and tree map were not so awful either. Dot graph are relatively okay, with average time to finish was around two minutes. In previous section it was mentioned that task 10 (which involves tree map) had low percentage in term of effectiveness. However, as also mentioned earlier, this was more because TPs did not manage to reach intended page. Once they used tree map they can find the answer within less than two minutes. Further discussion on tree map are in the next section about interview feedback, since TPs revealed they have somewhat mixed feeling about it during interview session.

6.3.2. Interview feedbacks

Interview sessions gave more in-depth suggestion as TPs have already used the dashboard prototype. General feedbacks about the dashboard are mixed as well. One feedbacks that particularly "extreme" came from one participant, "*I came from social science, reading data is easier for me than looking at graphic stuffs. OK, it's not easier, but I feel safer*". He also mentioned that, "*for (data analysis) expert there is no need visualisation, and for layman maybe show less data*". Another participants also opined, "*Questions for task analysis not really following the story, and a dashboard should be on a case basis instead of general purpose*". Nonetheless, there are also participants who said, "*The minute you open (the dashboard) it gives you feeling to explore*". Another participants also said that, "*it's a nice way of starting to show airport dataset*".

Participants also gave feedbacks regarding what went wrong or what annoyed them when they were using the dashboard prototype. One glitch that still unresolved is sometimes user needs to click the button twice to access relevant page. Another one is inconsistency of line graph in Passengers page, it should be adjusted with respected point symbol in the map, just like in page Home and Cargo. The condition that some features did not automatically reset also irritates some participants. There are also problem with selecting and hovering as mentioned by one participant, "*Selecting any of the views do not keep previous selection*".

There are also plenty of feedbacks regarding the visual design and what improvements that can be done. Regarding the visualisations of space component, generally maps (proportional point symbol and flow map) are well received. For time visualisations, heat map table is generally liked as well. One TP specifically mentioned that, "*it is easy to understand (the trend), I like it*". Dot graph is generally well received, too, although one TP mentioned that it would be better if we can zoom in for the dot map to reduce clutter. As for attribute visualisations, tree map had mixed reaction. General impression is it is not easy to see the information from tree map at the first glance, but when users have got accustomed then it is very useful. One TP mentioned that she was confused about the size of the box. Other, however, likes tree map since it contains a lot of information in one box. Overall advices regarding the dashboard are listed in Table 6-5.

Table 6-5: Summary of overall suggestions by test participants regarding the dashboard prototype

Component	Suggestion
Layout design	Make all buttons always appeared in top of the page
	Put all views in the same hierarchical level
	Put sitemap of the dashboard in the Information page
Data	Add more data especially for hourly data
	Add specific origin destination information for monthly data
Flow map	Make it curved, origin and destination do not overlaid each other
Dot graph	Make it zoom-able to reduce clutter
	Make it interconnected between arrival and departure
Tree map	Put label in addition of colour to represent region for tree map.
	Write "medium" and "heavy" instead of their abbreviation M and H for aircraft size.
	Put legend of what colour of the boxes means.

6.4. Summary

Qualitative method was used to evaluate the dashboard prototype, in this case combination between eye tracking, screen log, video/sound recording, and interview. There were eight test participants, and the test was hold for two days. By conducting the test, information on usability of the dashboard prototype was collected in this research. In general, the levels of effectiveness and efficiency of adaptive feature are sufficient, although not as high as they were expected. There are several suggestions to improve the dashboard as well, either conceptually or technically.

7. CONCLUSIONS

7.1. Conclusions

The general objective of this thesis is to design a dashboard environment to get insight in origin-destination data, particularly of air traffic for airports. To achieve the main objective, five sub-objectives are proposed in the Chapter one. These sub-objectives have their respective questions to be answered by performing this research. This section draws conclusions from previous chapters of this thesis based on the answers of those questions to achieve the main objective and sub objectives.

1. To understand the basics of OD data.

Relevant research questions:

a) *What is OD data?*
b) *How can the spatial, attribute and time component of OD data being visualised?*
c) *What are the problems with those existing visualisation methods?*

Chapter two covers an understanding to the basic of origin-destination (OD) data. It includes definition, visualisations method, and problem with current visualisation methods. OD data is data about movement(s) which connect places and has components of spatial and attribute. There are various ways to visualise spatial and attribute component, amongst the common examples are flow map and OD matrix. As the time component is added, it becomes temporal OD data. While it is relatively simpler to visualise only spatial and attribute components, it becomes more complicated when time dimension is added. To cope with this problem, framework from Peuquet (1994) and approach from Li & Kraak (2010) were used to visualise spatial, attribute, and time components. Using this approach, each component focuses for each own distribution and is connected in the manner of coordinated multiple views (CMV).

2. To understand the characteristics of dashboards.

Relevant research questions:

a) *What is dashboard?*
b) *What are the problems with existing dashboard?*
c) *What role could dashboards play in getting insight of OD data?*

Chapter three reviewed the understanding of dashboard characteristics. A dashboard is a visual interface to the data that present information visually at a glance. Depending on the type, it should be able to allow users to explore the data to some degree. The problem with current dashboards is that they try too hard to look fancy while neglecting to communicate the data to the users. There are at least 13 common pitfalls of current dashboards that has been addressed by Few (2006), which mainly related to effective and efficient communication between data and the users. As for getting insight of OD data, the dashboard can serve as environment to host CMV feature. By incorporating CMV in the dashboard environment, users can explore the data that contained by the dashboard. To perform further exploration with more detailed data, adaptive feature was incorporated as well. It means visual representations of the data changes according to space attribute time related questions by the users.

