USING CENTERED TIME CARTOGRAMS FOR THE EFFECTIVE VISUALIZATION OF MOVEMENT DATA: DO THEY WORK?

ESKEDAR ZELALEM MENGISTU
February, 2015

SUPERVISORS:
Dr.C.P.J.M. van Elzakker
Prof..Dr.M.J Kraak

ADVISOR:
Rehmat Ullah

USING CENTERED TIME CARTOGRAMS FOR THE EFFECTIVE VISUALIZATION OF MOVEMENT DATA: DO THEY WORK?

ESKEDAR ZELALEM MENGISTU
Enschede, the Netherlands, February, 2015

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: Geo-informatics

SUPERVISORS:
Dr.C.P.J.M. van Elzakker
Prof..Dr.M.J Kraak

THESIS ASSESSMENT BOARD:
Chair: dr.ir. R.A. de By
External examiner: Ms dr. K. Ooms; (External Examiner, University Gent, Department of Geography)

ABSTRACT

Temporal data visualization has become a popular tool for extracting time information in transport systems. Very little is known about the usability of such temporal visual representations for scheduled movement data access. The goal of this research is to show the usability of the centred time cartogram for scheduled movement data visualization, based on a case study spatio-temporal dataset, which are the Netherlands 2010 railroad network data. In this research, two phase experiments were conducted in the laboratory and through an online survey. In both experiment phases, test participants were asked to perform tasks, and to reply to questionnaires in association with visual outputs. In the first and second test phase, 40 and 82 responses were collected and analyzed. The first phase was a qualitative evaluation that was implemented by eye tracking, thinking aloud, questionnaires and video recording usability study techniques. On the one hand, these evaluation results showed the usability of the CTC depending on the task type. On the other hand, from an average perspective, CTC with railroad design alternative among four alternative solutions of the CTC was prioritised through the feedbacks. The second phase was a quantitative evaluation that was implemented with an online survey. It was examined whether the CTC was usable with different and many user groups in comparison with a geographic and a schematic map. In this phase, general and detailed findings were presented with testing 5 hypotheses and by answering the test objectives that confirmed the quantitative test findings. The cumulative outcomes of the two experiments suggested that the effectiveness (accurate and correct answers to the spatio-temporal questions), efficiency (fastest answers) and the user satisfaction of the CTC to represent scheduled movement data depend on the task type. As a result, it is recommended that this cartogram is presented in an interactive environment with its different designs and starting points, and in combination with a schematic and a geographic map, so as to provide spatio-temporal information for all types of user request . This extensive study has shed a new light on the tested time cartogram design and for scheduled movement data users.

Key words: Qualitative test, Quantitative test, Usability evaluation, Scheduled movement data visualizations, Centred Time Cartogram, User research

ACKNOWLEDGEMENTS

All thanks, worship and adoration to my GOD: my friend, family teacher, leader and my everything in my life. He is merciful as the first and everlasting. My ever successes in my life is the accomplishment of his divine grace. Everything is possible to me because i am always in support of him; GOD is Leader of my journey throughout my life.

My at most gratitude goes to my first supervisor Dr. Corné P. J. M. van Elzakker. I am very fortunate having been supervised by him. He provides me a continuous and mythological support during the research period. His guidance and the encouragement were unconditional throughout the research. In the meantime supporting and encouragement to work with my own idea "to be Boss of my work" that helps me to work hard with interest until the end of the research. Specially, his detail feedback on every of my work, careful advising, hospitality and patient, being not only an excellent supervisor, but also i concerned father of the research.

I like to extend my special thank and respect to my second supervisor prof.dr. M.J. Kraak (Menno-Jan)for his constructive idea in the research period. I am grateful to my adviser Mr. Rhemat Ullah for sharing his knowledge and suggestion during this research.

I am indebted to the Netherlands Fellowship Programme, NFP for giving this chance to have an international standard education with covering all the expenses. I have a great thanks to my University; University of Twente, ITC for selecting me in such a wonderful prospect. I like to say thanks for all the staff of ITC for uncountable support, experience and knowledge sharing. Also, i would like to say thanks for all participants in my usability test and for all my friends in ITC.

I am always grateful to my beloved family, for their continuous inspiration, pray and for their guidance in my life. I have special thanks to my two mothers, Mrs MULU ABEGAZ and Mrs ABEBECH ABEGAZ and for my brothers; SOLOMON ZELELEM with his family and BELAY ABEGAZ.

Eskedar Zelalem
Enschede, the Netherlands
February 16- 2015

TABLE OF CONTENTS

1. Introduction....11
 1.1. Motivation and problem statement....11
 1.2. Research identification....13
 1.3. Research objectives....13
 1.4. Research questions....14
 1.5. Thesis structure....14
2. Visualizations of scheduled movement data and their usability....15
 2.1. Introduction....15
 2.2. Spatio-temporal data....15
 2.3. Movement data....16
 2.4. Visualization of scheduled movement data....17
 2.5. Previous usability studies of cartograms....19
 2.6. Conclustion....19
3. Research Methodology....20
 3.1. Introduction....20
 3.2. Research Workflow....20
 3.3. Methodological framework....22
 3.4. Approach....24
 3.5. Conclustion....28
4. Case study....29
 4.1. Overview....29
 4.2. Selection of visual representations....29
 4.3. Conclusion....40
5. User Research Implementation: qualitative testing of Four CTC design alternatives....41
 5.1. Overview....41
 5.2. Test objective....41
 5.3. Test setup....42
 5.4. Test procedure and execution....46
 5.5. Test implementation Result....49
 5.6. Test implementation analysis and findings....60
 5.7. Conclusion and feedback....83
6. Quantitative User Research Implementation....84
 6.1. Overview....84
 6.2. Test objective and plan....84
 6.3. Preparations for test implementation....85
 6.4. Test implementation....85
 6.5. Implementation results and findings....87
 6.6. Conclusion and outlooks....91
7. conclusions and recommendations....92
 7.1. Conclustions....92
 7.2. Recommendations....93

LIST OF FIGURES

Figure 1-1: Example for cartogram type: Point: A, Line: B and Area: C 11
Figure 1-2: Example of a non-centered: A and Centered time cartogram: B 12
Figure 1-3: Examples of the Netherlands geographic map: A and schematic map: B 12
Figure 3-1: Adopted UCD approach in this research, (van Elzakker and Wealands, 2007) 21
Figure 3-2: Work flow diagram of the research phase 23
Figure 3-3: Eye movement data visualization for analysis A) a fixation heat map 26
Figure 4-1: Evaluated CTC alternative design solutions from two starting stations 32
Figure 4-2: Evaluated CTC alternative solutions from two starting stations 32
Figure 4-3: Four alternative design solutions of the CTC in four presentation orders 33
Figure 4-4: Second iteration CTC 35
Figure 4-5: Schematic map 37
Figure 4-6: Geographic map 39
Figure 5-1: Qualitative test objectives and their testing 41
Figure 5-2: Test person visual grouping 43
Figure 5-4: Test execution environment of qualitative test 45
Figure 5-3: Project set-up of group data through Tobii studio 45
Figure 5-5: Test execution procedure 47
Figure 5-6: Task response comparison between and within the group 52
Figure 5-7: Time cost comparison of each task between and with in the group 55
Figure 5-8: Satisfaction comparison of each task between and within the group 58
Figure 5-9: Screenshot of user's satisfaction response for CTC 59
Figure 5-10: Effectiveness of CTC alternative solutions 60
Figure 5-11: Efficiency of CTC alternative solutions 61
Figure 5-12: Satisfaction of CTC alternative solutions 62
Figure 5-13: Likert scale questionnaires statistics graph 62
Figure 5-14: Heat map of CTC alternative solution selection: group 1), 2), 3) and 4) 72
Figure 5-15: Gaze plot of task 1 with one, two and three number of test person (TP) in the four groups . 74
Figure 5-16: Gaze plot of task 2 with one, two and three number of test person (TP) in the four groups . 75
Figure 5-17: Gaze plot of task 3 with one, two and three number of test person (TP) in the four groups . 76
Figure 5-18: Gaze plot of task 4 with one, two and three number of test person (TP) in the groups 79
Figure 5-19: Gaze plot of task 5 with one, two and three number of test person (TP) in the groups 80
Figure 5-20: Gaze plot of task 6 with one, two and three number of test person (TP) in the groups 81
Figure 5-21: Ten test person gaze plot of task 7 in the groups 82
Figure 6-1: Test objectives of the quantitative evaluation 84
Figure 6-2: Quantitative test execution procedure through online survey 85
Figure 6-3: General comparison of the effectiveness of the CTC, schematic and geographic map 87
Figure 6-4: General comparison of the efficiency of CTC, schematic and geographic map 88
Figure 6-5: General comparison of the satisfaction with the CTC, schematic and geographic map 88
Figure 6-6: Average correctness of each map per task 89
Figure 6-7: Average time cost of each map per task 90

LIST OF TABLES

Table 3-1: Usability evaluation methods applied in this research 27
Table 5-1: Pilot test feedback and improvement 48
Table 5-2: Success of task execution in group 1 worked via CTC with railroad 51
Table 5-3: Success of task execution in group 2 worked via CTC with out railroad 51
Table 5-4: Success of task execution in group 3 worked via CTC with emphasized railroad 51
Table 5-5: Success of task execution in group 4 worked via CTC with emphasized time circle 51
Table 5-6: Time cost of group 1 worked via CTC with railroad 54
Table 5-7: Time cost of group 2 worked via CTC with out railroad 54
Table 5-8: Time cost of group 3 worked via CTC with emphasized railroad 54
Table 5-9: Time cost of group 4 worked via CTC with emphasized time circle 54
Table 5-10: Likert scale questionnaire response of group 1 57
Table 5-11: Likert scale questionnaire response of group 2 57
Table 5-12: Likert scale questionnaire response of group 3 57
Table 5-13 : Likert scale questionnaire response of group 4 57
Table 5-14: CTC alternative solution prioritization result of group 1 59
Table 5-15: CTC alternative solution prioritization result of group 2 59
Table 5-16: CTC alternative solution prioritization result of group 3 59
Table 5-17: CTC alternative solution prioritization result of group 4 59
Table 6-1: Quantitative test participant user profile 86
Table 6-2: Summary of the general findings of the comparison between the CTC, geographic map and schematic map 89
Table 6-3: Average satisfaction of each map per task 90

ACRONYMS

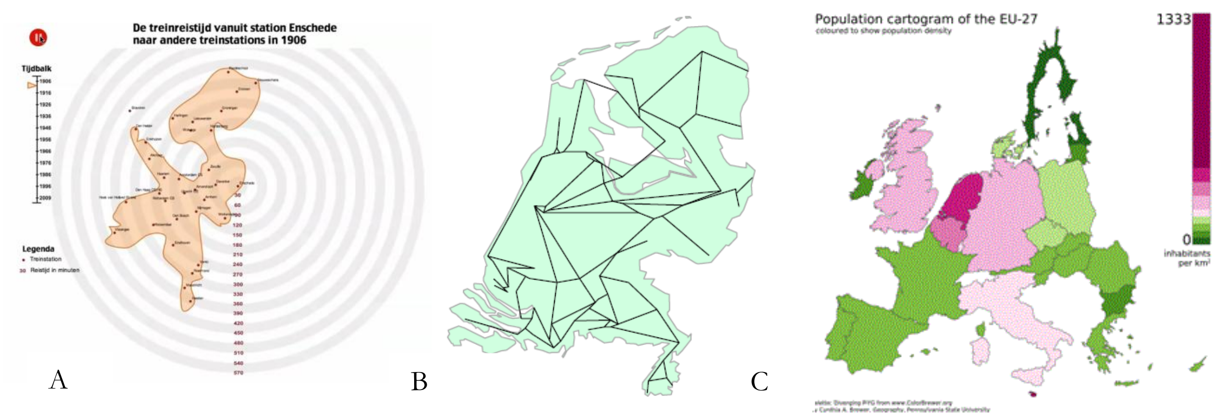
CTC	Centered Time Cartogram
TP	Test Person
UCD	User Centered Design

1. INTRODUCTION

1.1. Motivation and problem statement

Nowadays people prioritize time information above distance information in transport systems. Therefore, temporal data also become more dominant in different visual spatio-temporal data representations. In most traditional maps, it is difficult to associate time and distance information together (Buchin, Goethem, Hoffmann, Kreveld, and Speckmann, 2014). Nevertheless, transport network temporal information, like train trip time, is more important for transport users. As a result, visual representation features of transport networks, like travel speed and congestion levels, are getting to be integrated with travel time data (Wu and Hung, 2010). Further, these days in most visual representations of the great amount of geographic data the temporal component gets a larger share. In this situation, the so-called time cartogram can be regarded as a known visual representation of temporal data. One type of time cartogram that requires usability studies is the centered type of cartogram, which is a new visualization method for representing scheduled movement data in transport networks.

A time cartogram is a type of cartogram that visualizes time related variables (e.g., travelling time). Cartograms are a particular way of visualizing geographical information, different from traditional maps due to their geographically distorted nature. There are three types: point, line and area cartograms (see Fig. 1). This research focuses on an integrated visualization of a point and line cartogram, called CTC, as produced by (Ullah and Kraak, 2014)(see Fig. 1-2-B). A line cartogram could visualize travel time or travel cost that usually increases with distance (see Fig. 1-1-B). Similarly, point cartograms could visualize travelling time by displacing points (see Fig. 1-1-A). A time cartogram could also be an integration of a line and point cartogram where distance corresponds to travel time. It can have two types: centred and non-centred (Bies and Kreveld, 2013). The non-centred type represents travelling time between pairs of locations (see Fig. 1-2-A), while a CTC shows travelling time from a specific starting location to any other location in a particular region (see Fig. 1-2-B). Although it is claimed that this cartogram may have the potential to provide answers to spatio-temporal questions of scheduled movement data users, very little is known about their practical usage.



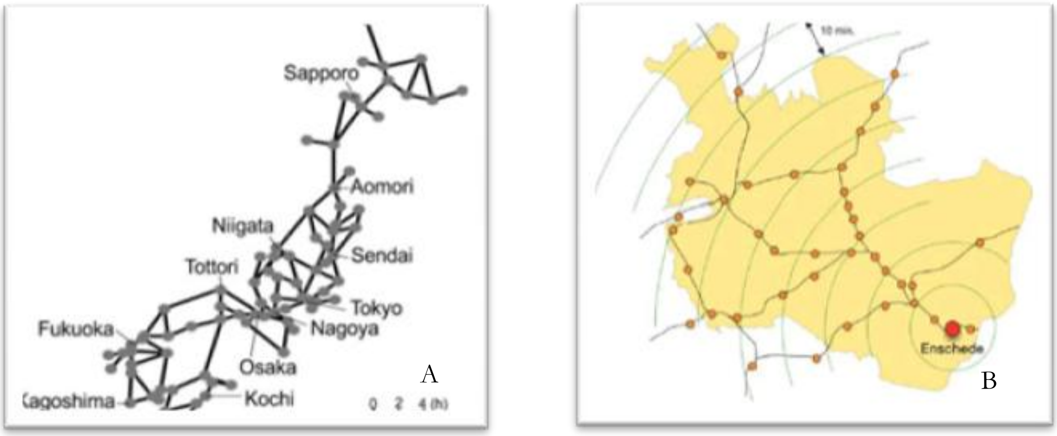
Point cartogram: Train travelling time from Enschede, Netherlands, 1906 - 2009 (www.youtube.com)

Line cartogram: Expected train travel time during morning rush hour in the Netherlands (Shimizu & Inoue, 2009b)

Area cartogram: EU Population (https://www.google.nl/search?q=area+cartogram+netherland+agile)

Figure 1-1: Example for cartogram type: Point: A, Line: B and Area: C

The CTC that is produced by Ullah and Kraak (2014) indicates a new insight into scheduled movement data (fixed and timetable based movement data like train or bus travelling) visualization (see Fig. 1-2-B). They applied a method that deforms the travelling time map network and boundaries together. As a result, they produced a static CTC as shown in Fig. 1-2-B. Furthermore, their cartogram has four visualization options that we prefer to call alternative solutions, i.e. CTC with and without railway network, with emphasized time circles and with emphasized railroads.



Non-centered time cartogram of Japans' rail way network; showing rail way travel time from different cities (Shimizu & Inoue, (2009)

Centered time cartogram of Netherlands railroad; showing railway travel time from Enschede. (Ullah&Kraak, 2014)

Figure 1-2: Example of a non-centered: A and Centered time cartogram: B

Consequently, their CTC is a smooth and easily understandable visualization, without damaging global shape and losing study area recognisability. In addition, Ullah and Kraak (2014) claim that their CTC is better than a geographic map (see Fig. 1-3-A) and a schematic map (see Fig. 1-3-B) for temporal data visualization. Generally, their research clearly points out that CTCs are a preferable visualization for scheduled movement data, irrespective of the cartogram's distorted nature. But although this new solution looks promising indeed, it is not known yet whether it is usable for people who have spatio-temporal questions, specifically on scheduled movement data. This is the main motive to conduct this research.

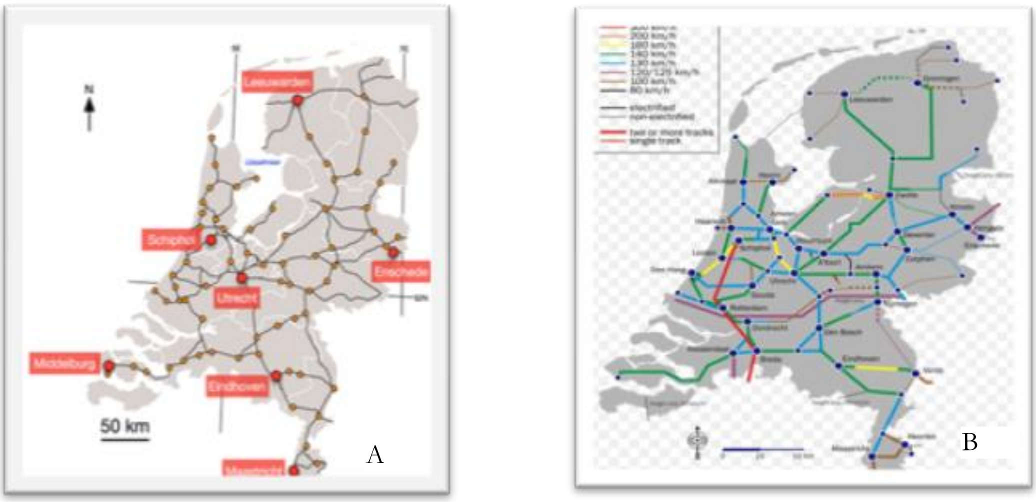


Figure 1-3: Examples of the Netherlands geographic map: A and schematic map: B
http://en.wikipedia.org/wiki/Provinces_of_the_Netherlands

In this respect, this research is a continuation of the work of Ullah and Kraak (2014) and investigates the usability (effectiveness, efficiency, and satisfaction) of the CTC for scheduled movement data visualization. To perform these usability tests, Dutch provinces railway travelling time maps were used as a case study. The tests include the CTC produced by Ullah and Kraak (2014), a traditional schematic map, and geographic maps. The case study data were used to provide spatio-temporal information (e.g. train trip time information) to test persons during a usability exploration.

1.2. Research identification

Cartograms represent thematic variables like travel time, population election results and national gross products. The main idea is to represent these quantitative variables by resizing map elements, but with preserved map recognisability, which can result in a great visual impact on the map reader (Wu and Hung, 2010). Cartogram usability depends on task complexity and shape, orientation and contiguity of map topology (Kaspar, Fabrikant, and Freckmann, 2011). However, it is hard to give a usability evidence for cartograms due to their distorted nature (shape and area error and optimization problem). This nature of cartograms promoted different usability studies , relating them to comparable cartographic products (Keim, North, Panse, and Schneidewind, 2002)

This research focuses on usability of CTC based on the case study dataset, which were expected to provide evidence for user's requirement on the cartogram effective, efficient, and user satisfaction for accessing scheduled movement data.

Based on the CTC alternative design, first we were selected four alternative solutions in order to investigate the most usable solution. Second, according to the CTC producers' claim, we used two candidate maps, geographic map and schematic map, to compare with the redesigned CTC in order to identify the preferable visualization for scheduled movement data among the three.

The CTC is a new solution for scheduled movement data visualization like train trip time (Ullah and Kraak, 2014). Similarly, a schematic map is a well-known representation of transportation networks such as the map of the London Underground (Antonius and Verbeek, 2012). A geographic map is the traditional cartographic solution for the representation of transportation systems through linking the origin and destination of movement flight spatio-temporal data (Weisbrod, 2011).

1.3. Research objectives

The main objective of this research is to investigate the usability of the CTC for scheduled movement data visualization.
The main sub-objectives are:

A) To determine the effectiveness of CTCs' for scheduled movement data visualization.
B) To determine the efficiency of CTCs' for scheduled movement data visualization.
C) To determine the users' satisfaction, i.e. to explore the users comfort and attitudes towards CTC.
D) To identify and suggest the preferable visualization for scheduled movement data through a CTC or by other means (geographic and schematic map).

1.4. Research questions

1. Who are the users of scheduled movement data? What are their characteristics?
2. What spatio-temporal questions do users have? In which use contexts do users want to have answers to their spatio-temporal questions (e.g. behind the desktop, in the field with a mobile device or by other means)?
3. How can scheduled movement data be visualized?

Related to sub-objective A

4. Can the CTC provide effective answers to the spatio-temporal questions of users?

Related to sub-objective B

5. Can the CTC provide efficient answers to the spatio-temporal questions of users?

Related to sub-objective C

6. Is the CTC visualization satisfactory for scheduled movement data users?

Related to sub-objective D

7. Which scheduled movement data visualization can be recommended? For what type of users? For what type of spatio-temporal questions?
8. What improvements can be suggested with respect to the CTC visualization?

1.5. Thesis structure

This thesis includes seven chapters, which are:-

Chapter 1 **Introduction:** Presents motivation, problem statement and research identification of our research followed by the research objective and questions.

Chapter 2 **Previous works:** Revises the characteristics and users of spatio-temporal data, focused on scheduled movement data. In addition, it highlights scheduled movement data visualizations theory and contains research reviews of the geographic map, schematic map and particularly the CTC. Finally, the chapter concludes with related usability studies of cartograms and usability methods with our research.

Chapter 3 **Methodology:** It is about the methodology that was applied in this research, including the workflow, framework and approaches of this thesis work.

Chapter 4 **Case study data:** Discusses the case study data that were used to in qualitative and quantitative test phase and, presents the selected visual representation for the experiments.

Chapter 5 **Qualitative test:** It is about the qualitative experiment of four alternative solutions of CTC. It begins with formulation of test objective, followed by explaining the setup preparation and implementation, and finally the test result and findings of a qualitative test were presented. Generally, the chapter includes the qualitative test phase set-up plan, the preparation of test person, the test environment, the test project, tasks and questionnaires, the pilots test, test procedure and execution. Finally, the chapter concludes and recommends according to the test findings that were analysed

Chapter 6 **Quantitative test:** This is about quantitative experiment of three comparable scheduled movement data visualization. First the test preparation presents, then the test implementation, followed by test result and analysis. Generally, the chapter includes, test set-up and implementation, and ends by the discussing general and specific findings.

Chapter 7 **Conclusions:** Finally this chapter concludes the overall findings of this thesis and recommends key ideas for further research

2. VISUALIZATIONS OF SCHEDULED MOVEMENT DATA AND THEIR USABILITY

2.1. Introduction

In order to lay a foundation for the user research reported on in this thesis first some basic concepts need to be explained and previous research work cited. The chapter starts with introducing the nature of spatio-temporal data focused on scheduled movement data. Subsequently, it discusses about the availability of movement data with visualizations such as CTCs, which is the main focus of this research. In the meantime, the schematic map, geographic map and four alternative solutions of the CTC are described as possible visualizations of scheduled movement data. Finally, the chapter will close by indicating some related previous usability research works.

2.2. Spatio-temporal data

Time and space are the most representative aspect of real world phenomena. Spatio-temporal data are a common data type that includes both time and space features (Keim et al., 2008). These features give a unique characteristic for spatio-temporal data than a traditional relational and transactional data type, which changes with explicit update of time. Complex methods are applied in most repositories and representations of spatio-temporal data in order to enhance spatial and temporal information readability. Furthermore, spatio-temporal data types can be represented by extending temporal dataset together with spatial data process or in the opposite. As specified by (Peuquet, 2006), spatio-temporal data structures categorize spatio-temporal questions based on the following three components.

- Location: Questions related to Where?
- Attribute: Questions related to What?
- Time: Questions related to When?

From these components it is possible to create more complicated or other simple questions, addressing different spatio-temporal data users' requests. Further, from these three components user tasks can be constructed towards spatio-temporal aspects (Andrienko and Augustin, 2006). Visual spatio-temporal data representations can be used to answer spatio-temporal tasks or queries (Li and Kraak, 2010). van Elzakker (2004), argued that spatio-temporal task performance based on visual representations should be tested through intensive usability research of the map use activities involved.

Visual representations of spatio-temporal data may have different viewpoints. For instance, some visual representations focus only on temporal aspects. Temporal visualizations show temporal distributions, trends and characteristics, according to the users' expectations when they perform tasks with a temporal component. (Andrienko and Augustin, 2006) investigated important nature of spatio-temporal data that represent varies tasks related to user's expectation. For instance, temporal aspect has different view of time based on the users' expectations (i.e. can be formulated as task in usability study), data availability and visualization alternatives, which can also influenced by human cognition and perception of time (Li and Kraak, 2010).

Temporal data can also be related to movement, which can be free movement (e.g. birds) or movement over a fixed network (e.g. transport network). Movement within fixed networks can be non-scheduled, such as trips by private cars or scheduled such as in public transportation systems (e.g. train trips). Many studies attempted various algorithms and techniques to represent movement data easily (Kraak, 2014). The section below briefly discusses the nature of movement data.

2.3. Movement data

Movement data which occur in space and time are highly integrated in human life, (Andrienko et al., 2011). Humans use these data to seek answers to questions about time or distance, such as in transportation systems. For example, questions like: Which path is the shortest to reach a certain destination? How much time is needed to travel? What is the alternative shortest path in time? Higerstrand (1970) discussed about time geography, which specifically addresses spatio-temporal trends related to movement data in the society. The dominant idea of time geography is the inseparable view of space and time. Kraak (2003) claimed that exploring movement data through visualizations is time-consuming and expensive and the rise of new visualization technologies did not address these issues as well. Moreover, the new technologies did not include the qualitative description and interactive nature of movement data (Moore, Whigham, Holt, Aldridge, & Hodge, 2013).

Movement data can be retrieved from space and time entities, which refers to the data properties of space and time respectively. Miller (2004), suggested basic theories that shows the relationship between space and time entities, which is a base for time geography query and analysis. (Miller, 2004) and Higerstrand (1970) clearly identified time as an inseparable aspect of spatio-temporal data which is also the main aspect of movement data. A trajectory, a well-known term in movement, matches time movement with spatial position (Andrienko, Andrienko, and Pelekis, 2005). To observe movements and explore movement data, there are infinity pairs of trajectory data that are referenced with infinite time based sequence (Andrienko et al., 2005). Accordingly, these pair of sequences (space and time) can be recorded based on:-

- time: objects based on regular movement of time
- change: objects recorded based on different positions
- location: objects recorded based on closer distance
- event: position and time recorded based on the occurrence of events
- records: can be a combination of sequences listed above

Andrienko et al. (2005) suggested these sequences of data recording to movement entities, which can be grouped depending on the following characteristics:-

- entity's position in time or space
- entity's position in space
- entity's direction in movement
- entity's movement speed
- entity's direction of change
- entity's speed change
- travel time and distance together

Generally, Miller (2004) identified trajectories that can be compared with spatial and temporal relations based on the following main interactions:

- Space co-location:- that consists of full or partial trajectories that have common positions
- Time co-existence:- that consists of full or partial trajectories that have a similar time period or overlap in time
- Time and space co-incidence :- that consists of full or partial trajectories that have a similar time and position
- Delayed co-incidence of the same positions in time:- that is due to trajectories with different time period of
- Space and time of distance:- that can be space with time or distance trajectories

Therefore, movement data can be identified with three principal components. These are time (moment of data), population (moving object) and space (locations occupied by the entities). Movement data can also be retrieved from fixed network entities, either scheduled or non-scheduled. However, movement data representation may not hold information about the path (where the movement take place), the object (what was moving) or the time frame (when it was moving), which are the main elements of movements over trajectories in transport networks. As Andrienko et al. (2005) suggested, visual representations should consider methods that can assist a suitable query analysis and answer questions of taxonomy such as correlation and dependency between location, time, and movement entities. Considering this temporal data type, particularly for scheduled movement data exploration, review of literature indicated the availability of different types of visual representations. Among these, three types that are commonly used are discussed below.

2.4. Visualization of scheduled movement data

Currently, a number of solutions for movement data representation are available that address the user's expectations in different perspectives (i.e. spatial or temporal). As discussed above, scheduled movement data have a spatio-temporal nature. However, most visual representations do not answer this integrated nature of movement data. For example, a time cartogram is a preferable representation from a temporal perspective but it has limitations in visualizing spatial data reality due to the cartogram's distorted nature (Bies and Kreveld, 2013). In contrast, flow maps(a map to show movement between location) and geographic maps focus on spatial representation (Nelson, 2013).

It is very important to represent time information in different perspectives of visual representation in order to analyse events, show future scenarios and changes and trends over time. For instance, visual representations are expected to show changes due to the nature of road and terrain, and aid user to choose travels routes with different time information that cover the same distance. In such circumstances, time-scaled maps can provide a clear picture of the geography and quality of movement data in transport networks (Spiekermann and Wegener, 2004). In the next sub-sections, three the most candidate visual representations (i.e. used in our usability test) that can be used to represent scheduled movement data will be discussed. This are commonly used maps in transport system for spatio-temporal visualization (schematic and geographic map) and a new cartogram design (CTC) that is produced with the same purpose.

2.4.1. Schematic map

A schematic map is a simplified map that represents reality through abstract graphic symbols in stead of through a realistic picture. It has a simplified shape and structure with intentionally deformed spatial relations between objects in distance or orientation, while keeping the real topological relation (Freksa, Moratz and Barkowsky, 2000). The main objective of a schematic map is to eliminate unnecessary features that reduce the cognitive load of the map user (Ormeling, 2009). For example, a schematic map might use a combination of vertical, diagonal and horizontal lines, followed by specific colours and labels (Kraak, 2014). Schematization is a typical method applied for most transportation networks (Ware, Taylor, Anand and Thomas, 2006), which helps to emphasize and de-emphasise certain aspects of the network (Weihua Dong, Qingsheng Guo, 2008). It is a known example of a public transport system map, for instance, the London Underground map ; (Schwandl, 2006). Mainly, it represents spatial data, with the orientation of a line representing orientation of reality and distance represented by the number of train stations, in contrast to a metric distance in nature (Gero, Tversky and Knight, 2004).