3. To understand the users and their requirements.

Relevant research questions:

a) *In the context of the application, what kind of question do users have which have to be answered by the dashboard?*

Users of this dashboard are the readers of Schiphol airport annual report, who basically can be everyone. They might be casual reader or airport data enthusiast or even analyst from certain airlines. This dashboard has to be able to address questions by users which related to space attribute time. Those questions were grouped into elementary, intermediate, and overall questions. Elementary questions mostly deal with simple **what/where/when** questions, while intermediate questions deal with **which… has…** questions, and overall questions deal with **what trend/pattern** questions. This process was covered in Chapter four.

4. To develop the conceptual design of the desired dashboard.
Related research questions:
a) *Based on the previous, what information should be represented on the dashboard to allow users answer their questions?*
b) *What kind of dashboard design that suits adaptive feature?*
c) *What kind of graphic representation and functionality are needed?*

In Chapter four, conceptual model for desired dashboard were designed. Information represented in the dashboard are number of flights, number of passengers, amount of cargo, name of airlines, aircraft size, aircraft type, time of arrival, and time of departure. Number of flights information has time component range from yearly to daily. Number of passengers and amount of cargo only have time component yearly and monthly, while the rest information only have time component daily. The dashboard also has adaptive feature, in terms of changing its visualisation based on users' queries related to space time attribute components. To support adaptive feature, the dashboard that designed here is a "two-in-one" dashboard, a general (strategic) dashboard and an adaptive (analytical) dashboard. General dashboard uses yearly data and has at least three different visualisations for space, attribute, time, or combination between those three. On the other hand, adaptive dashboard has three different views which are connected by mutual buttons that act as users' questions gateway (multiple-page dashboard). As for graphic representation, components of spatial, attribute, and time are represented differently. Spatial/space components are represented by flow map and proportional point symbol map. Attribute components are represented by bar graph and tree map. Time components are represented by line graph, time slider, heat map table, and dot graph. All of those visual representations are equipped with interactivity features such as zoom in/out, pan, filtering, highlighting, and selecting.

5. To implement and evaluate the dashboard.
Related research questions:
a) *How to implement the prototype dashboard?*
b) *Which methods and techniques can be used to evaluate the dashboard?*
c) *How to conduct the experiment to evaluate the dashboard?*

Chapter five illustrates implementation processess of the dashboard. It started with selection of tool, data preparation, and actual implementation using the selected tool based on conceptual design from Chapter four. Evaluation process of the dashboard is covered in Chapter six. Given the characteristics of the subject of evaluation (a dashboard, as a digital environment), qualitative method was chosen to evaluate the dashboard. This method combined eye tracking, task analysis, screen log, video/sound recording, and interview. The evaluation process focused on effectiveness, efficiency, and usability issues of the dashboard, particularly dashboard with adaptive feature.

Overall, it can be concluded that dashboard with adaptive feature is applicable to get insight from OD data. The adaptive dashboard could be delivered as single page or multiple pages dashboard. This research delivered prototype of adaptive dashboard with multiple pages. As discovered in evaluation, the delivered multiple-page adaptive dashboard did not really meet the expectation in terms of effectiveness and efficiency. On how this was the case is discussed in the following sub-chapter.

7.2. Discussion/Reflection

This research aims to design an adaptive dashboard, and to know whether adaptive feature of the dashboard is applicable to get insight from OD data. The resulted dashboard prototype was able to explore and get insight from OD data of Schiphol airport as expected. However, in terms of effectiveness and efficiency the prototype did not proceed splendidly as expected. Looking back at the theory, the dashboard prototype design, and the evaluation, there are several things that can be reflected from this research.

Adaptive feature

The original notion of dashboard being adaptive is the dashboard's form will change within a single page to emphasize visualisations based on questions that asked by users. However, due to time and resources limitation, *the change of visualisations* was modified into *change to another page* (multiple-page approach). The original way of addressing questions is even more sophisticated, by providing question box with which users could type their questions instead of simply click button to another page. However that notion is beyond the scope of this research.

Dashboard design

As mentioned in Chapter three, since it has to display prominent information at a glance, by nature, dashboard is not really great at exploring the more detailed data. It is still able to perform exploration, but not too focus, since it will neglecting original purpose of the dashboard. Adaptive feature was added in order to enhance the "exploration ability" of the dashboard with focusing more into changed visualisations. This feature was incorporated by using multiple-page approach. Looking back at Chapter three, the first common pitfall of dashboard design is "exceeding the boundaries of a single screen". By itself the multiple-page dashboard approach has fallen into this trap already. The reasoning to go for multiple-page approach was to provide an adaptiveness in simpler and more direct way. However, although it increases the exploratory aspect, it has downside as it reduces effectivity. There is a risk that the more detailed the exploration ability the more likely the dashboard derailed from original purpose of the dashboard

Visualisations

In Chapter three it was mentioned that to have effective dashboard it is better to avoid using visualisations that show comparison based on angles, area, volume, or colour. In the delivered dashboard, there are several visualisations that fall into those categories, namely heat map table and tree map. As a justification, heat map table uses colour comparison but it did a good job in representing trend. On the other hand, tree map uses area based comparison and did not work as well as heat map table. It did not give information at a glance. Justification of using tree map was it can contain several information, and to do exploration users indeed have to go further than just glancing at the first sight. It corroborates previous reflection that more exploration tend to be less effective and efficient a dashboard.

Data

Initially, the data that was used in this research is only from Schiphol Airport annual report. However, that data is only for incoming to Schiphol, there are no data for leaving from Schiphol. The monthly data that was added later on is also has limitation as it has no actual origin or destination. The one day data has origin and destination, even exact time of arrival/departure. However, those data has no number of passengers' information.

Users intended

Users intended for this dashboard are too general. It is good to have wide range of users in terms of variability. However, if the dashboard is more to be exploratory tools it is better to have specific users.

Feedbacks from evaluation

As explained in Chapter six, particularly Section 6.3, there is a room for technical improvement for this dashboard prototype. Another point of reflection is that the idea of implementing heat map table is generally well received. However, the idea of implementing tree map is still a bit tricky for majority users since it does not really tell any information at the first glance.

7.3. Recommendations and future work

Recommendations for further research are:

a. This research has designed adaptive dashboard with multiple-page approach. As observed in this research, multiple-page approach has a downside since it makes dashboard less effective to read. Hence, for further research it is recommended to focus more on dashboard with adaptive feature with single page approach. Using this approach, the change of visual representation is expected to be taken place in a single page instead of move to another page.
b. Since the variety of data that used in this research is small, wider variation of data are expected for future research. It could be started by adding day data into one week data, and getting actual origin/destination for monthly data.
c. The evaluation process for this dashboard was using modified qualitative method. Suggestion for future research is to do full-fledged usability test to ensure the designed dashboard is indeed what users want.

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APPENDIX 1

Test Scenario

1. Before the test start
   - Arrive 20-15 minutes earlier in the laboratory. Turn on the PC and eye tracker.
   - Open Tobii Studio and do final check of microphone and camera.
   - Make sure the dashboard is loaded in the application.
   - Put the hardcopies in the table.

2. Welcoming test person and introduction
   - Thank you *the test person's name* for coming and welcome. Have a seat.
   - First, please fill this participant's information document
   - This is the introduction document of the dashboard. It explains about structure of the dashboard and the buttons it contains.
   - This is the additional guidance document for specific visualization. You might need it during task analysis.
   - And this is the task analysis document. You are expected to do all tasks written in there using the dashboard that will be loaded on this PC. This test will be recorded for analysis purposes.
   - Make sure you're sitting comfortably.
   - *Set up distance and height of screen accordingly*
   - Do you have any questions? We can proceed to the test.

3. During the test
   - Open the project, insert participant's ID
   - Start eye calibration. Please focus on the screen and follow the red circle. And now, the video recording is starting.
   - Briefly read the introduction document. You can look at it again later if you need.
   - Now, read the instruction in the task analysis document and carry on the tasks to answer questions.
   - First part is to familiarize yourself with the dashboard. Second part is the actual testing for the dashboard. Use the provided additional guidance if you need it.
   - During the tasks, please speak out loud what's in your mind when you find difficulties or find the answer.

4. After the test

   Now I need to ask several questions. You may look back at the dashboard if necessary.

   a) How's your impression of the dashboard?
   b) Which task that most difficult to do according to you? Why?
   c) Could you easily determine where (which page) to find the answer for each task?
   d) Which visualisation that you think easy to understand, which one that is difficult?
   e) What's your suggestion for this dashboard?

5. Thank the test person
   - Thank you very much for your time and participation. It means a lot for my research.
   - I hope you've got some new knowledge and experience, and also enjoyed it.

APPENDIX 2

Test Person invitation letter
Dear ITC staff /student,

My name is Arif, I am an MSc student in the Department of Geo-Information Processing. I am working on designing a dashboard for temporal origin-destination (OD) data under supervision of Menno-Jan Kraak and Parya Pashazadeh.

During my MSc thesis research I have designed and developed a dashboard, a visual display that provides the most important information at a glance as a visual interface to the data. As the last stage of my research, I am conducting a usability survey to evaluate the dashboard. As a case study, we are working with Schiphol Airport data which consists of annual report, monthly report, and one day data. The target user of this dashboard is any person who may want to read Schiphol Airport annual report or has interest in flight statistics and visualization. Therefore, you, as everyone else, are a potential user of this dashboard.