In addition, a schematic map simplifies different links between routes that provides users to get to the right station and destination that helps to take the right transfer easily. A schematic map further, helps to visualize flight routes in the traffic control, which maximizes the representation of relevant visual information in route networks like line metro and stops. Generally, it provides a quick insight into the transport network layout without creating confusion by hiding unnecessary information like detail networks between routes (Weihua Dong, Qingsheng Guo, 2008). It also answers questions about locations, attributes and time, based on a specific design in a particular topic (Kraak, 2014). Schematic map, however, have limitations to present temporal information simultaneously with different routes of movement data (Tong, 2014).

2.4.2. Geographic map

Geographic movement has vital importance, since a change in the world is mainly related to movement: movement of people, material, energy and so on (Tobler, 2003). A geographic map is one representation that movements can be represented in it (Tobler, 2003). It is a generalized representation of the earth's surface that shows the distribution of natural and social phenomena. It can be produced based on a particular purpose, and can represent spatial changes within a period of time. Due to the increasing accessibility of navigation tools with static and interactive maps, spatio-temporal information is becoming easily available to the potential users. A geographic map is one known representation of complex and large spatio-temporal datasets, sometimes with an "information overload", unless the representation is designed carefully (Kaiser, Walsh and Farmer, 2010).

A geographic map can use time distance mapping to represent spatio-temporal data. Time distance mapping is used to visualize time in travelling networks with deformed space. For example, as Kaiser, Walsh, & Farmer (2010) shows interactive London Tube Map are time distance representations that provide time information to most potential users without confusing them due to the deformed nature. However, this representation is not sufficient for all users to access time information easily for making decisions about their everyday transportation Kaiser, Walsh, and Farmer (2010). On the contrary, and, therefore, Kaiser, Walsh and Farmer (2010) applied two algorithms that are a user centric mode of representation (features or locations closer to the user's current location) and a route centric representation (specifies routes within the road network). These algorithms are constructed based on Open Street Map to provide travel time data easily and can be applicable wherever a road network is available. The algorithm provides time in distance representation in terms of the time dimension. Again, it is not possible to consider this representation to be perfect in every temporal perspective (Kaiser, Walsh and Farmer, 2010).

2.4.3. Centered time cartogram

In order to visualize scheduled movement data with a centred time cartogram, different graphic variables are used. Mainly, lines can show the railroad network, points shows the stations and concentric circles show the specific time intervals (Ullah and Kraak, 2014). To display time information of scheduled movement data, Ullahz and Kraak (2014) propose that a centred time cartogram (see figure 4-2-B) may have four alternative solutions with different designs, which is to choose the appropriate design for time visualization among them. One alternative design of the centred time cartogram is produced without the railroad network in it; it can represent time information using points (i.e. stations) and concentric circles (i.e. time intervals). This representation may create a problem when users have to find alternative routes.

In addition, the second alternative is a CTC with railroad. This design can be considered to be the main type of CTC, which contains points (stations), lines (railroads) and features (concentric circles / time intervals). It can display time with a clear representation of geographic locations (stations) and routes.

Both alternatives cannot be considered as preferable representation as they may create confusion and can be ambiguous about alternative routes and time intervals. In order to solve the two first alternative design problems discussed above, there are two other design options. These are centred time cartograms designed by emphasizing either its features (circles) or one map element (the lines), which are the concentric circles and the railroad network of the centred time cartogram respectively. This design approach results in two additional alternative solutions (centred time cartogram with emphasized time circles or railroads), which may provide more clear information about time than the previous two designs. For example, using these alternative solutions it might be possible to get information about alternative routes or the user may count the time intervals easily. Generally, this CTC was produced with advanced methods (vector and moving least squares) that deform travelling map stations, the network and boundary together, which is essential for an easy use of it (Ullah and Kraak, 2014). However, the increase use and usability metrics on effectiveness, efficiency, and user satisfaction of the cartograms are contrasted with their distorted nature, accordingly it may not be possible to consider this cartogram as a preferable choose for scheduled movement data representation.

2.5. Previous usability studies of cartograms

Some literature supports the effectiveness of cartograms in spite of their distorted nature. Such researchers focused on falsifying the traditional thoughts, which gave a negative interpretation about the effectiveness of cartogram visualization due to its distorted nature. Bhatt (2006) and Panse (2004) identified the positive impact of a kind of cartogram distortion that verifies its recognisability through resized regions. The cartograms' creative design and attractive nature supported them to be a popular tool to visualize geographical or statistical data (Kocmoud, 1997). In addition, Dorling (1996) applied alternative and wide construction techniques that can enhance the importance of cartograms. These and similar researches are applied varies techniques to improve the use of cartograms for different purpose, which can be valuable inputs to this research. However, most of these results were not supported through intensive usability studies.

On the one hand, previous researches on the usability of time cartograms for movement data visualization did not exist. However, Shimizu and Inoue (2009) applied a new construction approach that indicates the use of distance cartograms, which visualize the yearly change of the Japanese railway network. Wu and Hung (2010) visualized traffic movement using non-connective cartograms with line segments and colour variables. Again, these researches have just postulated the effectiveness of cartograms for movement data visualization without intensive usability testing. On the other hand, Kaspar et al. (2011), reported the empirical usability evaluation of contiguous cartogram that shows cartogram effectiveness and efficient for simple task and for complex task level its of designing. Sun and Li (2010) applied a two step comparative study: between cartogram and area cartogram, and among area cartogram types, which shows cartograms are more effective for qualitative information deliver than quantitative data access. Street (2006) applied a comparative evaluation between a centre point cartogram and an isochrones map that shows a greater effectiveness of the isochrones map.

Further, in the research of Ullah and Kraak (2014) user tests were executed as a pre-requisite for its post construction phase, which is the starting point for their research. In this research also the usability test execution were not detail (i.e. using varies usability techniques and with many real user representatives). Generally, still very little is known about cartogram usability for movement data visualization (Kaiser, Walsh, Farmer, and Pozdnoukhov, 2010). It is true that finding suitable candidates for representing schedule movement data among visual outputs is hard, but a combination of usability research methods which can cope with the most important user requirements would be able to choose the preferable visualizations for scheduled movement data

2.6. Conclusion

Based on the review of literature and from the relevant descriptions of the listed visual representation theories, it is possible to identify candidates for scheduled movement data visualization and their characteristics. These visual representations were applied according to different strategies and algorithms to represent scheduled movement data. Aiming to explore the preferable visualization, usability research is pertinent. Specifically, this study is compulsory to investigate the usability of the CTC and to identify the preferable design among the four alternative solutions.

3. RESEARCH METHODOLOGY

3.1. Introduction

This chapter represents the workflow of the research and discusses the methodological framework, including the theoretical approach of usability research methods, along with the reasons for their selection. The usability evaluations are conducted in two phases.

3.2. Research Workflow

This usability research is part of a User-Centre Design (UCD) approach that contributes to the possible redesign of Ullah and Kraak (2014)'s prototype of the CTC. UCD is an interactive process, which categorizes products and user requirements into sub-tasks. The disposed requirement functions and sub-tasks allow the conceptual designer to get a comprehensive understanding of the users' requirements. Based on the representative users' requirements the approach also evaluates different designs of prototypes iteratively.

UCD methodology assists to analysis results of an evaluation process based on users' activities through an execution process. Users are influencing factors in the UCD process while the producer should consider their requirements to confirm that the design is fit for purpose it is produced for. International Standard Organization 13407 provides a definition of UCD that considers usability as a goal of this approach. As Norman (1988) indicated, for a design to be usable in an UCD context, it needs to include the following main points:

- consider user expectations in the design process starting from a conceptual model of alternative solutions up to the final result of the design
- perform easy and intensive evaluation in each state of the product
- take an easy decision to determine the possible action at any movement of evaluation phase
- consider the complement of need and the required actions; resulting an effect, visible information and user interpretation

Generally, UCD is focused on verifying the usability of a particular system according to the users' assumptions and requirements. UCD has three phases van Elzakker and Wealands (2007): requirement analysis, prototyping, and usability evaluation. In the research of Ullah and Kraak (2014) the first two phases of the UCD approach were already done.. In this research, the third main phase of UCD will be performed: usability evaluation. This phase can be considered as a multi-stage problem-solving process. For the designer, it cannot only provide the analysis and foreseeing how users prefer to use a particular product, but also to test the validity of user expectations in real world tests with representative users. Further, usability evaluation is necessary for the designers to understand intuitively how and what the first-time user of the design experiences and to identify their user's intent.

Usability evaluation is a necessary step in the UCD approach, and it can take place in all steps of the different products' life cycles. Products are evaluated based on an initial set of user requirements. The goal of the evaluation differs in the context of use. It is mainly to provide feedback to the designer, to assess the achievement of user objectives and to proof the multi-dimensional and long-term use of the product. The result of the evaluation should be presented in the form of a report that describes the evaluation objectives or context, methods, and summarizes the outcomes.

Following the UCD approach as adopted in Figure 3-1 below, this research implementation started with a preparation of first iteration prototype of the CTC by the producer of the design, Ullah and Kraak (2014), which consisted of the four alternative solutions of the CTC, following four main steps are conducted in the research. First, a qualitative experiment was implemented with the help of four evaluation methods in the usability laboratory. Second, as findings of qualitative evaluation, feedbacks were provided to the prototype producer. Then, a second iteration prototype of the CTC in combination with a schematic and a geographic map was made ready by the producer for a quantitative test. As shown in Figure 3-1 in the third stage, the quantitative experiment was implemented that were with online survey. Finally, in the fourth step the usability level of the CTC was explored as a result of the two main phase evaluations (i.e. qualitative and quantitative experiments), which will determine user's opinion to accesses time information from the prototype, or that will prove "Do CTC usable?"

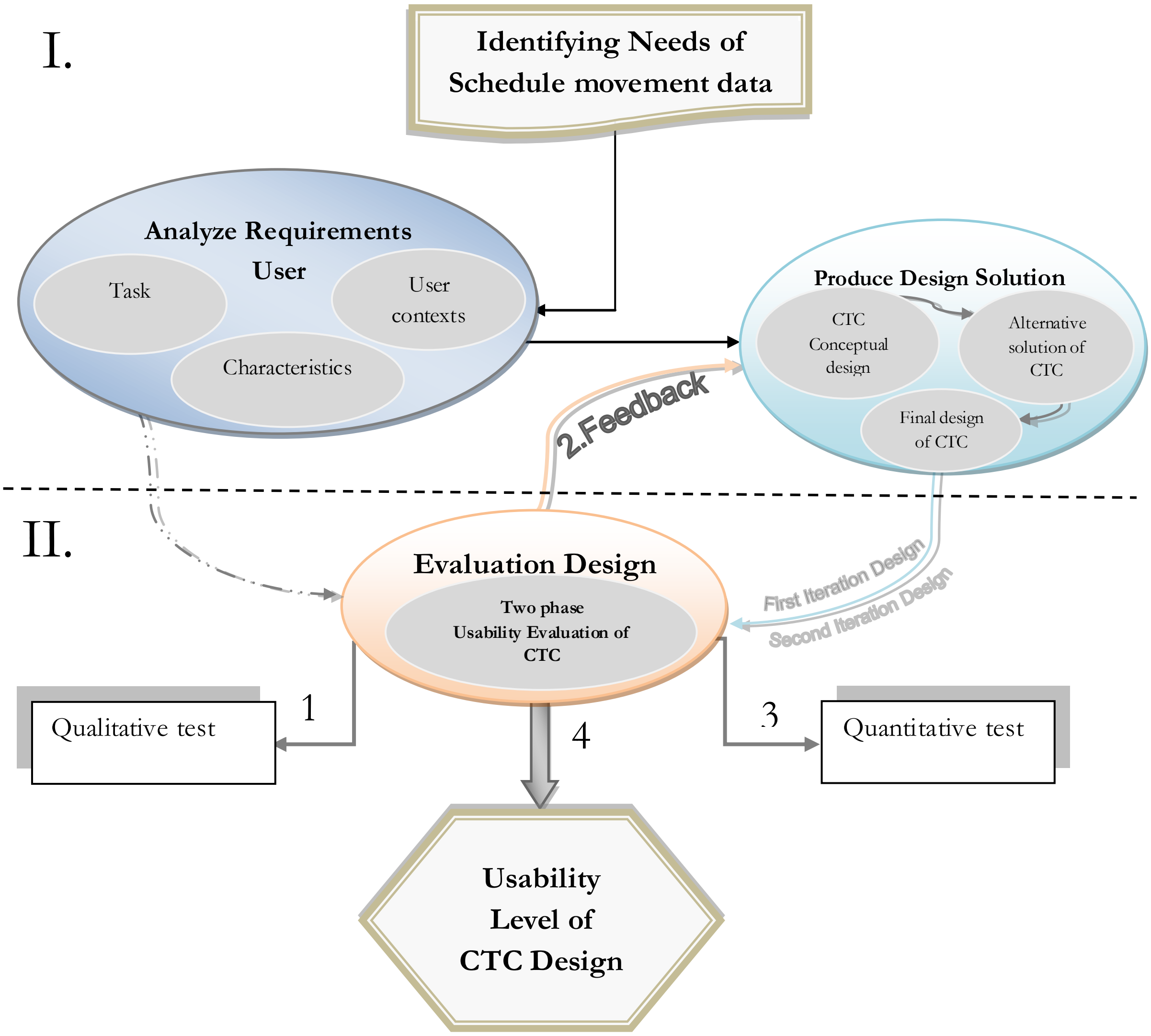


Figure 3-1: Adopted UCD approach in this research, (van Elzakker and Wealands, 2007)

3.3. Methodological framework

Usability research is a tool of this study as a way of investigating and justifying how well the designed CTC can be implemented according to the users' requirements. The ISO 9241-11 standard explains about usability in three main perspectives: effectiveness, efficiency, and satisfaction (Bevand, 1994):

- Effectiveness: goal of the product obtained when users complete tasks, which is what users want to do accurately and completely
- Efficiency: it is a measure of resources, how much time users need to perform tasks
- Satisfaction: measure of comfort and pleasance, what user think about the easy use of products

Usability evaluation of visual representations has got a wide cover in recent studies (e.g. Fabrikant, Hespanha, Andrienko, Andrienko, & Montello, 2008; Fabrikant, Hespanha and Montello (2008)). The evaluations deal with many products and systems, taking into account the user's needs and requirements. It are evaluation approaches according to a particular methodology like UCD that is implemented with real users or representative users (Nielsen, 1994). There are various usability evaluation methods that are used to qualitatively and quantitatively measure user expectations. For example, questionnaires (Mercurio, Riley, and Sokolov (2008) and van Elzakker (2004)),focus group discussions (Liamputtong (2010)), thinking aloud (Barnard and Sandberg (1994)), video observation (Blok (2005)), screen logging (Barnicle, 2000) and eye movement tracking (Coltekin, Heil, Garlandini, and Fabrikant (2009)) are known methods which are used in different usability studies.

The methodology in this research includes two main phases that apply qualitative and quantitative usability testing methods respectively. Qualitative tests are used to explore properties that can be observed without quantifying, while quantitative tests may lead to statistical analysis. Both can be applicable in combination or individually in map use research (van Elzakker, 2004). It is preferable to combine both tests if the design of a prototype will be improved based on a thorough task analysis, and tested later in a quantitative way. In addition, if maps to be tested are visualized a particular geographic features Maceachren, Hardisty, and Gahegan (1998) recommend a qualitative test to be first. Furthermore, preferable and new insights of visual representations can particularly be discovered through qualitative evaluation of static or interactive visualizations, which have not been considered before or are not known by the producers themselves (van Elzakker, 2004).

In this research, first four alternative solutions of the CTC were used to explore their usability in representing spatio-temporal data. Thereafter, an improved CTC was tested together with two other stimuli (schematic map and geographic map) in a static environment. In the two cases, the aim is to find the preferable visualization for scheduled movement data. In doing so, a single usability method cannot answer our question "DO THEY WORK?". Further, we are interested in exploring how long it takes users to find the answers to the tasks (efficiency), how correct the answers are (effectiveness) and how easily it works and what are the user opinions while performing the tasks (satisfaction). This requires a combination of qualitative and quantitative evaluation methods, executed sequentially. In addition, our research aims to discover what kind of tasks and questions, related to spatio-temporal data (particularly scheduled movement data) could be answered easily by the CTC. It is hoped that this will prove the usability of this cartogram for scheduled movement data visualization based on user expectations and requirements. Meanwhile, we are interested in exploring alternatives for scheduled movement data representations and in identifying scheduled movement data users'.

Generally, a set of tasks and questionnaires was prepared in order to be able to explore the usability of visual representations of scheduled movement data. First, on the basis of scheduled movement case study data (see Chapter 4) four CTC designs were prepared. Secondly, an improved CTC, geographic map and schematic map were prepared. Tasks and questionnaires were produced in consideration of the case study data and used to analyze and explore the effectiveness and efficiency, whereas questionnaires are used to verify the users' opinions toward the visualizations. Hypotheses are formulated (see section 3.4.2 below) on which alternative design solutions of the CTC are preferable to answer specific spatio-temporal questions in the proper usability context and again to test the usability of the improved CTC in comparison. As said, the hypotheses were tested through two phase usability testing, that is a qualitative and a quantitative test. Both test phases had three main implementation procedures: test set-up, test execution and result analysis. Finally, the test objectives were achieved and the hypotheses accepted or rejected based on the experiments performed in consideration of the evaluation objectives, so as to answer the overall research objectives (see Fig. 3-2). In addition to the visual output selection and task preparation, several other user research methods are used in the experiment in order to explore detailed information about the performance of the selected scheduled movement data visual representations.

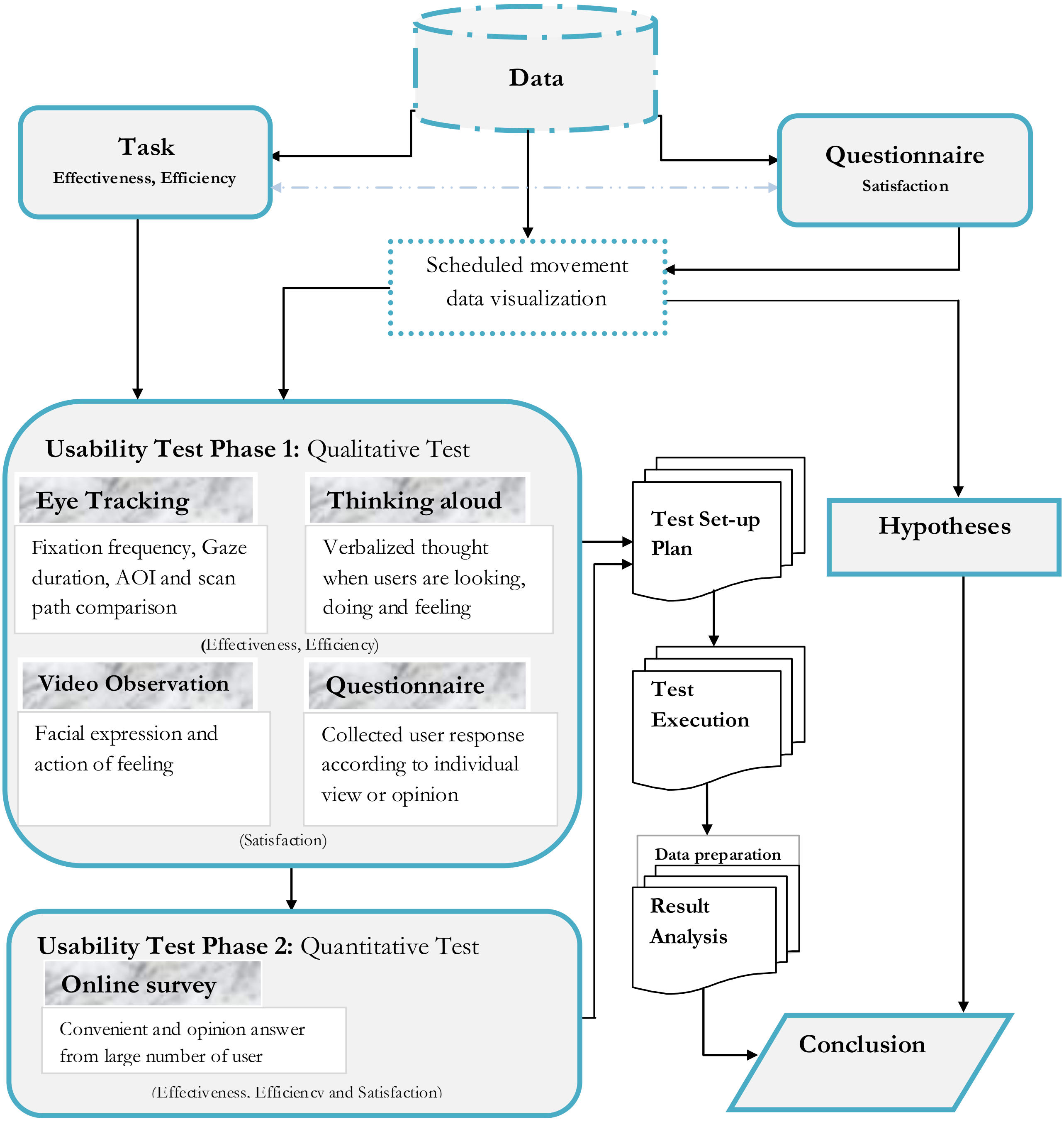


Figure 3-2: Work flow diagram of the research phase

3.4. Approach

The research was carried out by following the methodological framework illustrated in the Figure 3-2. The research work was started with a review of relevant literatures to identify the various scheduled movement data visual representations and to justify the user research methods which are adopted in this project. The preparation and implementation of the usability methods, the identification of data and visual representations were based on the previous work in the lectures. These reviews were accomplished by the selection of appropriate methods, determination of participants and preparation of visual representations for the research.

3.4.1. Visual output preparation

In this phase (see Figure 3-2), the characteristics of the spatio-temporal data were checked focused on scheduled movement data. This included the determination of the case study area for visual outputs preparation that fit with the test objectives. Then, CTC; a schematic map and a geographic map, were reviewed from the literatures. Based on the case study dataset (the Overijssel railroad network in 2010), four alternative design solutions of the CTC from six different starting stations were prepared by the CTC producer for the qualitative test. Similarly, for the quantitative test the whole of the Netherlands railroad network dataset 2010 was used to produce three visualizations (second iteration CTC prototype, geographic map and schematic map). The performances of each visual output were determined in consideration of evaluation process. In one hand, the complexity of tasks and questionnaires are considered during the visual output preparation. In the other hand, the test environment has been taken into consideration such as task type, display resolution, visual complexity and order of display.

3.4.2. Formulate hypotheses

A usability evaluation was implemented to achieve the all research objectives through proving five formulated hypotheses. These will be considered as objectives of the two evaluation phases (qualitative and quantitative test) in Chapters 5 and 6.

1. The CTC has a preferable design to improve the users' understanding in accessing scheduled movement data. Therefore, this design can answer all tasks and questionnaires effectively, efficiently and with user satisfaction.
2. The CTC has a preferable design to visualize scheduled movement data without creating a false impression of time. Therefore, this design can answer all tasks and questions effectively, efficiently and with satisfaction.
3. The CTC has a preferable design to perform particular simple and complex tasks. Therefore, its usability depends on task types.
4. The second iteration prototype of the CTC is more usable (effective, efficient and satisfactory) than the geographic and schematic map for scheduled movement data visualization.
5. The second iteration prototype of the CTC can answer spatio-temporal questions better than the geographic and schematic map without being affected by the distorted nature of cartograms.

3.4.3. Selection of usability evaluation methods

Since, the main goal of our research is to explore the usability of a new design (i.e. a CTC), a combination of qualitative and quantitative test will be applied. This section will describe the qualitative and quantitative evaluation methods that are selected for this study, along with their theoretical background.

Nowadays, a variety of qualitative and quantitative evaluation methods and techniques are commonly used in map use research. Quantitative methods are evaluation techniques of gathering and analysing the respondent's data with their physical reactions, insights of cognitive processes and their reasoning. In contrast, quantitative methods are approaches for mathematical and statistical data gathering and analysis. In order to conduct the usability tests in this research, the following combinations of usability evaluation methods were applied: eye-tracking, thinking aloud, questionnaires and video observation in the usability laboratory for qualitative testing and an online survey for the quantitative testing. These methods, and the reason of selection for our research, are discussed below.

In numerous usability evaluations thinking aloud is applicable for recording and analyzing qualitative information of cognitive processes (MacEachren et al., 1998). Its main purpose is to collect user thoughts by keeping users to talk or speak out loudly whatever thoughts come in their minds related to their performing the tasks (van Elzakker, 2004). This can help to investigate what the users are actually thinking before, whilst and after they interpret the visualizations (van Elzakker, 1999). The method encourages users to concentrate on the task, and to speak out loud what they are doing and thinking simultaneously. Its whole process is recorded through audio and video. However, this sometimes creates an unnatural environment that leads test persons to feel stressed. Generally, as indicated by van Elzakker (1999) this method has the following advantages and disadvantages:
Advantages:

- Its result can be recorded by audio and video techniques that drive verbal protocols for analysis
- It guides test persons to concentrate more on their task due to the expected vocalization.
- It does not allow the test persons to memorize the tasks because during test execution it is expected from them to think, do and feel simultaneously.

Disadvantages:

- It is time consuming during data collection and analysis.
- It does not provide more access to the test persons about their detailed cognitive thoughts.
- The collected results of this method may be difficult to interpret, because the test persons might face difficulties to translate their thoughts into words. This might be due to the influence of the research leader or a lack of experience in expressing thoughts.

Because of its advantages, in this research the thinking aloud method will be used to collect the users' first insights when they are performing tasks with the CTC prototype. As stated by Nielsen (1994) the researcher will be able to identify misconception or understanding of the users about the prototype. For example, users might face difficulties when they try to solve some particular tasks or they might appreciate the prototype to solve other specific tasks, and in this way they provide answers to the questions with confusion or with a clear understanding. Without thinking aloud, the problems of the prototype and whether it could be used easily would never have been known by the evaluator. In this context, participants will have to be motivated to speak out loudly what they are looking at, and how they reply to the tasks based on their feelings and thoughts. However, a usability exploration of such a new design (i.e. the CTC) via verbal recording of thoughts resulting from the think aloud method only would not be sufficient. Accordingly, we combined the think aloud method with other methods (i.e. eye movement tracking and video recording) to limit its disadvantages.

.

Video observation is used to investigate the response of the test person's immediate view according to their facial expressions (van Elzakker, 1999). This method is being able to explore the test persons' facial expressions that cannot be verbalized. However, it has drawbacks in providing confidential analysis result because of non confidence recording, for example test results from non focused cameras recording.

To compensate the limitations of the two qualitative evaluation methods in this research eye tracking was applied as well. Eye tracking is a technique in which an individual's eye movements are recorded. This identifies where the participants are focused at at particular times, including the order of shifting their eyes from one location to another (van Elzakker, 2004). This recording of eye movements is helpful to explore the use of visualizations by the test persons thoroughly (Razeghi, 2010) provides a detailed evaluation of how test persons interact (eye fixations) while performing each task without the need of mouse or keyboard input. Hence, eye tracking can give valuable information on when, where and what the test person is looking at during performing each task with the visualization.

There are different eye movement metrics. Fixation is the main metrics used in eye-trackers, which is an eye movement measure of when the eyes are relatively stationary. A number of single fixations or a clustered fixation indicates an uncertainty to interact with the target. In other words, the shorter fixation represents an easy access of representations than longer fixations. Also longer fixation could show the correct response of the wanted information but with long time cost. Fixation time also measures the time spent to retrieve a particular target area. In addition, saccades are metrics that are used to measure the movements of the eyes in between fixations. These metrics cannot help to identify the complexity and easy use of the target representation. However, backtracking eye movements (regressive saccades) can be used to measure saccades or difficulties during the test execution processes. Similarly, scan paths are the third alternative measure that determines the sequence of fixation saccades. During searching for answers in particular tasks the straight line to the desired target can be considered as an optimal scan path. Figure 3-3 shows four examples of the visualization of eye movement data, which include fixation frequency, gaze (saccades metrics) duration, and Area of Interest (AOI) and scan path. In this research, the tracked eye movement detail report was used, which typically reports about temporal data (time stamp) and gaze point location within a configured screen coordinate system (spatial data).

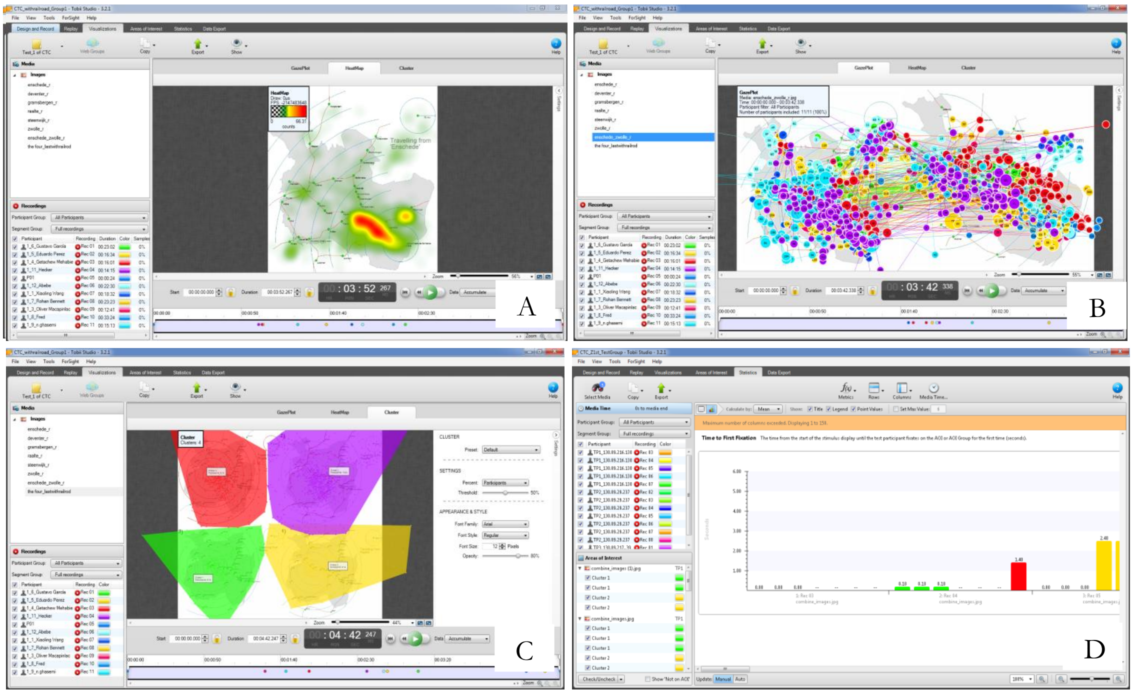


Figure 3-3: Eye movement data visualization for analysis A) a fixation heat map B) gaze plot C) Area of interest (AOI) and D) statistical graph of AOI

Questionnaires are another method of usability evaluation in which test persons are asked to reply to a list of questions related to the products to be tested. Questionnaires are capable of retrieving the responses of a small group of test persons as representatives of the users (Nielsen, 1997). However, it needs careful preparation of questions, which may not to be too long or unclear. It is preferable to refine the questions through a pilot test before the actual test is performed. (Nielsen, 1997) categorizes questionnaires into three different states:

- *factual type questionnaires* - based on observable information that is public and fact
- *opinion type questionnaires* - based on users' opinions and comfort, without exactly right and wrong answers

- *Attitude type questionnaires* - based on facts, user knowledge and life experience.