I would like to invite you to take part in a user test. I need at least 8 participants for this test. The test is using eye tracking analysis, and it will be held in the Eye Tracking Laboratory (room 1-066). Each period of test will be conducted for 1 participant, and scheduled to be done in approximately 1 to 1.5 hour. The suggested schedule is the following:

Thursday, 26 January 2017
Period 1. 09.00 – 10.30
Period 2. 11.00 – 12.30
Period 3. 13.30 – 15.00
Period 4. 15.30 – 17.00

Monday, 30 January 2017
Period 1. 09.00 – 10.30
Period 2. 11.00 – 12.30
Period 3. 13.30 – 15.00
Period 4. 15.30 – 17.00

If you are willing to participate, I would like to ask you to fill your name upon your convenient schedule on the following spreadsheet document: https://goo.gl/tZHDMM or send me a reply to this email and I will reserve you the spot.

Be informed that in reporting the research results your name and identity will never be revealed and you will remain anonymous.

Thank you in advance for your time and consideration.
I highly appreciate your participation!
With best regards,

-Arif Rahman-

APPENDIX 3

Participant's Information Document

Please write down your information:

- Name

____

- Nationality

____

- What is your highest education degree at the moment?
  a. Secondary education
  b. Bachelors
  c. Masters
  d. Doctoral

- What was your field of studies in the highest educational degree you have obtained so far?
  a. Geography or Geo-Information science
  b. Cartography
  c. Computer science
  d. Engineering
  e. Transportation
  f. Education
  g. Humanities and Arts
  h. Social sciences / Law
  i. Economy
  j. Others, please specify: ____________________________________

- Have you ever work with this kind of dashboard environment before?
  a. Yes
  b. No
  c. Not sure

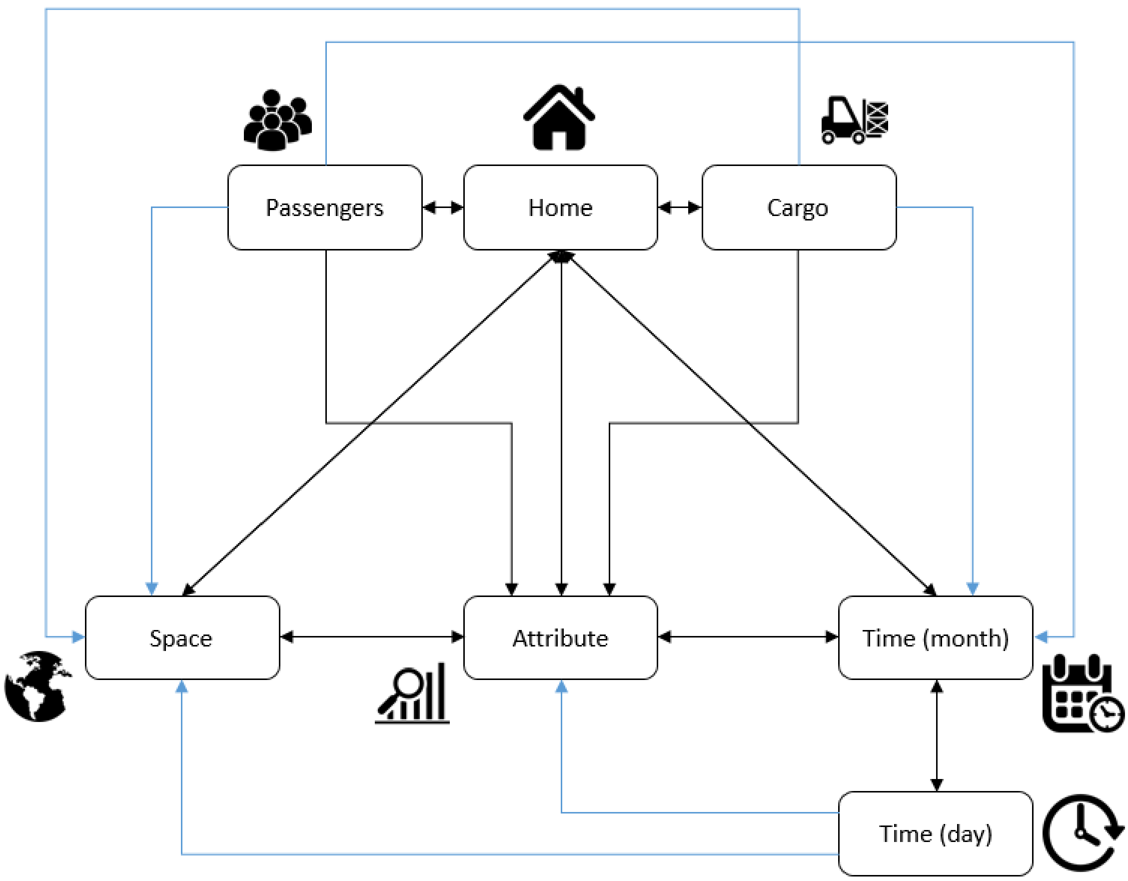
- How often you did travel by plane in the past 5 years?
  a. Less than 5 times
  b. 5-10 times
  c. More than 10 times

APPENDIX 4

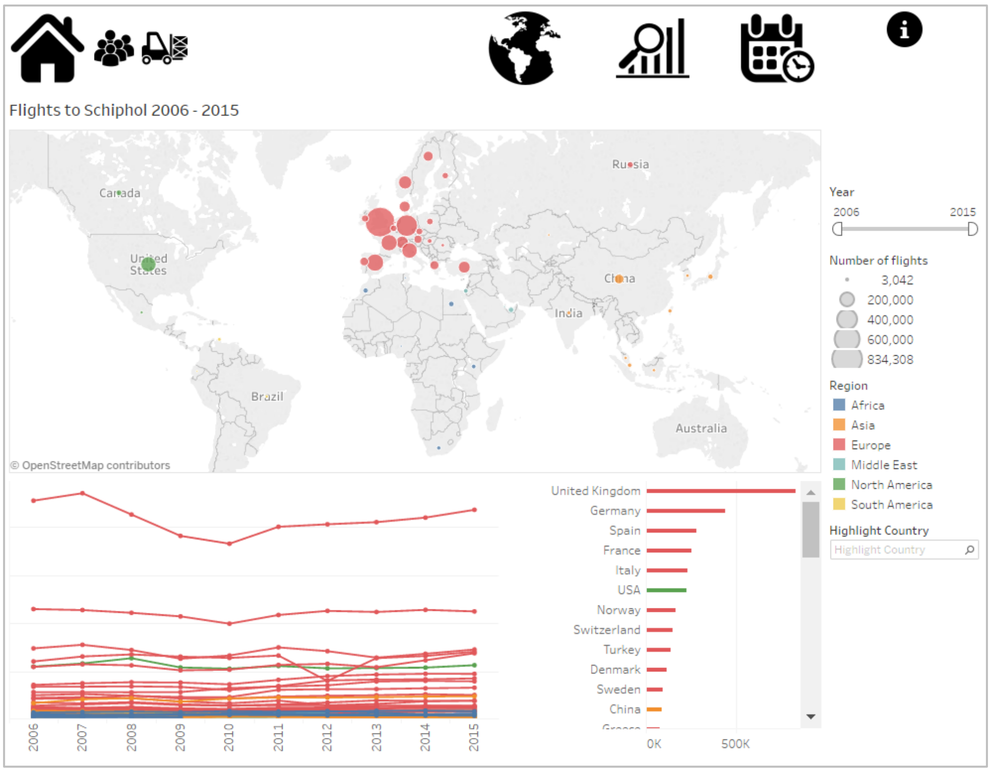
Introduction Document of Schiphol Airport OD Data Dashboard

This dashboard is designed to get insights from Schiphol Airport data. It contains representation of various types of data such as number of flights, number of passengers, and amount of cargo (in tonnes) to Schiphol within the period of ten years. To add more details, monthly data and daily data are also added with their own specific attribute characteristics. This dashboard has a feature with which the user can browse a different visual representation depending on the nature of a questions s/he has. This is done by choosing from space, time, or attribute buttons. We opine this feature as being "adaptive".