In this research, questionnaires, more of opinion and attitude type are used in the qualitative test in order to retrieve how the test persons accessed information from the representations. In addition, they are applied in the quantitative test through an online survey that is to evaluate how complete and correct, how fast and how easy the prototype is in answering the questions. The quantitative test uses an online survey that is capable of exploring the users' feedback from their point of view, and is quick, cost effective and can be used as a reliable user response. It helps to let users participate from different locations and is easy to administer. However, similar to other methods, it has some drawbacks such as it is not possible to describe detailed users responses, which are limited by the question type and the researcher has to rely on the users' answers.

Generally, this research was used usability methods for qualitative and quantitative test in consideration of the advantage and drawback of the above described method (see table 1-1). In this case, the combination of thinking aloud, eye tacking, and video observation helps to explore test person verbal, face and visual expression with video recording of each interaction. Accordingly, this research was asked test person to verbalize tasks (what they are doing) on what they do (i.e. task and visualization), and what they see (i.e. visualization interactions). In addition, they were specifically asked to justify their task, which was recorded with video and eye movement record. Further, questionnaires are used for online survey and laboratory usability test.

Table 3-1: Usability evaluation methods applied in this research

Method	Description	Advantage	Disadvantage	Why it is selected?
Thinking aloud	Participants immediate thoughts are collected from vocalization during usability testing	TP to concentrate more on their task, TP to perform tasks without memorization, to collect immediate thought of users	Unnatural environment that results in stress to the test persons (TPs)	To record verbal data responses of TPs without memorized thoughts and to analyze this recording together with documented responses
Video observation	Participant action is recorded via video through out the whole usability test	Used to explore users' feelings from their facial expressions	Difficult to analyze alone, might be determined by analyzer interpretation	To record the TP's behaviour through the whole usability exploration and to analyze according to their reactions.
Eye tracking	To collect eye movement (time to first fixation, count, duration gaze time distribution, average time and transaction with visualization) during task execution by participants.	The eye tracking software makes data analysis easier and more efficient	Its result is dependent on the techniques applied correctly, such that it requires the operators to operate and interpret the result properly	To record the gaze and fixation data of TPs when performing each task during usability testing and to analyze it in combination with the other methods. Also it could enhance our usability exploration with a clear insight of AOIs.

Questionnaire	To collect the participant's response to a statistical survey with posted questionnaires.	Capable of doing with a large number of participants, a broad range of data can be collected (e.g. attitudes, value opinions)	Participants may not feel encouraged to respond accurately and may not be fully aware of the response	To collect and analyze data from numerous TPs with different profiles and varieties of view, To compare user responses statistically.

3.4.4. Tasks and questionnaire

The formulated hypotheses were tested based on prepared tasks and question sheets in relation with the different visualizations as will be discussed in Chapters 5 and 6. The tasks and questions were prepared in consideration of exploring the usability of the four alternative CTC solutions via a qualitative test. Further the quantitative test was used to explore the second CTC iteration prototype in comparison with a geographic and a schematic map.

3.4.5. Test set-up plan

A two phase test set-up plan was prepared to test the formulated hypotheses and to consider the overall research questions. The first test set-up plan was to test four alternative solutions of the CTC through a qualitative test which was supposed to answer hypothesis 1, 2 and 3, as described in Chapter 5. The second test set-up plan was prepared to test the selected design solution of the CTC, with schematic and geographic map stimuli in comparison. This addressed hypothesis 4 and 5, as described in Chapter 6.

3.4.6. Test execution

The qualitative and quantitative tests were implemented in different platforms. For the qualitative test, user profiles were collected though an online survey via Survey Monkey (URL.2), and scheduled with doodle.com (URL.3), the real test was done with eye tracking software Tobii Studio(URL.1), while the quantitative test execution was through an online survey via Lime Survey (URL.4).

3.4.7. Data preparation and Analysis

In order to answer the test objectives in each evaluation, the test execution results were prepared and analyzed.

3.5. Conclusion

The proposed methodologies are in consideration of the research objective achievement whilst to answer the research questions. We expect to address the research objectives by going through the proposed methodological framework.

4. CASE STUDY

4.1. Overview

The case study of this research is the Netherlands, a European country that is administrated with twelve provinces and 408 municipalities(Wikipedia, 2015). From the fourteen provinces of the Netherlands, Overijssel is one with the capital of Zwolle. It consists of 25 municipalities including Enschede, Deventer, Raalte, Steenwijk and Gramsbergen.

Rail transport in the Netherlands has long history since 1839, the year in which the first short railroad stretch between Amsterdam and Haarlem was opened (Wikipedia, 2015). The demand of rail users increased in the 20th century and that resulted in the electrification of the main lines. The railway network in the Netherlands is mainly operated by state-owned companies, which provide travel information with static and interactive maps. The Dutch train network covers a track length of almost 2,900 km, 405 stations and over 1.2 million passengers in every day (Wikipedia, 2015). The motivation to choose the Netherlands is the availability of data to prepare the evaluated visualization and the availability of participants to conduct the usability evaluation.

Accordingly, a spatio-temporal dataset was used as the case study dataset: the Netherlands 2010 train travelling time network. The visual representation (CTC in four alternative design solutions of CTCs of the province of Overijssel) of this dataset was prepared by the CTC producer (Ullah and Kraak, 2014). Based on these visualizations, user tasks and questions were prepared, to explore the effectiveness and efficiency of them. At the same time, questionnaires were prepared to investigate the satisfaction of the users after performing each task and about the whole design. Similarly, after the analysis of the qualitative test results the whole of the Netherlands train time trip dataset (with 33 selected train stations, and map of the Netherlands with provincial boundaries) was used to prepare three visual representations: a second iteration CTC, a geographic map and a schematic map, in order to compare the three stimuli in a quantitative way.

4.2. Selection of visual representations

The datasets mentioned above were applied to the production of four alternative design solutions of the CTC with six different starting stations. In addition, out of the scheduled movement data visual representations, as mentioned in Chapter 2, a geographic and a schematic map were also prepared, including the second iteration design of the CTC. The CTC organizes different spatio-temporal information with different designs. Particularly for this case study dataset, a set of 24 CTCs was prepared for the first evaluation (qualitative test), based on the four designs and six starting stations. Similarly, a set of12 scheduled movement data representations was produced for the second evaluation (quantitative test), based on the three different kinds of visualizations (CTC, schematic and geographic map) visual output and four starting stations.

The reasons for the stated visual outputs selection was that the four alternative design solutions of the CTC, based on six starting points, helps to formulate different tasks accordingly. Also it was possible to explore one alternative solution of the CTC for a particular task that proves hypotheses 1, 2 and 3. The later three visualizations were selected and prepared for the quantitative evaluation, which are typical and comparable representations of scheduled movement data. Accordingly, it was possible to prove hypotheses 4 and 5.

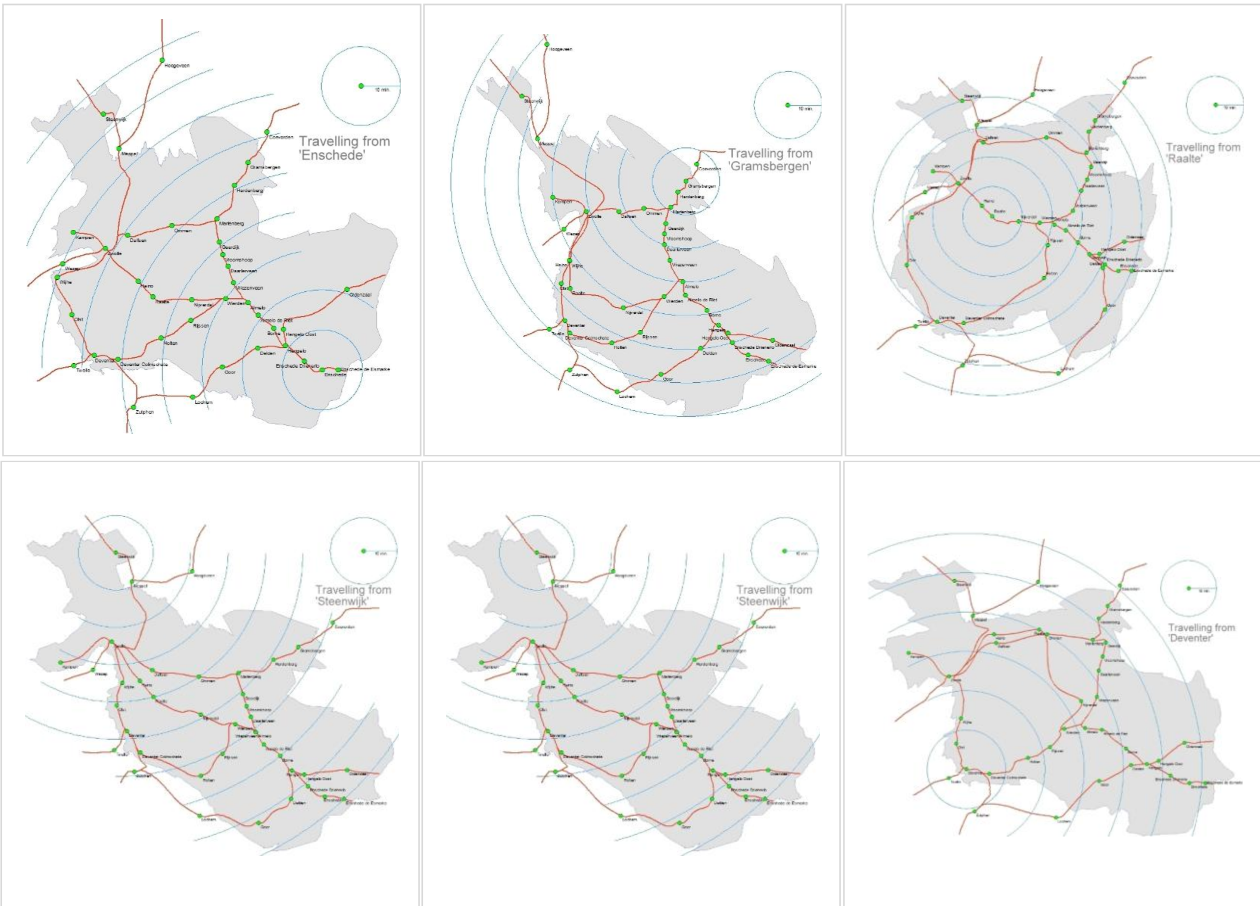
4.2.1. Characteristics of the four alternative CTC design solutions evaluated in the qualitative test

Description: Single display of CTC alternative design solutions from six starting points
The CTCs in Figure 4-1 1) were prepared based on the design of a CTC with railroads. In these cartograms, the red lines show the railroad lines and the blue lines or concentric circles represent a time interval of 10 minutes. The green point symbols show the stations, which are also labelled with their names. The Figure represents CTCs from six starting points (stations Enschede, Gramsbergen, Raalte, Steenwijk, Zwolle and Deventer), and the time interval of 10 minutes starts from zero at the starting stations to stations farther away. These cartograms are the result of railroad lines and time circles shown with "normal" line sizes and without any emphasis on either of the two. Figure 4-1, 2) was prepared in a similar way as the cartograms in Fig. 4-1 1). However, this representation of the CTC does not include the railroad lines. As a result, we prefer to call this the "CTC without railroad". Figure 4-1, 3) and 4) also have a similar design except for the fact that the railroad and time circles are emphasized, as their names imply. The four different designs were presented to four different testing groups when the usability evaluation was conducted (see Chapter 5).

1) Group 1: CTC with railroad

2) Group 2: CTC with-out railroad

3) Group 3: CTC with emphasized railroad



4) Group 4: CTC with emphasized time circle

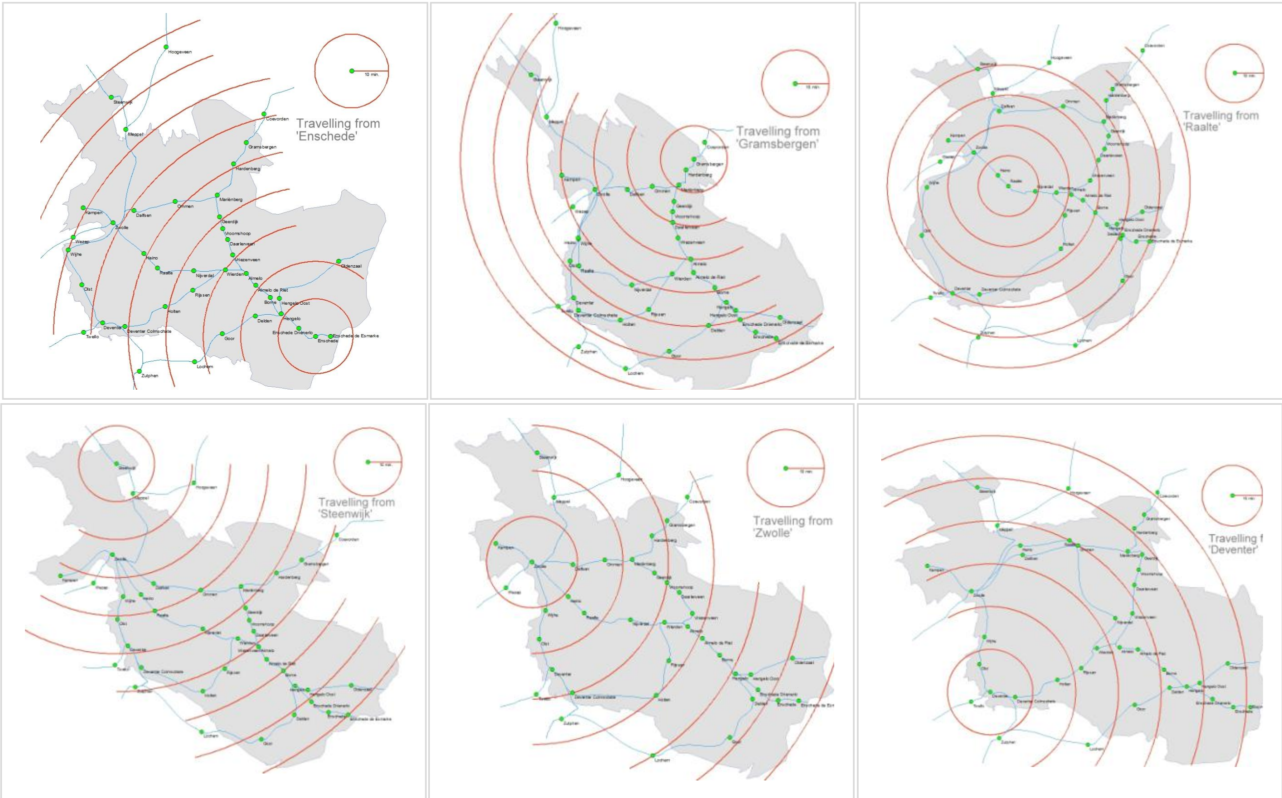


Figure 4-1: Evaluated CTC alternative design solutions from two starting stations

Description: Coupled display of CTC alternative design solutions from two starting points
The CTCs in Figure 4-2 were prepared based on the alternative design solutions of the CTC and were offered as pairs to the test persons to perform one particular task (see Chapter 5). The designs are the same as in Figure 4-1. However, here the cartograms are prepared from two starting stations (i.e. Zwolle and Enschede), which is to present the cartogram information with a comparative view.

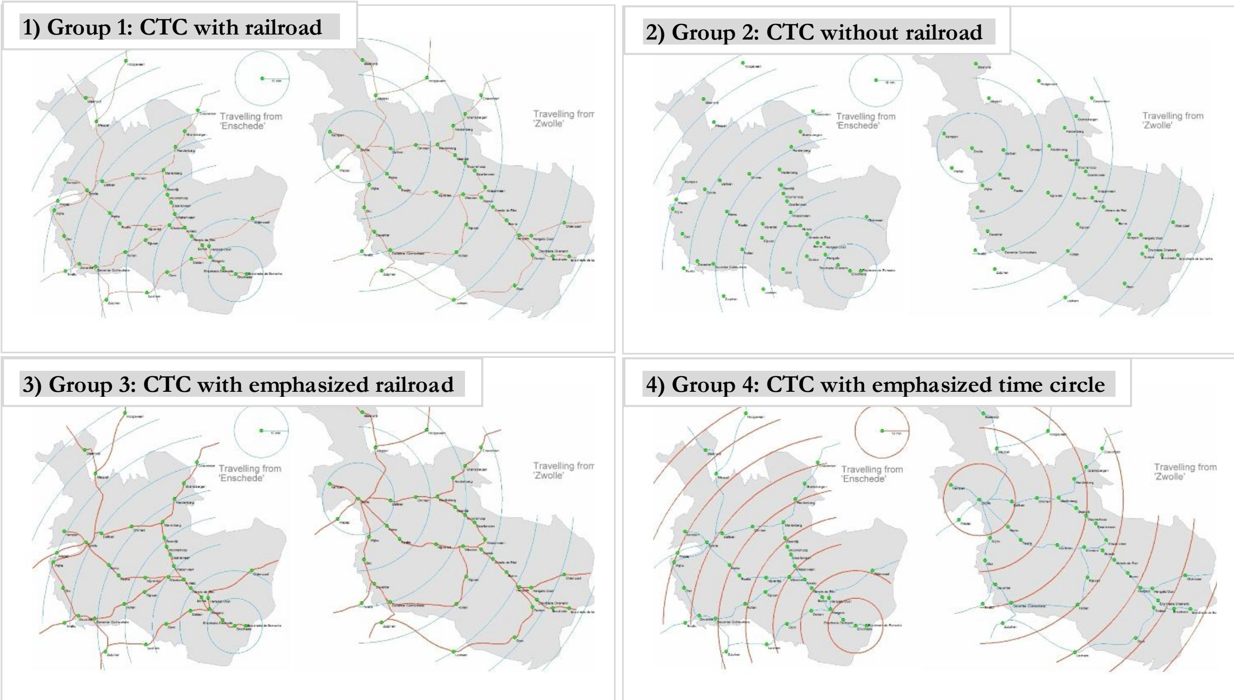


Figure 4-2: Evaluated CTC alternative solutions from two starting stations

Description: Combined display of the four alternative CTC design solutions with one starting point (Raalte). The CTCs in Figure 4-3 were prepared based on the alternative design solutions of the CTC. However, here the four designs (from the same starting station: Raalte), are presented together in order to allow test persons prioritize among them. The order of presentation of the different designs is related with the grouping of test persons. For instance group 1 performed the tasks via the CTC with railroad, and, therefore, this design was put in the last position (four) in order to control the participants' learning bias.

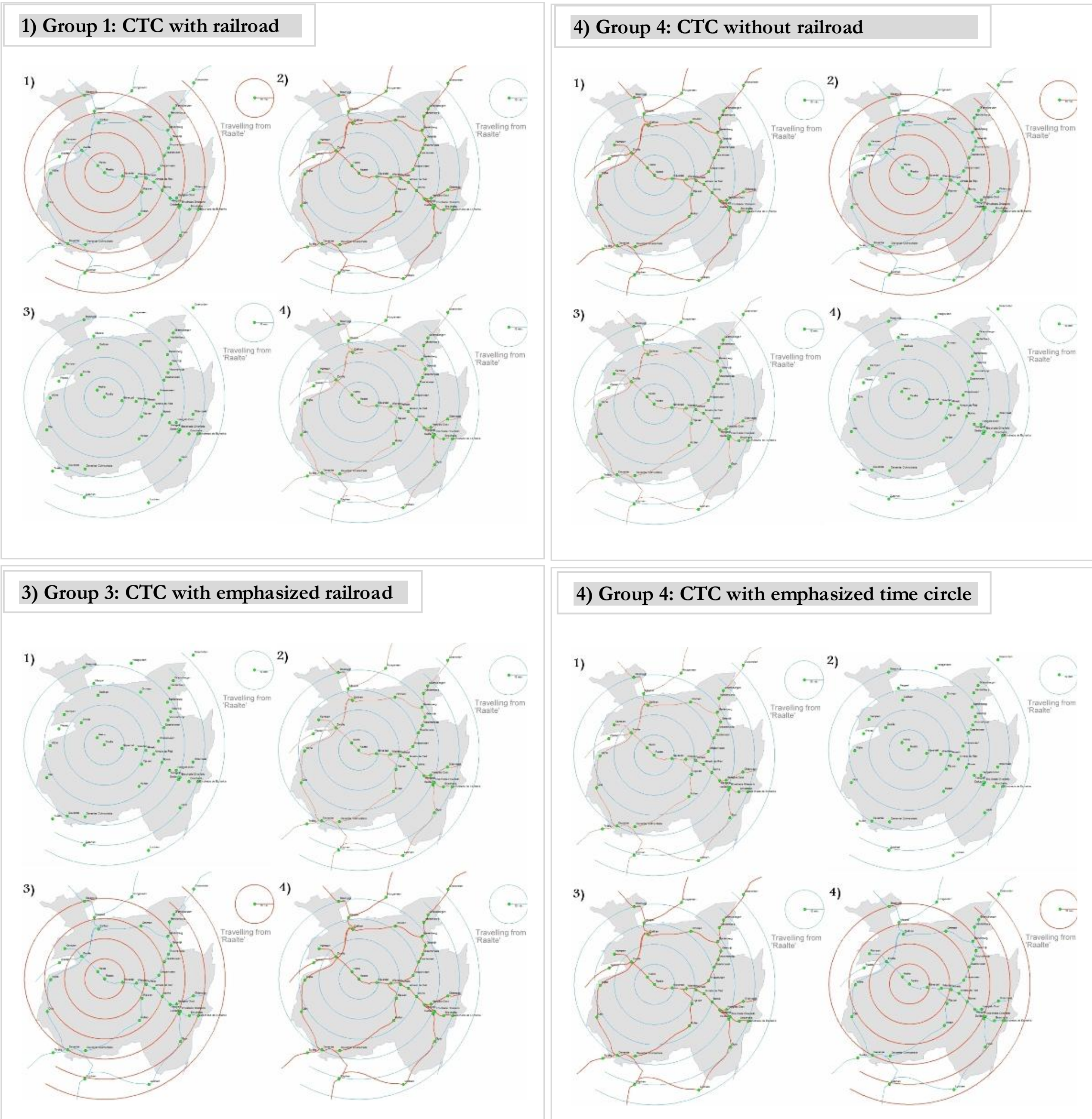


Figure 4-3: Four alternative design solutions of the CTC in four presentation orders

4.2.2. Characteristics of potentially suitable scheduled movement data representations, as evaluated in the quantitative test

As believed by the UCD approach, an appropriate visual representation should support as many of the users' requirements as possible and should be evaluated in the proper use and user contexts. According to the information achieved from literature and based on the objectives of our research, three candidate visualizations have been selected to compare their performance for scheduled movement data representation. Geographic and schematic maps are considered as candidates, together with a second iteration CTC. The first two are common types of representation of transport networks that provide time information. But there are still some other representations which are not considered in this study, such as flow maps (combined representation of flow charts and maps that represent objects of movement with locations like migration of people). They can represent movement data but in different contexts. So we could not consider these as a good candidate for scheduled movement data representation. Figures 4-4, 4-5 and 4-6 represent the CTC, schematic map and geographic map respectively which are evaluated in the quantitative test. Their characteristics are discussed first:

Characteristics CTC:	
A CTC represents scheduled movement data along transportation routes by concentric circles; which are drawn from the starting station to all other stations. For a particular station the time information can be known by counting the concentric circles starting from the starting station.	
Information represented by	
Lines	Represent railroads
Nodes	Connectivity between rail road junctions
Attributes	Movement between specific stations in the region
Points	Represent stations
Time	Indicated by concentric circles
Map capacity (can be)	
Spatial aspect	Partially answer "where" (location) questions. Fully answer "what" (feature) questions (like stations).
Temporal aspect	Fully answer “when” (time) questions.
Display connectivity	Stations are connected through railroads.
Geographical correctness	Geographical location and spatial relationships are modified according to travelling times.

Figure 4-4 illustrates the CTCs of the Netherlands' railway network from four starting stations i.e. Eindhoven, Utrecht, Maastricht and Schiphol. In the figure the total combined track flow and stations of the Dutch train network are shown. The stations of interest according to the four tasks were labelled.

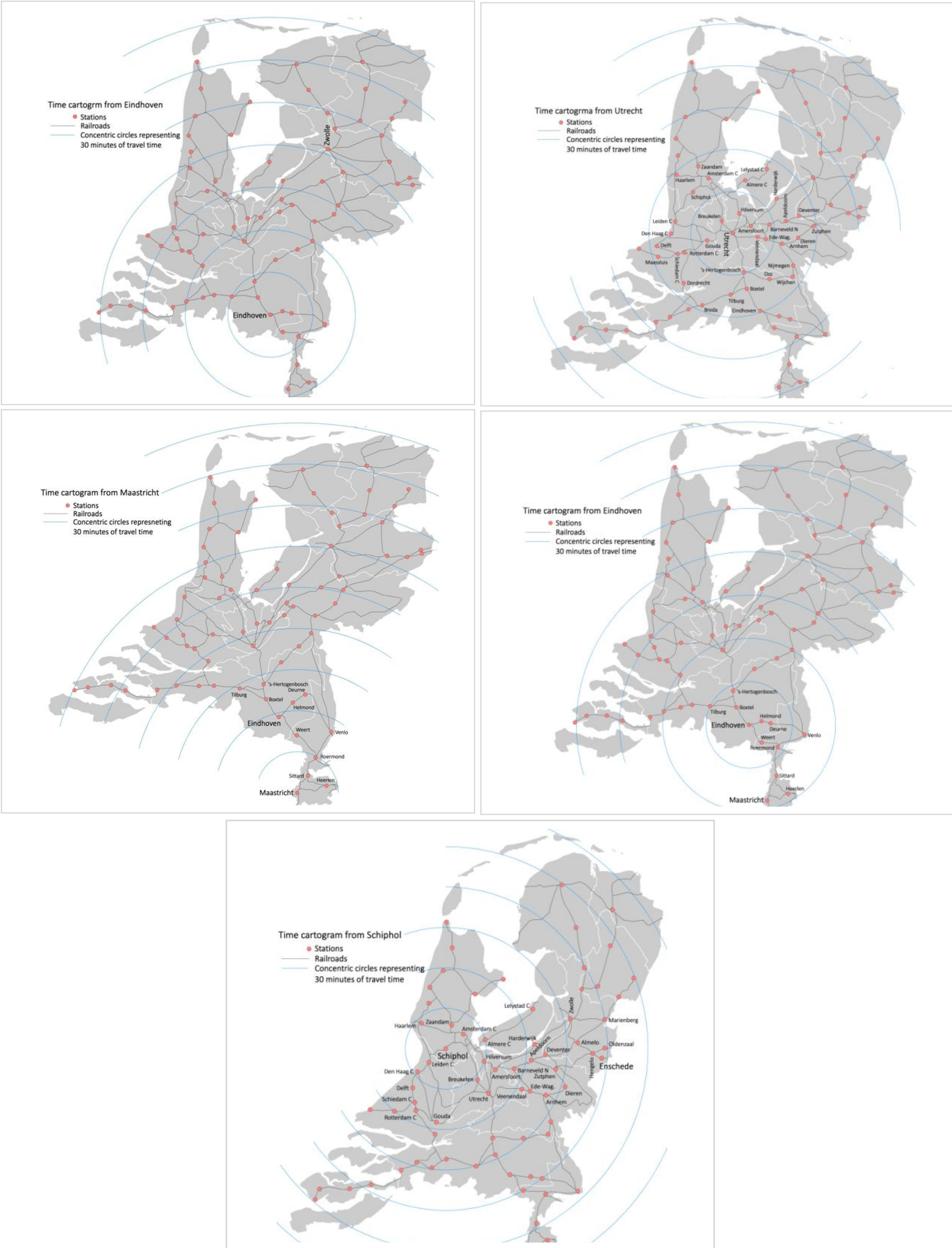


Figure 4-4: Second iteration CTC

<table>
<tr><th colspan="3">Characteristics Schematic Map</th></tr>
<tr><td colspan="3">A schematic map is an often used map for representing routes in terms of distance and time within transport systems and are created by selecting the original line network, which is then schematized and symbolized.</td></tr>
<tr><th colspan="3">Information represented by</th></tr>
<tr><td>Lines</td><td colspan="2">Represent railroad segments of the network</td></tr>
<tr><td>Nodes</td><td colspan="2">Connectivity between rail road junctions</td></tr>
<tr><td>Attributes</td><td colspan="2">Movement between specific nodes in the region</td></tr>
<tr><td>Points</td><td colspan="2">Represent stations</td></tr>
<tr><td>Time</td><td colspan="2">Indicated by numbers along the railroad segments</td></tr>
<tr><th colspan="3">Map capacity (can be)</th></tr>
<tr><td colspan="2">Spatial aspect</td><td>Fully answer "where" (location) questions
Fully answer "what" (feature) question (like stations)</td></tr>
<tr><td colspan="2">Temporal aspect</td><td>Fully answer “when” (time questions)</td></tr>
<tr><td colspan="2">Display connectivity</td><td>Stations are connected through railroads</td></tr>
<tr><td colspan="2">Geographical correctness</td><td>Schematize the geographical location or spatial relationships to improve readability</td></tr>
</table>

Figure 4-5 illustrates schematic map maps of 4-5 the Dutch railway network which label the stations targeted to the quantitative test questions including Eindhoven, Utrecht, Maastricht and Schiphol. The map covers the whole train network of Netherlands with segmented nodes.