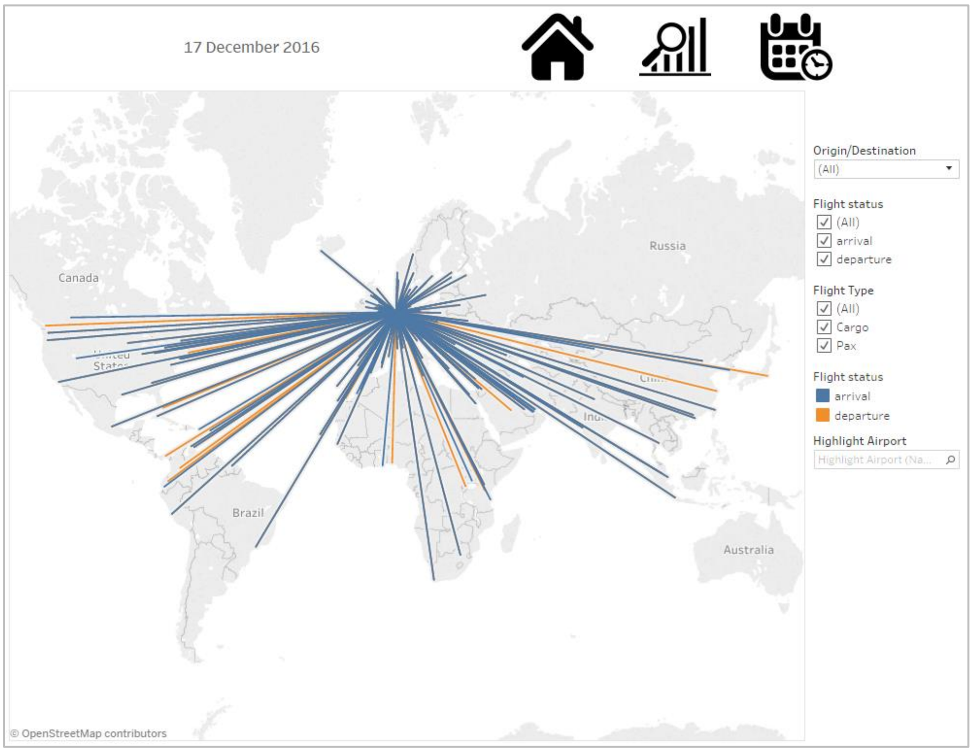
Sitemap of the dashboard



Screenshot of Home page of the dashboard



Screenshot of Space page of the dashboard



List of buttons

Button		**Explanation**
		Data category button (data from Annual Report)
	Home	Navigate to main dashboard with data about flights to Schiphol 2006-2015 Visualisation: proportional point symbol map, line graph, bar graph Serves as home/landing page
	Passengers	Navigate to dashboard with data about passengers to Schiphol 2006-2015 Proportional point symbol map, line graph, bar graph
	Cargo	Navigate to dashboard with data about cargo to Schiphol 2006-2015 Visualisation: proportional point symbol map, line graph, bar graph
		Questions related button (additional data monthly and hourly)
	Space	Navigate to dashboard with spatial related questions (where), flights from/to Schiphol, and connected **airports** on 17 December 2016 Visualisation: **flow map**
	Attribute	Navigate to dashboard with attribute related questions (what), dig further to **airlines, aircraft model/type and Wake Category (aircraft size)** Visualisation: tree map
	Time (monthly)	Navigate to dashboard with time related questions (when), **monthly data of number of flights and passengers from 2006-2015** Visualisation: heat map table
	Time (hourly)	Navigate to dashboard with further granularity of time related questions (when), all **exact time** of flights to/from Schiphol on 17 December 2016 Also featured **airlines, origin/destination, flight's no.** Visualisation: dot graph *Only appear in Time (monthly) page*
		Other buttons
	Info	Navigate to information page, credit of the data and icons used in this dashboard

Additional document that specifically explain Attribute and Time dashboard pages are also provided to be used when needed.

--o-o-0 === Happy Exploring === 0-o-o--

APPENDIX 5

Guidance for Attribute and Time related dashboard

Attribute related dashboard

The visualisation used here is called **tree map**. The tree map is grouped into the following order:

Aircraft size

Airlines

Number of flights (size of the box)

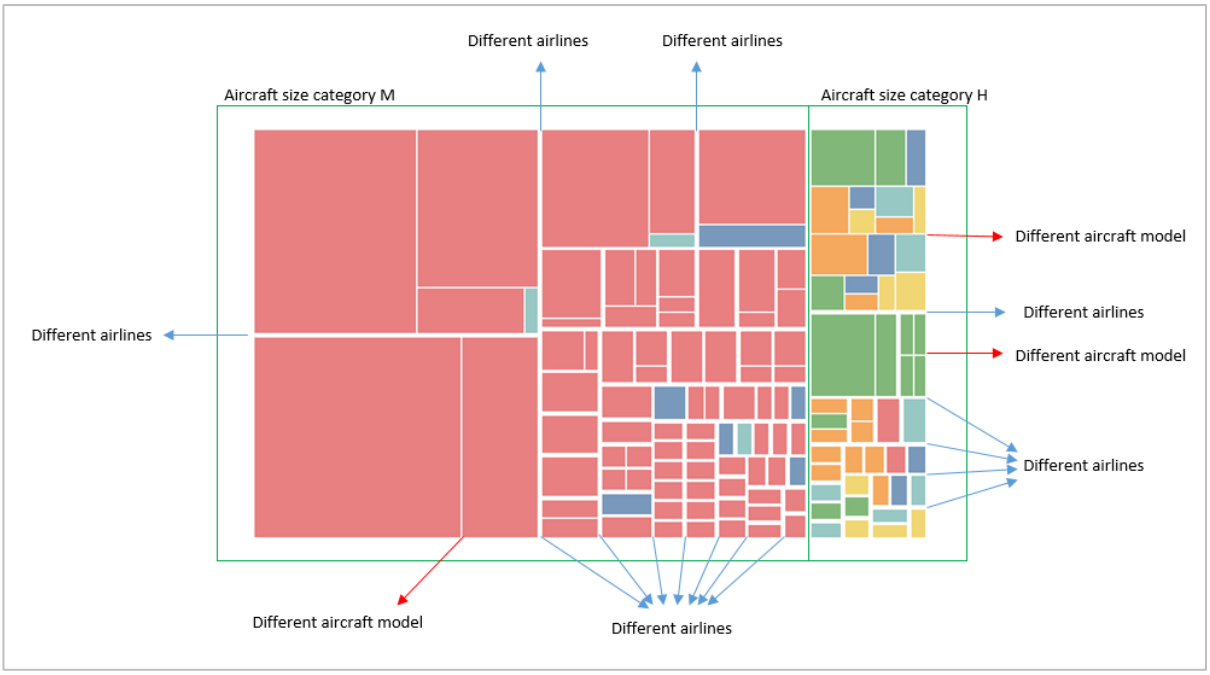
Aircraft model/ type (caption)

Flight type (caption)

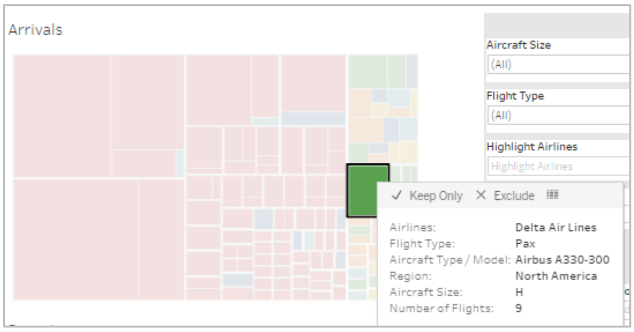
Region of origin/ destination (colour coded)

The individual boxes represent aircraft model for each airlines in each aircraft size category. The size of the box represents how many flights of that particular aircraft model. The colour represents region of origin/destination.