Figure 4-5: Schematic map

Characteristics Geographic Map:		
A geographic map represent scheduled movement data or time information by means of labelled numbers (time) along railroad segments. These maps, illustrates time between particular stations in a specific location. The differences in time between stations can be calculated by counting between two consecutive segments.		
Information represented by		
Lines	Represent railroads	
Nodes	Connectivity between rail road junctions	
Attributes	Movement between specific nodes in the region	
Points	Represent stations	
Time	Indicated by numbers along the railroad segments	
Map capacity (can be)		
Spatial aspect		Fully answer "where" (location) questions Fully answer "what" (feature) question (like stations)
Temporal aspect		Fully answer "when" (time) questions
Display connectivity		Stations are connected through railroads
Geographical correctness		Geographical reality preserved

Figure 4-6 illustrates geographic maps of 5the Dutch railway network which label the stations targeted to the quantitative test questions including Eindhoven, Utrecht, Maastricht and Schiphol. The map covers the whole train network of Netherlands with segmented nodes.

Figure 4-6: Geographic map

Below the table discuses about the advantage and disadvantage of selected three comparable maps for scheduled movement data representation. Although, they are comparability for spatio-temparal representation in general, but from technical perspective they used different approach of representing temporal information.

Map type	Advantages	Disadvantages
CTC	– Gives a comprehensive view of the entire network. – Emphasizes the travelling times over the other map content. – Can be helpful to discover patterns within the data that would, if mapped otherwise, be obscured.	– Geographical locations or spatial relationships are modified to suit travelling-times. – Need a different CTC for each starting station
Schematic map	– Objects seen on such maps represent real world features. – Simplified representation of features which increases readability.	– User has to read labels to derive travelling times. – Labels take up space and can make the map crowded
Geographic map	– Objects seen on such maps represent real world features.	– User has to read labels to derive travelling-times – Labels take up space and can make the map crowded.

According to the theoretical characteristic of the above listed candidate maps, finding the scheduled movement information for transport networks is not hard and the three maps are comparable for spatio-temporal reading level. However it is difficult to estimate which one is suitable for temporal data reading.

4.3. Conclusion

In this chapter, based on information achieved from the literature study phase and according to the claim of CTC usability, four candidate designs of the CTC and three candidate maps of scheduled movement data representation were identified, which consider the context of use and user requirements. According to their characteristics, user requirements, advantages and disadvantages, hypotheses were formulated in Chapter 3 and the test objectives will be defined in Chapters 5 and 6. As a result, the maps were selected to facilitate the two phased usability evaluations as discussed in Chapters 5 and 6.

5. USER RESEARCH IMPLEMENTATION: QUALITATIVE TESTING OF FOUR CTC DESIGN ALTERNATIVES

5.1. Overview

In this research study, a qualitative experiment was implemented in order to test the first formulated three hypotheses (see Chapter 3), which describe the satisfaction, efficiency and effectiveness of the four CTC designs. It is aimed to prioritize among the four alternative solutions of the CTC. Twelve sets of visual outputs were presented to individual participants in four groups. With the help of task forms and instructions, the test persons answered particular tasks, executed thinking aloud, and their eye movement was video recorded. The test persons also completed questionnaires, while the researchers used several user research methods to obtain information on the usability of the CTC from the experiment. This chapter describes the user test implementation plan with the three formulated hypotheses as the test objective. It contains three main sections, which are the test set up preparation, the test implementation results and the analysis of the results, preceded by the test objectives. The test set up preparation includes the test person selection, the tasks, the questionnaire the test project preparation and the pilot testing along with test procedures and execution. The implementation results section discusses the test execution in three aspects: performance data, time costs and results of the satisfaction measurement. Similarly, the result analysis presents the findings of the test in consideration of these aspects. Finally, the chapter is closed up by a conclusion and recommendations based on the findings.

5.2. Test objective

In the context of the whole research the qualitative test was applied with three test objectives Figure 5-1 gives an overview of this research usability test with the specific test objectives. It was aimed at proving the three test objectives, which are:

- Finding out whether railroads either improve understanding of CTCs or not;
- Finding out whether the railroads either create a false impression of time or not; and, finally,
- Finding out how the CTC performs in executing particular simple and complex tasks through its representation with different starting stations.

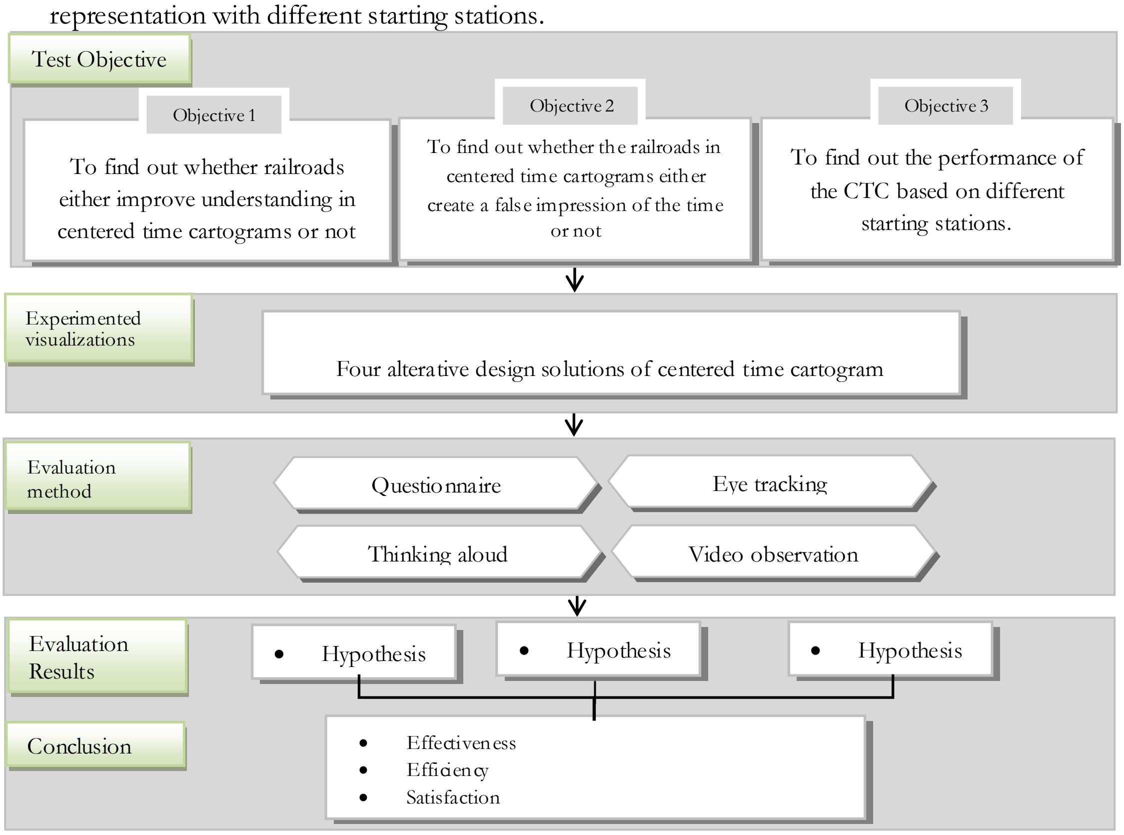


Figure 5-1: Qualitative test objectives and their testing

5.3. Test setup

5.3.1. Test person invitation

Test persons (TPs) can be distressed with the methods that were applied during the qualitative test such as video recording and the process of thinking aloud. Some people may also hesitate to have their name in the result analysis. To take these feelings into account, the qualitative test execution of this research was processed through willing participants, and they were informed that their name could not be referenced. It started by inviting them through an online survey that messages potential TPs to join the test based on their willingness (Appendix 1). The invitation was done before the test execution that is to collect user profile for the preparation of participant group of the test execution, a result, 48 valid responses were recorded, including their profile (based on the user profile survey questionnaire as in Appendix 2). However, among the registered 48 TPs 40 were active participants during the test execution. The remaining eight users were not participated during the test execution due to the announced time and the test implementation schedule different. The evaluator used these participant profiles for group allocation.

5.3.2. Test person selection and grouping

Usability evaluation typically deals with the exploration of user expectations to solve their spatio-temporal questions. To have an effective prototype testing, a task execution through users has to be performed while the main objective is exploring detail patterns and identifying the relationship between features in multivariate spatiotemporal data representations (Vlag, 2006).The real users are important for an effective usability evaluation result (Nielsen, 1997). However, it is difficult to assign test persons as real users in most usability experiments. During the selection of test person to consider as real users we have to be careful about the user profile that would be included (Nielsen, 1997). Accordingly, one of the pre-test preparations of qualitative test was collection of various participants' user profile that could represent real users.

To find out many usability problems and and to achieve comparable evaluation results many test persons with a diverse user profile are preferable (Nielsen, 1997). This test is a qualitative test that is used to explore the preferable alternative solutions among the four designs of the CTC. In this experiment, the TP profile was collected through an online survey via questionnaires (Appendix 2). These user profiles were collected aiming to create four groups which are as similar as possible in their composition (based on individual test person characteristics). Accordingly, four groups were formed; the distribution of each TP between the groups was balanced by justifying their allocation based on the user profile from the surveyed result (i.e. collected through Survey Monkey). In the test, four groups were necessary due to the four designs of the CTC. The aim was to find the most promising among these four alternative solutions through the usability test and discovering which usability issues are involved when users are working with the cartograms. In tota, in each of the four test groups there were 10 TPs who executed the tasks.

We were used thirteen criteria to assign TPs to each group. They include experience of travelling using Dutch trains, experience with the Netherlands geography, map use experience, map production experience, usual way of train trip planning, experience with cartograms, educational background and level, department or course, gender and age. These criteria which identify the characteristics of potential users were prioritized and grouped as in Figure 5-2. This priority order was in consideration with the most influencing user characteristics for the test result. The most important criteria's are on the left and least important ones on the right column of the figure. This criteria's are based on the collected user profile data during willing participant invitation that is according to user profile questions in Appendix 2. Accordingly, the coloured boxes represent the successive answers to each of the questions in the survey (e.g. the green in the top left hand corner box represents TPs who travel by train 2 to 3 times a month).All the criteria with different values (answers) were used to distribute the TPs over four comparable groups.

The visual grouping was processed using a technique called "matrices ordonnable", which is prepared within an Excel spreadsheet as follows:-

- ✓ First, by arranging all user profile data based on the questions response as Appendix 2
- ✓ Second, rearranging the cell size to be same cell size as Figure 5-2 columns
- ✓ Third, different colouring the results of the user profiling data; Excel cell based on the possible answers of each criteria that is the answer of user profile question(Appendix 2) ; results mosaic overview of the response
- ✓ Fourth, order in columns (13) based on the sequence of criteria as shown in the column heading of Figure 5-2
- ✓ Third, sort similar responses (i.e. mosaic) in a row according to the criteria that influence the test.
- ✓ Finally, distribute the similar mosaics in four groups with balance (visually), which results in the following 4 allocated groups of with a similar profile distribution (see Fig 5-2).

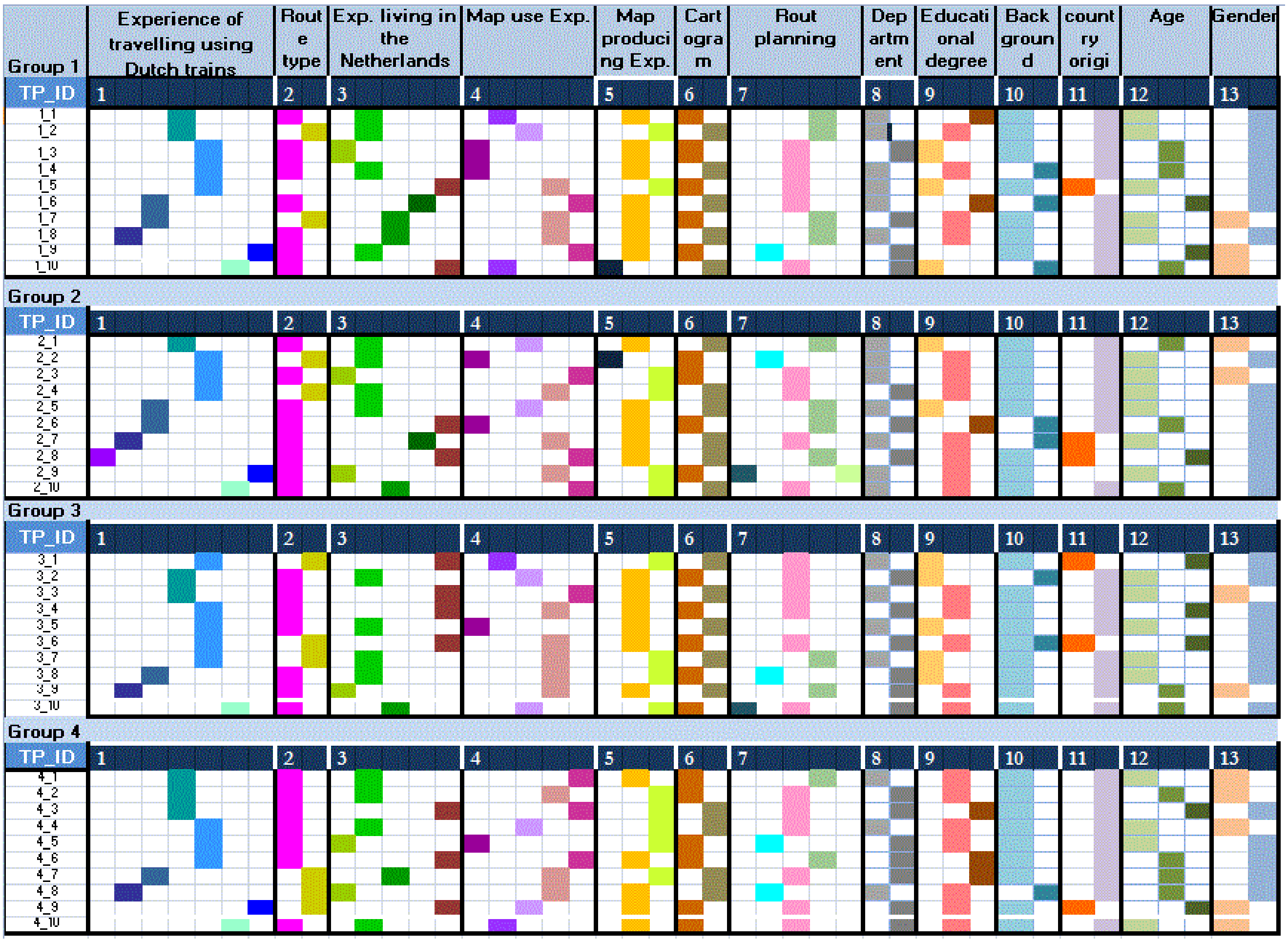


Figure 5-2: Test person visual grouping

5.3.3. Task and questionnaire preparation

During the test execution tasks had to be answered with the help of the visual representations (i.e. the four alternative design solutions of the CTC). These tasks, including spatial and temporal aspects, were prepared corresponding to six different starting points (see Appendix 6), which was to prevent learning bias by the particular shape of the resulting cartograms. We used six starting stations only that can represent different geographical complexity for Overijssel municipality, which were to test the CTC performance in different geographic nature. Further, likert questionnaires (to capture the feelings of users with ranges of responses) were prepared to get user opinions and recommendations towards alternative solutions (Appendix 7). Both tasks and questionnaires were a mixture of open and closed structured questions. The questionnaires had two purposes, first they aimed at exploring the participants' feelings about the performance of the CTC for each task and, secondly, to collect their opinions about the whole design of the CTC which may be interpreted in combination with their suggestions during their thinking aloud.

Six tasks of a different nature were prepared based on the six different starting points, the station names in these six questions were adjusted to the starting-point. Therefore, we had 6 (CTC starting point) * 6 (task) questions (Appendix 6). The order in which the questions are presented to the TPs is random in order to prevent learning bias. Accordingly, every TP were got 8 tasks of which task 7 and 8 with similar starting station of CTC for participants in all groups, but tasks 1 up to 6 were via CTC with different starting stations. Also for tasks 1 to 6 the nature of a particular task were always the same, the different was only due to the representation of CTC with six starting stations. Totally tasks 1 up to 6 each related with CTC six starting station (i.e. 36) plus a task 7 (related with CTC from two starting station) and a task 8 about the four design CTC from one starting station were prepared; total of 38 tasks. Also, a questionnaire; followed by each task and four questions presented at the final of task execution were prepared.

5.3.4. Test project set-up

We used Tobii Studio software to prepare and present the four alternative design solutions of the CTC from six starting points with randomization. Image, questionnaire and instruction media elements of Tobii Studio were used to present the instructions, CTCs' and questionnaires respectively. Tobii Studio is a platform that is able to achieve integrative recording of eye tracking with user video, sound recording and screen logging and these outcomes may be analyzed in various (statistical and visual) ways.

Figure 5-3 illustrates a project file that was built with the software of the eye tracking machine with structured test person data during the test execution. As shown in Figure 5-3 each project file was named after the CTC design alternative solutions and each contains 10 test persons. Each set of the same 6 CTC image interfaces is presented to the TPs randomly. Under each four projects the TP data were created with a unique ID (e.g. 1_1, 2_2, 3_3 and so on, i.e. TP number 1 in group 1), which was to record the evaluation process of each TP based on their groups (see Figure 5-3). Further, instructions at the start, in between and at the end of the displayed CTC images were also created using instruction media element of Tobias Studio. Finally, four questionnaires were set on, which were followed by eye tracked tasks. The running of the projects started after an introduction to the test session that was to control the test procedure.

Simultaneous with randomized (i.e. presentation of CTC design based on three stating points in each group) were displayed in Tobii Studio. Further, lists of tasks were prepared in the task form by referring to alternative solutions from six starting points. As a result, the test persons were supposed to answer the tasks with the task form (Appendix 6), which corresponds to the displayed alternative solutions from Tobii Studio randomly. The randomization was also with a different order of task presentation (on paper) and randomly displayed stimuli from Tobii Studio. The randomization was applied aimed to avoid a learning bias of test persons within a group.

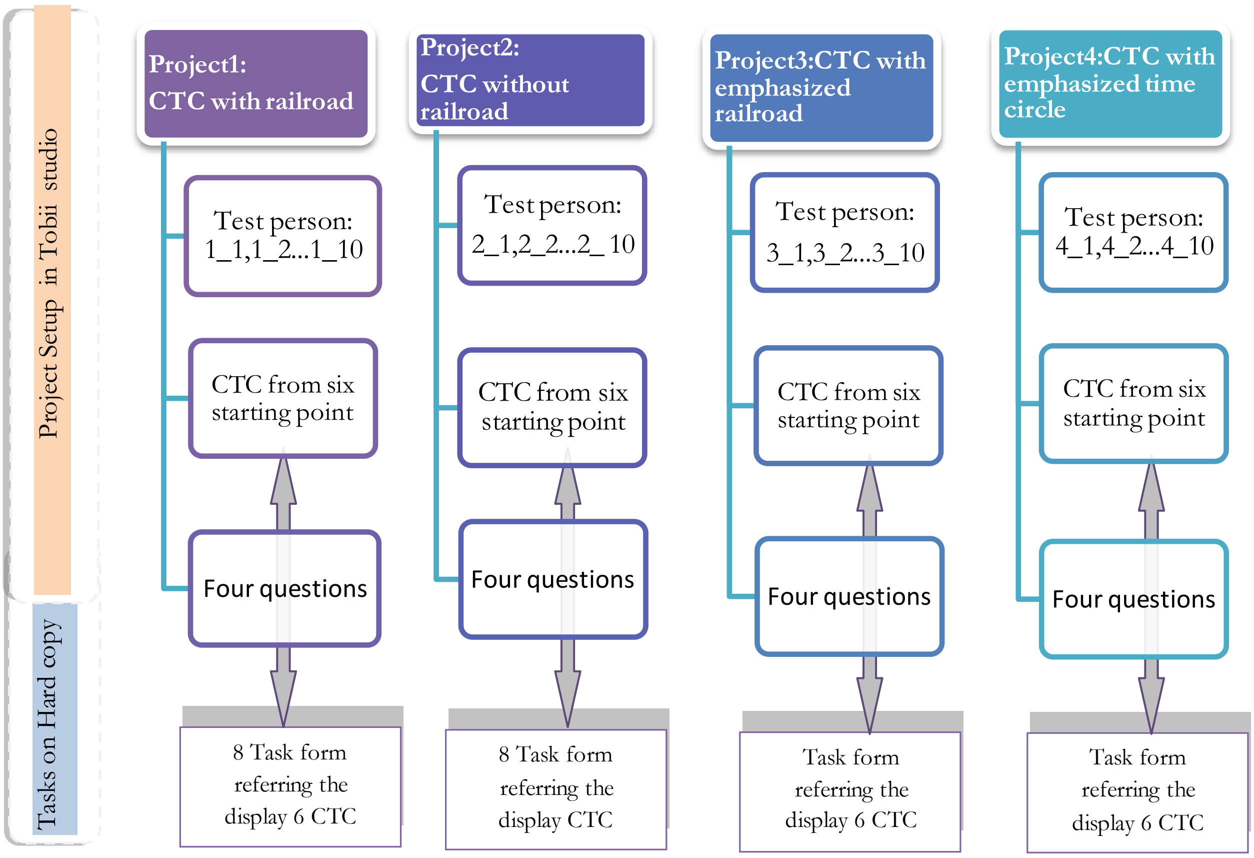


Figure 5-3: Project set-up of group data through Tobii studio

5.3.5. Test Environment

Successful usability testing requires a test environment with well-equipped material (van Elzakker, 2004). In this research the ITC usability laboratory was used to conduct the experiment (see Figure 5-4). A quiet testing condition was set for uninterrupted sound recording of the thinking aloud and video recording of the whole testing phenomena. A research lab, equipped with materials on the table, was used as the test site. The qualitative test environment includes the material: desktop monitor (64-bit operating system, 3.4 GHz ,4RAM, resolution (1280 x 1024 pixels)), Task form, Pencil, and Tobii studio software 2.2.

Figure 5-4: Test execution environment of qualitative test

5.4. Test procedure and execution

5.4.1. Test procedure

The test sessions took place two days after the test persons' notification about the final test schedule. This test schedule was sent to all test persons in consideration of their willingness and accessibility. This individual qualitative evaluation was performed from 1-Dec-2014 to 16-Dec-2014. Each test person finished the experiment in, on average, 45 minutes (12 minutes introduction + 5 minutes warm up questions (see Appendix 9) + 21 minutes for the task reply + 7 minutes for questionnaire) (Appendix 3). An hour before each session all the necessary equipments were checked by the researcher based on a checklist (Appendix 8).

A. Before starting the test with individuals'

The researcher received the test persons with a kindly welcome and introduced them to the objectives of the evaluation, test procedure and about the purpose of tasks and questionnaires within 5 minutes (Appendix 5).Then the TP received a hard copy of an introduction about one of the four alternative design solutions of the CTC (Appendix 4), which will familiarize the TP within 7 minutes at maximum. Within this time, the researcher will also show them the experiment process (how the evaluation methods are applied during the test, how they interact with alternative solutions and how they will have to reply to the tasks, etc.). If this step is completed successfully, a clear understanding was created for them about the whole test objective. In the next 5 minutes, the TP was performing three warm-up tasks (Appendix 9). In this step, a clear understanding of TPs is expected, i.e. about at what prototype they will work with, what tasks they will perform, with what test methods, how and so on. Finally, the TPs settings were adjusted for eye tracker calibration to make sure that their settings are comfortable for recording the task execution. Accordingly, the eye calibration was processed and the TP project ID was made active for the task execution according to their group allocation.

B. During the test

After the researcher determined the participants' understanding of the test procedure, theTP was informed about the start of the video recording. They started performing the tasks through thinking aloud and eye movement recording simultaneously. After the execution of each task, the question about user satisfaction towards the alternative solution was answered by the test persons. During the users' task execution the researcher did the following:

- Providing the task form to the TP according to the randomized image display in Tobii Studio.
- Taking notes about the whole execution process.
- Remaining silent so as prevent any hint on the task execution to the TP.
- Motivating the TP to perform the task with vocalization.

C. After the individual user test

TPs were requested to answer four questions (Appendix 7) about the alternative solutions they worked on, which helps to explore their satisfaction about the alternative solutions. The post execution stage includes organizing the answer form and back up the execution process.

5.4.2. Test execution

The test execution was in the sequence that was managed by the instructions and the researcher. During the test execution of each participant, after eye calibration the execution starts with the instruction "press any key to continue with this task" on the screen that is to display the CTCs for the particular task.

According to the instructions, the task number and the immediately displayed CTCs, the researcher provides the applicable printed task form to the TPs. As a result, the TP reads the task from the task form and provides his/her answer on the task form whilst thinking aloud. Secondly, following each task, they had to answer the question on satisfaction on the task form. Thirdly, they read the instruction to continue with the next task on the task form (i.e. by clicking "press any key to continue with this task"). After proceeding with eight tasks with a similar sequence, finally the satisfaction questions displayed on the screen were answered. The test execution procedure, instructions, questionnaires, and images displayed on the screen, and the task description and instructions on the printed sheet were self-manageable to perform the tests by every individual (see Fig 5-5).

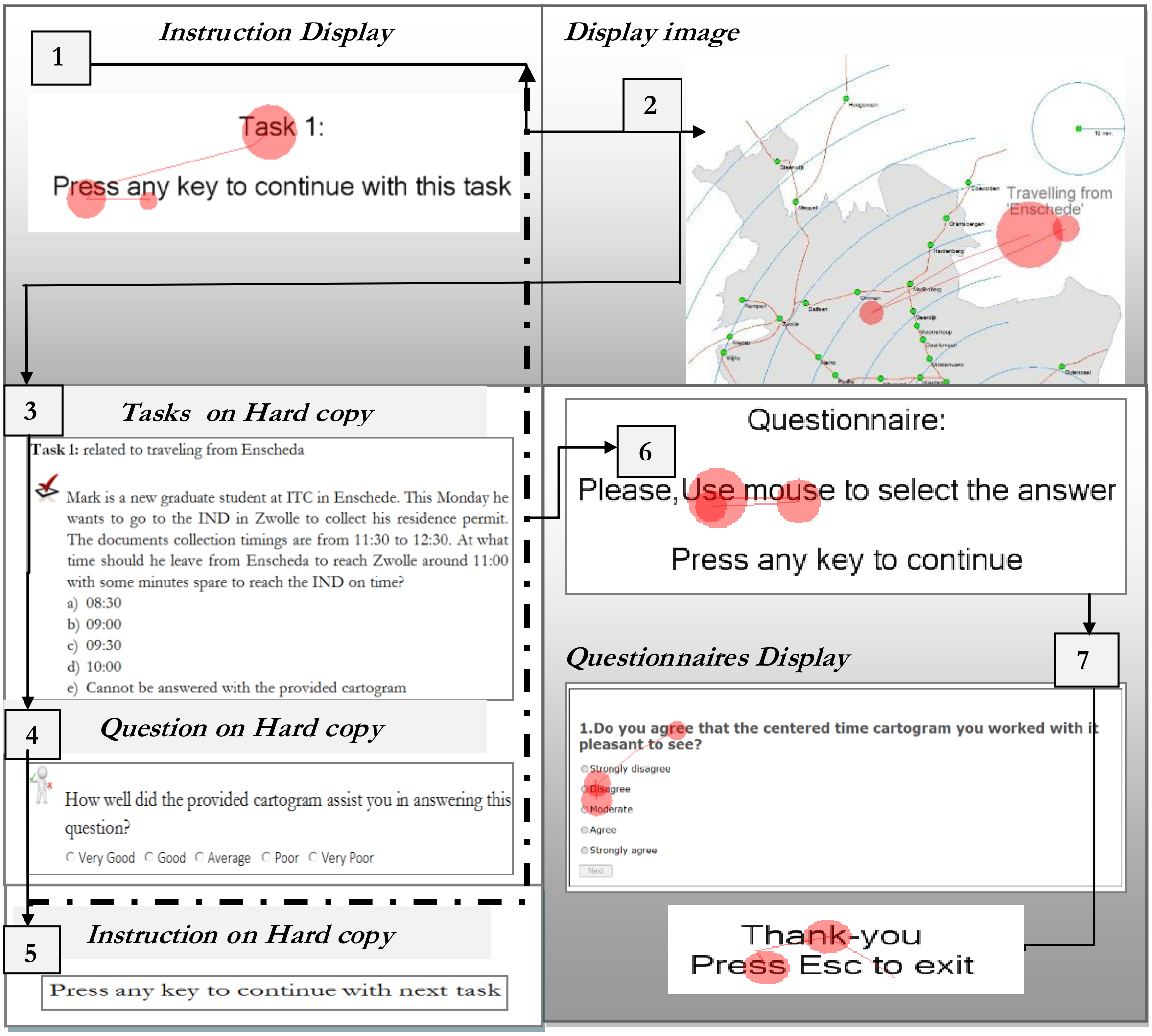


Figure 5-5: Test execution procedure

5.4.3. Pilot test

Three pilot tests were implemented on November 27 and 28, 2014 before the final experiment implementation. The pilot test execution tested the real test set up scenarios, which were to assess potential test set up problems for further improvement before the real experiment implementation. My supervisors (Dr.C.P.J.M. van Elzakker and Prof..Dr.M.J Kraak) and my advisor (R. Ullah) were invited to attend the pilot test because they could potentially evaluate both the presentation of the CTCs and the overall test set up from a professional and user perspective. As a result, their comments as listed below in the Table 5-1 that were collected and they were helpful to figure out the potential problems of the test set up. All these problems were corrected intensively before the final test execution.

Table 5-1: Pilot test feedback and improvement

	Comment	Improvement
Pilot test 1	Task 7 images of CTC had to be of a similar design as the alternative solutions worked with in the group.	The presented images of task 7 were prepared and represented with the four alternative design solutions.
	Introduction about video recording and eye calibration needed to be performed early before test execution started.	Participants were introduced about the test procedure including video recording and eye movement calibration after the introduction of the CTC, before the test execution starts.
	The image mentioned from question sheets for Task 8 and the displayed image was not compatible.	The tasks in the sheet including task 8 were revised and edited. Further, they were rechecked with the presentation of images through Tobi Studio.
	The test environment needed to be quiet.	During the real test execution for individual TPs an uninterrupted environment was set by the researcher.
	Task 4 and 6 needed to refer distance to explore the users' understanding about the cartograms.	The tasks were edited accordingly.
Pilot test 2	Task 8 presentation of the CTC, combination of four alternative solutions needed to be in rotated order, which might help to eliminate learning bias of participants.	The images were prepared in a rotating order. For each group the four solutions were presented together, but the alternative solution they worked on was shown last.
	Question 4 should request participant's comments and suggestions together.	The questions were edited as a choice of answers that participants could give or either speak out loudly their suggestion and comments or not.
Pilot test 3	Introduction before test execution should make clear about distance meaning in the CTC.	The introduction clarified the term distance that is indicated in the tasks mean distance in time.
	Replace task 8 with distance related task as task 6 and needed to indicate the task separately.	The tasks were edited accordingly.

5.5. Test implementation Result

Here, from huge test recode of Tobii software that includes results of visualizations such as gaze plots, density map and, area of interest (AOI) and statistical graphics for AOI the test results of this research were organized and prepared for analysis. The test execution result preparation stage starts with creating sense, segment and AOI. The result data gathering and preparation were complemented by verbal and action protocol data of thinking aloud.

As a result, before the step in analyzing the outcomes of the experiment we present the results with some interpretation, which is to note how the data (i.e. test execution raw data) organized from the documents and recordings with some explanation. This result section organizes as follow: with table summary of test implementation result that contains: the four group's performance data, time cost result and user satisfaction response result. The success of task execution is discussed first, followed by time spent result and finally the results about satisfaction are presented. The three results is prioritized by discussions and summarized with illustrations (i.e. information about CTC performance result comparison). The data discussed below mainly direct towards the analysis of usability aspects: effectiveness, efficiency and satisfaction.

5.5.1. Task performance response result

The success of task execution in each four group's statistically organized. During the experiment, the answering were optional, task forms requests test persons either to choose multiple or single choose questions or requests to write down their response (Appendix 6). The answer is documented in groups according to individual test person response for each task. In addition, this data is organized with the help of the video recorded test execution process, reasoning, and eye movement. In other words, the prepared experiment results, answer of tasks in categories are discussed and presented in tables, including an explanation of outlier values in support of the thinking aloud recode and eye tracking records.

Accordingly, table 5-2, 5-3, 5-4 and 5-5 shows the response of tasks in four groups, group 1: worked with CTC with railroad, group 2: worked with CTC without railroad, group 3: worked with CTC with emphasized railroad and group 4: worked with CTC with emphasized time circles. The answers interpreted into four categories and organized as follow:

- "1" represents the task has been ***fully answered*** by the corresponding CTC
- "0.5" represents ***partial answer*** of tasks where the answer was less than 50% correct from the expected response. For instance, from task two it was expected listed stations reachable within 20 minutes that means list of stations only within two concentric circles of CTC. If participants provide additional stations out of two concentric circles or if they listed only some of the stations within the two circle, it was considered as partial answer.
- "0" represents ***wrong answers***. If participants tried to answer but, with different reason the answer was wrong, it was considered as wrong answer. These answers were different from the response "*cannot answer*" because here users had considered the provided tasks can be answer by the displayed CTC. However, the reason of wrong answer can be, participants' being stressed or luck of full attention.
- "-1" represents the provided answer by participants after trying to answer the task and finally their response as "***cannot answer***" with the provided cartogram". It was an optional answer for all tasks except task 3. These answers were regarded as an option that was to test difficult tasks that were not replied by participants with the alternative solutions of CTC.

Therefore, the response to each task with a value of correct: 1, partial: 0.5, wrong: 0 and cannot: -1 was considered in result preparation. Some responses odd value of tasks regarded as the same validity with task form response after crosschecking of the video record and thinking aloud. In the case of fluctuation between the documented answer and the recorded video, the answers were determined according to users feeling from the video recording and thinking aloud. Unfortunately, these rarely happened, that means the majority response collected from the task form and recordings was compatible.

Therefore, the table 5-2, 5-3, 5-4 and 5-5 gives task response results overview of CTC alternative solutions. It is about the response of each group, which tasks were answered correctly, partially, wrongly or as cannot answer and including the total correct answers and the percentage per task and per group. In the tables, the first row represents number of test participants. For example, 4_1 means TP number 1 in group 4, while the column refers tasks performed by them. Most of the responses in the four tables were correct and scored more than 0.5 percentages, which might indicate the effectiveness of the CTC to answer the majority of tasks.
As illustrated in the tables below, in groups 1: task 1 and 2 with 8, task 5 with 9 and task 3 with 10 participants were answered correctly. Similarly in group 2 more than 8 participants answered task 1, 2 and 3 correctly. Again three participants in group 3 answered all 7 tasks correctly and in this group 5 and more resonance were correct similar with group 4. However, task 4 in group 1, task 4 , 5 and 7 in group 2 and task 4 of group 4 gets less than half percent of average correct score. Particularly participates in group 1 exceptional that all participants were not responded correctly task 4. The reasons for such outliers are explained based on the participants thinking aloud data recordings in each group below.

All responses to tasks whether correct or non-correct were executed through the planned methods of the test and considered in the analysis in a different context. In one hand, non-correct answers were used for identifying missing points of alternative solutions of CTC that helped to provide feedback for further improvement of the cartogram. In the other hand, the correct answers were used to compare the alternative solutions in terms of usability aspects.

Table 5-2; shows the task performance result of group 1 that was worked with CTC with railroad. Out of 70 success of task execution 46: correct, 7: partial, 10: cannot and 7 of them were wrong answer. Task 3 in this group all test users executed correctly with the cartogram. In contrast, task 4 response of this was: 7 can not and 3 wrong. The reason were the task was requesting stations within less than 5 minutes time difference intentionally, which is to prove users' understanding how they access time information from CTCs'. It is possible to reason out this non correct response: one might be due to some overlapping of cartogram thin railroad lines and time circles, which could created confusion to calculate the requested time; or their searching of longest time led to confusion because the participate might answered in terms of longest distance.

Table 5-3; shows the task performance result of group 2 that was worked with CTC with out railroad. Out of 70 success of task execution 41: correct, 12: partial, 13: cannot and 4 of them were wrong answer. In this group task 4, 5 and 7 score less than 50% that is only responded by 3 and 2 numbers of participants only. These three tasks have similar aspects which this cartogram lucks, requiring searching of spatial and temporal information. The participants were faced difficult to search spatial (i.e. stations and routes) information due to this CTC was not designed with railroad. Task 4 had one more correct response than tasks 5 and 7; because searching answer for task 5 and 7 more related with path reading than task 4. In contrast, the respondent number of task 1, 2 and 3 was with 9 and 10 numbers of participants, these tasks are same type of tasks, needs searching temporal, this CTC can answer the task through time circles.

Table 5-4; shows the task performance result of group 3 that was worked with CTC with emphasized railroad. Out of 70 success of task execution 51: correct, 6: partial, 7: cannot and 6 of them were wrong answer. Related with the other groups this group answer the task correctly and the number of wrong and can not response are less, further the group average score is better than the other groups.

Table 5-5; shows the task performance result of group 4 that was worked with CTC with emphasized time circles. Out of 70 success of task execution 48: correct, 8: partial, 6: cannot and 8 of them were wrong answer. Task 1, 2 and 3 in this group: participant's response shows that this task better answered by CTC with railroad than the other alternative solutions of CTC; participants searching strategies were same but, much better easy with this cartogram, since the cartogram designed with emphasized time circle. In contrast still task 4 can not be confirmed by this cartogram as group 1 and 2. Although, this task requests spatial and temporal information as task 5 and 7, it gets 4 non-correct responses, because the too thin lines representation of railroad were affect the path searching.

Table 5-2: Success of task execution in group 1 worked via CTC with railroad

	1_1	1_2	1_3	1_4	1_5	1_6	1_7	1_8	1_9	1_10	Total	Percentage
Task 1	0	1	1	0	1	1	1	1	1	1	8	0.8
Task 2	1	1	0.5	1	1	1	1	1	1	0.5	8	0.8
Task 3	1	1	1	1	1	1	1	1	1	1	10	1
Task 4	-1	-1	0	-1	-1	0	0	-1	-1	-1	0	0
Task 5	1	0	1	1	1	1	1	1	1	1	9	0.9
Task 6	1	1	1	1	-1	-1	1	0.5	-1	1	6	0.6
Task 7	0.5	0.5	1	1	0.5	0.5	1	0	1	1	5	0.5
										correct response per group	46	0.66

Table 5-3: Success of task execution in group 2 worked via CTC with out railroad

	2_1	2_2	2_3	2_4	2_5	2_6	1_7	2_8	2_9	2_10	Total	Percentage
Task 1	1	1	1	1	1	-1	1	1	1	1	9	0.9
Task 2	1	1	0	1	1	1	1	1	1	1	9	0.9
Task 3	1	1	1	1	1	1	1	1	1	1	10	1
Task 4	-1	0	0	1	-1	0	-1	1	1	-1	3	0.3
Task 5	-1	0.5	1	0.5	-1	0.5	0.5	-1	-1	1	2	0.2
Task 6	-1	1	1	1	1	-1	1	-1	1	0.5	6	0.6
Task 7	1	0.5	0.5	-1	0.5	0.5	0.5	0.5	1	0.5	2	0.2
										correct response per group	41	0.59

Table 5-4: Success of task execution in group 3 worked via CTC with emphasized railroad

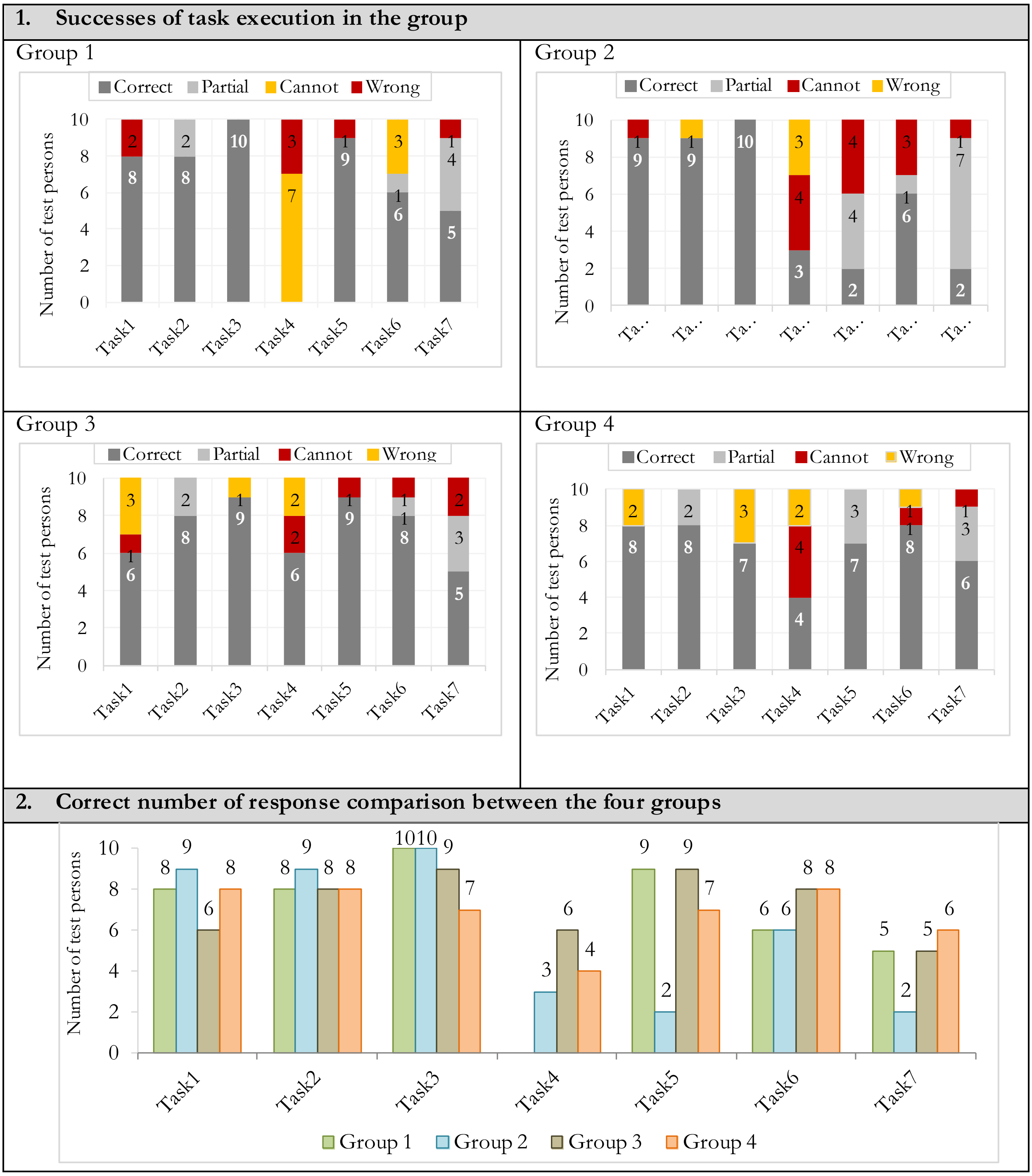
	3_1	3_2	3_3	3_4	3_5	3_6	3_7	3_8	3_9	3_10	Total	Percentage
Task 1	1	0	1	1	1	-1	1	0	0	1	6	0.6
Task 2	1	0.5	1	1	1	1	1	1	0.5	1	8	0.8
Task 3	1	1	0	1	1	1	1	1	1	1	9	0.9
Task 4	1	1	0	0	1	1	1	-1	-1	1	6	0.6
Task 5	1	1	-1	1	1	1	1	1	1	1	9	0.9
Task 6	1	1	0.5	1	1	1	1	1	-1	1	8	0.8
Task 7	1	1	0.5	0.5	1	1	1	-1	-1	0.5	5	0.5
										correct response per group	51	0.73

Table 5-5: Success of task execution in group 4 worked via CTC with emphasized time circle

	4_1	4_2	4_3	4_4	4_5	4_6	4_7	4_8	4_9	4_10	Total	Percentage
Task 1	1	1	0	1	1	1	0	1	1	1	8	0.8
Task 2	1	1	1	1	1	0.5	1	1	1	0.5	8	0.8
Task 3	1	0	1	1	1	1	1	1	0	0	7	0.7
Task 4	1	-1	0	-1	-1	1	1	-1	0	1	4	0.4
Task 5	1	1	1	1	1	0.5	1	0.5	0.5	1	7	0.7
Task 6	1	1	1	-1	1	0	1	1	1	1	8	0.8
Task 7	0.5	1	1	1	1	1	0.5	1	0.5	-1	6	0.6
										correct response per group	48	0.68

Figure 5-6 illustrates the successes of task execution in teams of correct, partial, and wrong and can not response in each group for all 7 tasks. The figures also compare the number of correct responses. There are totally 280 replied tasks as illustrated in the figure that shows the correct response a task varied between and within the groups. Generally, the success of task and correct response bars in the figure 5-6 indicates the task performance result was not stable with a single alternative solution of CTC. As a result, it can reason out that the performance of the cartogram was highly dependent on the task types. This provides hypothesis 3.

Figure 5-6: Task response comparison between and within the group



5.5.2. Task performance time cost result

In order to observe the time cost of CTCs' in performing each task and to compare between the groups, the time consumption of each task execution per individual were prepared. Also to compare the efficiency of CTC alternative solutions, the average time cost of correctly execute task was calculated. In addition, the average time spent to complete the entire assigned task per each alternative solution was calculated. Accordingly, this section discussed about the time cost results that towards the efficiency measure.

Table 5-6, 5-7, 5-8 and 5-9 shows organized and calculated time cost results (unit in seconds) in each group that was the time of execution to complete the provided task with CTC alternative solutions. The "*Average time per task*" column represents average time consumption of 10 participants for each task, while the row "time cost per group" indicates the average total time of 10 participants in one group for all 7 tasks. The majority of the time cost is consistent and comparable between the groups. However, there are some doubtful time costs observed from the tables. Nevertheless, both majority time cost and the doubtful were considered to be the time spent of individual while performing the task, because the results are organized with the recording of thinking aloud. Further, these times costs are prepared with segmentation of participants test execution record data within each group that includes only the time when individuals processed the task.

Table 5-6 shows time cost of group 1 worked via CTC with railroad. The table illustrates that, all time cost of tasks with most test person had closer result except the time cost of TP 7 and TP 10; which consumed more time in executing task 1,5 and 7, and task 4 respectively. Both participants were none experienced about the geographic location of Nethelansds, particularly TP 7 spent much time to familiarize himself with representation and to identify the stations. In contrast participants which have more map reading and producing experience and familiarized about the geography of Nethelands were answer the task quickly like TP 1 and 2.

Table 5-7 shows time cost of group 2 worked via CTC with out railroad. Against to group 1 the time consumption of tasks with majority test person were higher and fluctuated. For instance, the time cost of TP 4, 5 7 and 8 in performing task 2 took much time. They consumed more time related with other participants: which is TP 4 in executing task 4, TP 5 in executing task 1 and TP 7 in executing task 1 and 4 and TP 8 in executing task 1 and 4. These participants were confused to reply the tasks quickly because performing these tasks needs railroad lines. This participant's time consumption indicates the difficulty of this cartogram to execute path related tasks than the other tasks. This proves hypothesis three.

Table 5-8 is about group 3 (CTC with emphasized railroad) time cost; it shows the time cost per individual participants, and in total average measure, which is the time consumption to complete the assigned 7 tasks with CTC with emphasized railroad. The table illustrates that all time records to task by all test person had closer result except the time cost of TP 1 and 2; which consumed more time related with other participants to answer task 4 and 5, because it seems the too emphasized railroads deign of this CTC create confusion to count the time, even this participant were much familiarize with the geography of Netherlands. Again, this proves Hypothesis 1.

Table 5-9 is about group 4 (CTC with emphasized time circle) time cost. The table illustrates that, all time records to task by all test person had closer result except the time cost of TP 2, 3 and TP 6; which consumed more time related to other participants: TP 2 in executing task 6 same reasons as group 1. Additionally, TP 3 and 6 takes much time in executing task 5, which indicates the too emphasized rail road representation created difficulty of the route finding in this task than the other tasks. Proves Hypothesis 2

Table 5-6: Time cost of group 1 worked via CTC with railroad

	1_1	1_2	1_3	1_4	1_5	1_6	1_7	1_8	1_9	1_10	Average Time per task
Task 1	94.2	79.8	68.4	62.4	118.8	57.0	350.4	103.2	64.2	210.6	105.2
Task 2	81.0	52.2	98.4	122.4	120.6	111.0	121.2	130.2	62.4	105.6	80.1
Task 3	84.6	20.4	57.6	52.2	51.0	70.8	123.6	43.2	55.8	98.4	65.7
Task 4	54.6	46.2	54.6	56.4	109.2	187.2	147.6	70.2	37.2	195.0	
Task 5	91.2	49.2	231.6	122.4	169.2	72.6	405.6	89.4	87.0	72.6	134.1
Task 6	67.2	43.2	47.4	61.2	58.8	49.2	121.2	61.8	48.6	108.6	66.7
Task 7	95.4	103.8	108.6	96.6	173.4	155.4	196.2	140.4	117.6	106.2	62.5
Average total time per group											514.5

Table 5-7: Time cost of group 2 worked via CTC with out railroad

	2_1	2_2	2_3	2_4	2_5	2_6	2_7	2_8	2_9	2_10	Average time per task
Task 1	134.4	188.4	157.8	137.4	371.4	117.6	336.6	247.2	79.2	79.2	173.1
Task 2	46.8	98.4	87.0	92.4	207.6	133.2	146.4	135.0	52.8	93.0	100.5
Task 3	21.0	57.6	55.8	90.6	129.0	51.6	125.4	48.6	52.2	57.6	68.9
Task 4	109.2	54.6	196.8	260.4	154.8	59.4	308.4	138.6	36.6	60.6	43.5
Task 5	101.4	231.6	62.4	108.6	194.4	190.2	137.4	201.0	63.6	225.6	28.8
Task 6	58.8	47.4	58.2	110.4	168.6	117.6	118.2	114.6	82.8	73.2	58.5
Task 7	88.2	108.6	51.6	181.2	154.8	187.2	235.2	121.8	87.0	147.0	47.8
Average total time per group											521.4

Table 5-8: Time cost of group 3 worked via CTC with emphasized railroad

	3_1	3_2	3_3	3_4	3_5	3_6	3_7	3_8	3_9	3_10	Average time per task
Task 1	128.4	103.8	117.0	99.0	111.6	90.6	109.2	84.6	102.6	78.6	64.3
Task 2	16.2	84.6	114.6	54.6	69.0	109.2	111.0	109.2	83.4	86.4	67.0
Task 3	65.4	96.6	40.8	17.4	48.6	84.6	77.4	67.8	46.8	25.2	47.4
Task 4	237.0	85.8	86.4	100.2	136.8	63.6	125.4	181.8	90.6	61.2	66.3
Task 5	226.2	102.6	111.6	133.2	2.95	155.4	219.0	174.6	132.6	55.8	83.6
Task 6	85.2	465.0	63.6	86.4	63.0	100.8	73.8	76.8	41.4	27.0	97.8
Task 7	91.8	46.8	159.0	190.8	54.6	49.2	70.2	98.4	99.0	58.2	31.2
Average total time per group											457.8

Table 5-9: Time cost of group 4 worked via CTC with emphasized time circle

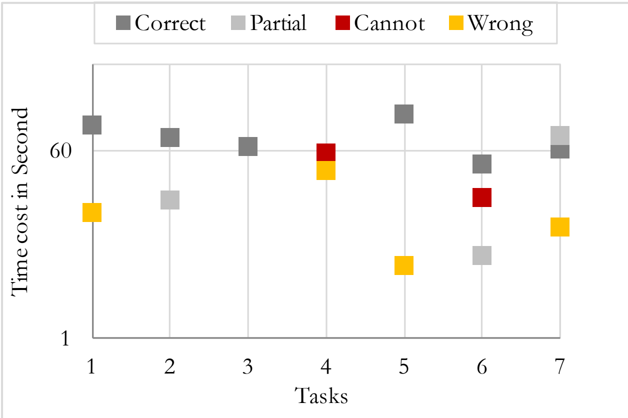
	4_1	4_2	4_3	4_4	4_5	4_6	4_7	4_8	4_9	4_10	Average Time per task
Task 1	24.6	105.0	172.2	64.8	38.4	118.2	139.8	108.6	55.2	157.2	70.3
Task 2	43.2	108.6	141.0	72.6	49.8	197.4	114.6	123.0	32.4	140.4	68.5
Task 3	14.4	73.8	94.2	42.6	16.2	64.2	83.4	37.2	26.4	43.2	35.2
Task 4	57.0	172.2	115.8	43.2	35.4	57.6	116.4	72.6	45.6	66.6	29.7
Task 5	90.6	103.8	264.6	94.8	37.8	266.4	207.6	159.0	71.4	180.6	97.9
Task 6	46.2	596.4	76.2	33.0	30.6	78.6	67.8	55.8	28.2	63.0	96.4
Task 7	98.4	138.6	160.8	133.2	61.8	113.4	117.6	124.2	39.6	129.6	73.2
Average total time per task											471.4

Figure 5-7 below shows the average time consumed (units in seconds) by 10 participants in each group for seven tasks calculated from segmented test execution. As indicated by time cost plots in the groups, and the average time cost comparison graphs between groups, the time consumption for each task were not stable per group and between the groups. This proves hypothesis 3.

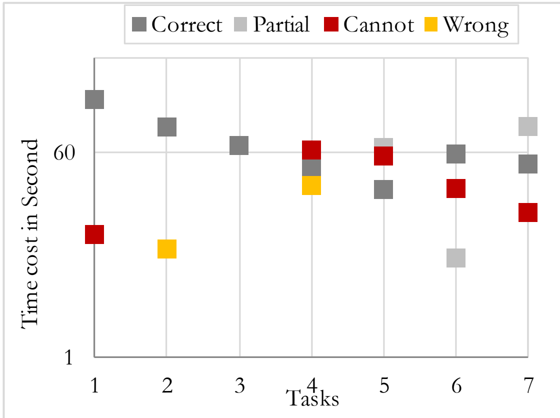
Figure 5-7: Time cost comparison of each task between and with in the group

1. Time cost of tasks in each group

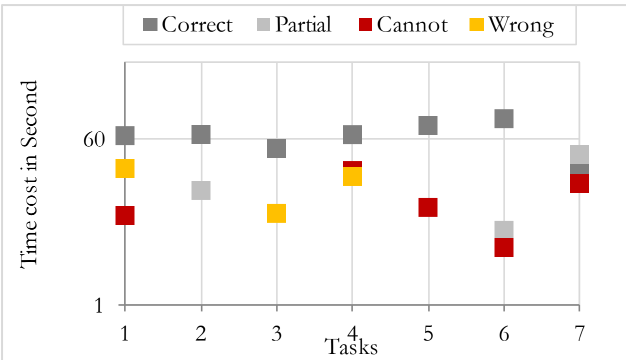
Group 1



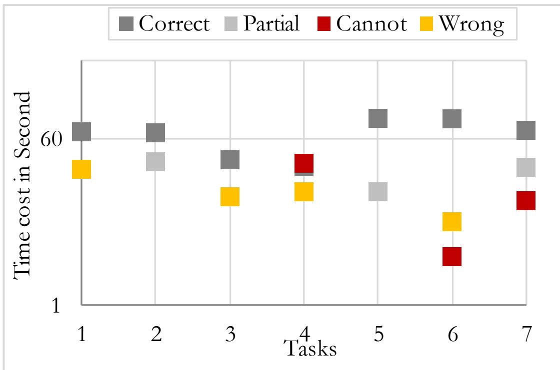
Group 2



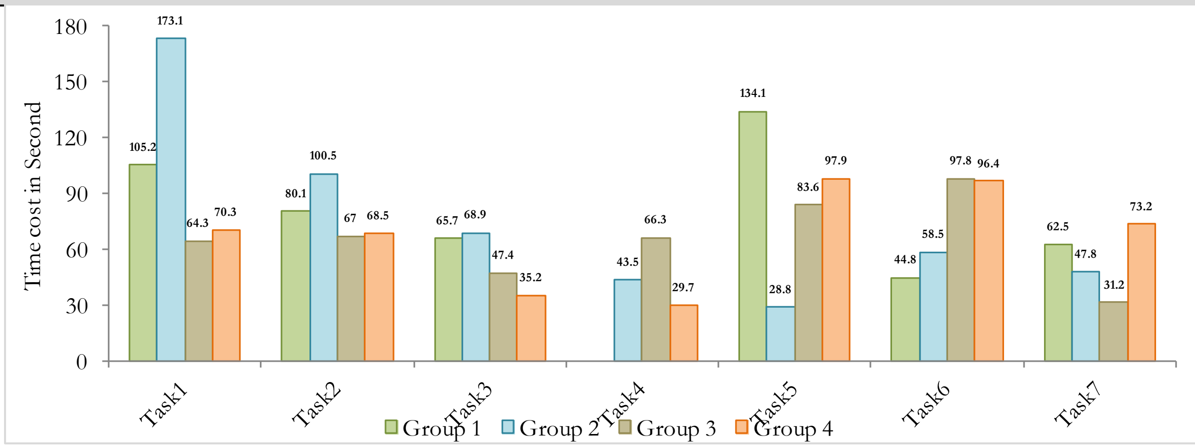
Group 3



Group 4



2. Average time cost comparison for correct tasks



5.5.3. Questionnaires response result

5.5.3.1. Satisfaction response about each task

Similarly, Table 15 for group 16 for group 2 , 17 for group 3 and 18 for group 4 shows the answer of satisfaction questions after test person perform each task, which was to get their feeling how the cartograms' support them to answer to particular task. Accordingly, the answer of likert scale questionnaires interpreted as 5,4, 3,2 and 1 to represent strongly agree ,agree, moderate , disagree ,strongly disagree respectively. Similarly the average satisfaction per group also calculated. The tables shows which likert scale questionnaires could answered as very good, good, average, poor: and very poor and also the value number of very good and good answers per task and per group , including the average satisfaction, calculated as per task and per group. The values of the lowest level are 1 and the highest level is 5; the interval between this continues level is 1. The maximum value for each task in the group is 350 (10 * 7* 5), if the entire test person (10) agreed for the whole (7) as very good that is value of 5. The frequency of very good value for each task was counted, accordingly the values obtained for each task was calculated. The average satisfaction indicates the priority level of the CTC. The higher level represents the higher priority level in satisfaction.

Table 15: the CTC with railroad satisfaction score is 286 values and 0.81 percentages as a group. The reason of the participants made these choices on the Liker scale questionnaire were observed and interpreted from thinking aloud. They opinion was that the alternative solution can provide the spatial-temporal information easily. They suggested the drawback such as colouring, legend and the overlapping thin lines to be improved..

Table 5-10: the CTC without railroad satisfaction score is 258 values and 0.73 percentages as a group. It has the lowest level of satisfaction because participants were considered difficult to reply the task with the cartogram. They suggested that, they faced confutation to perform tasks that needs railroad, because the representations of stations are scatted and to find the routes with this CTC was not easy. Another problem was the cartogram neither symbol of its stations and lines self neither representative nor supported by legend.

Table 5-11: the CTC with emphasized railroad satisfaction score is 258 value and 0.73 percentage as a group. It is in the second satisfaction score from the four alternative solutions. The difficulty here was the too thick railroad representation was created some misunderstanding. The advantage of this CTC is that can provide both spatial and temporal information, particularly it serves spatial tasks by offering highly visible railroads.

Table 5-12: the CTC with emphasized time circles satisfaction score is 245 values and 0.70 percentages as a group. It is in the third satisfaction score from the four alternative solutions. The difficulty here was the too thick time circles representations were created some misunderstanding, in searching routes. The advantage of this CTC is the cartogram can provide both spatial and temporal information; particularly it serves temporal tasks by offering highly visible time circles.

Figure 5-13 below shows the satisfaction response by 10 participants in each group for seven tasks, it is calculated from Likert scale questionnaires. As indicated by plots in the group, and the satisfaction response comparison graphs between groups, the user opinion for each task were not stable per group and between the groups. Again this proves hypothesis 3.