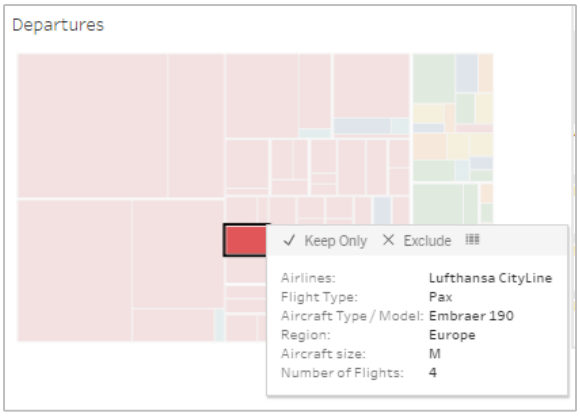
One characteristic of tree map is it has many gaps. In this dashboard, big gap within same "Aircraft size" category means different "Airlines". Small gap within same "Airlines" means different "Aircraft Type/Model" or "Region" of origin/destination.



You can hover (or click) on each box in the tree map to get all available attribute information. Here is some example how to read the information of selected box:

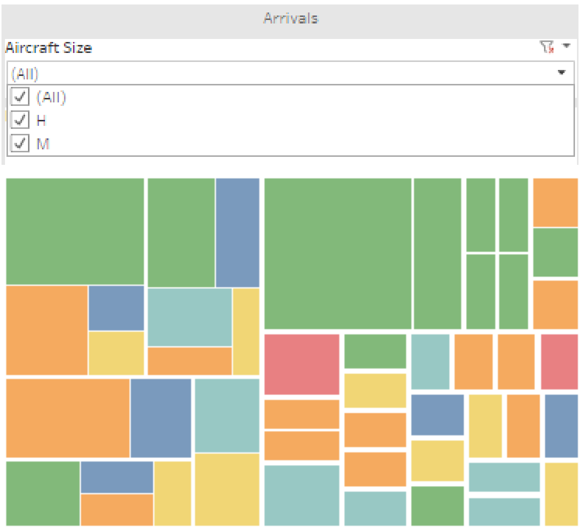


It means: there are 9 passenger flight of Delta Air Lines arrived from North America whose aircraft model is Airbus A330-300 and their size category is H (heavy).



It means: there are 4 passenger flights of Luthfansa CityLine going to Europe whose aircraft model is Embraer 190 and their size category is M (medium).

When you select checklist on "Aircraft Size" or "Flight Type" dropdown boxes, the tree map will change its shape accordingly

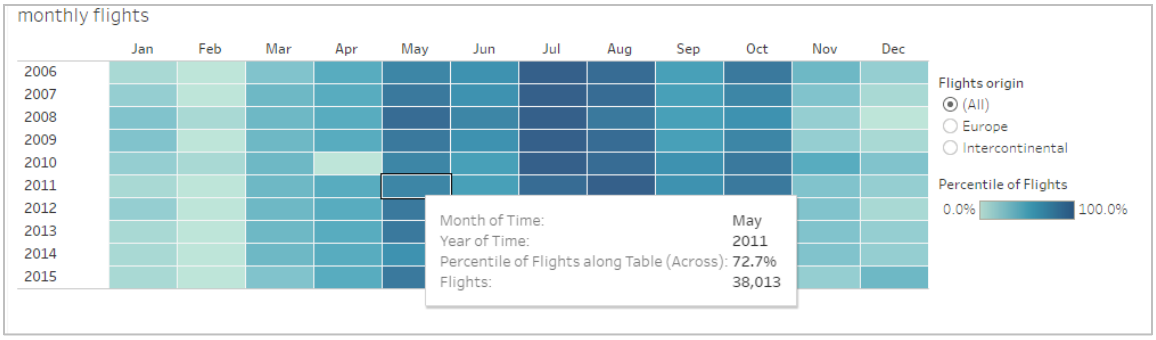


Time related dashboard

There are no origin countries or airports in this data, only aggregated to Europe and Intercontinental.

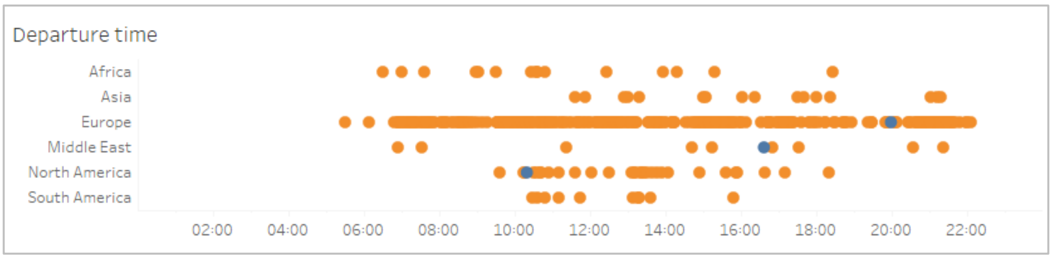
The lightest month is the smallest amount on that year. On the other way round, the darkest month represents the most amount. It means that comparing years is only relative. However, you can hover on the cell to see the actual amount of flights/passengers, and you can also select to see from Europe flights, Intercontinental flights, or sum of both in the right panel.