Table 5-10: Likert scale questionnaire response of group 1

	1_1	1_2	1_3	1_4	1_5	1_6	1_7	1_8	1_9	1_10	Value	Percentage
Task 1	3	4	5	5	5	4	5	5	4	3	43	0.86
Task 2	4	5	5	5	5	5	5	5	5	5	49	0.98
Task 3	4	5	3	5	5	2	5	5	5	5	42	0.82
Task 4	3	2	4	1	1	2	5	4	1	2	25	0:50
Task 5	4	2	3	5	5	4	5	5	4	4	41	0.82
Task 6	5	5	5	3	1	1	5	4	2	5	46	0.92
Task 7	5	3	5	4	5	2	5	4	3	4	40	0.80
								Satisfaction per group			286	0 .81

Table 5-11: Likert scale questionnaire response of group 2

	2_1	2_2	2_3	2_4	2_5	2_6	1_7	2_8	2_9	2_10	Value	Percentage
Task 1	2	4	3	4	3	4	5	4	5	4	38	0.76
Task 2	5	3	5	5	3	5	4	4	3	3	40	0.80
Task 3	5	4	3	5	3	4	4	1	3	4	36	0.45
Task 4	1	4	5	3	1	3	3	4	4	3	31	0.62
Task 5	1	4	5	3	2	2	2	2	3	3	23	0.46
Task 6	1	4	5	4	3	2	3	2	4	4	30	0.60
Task 7	4	5	4	2	4	4	4	3	4	5	39	0.78
									Satisfaction per group		237	0.68

Table 5-12: Likert scale questionnaire response of group 3

	3_1	3_2	3_3	3_4	3_5	3_6	3_7	3_8	3_9	3_10	Value	Percentage
Task 1	4	3	4	5	4	4	5	5	4	3	41	0.82
Task 2	4	5	3	5	4	5	5	5	4	3	43	0.86
Task 3	3	4	2	5	4	1	5	3	4	4	35	0.70
Task 4	3	3	3	5	3	2	1	2	4	3	29	0.58
Task 5	4	4	2	2	4	4	5	3	3	4	35	0.70
Task 6	5	5	3	4	4	2	5	4	4	4	40	0.80
Task 7	4	5	3	3	4	2	5	1	2	3	35	0.70
									Satisfaction per group		258	0.73

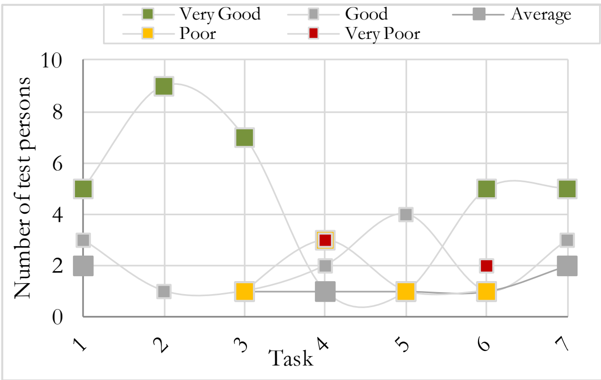
Table 5-13 : Likert scale questionnaire response of group 4

	4_1	4_2	4_3	4_4	4_5	4_6	4_7	4_8	4_9	4_10	Value	Percentage
Task 1	4	2	2	4	5	4	3	2	5	5	36	0.72
Task 2	5	5	2	2	2	5	4	5	2	5	35	0.70
Task 3	4	3	4	4	5	5	4	4	5	4	42	0.84
Task 4	3	4	3	3	2	5	3	1	5	5	34	0.68
Task 5	4	3	5	2	3	2	2	2	5	4	32	0.64
Task 6	5	3	5	2	3	3	3	4	5	5	38	0.76
Task 7	3	3	2	4	3	4	2	2	5	3	28	0.56
									Satisfaction per group		245	0.70

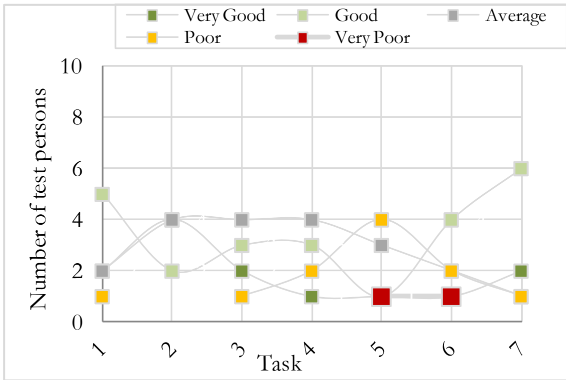
Figure 5-8: Satisfaction comparison of each task between and within the group

1. Likert scale questionnaires number of response

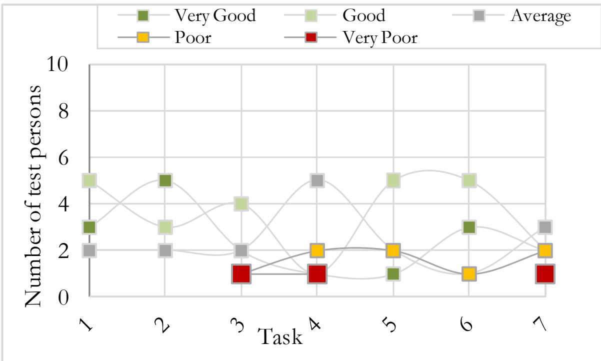
Group 1



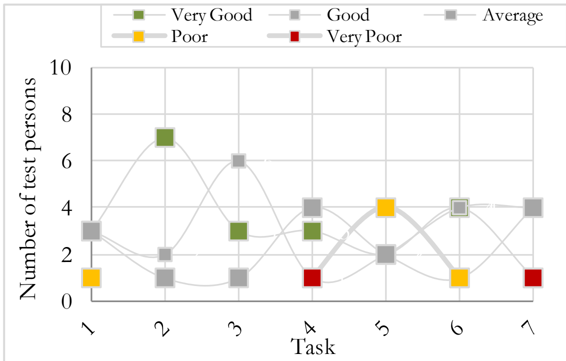
Group 2



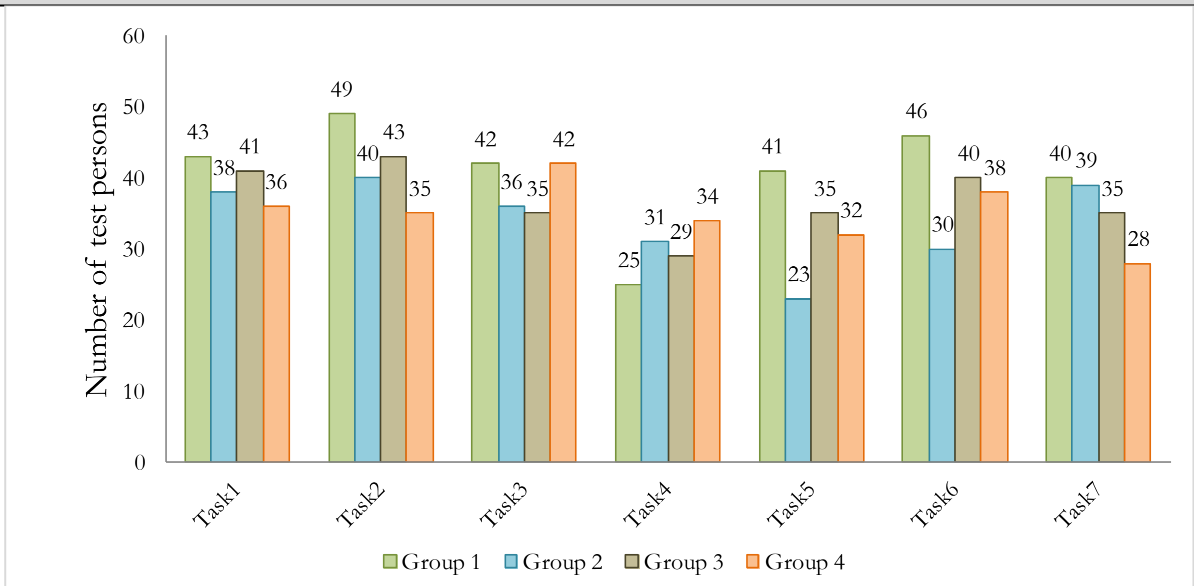
Group 3



Group 4



2. Satisfaction response comparison for tasks in "Very good " scale



5.5.3.2. Satisfaction response about particular design of CTC

Figure 5-9 below presents the screen shoot of participant answers for satisfaction questionnaires about particular CTC design. The column refers questionnaires number and the rows represent TP number in the groups. Based on this table result satisfaction comparison histogram generated in section 5.6.1(see figure 5-13).

Name	Q01	Q02	Q03
1_1	Moderate	Agree	Disagree
1_2	Agree	Agree	Moderate
1_3	Agree	Agree	Agree
1_4	Strongly agree	Agree	Agree
1_5	Agree	Strongly agree	Agree
1_6	Moderate	Agree	Moderate
1_7	Strongly agree	Strongly agree	Strongly agree
1_8	Strongly agree	Agree	Agree
1_9	Agree	Agree	Moderate
1_910	Strongly agree	Strongly agree	Moderate

Name	Q01	Q02	Q03
2_1	Strongly agree	Moderate	Strongly disagree
2_2	Strongly agree	Agree	Agree
2_3	Strongly disagree	Strongly agree	Strongly agree
2_4	Agree	Agree	Agree
2_5	Strongly disagree	Strongly disagree	Strongly disagree
2_6	Moderate	Moderate	Disagree
2_7	Agree	Moderate	Moderate
2_8	Agree	Moderate	Disagree
2_9	Agree	Strongly agree	Moderate
2_910	Agree	Agree	Strongly agree

Name	Q01	Q02	Q03
3_1	Agree	Moderate	Agree
3_2	Agree	Agree	Agree
3_3	Moderate	Moderate	Moderate
3_4	Agree	Agree	Agree
3_5	Agree	Agree	Agree
3_6	Agree	Moderate	Disagree
3_7	Strongly agree	Strongly agree	Strongly agree
3_8	Agree	Moderate	Moderate
3_9	Agree	Agree	Moderate
3_910	Moderate	Moderate	Disagree

Name	Q01	Q02	Q03
4_1	Agree	Agree	Agree
4_2	Moderate	Moderate	Agree
4_3	Strongly agree	Agree	Agree
4_4	Moderate	Disagree	Moderate
4_5	Agree	Agree	Moderate
4_6	Strongly agree	Strongly agree	Strongly agree
4_7	Disagree	Moderate	Moderate
4_8	Agree	Agree	Agree
4_9	Moderate	Agree	Moderate
4_910	Strongly disagree	Agree	Agree

Figure 5-9: Screenshot of user's satisfaction response for CTC

Further, the prioritization result of CTC alternative solutions by participants in each group are tabulated below (see Table 5-14, 5-15, 5-16 and 5-17). The table shows task 8 responses that request the preferred CTC by TP, the combined presentation order of four prioritized CTC shown in the figure 5-15. Although the correctness of answers and time spent had a fluctuation between the groups, the design selection result shown more than 90 % of the participants in each group give their vote for CTC with emphasized. This result is further interpreted in the analysis section.

Table 5-14: CTC alternative solution prioritization result of group 1

	1_1	1_2	1_3	1_4	1_5	1_6	1_7	1_8	1_9	1_10
Task 8	2	2	2	2	1	2	2	2	2	2

Table 5-15: CTC alternative solution prioritization result of group 2

	2_1	2_2	2_3	2_4	2_5	2_6	2_7	2_8	2_9	2_10
Task 8	1	1	3	1	1	1	3	1	1	2

Table 5-16: CTC alternative solution prioritization result of group 3

	3_1	3_2	3_3	3_4	3_5	3_6	3_7	3_8	3_9	3_10
Task 8	4	4	4	2	4	3	2	4	4	2

Table 5-17: CTC alternative solution prioritization result of group 4

	4_1	4_2	4_3	4_4	4_5	4_6	4_7	4_8	4_9	4_10
Task 8	3	3	3		1	4	3	4	4	4

5.6. Test implementation analysis and findings

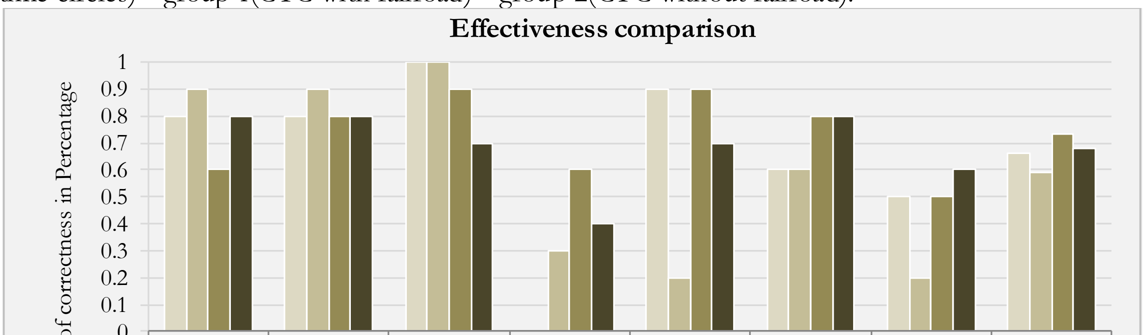
Here, the analysis of qualitative test are discussed, which is based on the result presented section 5.5 of this chapter. The discussion of qualitative finding focuses on the comparison of four alternative solutions of CTC that was experimented in four groups. It is presented in three parts the first part summarizes of the findings in terms of three usability aspect, the second part presents detail findings, which analysis each task based on thinking aloud records and finally the third part will present findings from eye tracking record that is mainly to find out the effect of starting stations difference in performing tasks with alternative solutions of CTC. These findings were proved the test objective of this experiment.

5.6.1. Part 1: Qualitative test finding summary

The analysis of quantitative test includes the response all participates, which is interpreted in terms of effectiveness, efficiency and satisfaction with illustration. In this context effectiveness evaluated from the performance data of participants, which is based on the number of correct answer between the groups; efficiency; the average shortest time cost completed in the groups. In addition, user satisfaction with four alternative solutions of CTC compared based on the collected response of likert scale questionnaires. These three usability aspects were discussed below:

5.6.1.1. Effectiveness

As qualitative test findings, the alternative solutions of CTC had different results in terms of effectiveness. Effectiveness was calculated in the context correct response that is how well the alternative solutions of CTC answer the tasks that are levelled as 1 in Table 5-2, 5-3, 5-4 and 5-5. The value in these tables and bars in figure 18 represents the total calculated number of test persons that answered the each task correctly per group. Then, the maximum percentages per task and for the whole group were calculated for effectiveness measure (see figure 5-10). It is difficult to compare the effectiveness between the four designs of CTC per task, but if from average percentage per alternative solutions illustrates better. Generally, figure 5-10 shows CTC with emphasized railroad scores better related to other three solutions of CTC. The ranking order is group 3 (CTC with emphasized railroad)> group 4 (CTC with emphasized time circles)> group 1(CTC with railroad)> group 2(CTC without railroad).



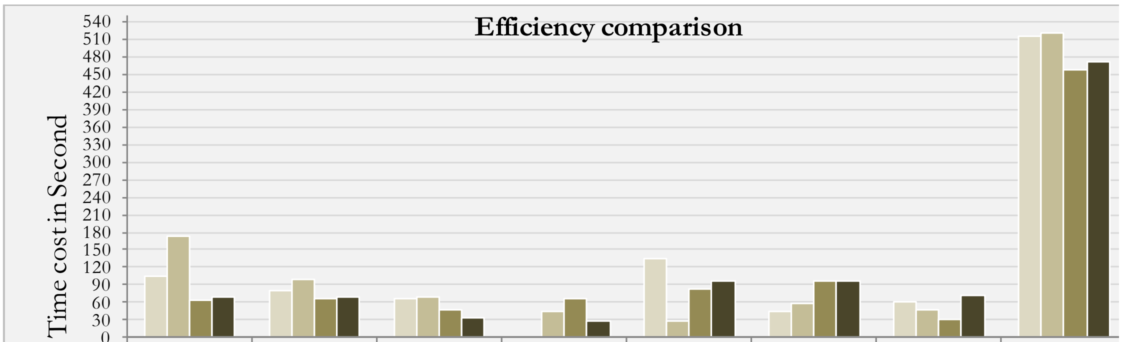
	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Percentage per Group
Group 1	0.8	0.8	1	0	0.9	0.6	0.5	0.66
Group 2	0.9	0.9	1	0.3	0.2	0.6	0.2	0.59
Group 3	0.6	0.8	0.9	0.6	0.9	0.8	0.5	0.73
Group 4	0.8	0.8	0.7	0.4	0.7	0.8	0.6	0.68

Figure 5-10: Effectiveness of CTC alternative solutions

Figure 5-10 show each of the four alternative solutions has different effectiveness. The CTC with emphasized railroad evaluated by group 3 has the highest effectiveness. The execution of the test shows users were performed spatio-temporal tasks easily with this CTC; particularly the cartogram was more suitable to locate paths and stations in time. The CTC with railroad; group 1 and CTC with emphasized time circle: group 3 was the second highest score of 0.66 and 0.68 respectively. In contrast with the CTC of group 3, user's feedback indicates, for temporal tasks CTC with emphasized time circle and for spatial task CTC with railroad performs better. CTC without railroad scored lowest, 0.59 of the total. Here users' suggestion indicates this cartogram is more difficult to access time information with locating paths and stations. Although, the effectiveness comparison of four the groups shows variation per task, based on the average percentage per group, CTC with emphasized railroad scores highest result.

5.6.1.2. Efficiency

Here efficiency is the time spent to answer tasks correctly, which is compares the four alternative solutions of CTC based on calculated average time cost of the correct answer. Efficiency considers the total time cost to answer tasks correctly, each alternative solutions CTC and effectiveness. Accordingly the average time that was needed to complete the assigned task with the four alternative solutions of CTC in each group was calculated. Also, the average time that was required to complete the whole assigned task with particular alternative solutions of CTC was calculated (see Table 5-6, 5-7, 5-8, and 5-9). These results illustrated to compare the efficiency in figure 5-11 below. The result shows that the time costs of CTC without railroad more than the other alternatives, as the user opinion indicates this cartogram is difficult to perform tasks particular for route finding. In contrast the CTC with emphasized railroad took least time; think aloud data of user indicates most tasks were performed easily with this cartogram. As a result, CTC with emphasized railroad had the higher score. The ranking order is: group 3 (CTC with emphasized railroad)> group 4(CTC with emphasized time circles)> group 2 (CTC without railroad) >group 1 (CTC with railroad).



	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Average time per Group
Group 1	105.2	80.1	65.7		134.1	44.8	62.5	514.5
Group 2	173.1	100.5	68.9	43.5	28.8	58.5	47.8	521.4
Group 3	64.3	67	47.4	66.3	83.6	97.8	31.2	457.8
Group 4	70.3	68.5	35.2	29.7	97.9	96.4	73.2	471.4

Figure 5-11: Efficiency of CTC alternative solutions

5.6.1.3. Satisfaction

The information about satisfaction with the evaluated four alternative solutions of CTC was collected from the likert scale questionnaires. The comparison of satisfaction presents the in two parts. First, figure 5-12 (shows average satisfaction per group and task) compares satisfaction according to the response of likert scale questionnaires that assess the performance of CTC for each task. Second, figure 5-13 compares satisfaction based on the answer of questionnaires that were requested user opinion regarding the whole design of CTC. Accordingly, in combination the two likert scale questionnaires result, the average satisfaction with CTC alternative solutions is determined, which is CTC with railroad had higher score (see figure 5-12). The ranking order is: group 1 (CTC with railroad)> group 3 (CTC with emphasized railroad)> group 4 (CTC with emphasized time circles)> group 2 (CTC without railroad).

	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Percentage per Group
Group 1	0.86	0.98	0.82	0:50	0.82	0.92	0.8	0.81
Group 2	0.76	0.8	0.45	0.62	0.46	0.6	0.78	0.68
Group 3	0.82	0.86	0.7	0.58	0.7	0.8	0.7	0.73
Group 4	0.72	0.7	0.84	0.68	0.64	0.76	0.56	0.7

Figure 5-12: Satisfaction of CTC alternative solutions

Further satisfaction in the figures 5-13 compared between the groups in terms of three aspects "Pleasant to see", "easiness to understand" and "use without confusion". In order to measure one of the alternative solutions of CTC satisfaction in comparison with other three alternatives, the test person response based on 3 questionnaires were also analyzed. Further, based on the test person reactions and expression from video recording and think aloud it was established either participants were satisfied or not. The analysis of satisfaction can be considered as satisfied if the response of the questionnaires and the analysis result of user opinion and reaction being compatible. In the other word the participants were not satisfied means that the design was not pleasant to see or there was some confusion to answer tasks or participants felt discomfort of the use. Further, participants suggestions are pointed out that were helped to improve the CTC design further.

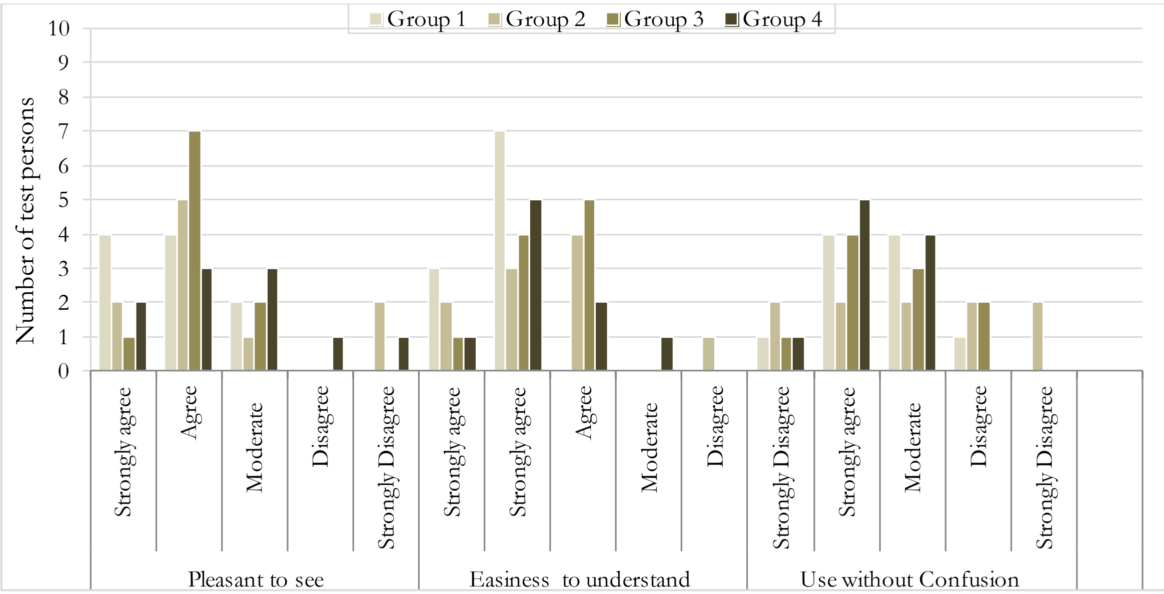


Figure 5-13: Likert scale questionnaires statistics graph

The above usability summary of CTC indicates that for answering the 7 tasks, CTC with emphasized railroad overall, both effective and efficient. This proofs the first and second hypothesis and the test objective one of this research. However, as shown in the figure 5-6 and 5-7 the higher correctness and time cost is not always with group 3 for each task. For instance, this group in one hand got higher correctness in task 2, 3, and 5, in the other hand they had equal and sometimes less correctness from other groups. This result is shown also related with time spent of each task in the graphs. This indicates that the cartogram was not always performed better than other alternative solutions. If we only depended on this summarized test implementation result analysis that may cause hiding of the weakness of the design for further improvement. In order to investigate the detailed potential of this design in related with the three others, part 2 presents with detail analysis of each task. Further interesting results from eye tracking going to be shown in part 3, which is to prove hypotheses 3.

5.6.2. Part 2: Detailed comparison of Effectiveness, Efficiency and Satisfaction per tasks

In this part, the analysis was detailed with think aloud data to prove the test objectives, which was by replaying video recorded data of the test. Since during the test executions participants performed the tasks with think aloud and also their eye movement was tracked, which can provide alternative analysis result related with the four alternative solutions of CTC. As a result,, below seven tasks were discussed using the graphs that were not only based on performance data, but, in consideration of thinking aloud record. Since the task reflects particular information that can be accessed from the alternative solution of CTC, the analysis is structure by tasks, and discussed in following tables and graphs. The description under the graphs is not only about correctness and time cost of each task, also interprets why this result happened by the aid of thinking aloud data. In the mean time user suggestion and comments were discussed that was useful to improve the selected solution of CTC.

In the graphs that illustrate effectiveness below, the y-axis refers test person number whereas the x- axis represents groups. Whereas in the graph of efficiency via average time cost of individual group, y-axis refers the average time spent in answering the tasks per group (unit: seconds) and the x- axis refers the groups. Also the satisfaction bar indicates the number TP response for likert scale questionnaires.

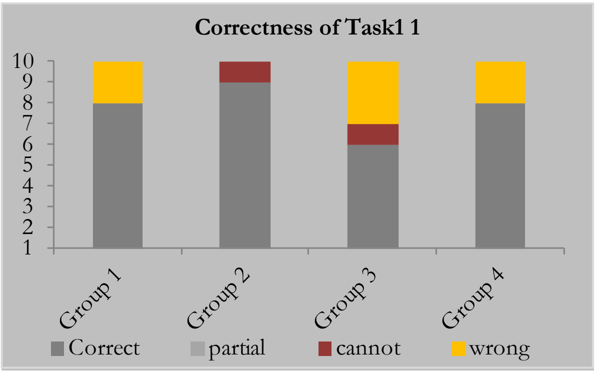
All responses to tasks whether correct or not correct were executed through the planned methods of the test and considered in the analysis in a different context. Thus, no correct answers were used for identifying the missing points of alternative solutions of CTC to reply the task that provided a feedback for further improvement for the prioritized cartogram whereas, the correct answers were used to compare the alternative solutions in terms of usability aspects.

Task 1: At what time one should leave to reach "x" station around 11:00?

Success of task execution	correct answer	partial answer	cannot answer	wrong answer
Group 1	8	0	0	2
Group 2	9	0	1	0
Group 3	6	0	1	3
Group 4	8	0	0	2

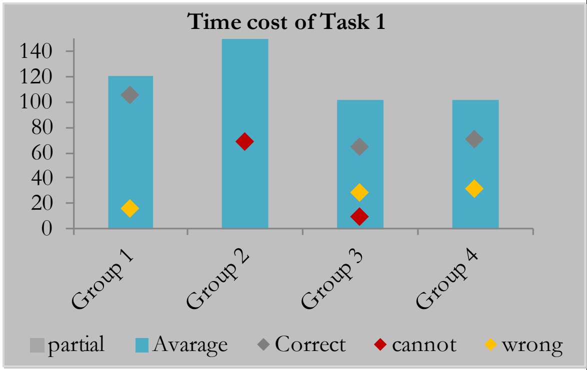
Average time cost	correct answer	partial answer	cannot answer	wrong answer	Average per task
Group 1	105.1			15.6	120.7
Group 2	106.2		68.4		174.6
Group 3	64.8		9.1	28.2	102.1
Group 4	67.2			31.2	98.4

Effectiveness



More than half test persons in each group find the answer of this task correctly. Particularly participants in group 2 were answered the task better that indicates CTC without railroad were provided the answer correctly due to the time circles had a great role to access the time information for such types of task. In one hand, most wrong answers were simple mistakes such as when participants were calculating the time difference. Also the wrong answers in group 1, 3 and 4 indicate railroad were created some confusion in this task. In the other hand, two participant provide choose "cannot answer"; in group 2 the TP faced difficulty to access the destination station, and group 3 TP was confused by the task that request to considers spare of time.

Efficiency



In this task test persons started by finding the target station followed by calculating the time of request. Most participants were clear about how to find out, they were counting the concentric circle until they locates the time. As shown from the result, group 1 and 2 takes more time to finalize all the tasks, it is because of group 2 could not fine the route easily and in group 1 the less bold route lines and overlap representation of station's was created some confusion. Generally, for this task emphasized railroad perform better in average time cost, because of the time circles supports TP to count the time interval easily with clear rout representation. However, group 4 cost more time than group 3 due to some route identification problem.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	5	3	2		
Group 2	6	3	1		
Group 3	3	5	2		
Group 4	5	4	1		

- The four alternative solutions were well suited to solve this task that was more than average score.
- CTC with railroad(group 1) and with emphasised time circles (group 4) had similarly satisfy participants with more than average score but, less than without rail road(group 2) that indicates time circles has more importance to identify this task with the other elements of the cartogram.
- User satisfaction in this task proven the influence of time circles in CTC for these types of task.

Task 2: List all stations that are reachable within 20 minutes?

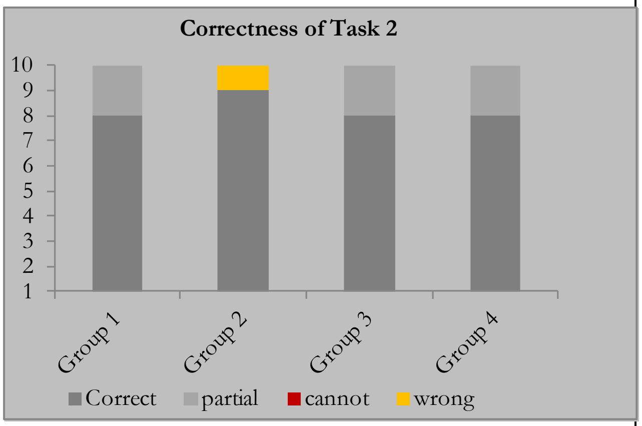
Success of task execution

	correct answer	partial answer	cannot answer	wrong answer
Group 1	8	2	0	0
Group 2	9	0	0	1
Group 3	8	2	0	0
Group 4	8	2	0	0

Average time cost:

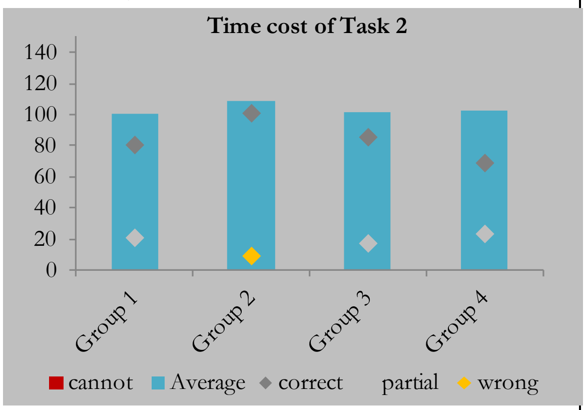
	correct answer	partial answer	cannot answer	wrong answer	Average per task
Group 1	80.1	20.4			100.5
Group 2	100.5			8.7	109.2
Group 3	85.1	16.8			101.8
Group 4	68.5	22.9			102.3

Effectiveness



The task is required to read station within two concentric circles. Most participants worked with this task feel easy to answer the task. However, some test persons from group 1,3 and 4 replies partially, which they listed additional stations out of 20 minutes and they didn't list all stations within 20 minutes. In addition one test person response wrong answer without understanding the task well. The higher score of group 2 indicates the concentric circles have a great role in answering such types of task or locating time.

Efficiency



Most test persons worked with the four alternative solutions of CTC answered this task easily. Further, they were provided the answer without confidence. As a result participants spent less time relatively in each group. The CTC with emphasised time circle had the fastest response times due to the reason explained for the effectiveness of this task.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	9	1			
Group 2	10				
Group 3	5	3	2		
Group 4	7	2	1		

- Participants were highly satisfied with the CTCs when answering this task related with the other tasks, 37 out of 40 participants were responded more than average satisfaction value.
- The response of group 3 shows participants satisfaction is inline with effectiveness and efficiency.
- again the result of group 2 indicates time circles has great contribution to answer as such tasks

Task 3: Which stations is closer in time?