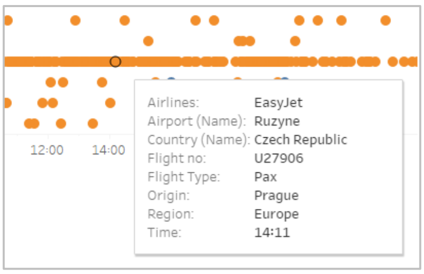
The colours are coded to percentage of actual range of number of flights/passengers in that row (year).



You can zoom in on time to day and hour by clicking this button  on the top of the dashboard. Here, there are origin/destination airports of the flights.

The visualisation used here is dot graph. Each dot represents each flight during that day. If you hover on it you will see information about airlines, origin/destination (airport, city, country, and region), flight no, flight type, and time of arrival/departure.





APPENDIX 6

Task Analysis Document

Intro

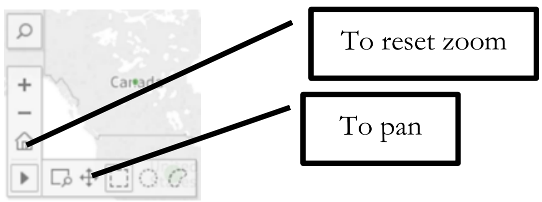
Imagine that you are a student who is affiliated with Geoinformation science and has studied topics related to Geovisualisation as well. You have an uncle who is a stock holder in Schiphol Airport. He wants to get insights of flights to/from Schiphol Airport, to make more reliable and informed decisions regarding his shares. For this purpose, he realises that he needs to read annual report of Schiphol Airport. However, he got bored easily when he read the printed book, and too lazy to scroll the static pdf format! He used to be a self-proclaimed tech savvy, after all. He has heard about a visualisation environment that provides insights into Schiphol Airport based on data from its annual report. He asks you to try working with this dashboard and see if you can find answers to his questions easily.

Now, please go ahead and get yourself acquainted with this dashboard by first completing tasks i. to vii. below. Sit calmly and observe the dashboard. If you feel the need, additional guidance about how to use the dashboard is provided to you in hard copies.

Getting to know the dashboard

(*Do not hesitate to express your reaction loudly when you find something difficult or interesting, or when you find the answer*)

i. Take a look on the map, understand how to zoom in/out the map, panning, and how to reset the zoom display.



ii. Play around with the time slider, 

and hover on the point symbols on the map. Pay attention on the label shown on it. Try also to playing with “Highlight Country” functionality.

iii. Repeat task ii. to page Passengers  and Cargo  briefly.

iv. Go to page Space  . Try to select Berlin on the “Origin/Destination” dropdown box. Take a moment to play with “Flight status” and “Flight Type” checkbox. Observe what’s changing on the map, try also to play with “Highlight Airport” option. Is there any cargo flight between Berlin-Schiphol?

v. Go to page Time  . Make use the guidance to know the data and how it’s being represented. In 2009, did number of passengers on June increased compared to May?

Next, go to Time (hourly) page. Play around with highlighting options and time sliders, observe what's changing in the graph. Find *Calgary* in "Highlight Origin" option in the arrival panel, at what time did it came? What airlines is it?

vi. Go to page Attribute . Understand how the data is being represented in this page, use information from the guidance if required. Hover around the boxes, understand what information in these boxes. Play around with "Aircraft Size" and "Flight Type" dropdown boxes, observe what happened to the boxes.
Find *Garuda Indonesia* airlines on the "Highlight Airlines" option on the rightside panel. What type/model of aircraft does Garuda Indonesia use? Next, search *Jet Airways* using the same way. How many flights does it have and from where (which region)?

vii. Take a moment to understand the dashboard again if you need. Then go to the Home page.

Now it's time for actual test. Use the dashboard to answer questions of task 1 to task 12. Use the guidance if necessary.

1. How many flights to Schiphol from USA in 2009?
2. How much cargo from Narita Intl Airport (in Japan) was transported in 2015?
3. Where do you think the farthest route of cargo flight from Amsterdam in the example day?
4. After 18:30, is there any British Airways flights depart from Schiphol? If yes, how many?
5. How many passengers arrived at Schiphol from Germany in 2010?
6. Looking at monthly flights pattern to Schiphol, could you guess the holiday season in The Netherlands?
7. At what time do the majority of flights from Asia arrive to Schiphol? (morning, afternoon, or evening)
8. How many flight routes between London and Amsterdam?
9. Which month has the highest number of flights in 2010?
10. How many Vueling flights departed from Schiphol in the example day?
11. Is there any flight from Asia or Americas that has Aircraft Size category M (medium)?
12. How many Fokker 70 aircraft type arrived in Schiphol in the example day?