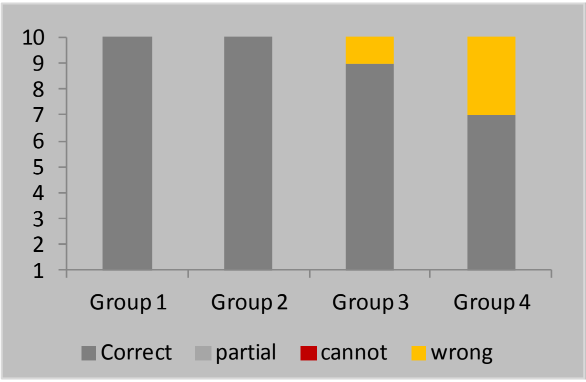
Success of task execution

	correct answer	partial answer	cannot answer	wrong answer
Group 1	10	0	0	0
Group 2	10	0	0	0
Group 3	9	0	0	1
Group 4	7	0	0	3

Average time cost:

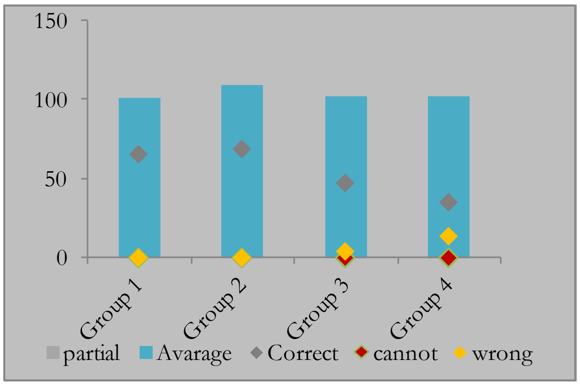
	correct answer	partial answer	cannot answer	wrong answer	Average per task
Group 1	105.1			15.6	120.7
Group 2	106.2		68.4		174.6
Group 3	64.8		9.1	28.2	102.1
Group 4	67.2			31.2	98.4

Effectiveness



All participants find the answer of task 3 easily, particularly CTC with railroad and without rail road. Although the CTC with railroad design is no railroad line, but to perform this task doesn't requires railroad. In contrast the reason why TPs get wrong answer in group 2 and 3 were because the railroad lines was created confutation in group 3 and the time circles were more emphasized in group 4 that results confusion with the railroads.

Efficiency



More than 6 participants find the answer of this task in each group. Finally, some of them provides the answer based on their own previous geographic experience of the area and others were answered based on their observation without exact evidence. However, test persons worked with emphasised railroad and time circles feels much easier to provide the answer of this task.. Generally the result proves the CTC with time circles easy to answer this task.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	7	1	1	1	
Group 2	6	3	1		
Group 3	2	4	2	1	1
Group 4	3	6	1		

- the CTC without railroad and with emphasised time circle shows better(more than average) satisfaction result for in tasks.
- the satisfaction of group 3 further proved that the CTC with emphasise time circles was not good to manage the task by counting time circles and locating the stations simultaneously
- the satisfaction result from group 2 shows moderate, the reason is in line with effectiveness

Task 4: Which path takes the longest to reach from "x" to "y" station?

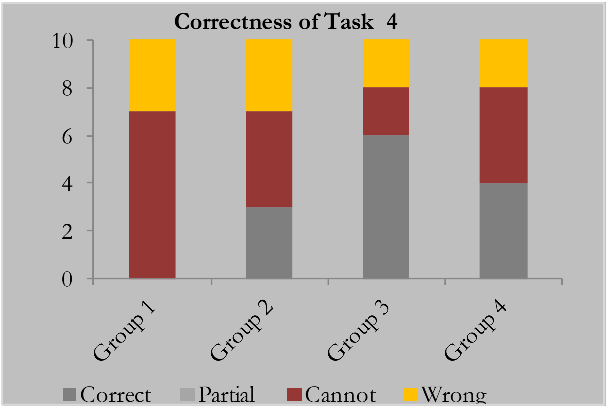
Success of task execution

	correct answer	partial answer	cannot answer	wrong answer
Group 1	0	0	7	3
Group 2	3	0	4	3
Group 3	6	0	2	2
Group 4	4	0	4	2

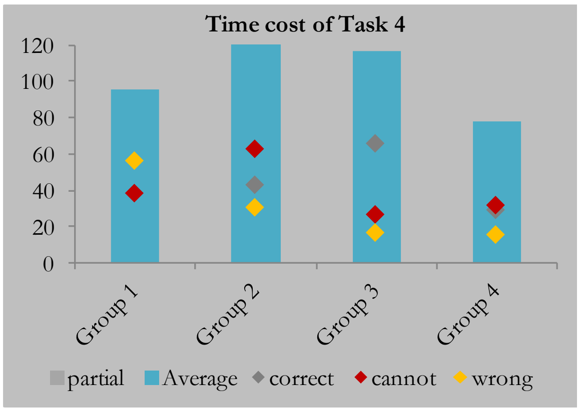
Average time cost:

	correct answer	partial answer	cannot answer	wrong answer	Average per group
Group 1			38.9	56.8	95.8
Group 2	43.5		63.3	31.1	137.9
Group 3	66.3		27.2	17.2	116.8
Group 4	29.7		32.3	16.1	78.2

Effectiveness



Efficiency



This task was much more confusing and difficult for all participants in each group, which was difficult to participants to interpreted distance in terms of time cartogram representation; as a result most they feel this is very difficult question. However finally they provide the answer without exact evidence and with ambiguity. As shown from the bar chart more than half of participants agreed about the task cannot answered or they were provided wrong answer In contrast to this CTC with emphasised railroad was the preference to provide good clue for their confusion

This confusion of participants with this task costs more time. Although group 3 participants answer better than the other group participates were taking much time to think. In the other hand, for group 4 participants with emphasized rail road help users to rethink about the time concept when finding their answer, which results shorter time than the other alternative solutions.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	1	3	1	3	2
Group 2	2	3	3	2	
Group 3	1	1	5	1	2
Group 4	3	1	4	1	1

- The satisfaction patterns here was in line with the analysis result about effectiveness and efficiency

Task 5: What is the number of possibly paths to reach "x" from "Y"?

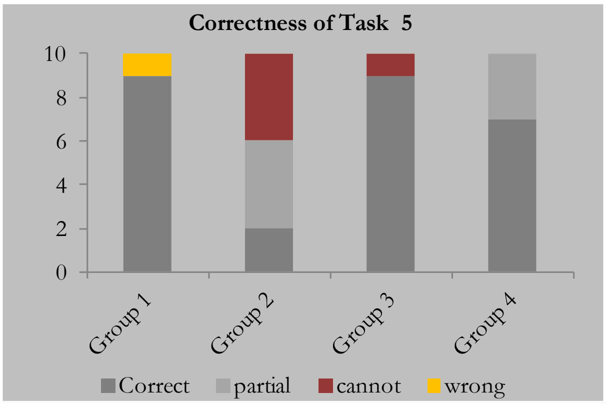
Success of task execution

	correct answer	partial answer	cannot answer	wrong answer
Group 1	9	0	0	1
Group 2	2	4	4	0
Group 3	9	0	1	0
Group 4	7	3	0	0

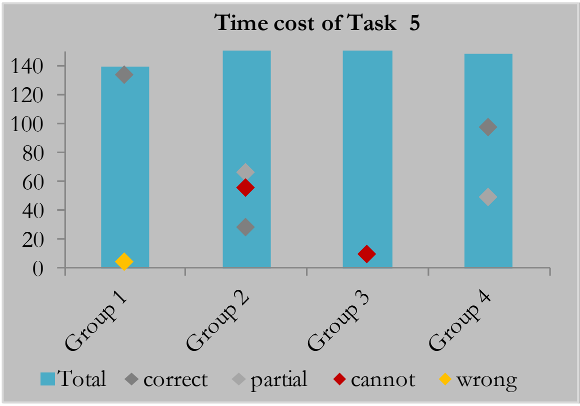
Average time cost:

	correct answer	partial answer	cannot answer	wrong answer	Average per group
Group 1	134.1			4.9	139.1
Group 2	28.8	66.7	56.1		151.6
Group 3	162.5		10.2		172.8
Group 4	97.9	49.6			147.6

Effectiveness



Efficiency



Majority of test person in the four groups understood the task well. In contrast to this for some participants, the concept of backtracking was created confusion. In one hand except some of the participants in group 1 and 3, which they provide wrong answers and "cannot answer", most participants answer this task with confidence. In the other hand the result of group 2 shows that it was not easy to answer the task with cartogram they worked on, due to the difficulty of finding route.

Although the participants in group 3 answered this task better, the railroads overlap and label of the cartogram creates the time cost too much. In addition, this group was active to answer this task without confusion but takes long thinking time. These is time cost higher for group 3 and the reason is in line with the effectiveness.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	4	5	1		
Group 2	1	3	3	2	1
Group 3	1	5	2	2	
Group 4	2	2	2	4	

- the satisfaction assessment result of this task show CTC of group 1 was better
- the worst satisfaction analysis result was from groups worked with CTC without railroad and with emphasised time circle, it confirms again such task requests easy reading of railroad line
- the group 3 participants satisfaction was moderate related to the other groups

Task 6: List the intermediate stations while trawling (via the shortest path in time) from "x" to "y"?

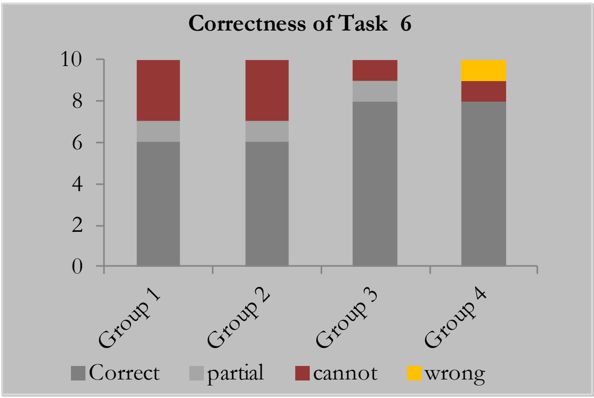
Success of task execution

	correct answer	partial answer	cannot answer	wrong answer
Group 1	6	1	3	0
Group 2	6	1	3	0
Group 3	8	1	1	0
Group 4	8	0	1	1

Average time cost:

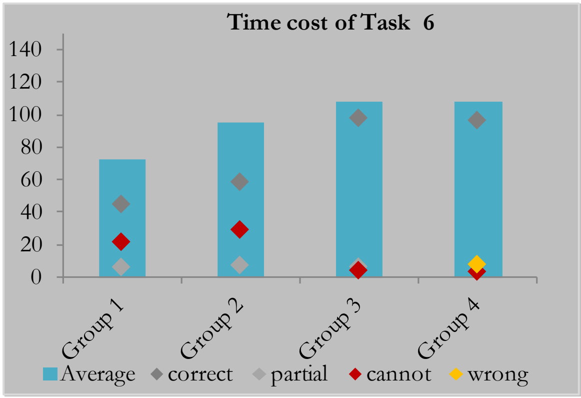
	correct answer	partial answer	cannot answer	wrong answer	Average per group
Group 1	44.8	6.1	21.6		72.7
Group 2	58.5	7.3	29.1		94.9
Group 3	97.8	6.3	4.1		108.3
Group 4	96.4		3.3	7.8	107.5

Effectiveness



When participants look for the intermediate stations the CTC used in group 1 and 2 was not helpful related to the final two groups (3 and 4), It is possible to identify that the thin railroad line of CTC in group 1 due to some overlapping of the railroads and stations and it is obvious CTC without rail road due is due to difficulty to follow the routes, which results these CTCs were poor to help in answering this task..

Efficiency



Although the participants in group 3 answered this task better, the some overlapping and thin railroads and the labels visibility of the cartogram creates the time cost too much. In addition, this group was active to answer this task without confusion but takes long thinking time.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	6		1	1	2
Group 2	3	2	1	2	1
Group 3	3	5	2	1	
Group 4	4	4	1	1	

- group 3 and 4 participants were more satisfactory preceding to group 1 and 2
- group 3 result show the least satisfaction, the reason is in line with effectiveness and efficiency
- Compared to the previous task the CTC in general scores poor user satisfaction because the task was refereed about distance.

Task 7: Where should he rest an apartment so that he is evenly close to Enscheda and Zwolle?

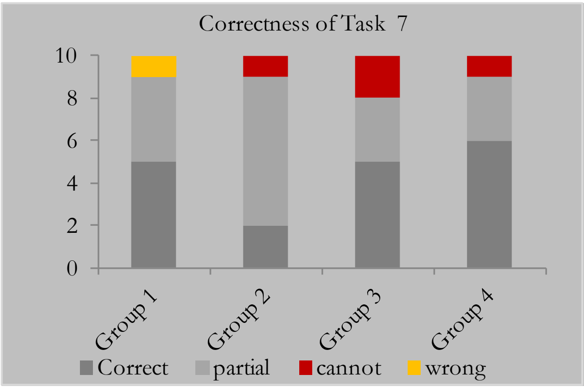
Success of task execution

	correct answer	partial answer	cannot answer	wrong answer
Group 1	5	4	0	1
Group 2	2	7	1	0
Group 3	5	3	2	0
Group 4	6	3	1	0

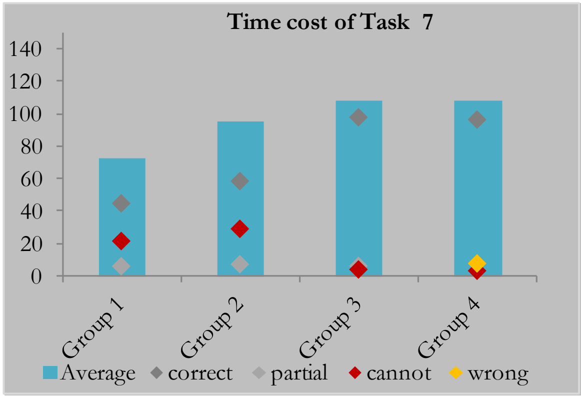
Average time cost:

	correct answer	partial answer	cannot answer	wrong answer	Average per group
Group 1	44.8	6.1	21.6		72.7
Group 2	58.5	7.3	29.1		94.9
Group 3	97.8	6.3	4.1		108.3
Group 4	96.4		3.3	7.8	107.5

Effectiveness



Efficiency



For this task the participant had to look at two CTC with two different starting stations. The task needs calculating time by following particular route. The better performance was CTC with emphasised time circle, which could provides easy look of routes and time intervals in support of emphasised time circles

The CTC with emphasised time circle were faster because of the time circles help them to calculate the time easily. Similar with to the result of effectiveness the time cost of group 4 was the highest due to users feel confidence to find the task from this cartogram that result they to spent less time.

Satisfaction:

Questionnaire: How well did the provided cartogram assist you in answering this question?

	Very Good	Good	Average	Poor	Very Poor
Group 1	4	3	2	1	
Group 2	4	4	1	1	
Group 3	2	2	3	2	1
Group 4	1	4	4		1

- most participants believe that this is not easy task in comparison with the former tasks
- the group 1 and 2 participant satisfies more than the other two groups, that is the task is more related with time searching.
- the general satisfaction of CTC for this task is was not good ,which is 16 TP provide less than average

5.6.3. Part 3: Further analysis based on thinking aloud and eye tracking data

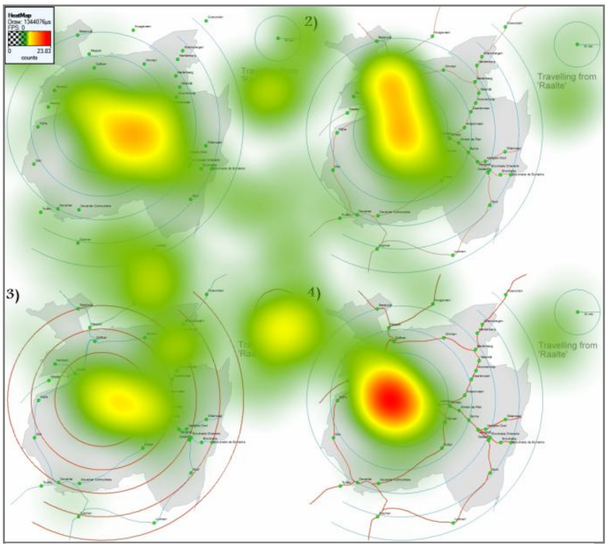
During test execution, what test person say or believes to do, is not always the same what actually they do. In this section thinking aloud and eye tracking result of the test is discussed along with the response data, which helps to address objective three of qualitative experiment. We were used video recode and think aloud of the test to analysis each test person while answering each task. Similarly, eye tracked data is collected from visualization of gaze points and heat map. In one hand using think aloud can assess participant's response and feeling in accordance with their verbalization when they answer each task. In the other hand eye movement tracking can provide situation related and an additional unobtrusive evidence of participant's behaviour.

Usability exploration with different designs can deliver different outcomes. In one hand, the designs show a potential to perform tasks faster. In the other hand, it can give more accurate results. Both cases can show an essential element that make the users perform better in one way or worst the other way. How such cases happed and why need to be answered by additional analysis of eye tracking, which allows recognizing where, is the person attention being focused in relation to the visual display and to study better and exploring usability metrics regarding the response time and completion average time accuracy.

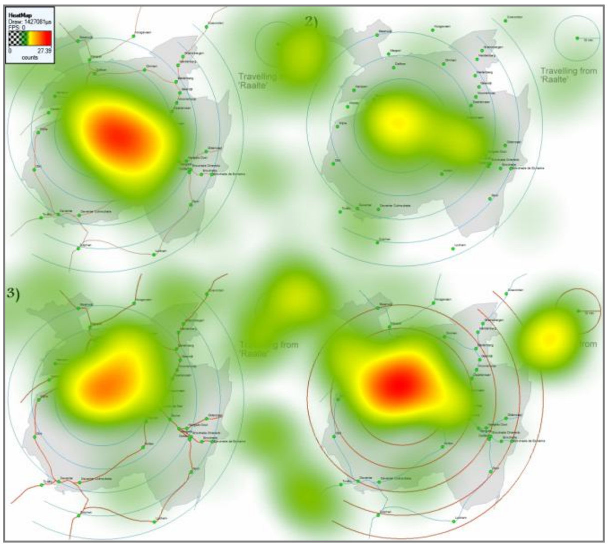
Accordingly, in our study from eye movement recording it was possible to identify where the problem areas are in the cartograms' and how the procedure of response was processed per task with CTC presented from different starting stations. In the other word we addressed test objective three of this experiment. Below, visualization of each task execution is presented and discussed. Figure 5-14 shows the heat map when participants selected one designs of CTC among the four alternative solutions, while Figure 5-15 ,5-16, 5-17 5-18 5-19 and 5-20 illustrates different number of participants gaze plots in each group, when the perform task 1,2,3,4,5 and 6 respectively. During this six task execution, one alternative solution of CTC's among the four with six starting point were displayed in each group. Finally, figure 5-21 shows the eye fixation of whole participants (1o in number) in each group during test execution of task 7.

Task 8: Task to choose one alternative solution of CTC among the four by TPs', (see Appendix 6 task 8)
All participants were used the combined (See Figure 4-3) four displayed alternative solutions of CTC to completes task 8. The task was about comparing the four alternative solutions of CTC that were presented in a different order. The participants have to identify the design difference first and then compare between the four alternative solutions of CTC. Task six were provided for participants to perform based on their preference design, but they do not have to go into detail, only we need to glance with which design they determine if this task is provided. Accordingly, the task was to list the shortest intermediate path in time between Raalte to Holten station. The heat map in figure 5-14 shows that the participants were started from overview and then identified their favourite design. Next they start to perform the task with their preference alternative by moving their eye through this design mainly.
As shown in figure 5-14 with an overview of the heat map on the four alternative solutions in four groups, which were extracted from the distributions of all participants absolute gaze duration. The densities of gazes are represented in red, yellow, green and black colouring area. In one hand red gazes' represents area were the longest gaze duration during the task execution, in the other hand from yellow to green area represents less eye fixation of participants ,while blank part show the gaze points were not exist or eye fixation were less. On these maps, the more red areas are around the CTC with emphasized railroad and next to with CTC with emphasized time circles. The CTC with railroad also attracted some participant's attention. There are also some gaze points shown around CTC without railroad; this seems participates looking for comparing among the designs. However, CTCs' with emphasized railroad and time circles

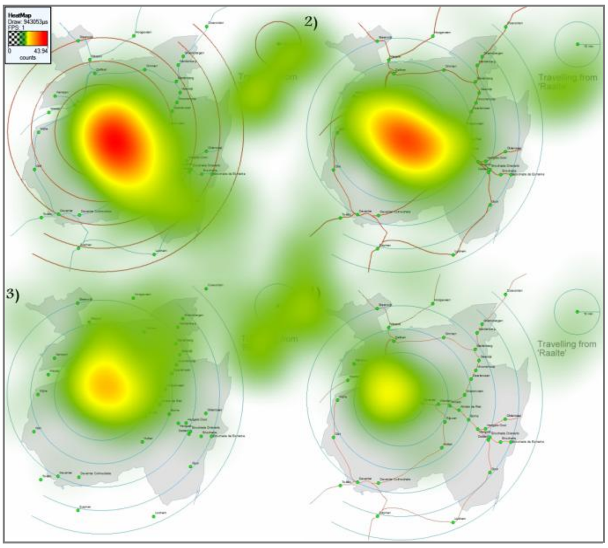
were given the most priority together as the heat map 1 and 3. Based on the heat maps 1 and 2, it looks the CTC with emphasized railroad was got more priority to be selected alone. This result is also similar to the selection response of TP as presented in the table 5-15, 5-16, 5-17 and 5-18.



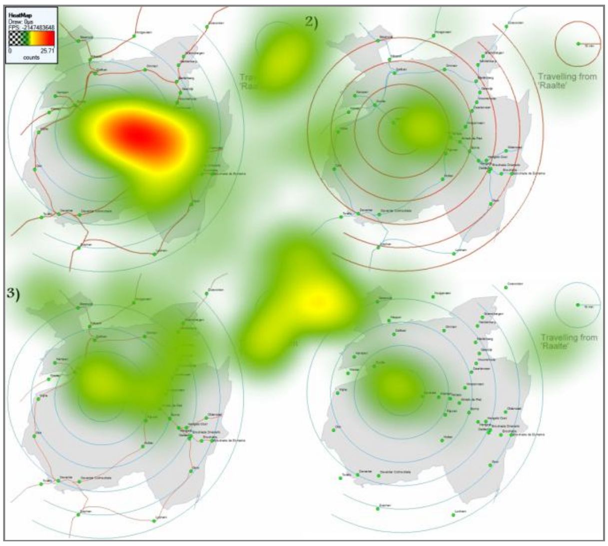
1) Group 3: with emphasized railroad



3) Group 4: CTC without emphasized railroad



3) Group 1: CTC with railroad



4) Group 2: CTC with out railroad

Figure 5-14: Heat map of CTC alternative solution selection: group 1), 2), 3) and 4)

Task 1: Task 1: At what time one should leave to reach "x" station around 11:00? (see Appendix 6 task 1)
Figure 5-15 shows the gaze plots of all test person eye movement in each group that tells the story of this task. The image in each group shows the story of each group with one, two or three TP at most that were executing the task with different starting points. The expected searching strategies for this task was the user starts from the overview of the displayed images and looks for the legend of time circle, followed by searching the two stations (place he live and has appointment).Then identify the time by counting time circles. All gaze points cover similar areas in different groups that worked with CTC of same starting stations, for example starting points from Gramsbergen of group 1, 2, 3 and 4. The gaze plots can be interpreted in two categories, gaze points in the same group but with different staring points and in different groups with the same staring points. In one hand, in the groups one or two participants' identifis by starting searching from legend reading and then focused on starting station proceeding by the target station, finally their gaze moved to on time circles several

times. Since the nature of the task more related with time circles, most moved gaze views confirmed that most participants could depend on the time circles without the influence of starting points. In the other hand, although in different groups the starting stations were the same, for example, Enschede, but the distribution of gaze was varied. For instance in group 3 the plots looks difference than group 1. This mean that the participants were confused more with the image in group 1. The cumulative result shows that there were difficulty to perform the task in design different and within the same design but represented from different the starting stations. This finding proves the expected searching strategy of the task and tests objective three.

Task 2: List all stations that are reachable within 20 minutes? :(see Appendix 6 task 2)
As the nature of this task, the test procedure expectation was starts by looking at the time representation legend, identify the starting station, and count the time circle until 20 minutes and finally to find the station within 20 minutes. The aim of this task was to find out whether, the task is oriented towards time circles, railroad lines or would users prefer both visual effects to perform correctly. Figure 16 shows gaze plots of 10 participants in each groups in two categories, one with two participants and another with one participant execution gaze that is based on the test execution performed with randomized algorism.

In group 2, 3 and 4 the eyes movement visualization of 10 test persons shown the more gaze distribution were around two-time circles. It looks as all participants followed similar searching strategies. However, this was not always true as shown in some tracked eyes movements, which are scatted out of the interest areas, with more plots and long paths. For instance participants executed tasks starting station from Steenwijk in group 1, 2 and 3; and Deventer and Raalte in group 1. In one hand the searching of this task with starting station Enschede, Zwolle, Gramsbegen and Raate was similar with the expectation searching strategy. In the other hand participants worked with starting stations from Deventer and Steenwik plots of their eye movement diverted out of the task answer zone.

In support of thinking aloud recording and gaze plot replaying possible to determine the story of a particular task. Generally, most execution procedure of this task in the groups confirms the easy performance of CTC alternative solutions. However, the exceptional results indicate that starting point difference with the in alternative solutions of CTC might influence the execution. For this reason, this task drives the user interactive design to response such task type in focus.

Task 3: Which stations is closer to "x" in time? : see figure 17:(see Appendix 6 task 3)
This is a typical spatio-temporal task. Figure 5-17 shows gaze plot of participates (i.e. 1,2 or 3 in number) task execution done with CTC of six starting stations. We predicted that the participants' behaviour for this task would cover all cartogram area. Most gaze plots prove this, the trend from all participants are similar. In group 1 the eyes movement of the TP (10 test persons) showed the more gaze distribution around the interest area. However, this was not always true, some tracked eyes movement was scatted out of the interest areas, with more plots and long paths like participants executed tasks with CTC of staring station from Steenwijk and Deventer and Raalte. Again this indicates the starting point difference might influence the task execution.

The gaze plots from single participants in the figures shows; the searching strategy to identify the closer station was first by moving around the circles to calculate the time. Then move to the locations of stations to determine the names, after that back to the starting stations to check the time interval and subsequently identify the closer station.The procedure was proven the predicted gaze movement pattern. However, the plots distribution and amount different still happen in this task. For instance, group 1 with same number of TP, the task execution gaze plot amount were different based on the staring stations. The execution might be similar if there was some interaction like zoom in out and pan. Again this task revealed the importance interactive nature for this cartograms.

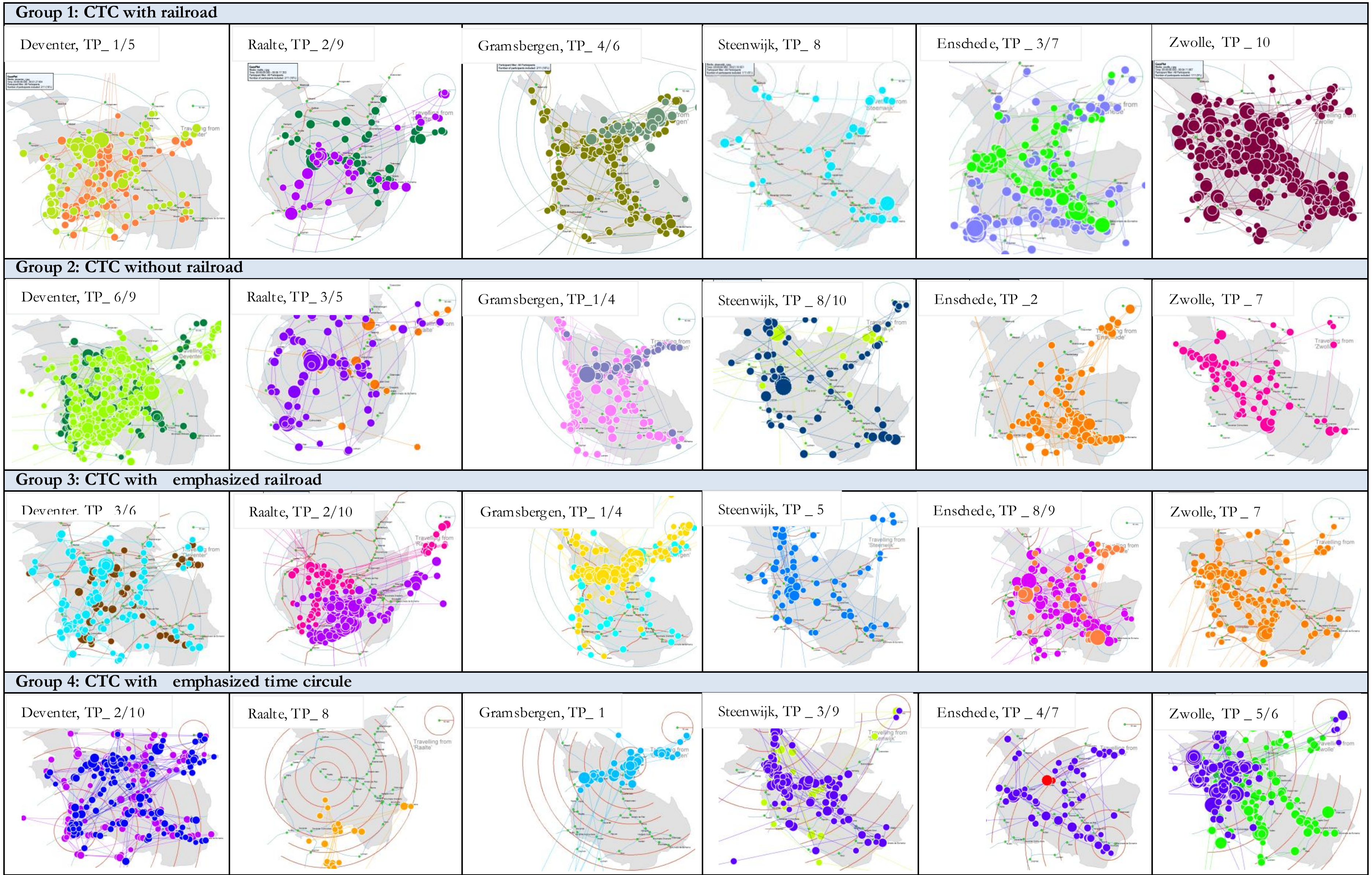


Figure 5-15: Gaze plot of task 1 with one, two and three number of test person (TP) in the four groups

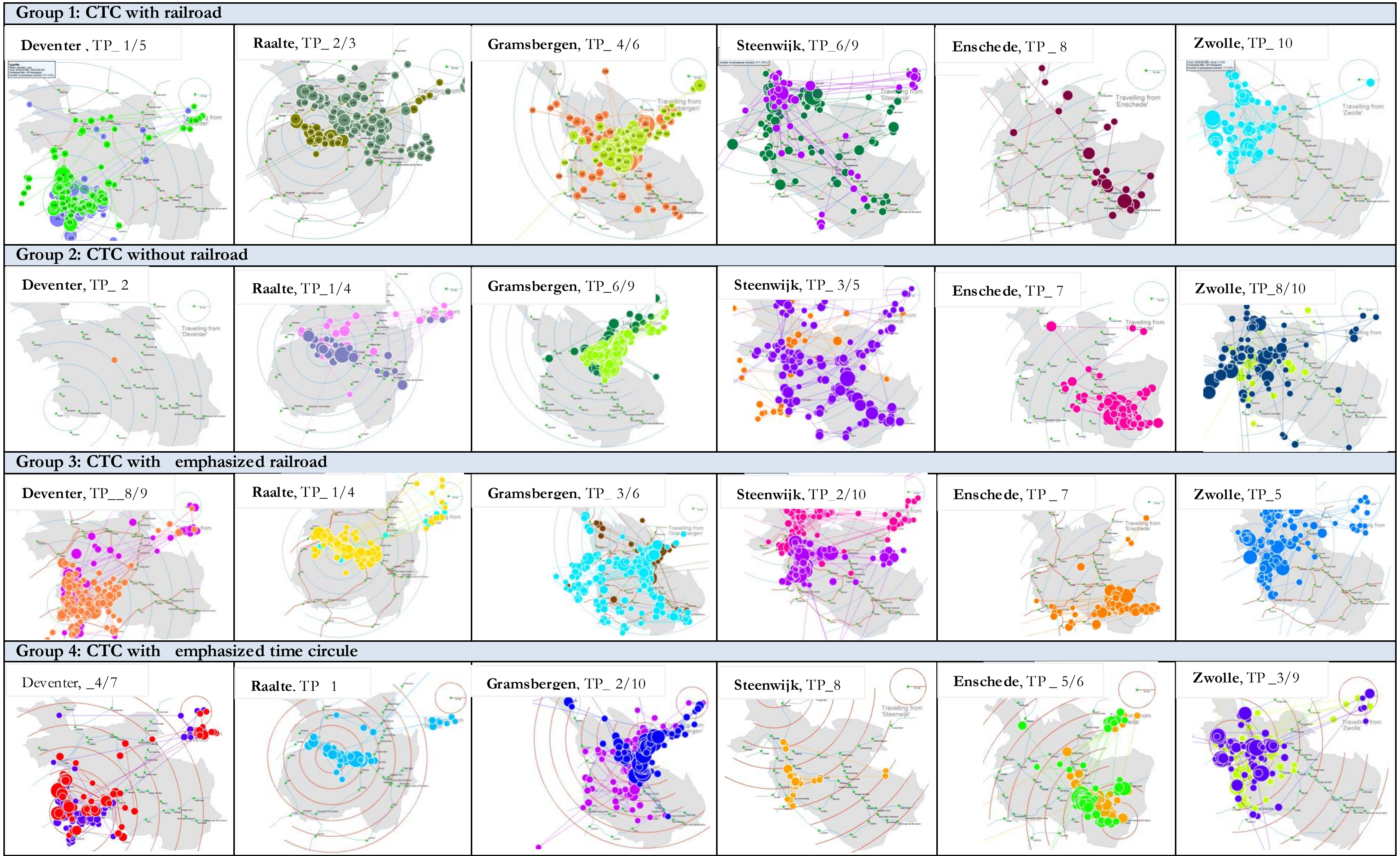


Figure 5-16: Gaze plot of task 2 with one, two and three number of test person (TP) in the four groups

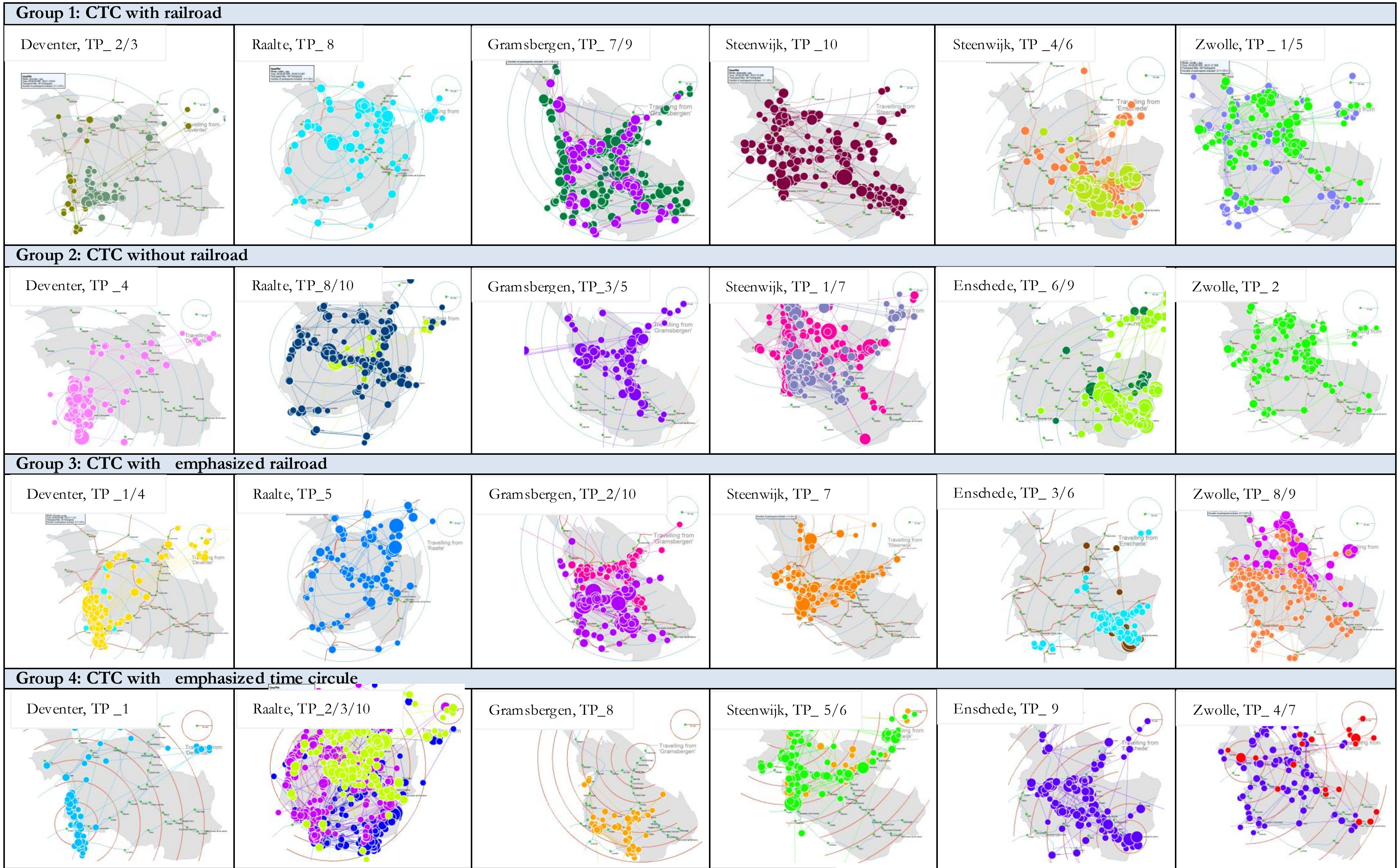


Figure 5-17: Gaze plot of task 3 with one, two and three number of test person (TP) in the four groups

Task 4: Which path takes the longest to reach from "x" to "y" station? : :(see Appendix 6 task 4)
The task requires participants to use railroads lines to find the stations and time circles to calculate the time interval. It is similar to task 3 but slightly more complicated. The participants in each group first find the alternative routes and then verified the time interval through counting the time circles. Finally, they checked the shortest path and responded based on with their conclusion. The recorded task procedure gaze plots shows similar behavior with all the test persons. However, in the figure 18 gazes of the groups 2 reveal different results. For instance in this group gaze distribution of two test persons worked with CTCs' starting from Gramsbergen is more than Zwolle and Raalte, which indicates their time spent difference, this mean that the shape of the cartogram had slightly influenced the task execution. In one hand, as a group the gaze plots indicates again the influence of the four design based on the starting stations , for example tasks done by one participant in group 1 and group 4. In the other hand, as individual9.++. group or design shows similar scattering the confirmed particular design is preferable for particular task , for example the gaze plots worked with CTC of Deventer starting station was scatted around the interest areas. It is also interested to observe that this four participants circled their target station and they reading was from left (starting station) to right (target station). Further, in group 3 shows the detailed look of participants than the other groups, as the result whole analysis indicated these participants were take more time to think for correct answering. This means that they were rechecked the time interval by moving goes back from targeted stations to starting station.

Task 5: What is the number of possibly paths to reach "x" from "Y"? :(see Appendix 6 task 5)
Figure 19 gaze plots: The aim of this task was to see whether participants faced problem during route identification. The gazes of this task execution are somehow comprised in most area of the cartogram. In gaze of group 1 two participants, TP1_7/9, TP 1_1/5 and TP 1_2/3 shows less denser than TP 1_ 4/6, that indicates the influence of starting stations for particular tasks in each design. Similarly, difference observed from gaze plot of single participant (see TP1_ 10 and TP1_ 8). Again group 2 participants (TP 2_3/5, TP2_8/10, TP 2_1/6/9) gaze plot shows this difference, specifically the gaze plots of single participants (TP2_7 and TP2_2) tracked eye indicates the response time difference. In this group their eye movement was random like TP 2_1/6/9, which indicates participated were found difficulty to follow routes without railroad lines.

Group 3 gaze result is similar to group 2, However, this was not always true some tracked eyes movement was scatted out of the interest areas, with more plots and long paths like participants executed tasks staring station from Zwolle and Steenwijk.. Again, this is an indication of the starting stations influences in the usability of a single CTC design. Related with the three groups the gaze plots of group 3 shown covers more area, as the replaying recode shows participants were taking more time to answer this task correctly. Here is very interesting to observe gaze plots of participants responded this task through Gramsbergen either 1, 2 or 3 in number, focused on the rectangular area at the centre of the cartogram, additionally all are start to read the cartogram from right to left that is from the legend they move to starting station and finally around the linked routes.

Task 6: List the intermediate stations while travelling (via the shortest path in time) from "x" to "y"? :(see Appendix 6 task 6)
The task is about spatio-temporal response as task 2 and 3. It requests to identify both routes and time from the cartogram. This combination is required to be able to identify the intermediate station that is shorter in time between two given stations. Figure 5-20 shows the gaze plots all participants this task execution. All stated from the starting stations or legend of the cartogram then followed the path of their target while to check the time interval. They followed the one route for a while, and they moved to another one to check the shorter time. It is also seen that some participants looked at out of the interested area like TP 1_ 4/6, TP3_ 8/9 and TP4_1. Figure TP1_ 10, TP2_7, TP3_ 5 and TP3_5 shows similar behaviour when they reply the task starting from Gramsbergen but with different complexity, that clearly indicates the tasks dependency with designs of CTC. Similarly, an interesting result of gaze can be observed in TP1_ 8, TP 2_8/10, TP 3_5 a TP3_ 3/9 their eye movement seem straight line with some scatter

gaze around. However, when we compare TP 2_8/10 with TP3_ 3/9 and TP1_ 8 with TP1_ 8, their gaze plot distribution is similar based on the effectiveness analysis result of this task.

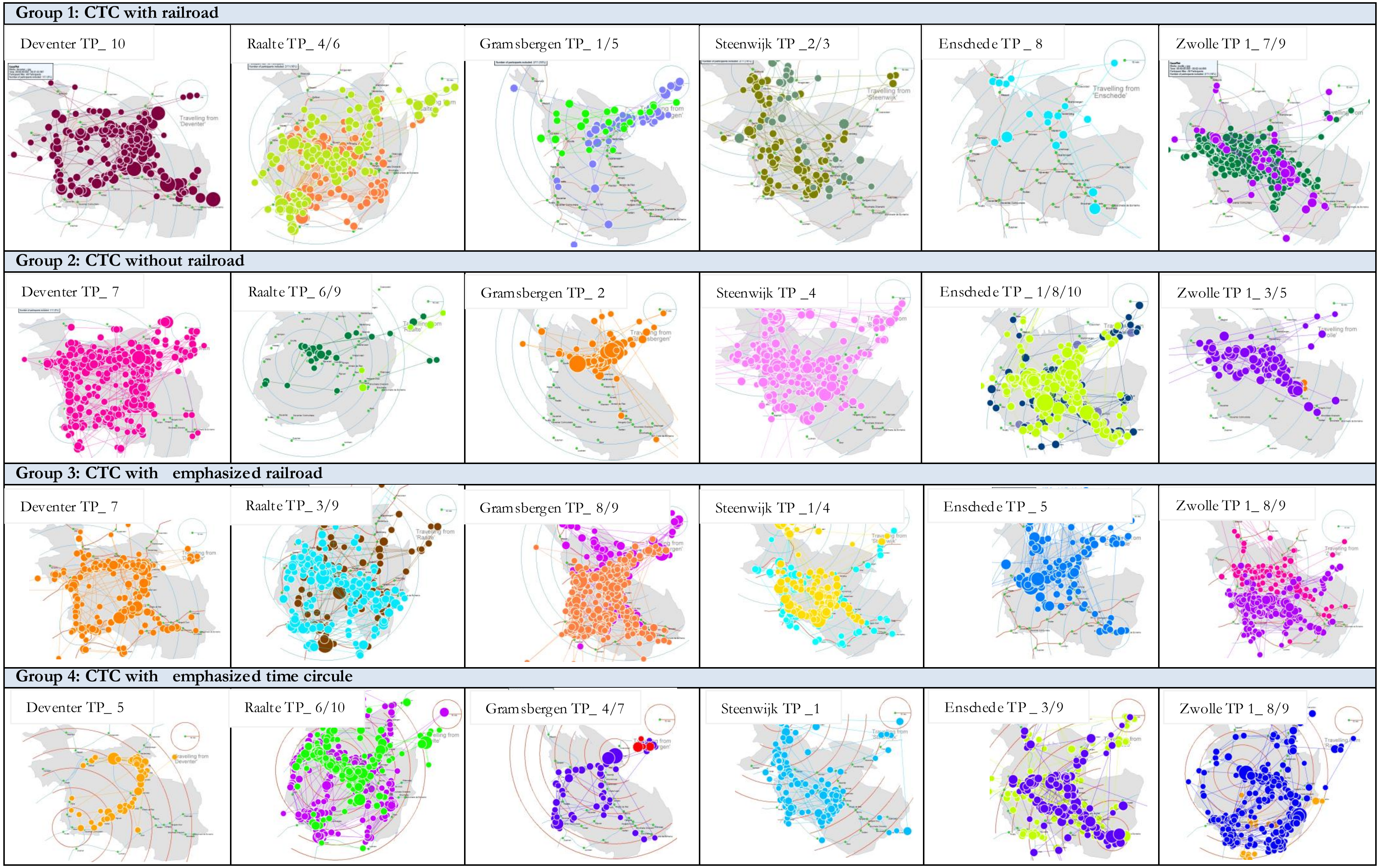


Figure 5-18: Gaze plot of task 4 with one, two and three number of test person (TP) in the groups

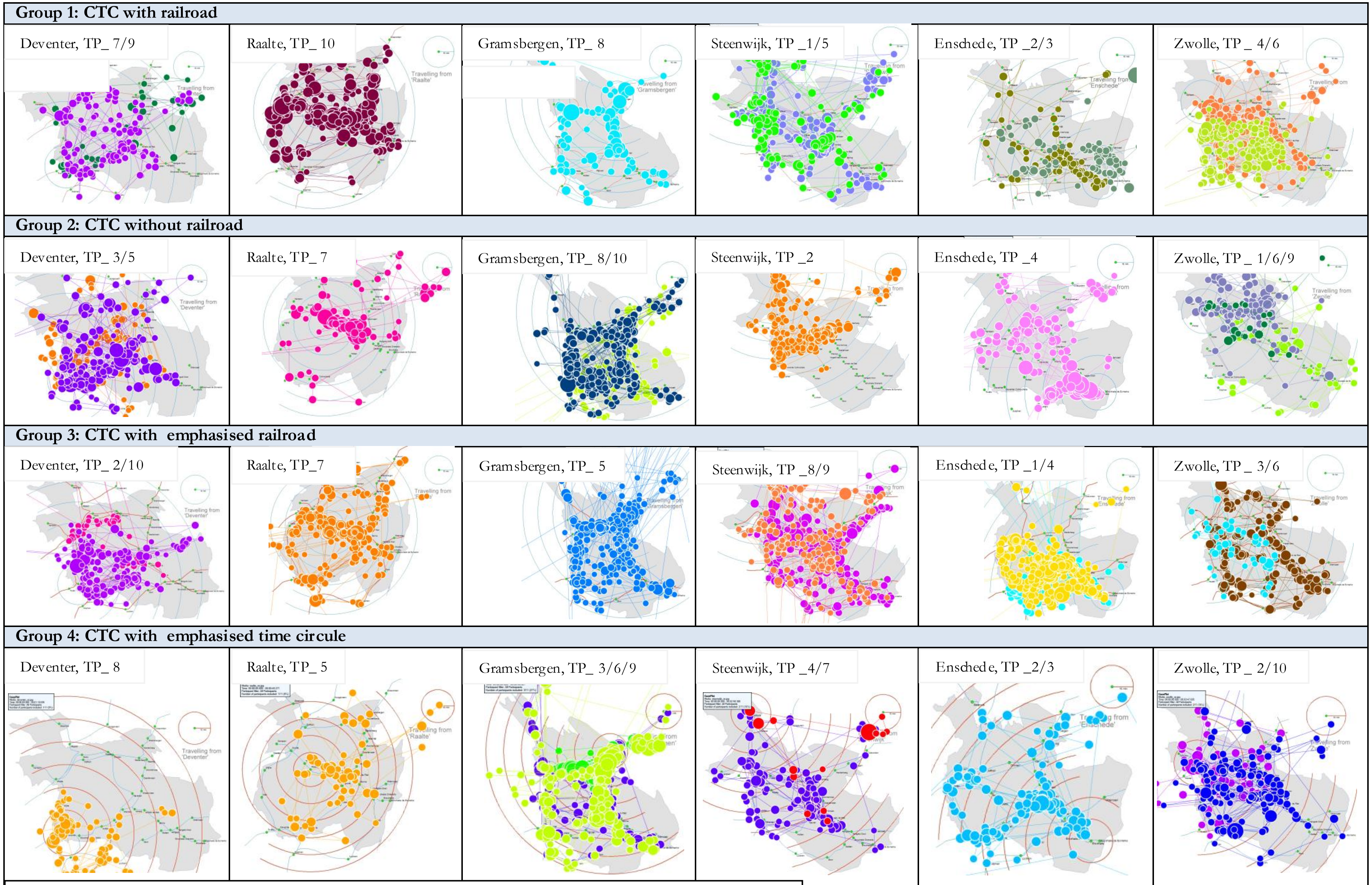


Figure 5-19: Gaze plot of task 5 with one, two and three number of test person (TP) in the groups

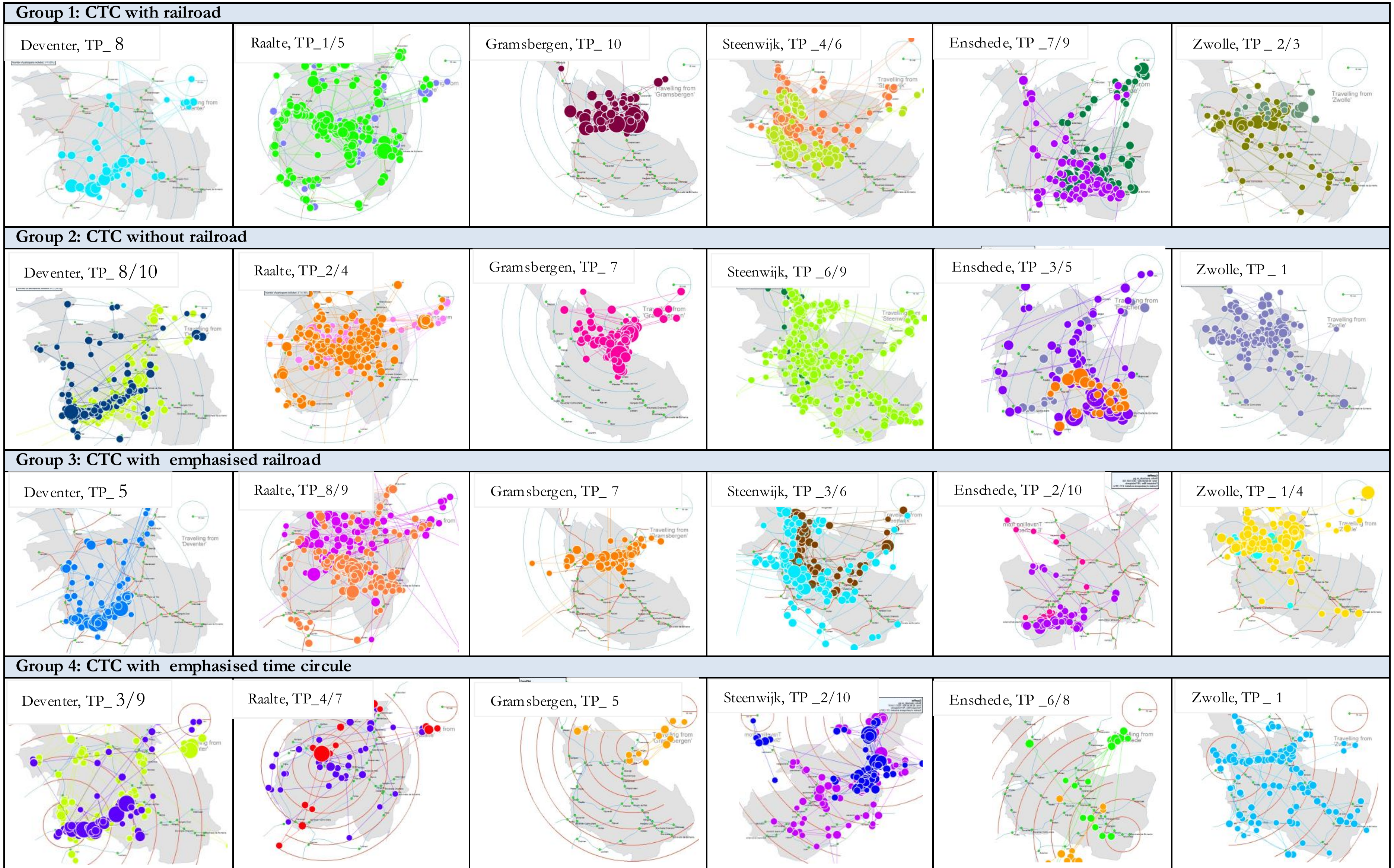


Figure 5-20: Gaze plot of task 6 with one, two and three number of test person (TP) in the groups

Task 7: Where he should rent an apartment so that he is time wise evenly close to Enschede and Zwolle?: :(see Appendix 6 task 6)

The task is about comparing time interval that is to identify and locates best suitable place as the case. Figure 5-21 shows the whole task execution view of task 7 in each group. It shows waved gaze plots between the two CTC starting point from Enschede and Zwolle. The combination of CTC was required to be able to compare the locations form CTC of two starting point with different complexity. Figure shows task 7 group 1 , 3 and 4 gives an overview of the participants gaze plot, which includes saccade eye movement of whole participant task procedure the through the scan paths. They started at the middle of the CTCs'; legend reading and then identified the two stations. They count the time circles to calculate time interval and followed the railroad lines for a while to identify their target stations. It seems that CTC with railroad was more helpful as shown from uniformly distributed gaze plots of group 3 than the scatted gaze path of group 1 and 2. It can also be seen that the distribution of gazes' plots is inline with the expected answer in group 4. In contrast group 2 gaze fixations shows more fixation on the legend that indicates participants go back again many times to the legend to read information when they confused. In summary, the eye movement pattern indicates participants in group 3 and 4 perform the task better than the other two groups.

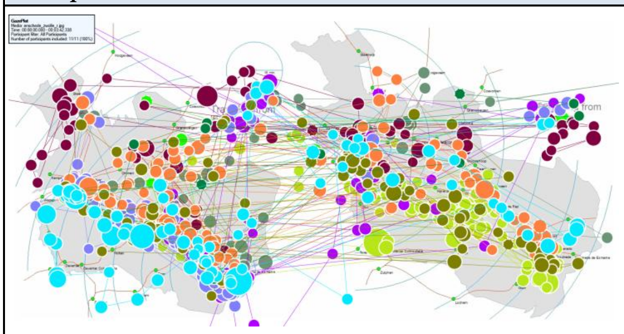
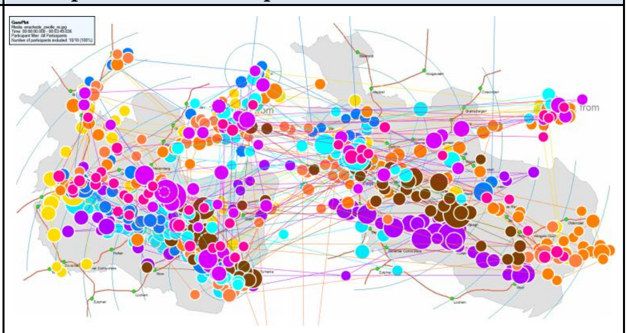
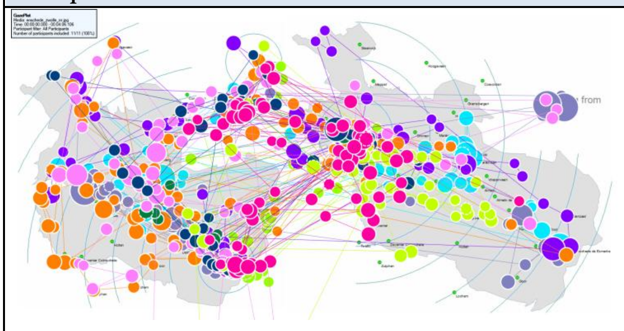
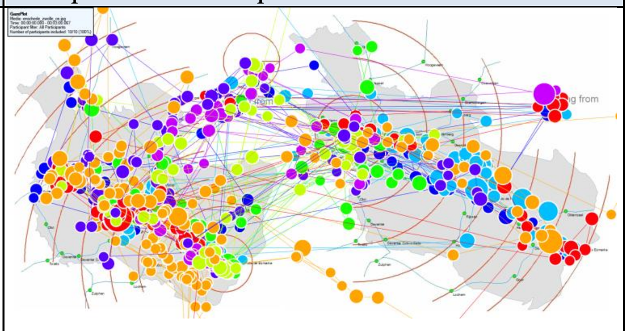
Task 7: Where should he rest an apartment so that he is evenly close to Enscheda and Zwolle?	
Group 1: CTC with railroad	**Group 3: CTC with emphisized railroad**
	
Group 2: CTC without railroad	**Group 4: CTC with emphisized time circule**
	

Figure 5-21: Ten test person gaze plot of task 7 in the groups

5.7. Conclusion and feedback

The reason of CTC development is to have a graphic representation that would allow access to scheduled movement data. Its four alternative design solutions have the same purpose on replying to spatio--temporal data questions. As such, they support participants in discovering temporal patterns and relations in executing the provided tasks. However, as the results indicate, the performance of the alternative solutions was varying in usability context. For instance, according to the usability evaluation the prioritized alternative solution of the CTC is a CTC with emphasized railroads, but it only scores the second satisfaction result, which indicates that the cartogram needs to be improved. For this reason, the results can be summarized as follows::

- Since exploring alternative shortest routes to stations in time are executed with locations, the CTC representation should visualize with a reference map that is a geographic map next to the CTC. The involvement of the reference map is necessary to reference some of the cartogram's distorted elements, such as stations as well. This means that the map elements and features of the cartogram could easily be identified through the real geographical representation.

- In addition, participants believe that map features such as the legend and northing might be another important factor to consider for the easy use of the CTC. Particularly, the legend was commented to have it including the main representations (station and railroads), in addition to time circle legend that is already included in the cartogram.

- Another potential effect of the experimented CTCs was related with labelling, which is suggested to be adjusted for the placement and font size of the labels. Participants were providing this comment due to the difficulty they faced to identify the names of some stations from some overlapped labels.

- Further, some participants commented on the colour, line size, and symbol of the CTC railroad: they suggested the railroad lines' colour to be replaced by other alternatives than the red colour and the symbols to be replaced by railroad symbols in place of the normal lines.

- On the one hand, the four alternative solutions of the CTC can be used to represent scheduled movement data even though the CTC with emphasized railroads holds the priority of performing most tasks in terms of effectiveness and efficiency. In addition, according to the participants' suggestions the satisfaction of this cartogram can be improved by redesigning according to the recommendations discussed above. Therefore, after this improvement this alternative solution can be considered as completely usable (effective, efficient and can satisfy users).

- On the other hand, it is difficult to give priority to a particular alternative solution of the CTC in terms of the whole task performance. Also the findings of a detailed analysis prove this, which shows that the CTC alternative design solutions performance varies per task. As a result, in case of different requirements based on the existing design of CTC, the following alternative solutions can also be recommended. This indicates interactive design might improve the performance of the CTC.
    - ✓ If users want to see the time interval between stations, the CTC with emphasized time circles and the CTC without railroad is preferable.
    - ✓ If users want to see alternative routes in time, the CTC with emphasized railroads is preferable.
    - ✓ If users want to see closer or farther stations in time, the CTC with emphasized railroads and the CTC with emphasized time circles are preferred.

- Further, it is now possible to find out their usability quantitatively in comparison with other scheduled data representations such as schematic and geographic map.

6. QUANTITATIVE USER RESEARCH IMPLEMENTATION

6.1. Overview

In this chapter, the usability aspects of visualizations of scheduled movement data are discussed in use and user contexts. To find out about and compare the usability of three visual representations (geographic map, schematic map and CTC), the chapter presents the quantitative test implementation and its results and findings. The chapter describes the user test implementation plan with the last two formulated hypotheses in Chapter 3 as a test objective. The entire chapter is about the quantitative test set-up preparation, participant data, task preparation, test implementation results and result analysis, preceded by the test objectives. Finally, the chapter ends with conclusions and outlooks based on the result findings.

6.2. Test objective and plan

The quantitative test was aimed to explore the usability of the CTC in comparison with two other map stimuli. The user research of this test was implemented and analysed with two test objectives (see Figure 6-1). It was aimed to find out the usability of the improved CTC design with emphasized railroad in comparison with a geographic and schematic map. Also, it was to investigate whether CTCs are preferable to answer spatio-temporal questions or not without users was being affected by the distorted nature of cartograms.

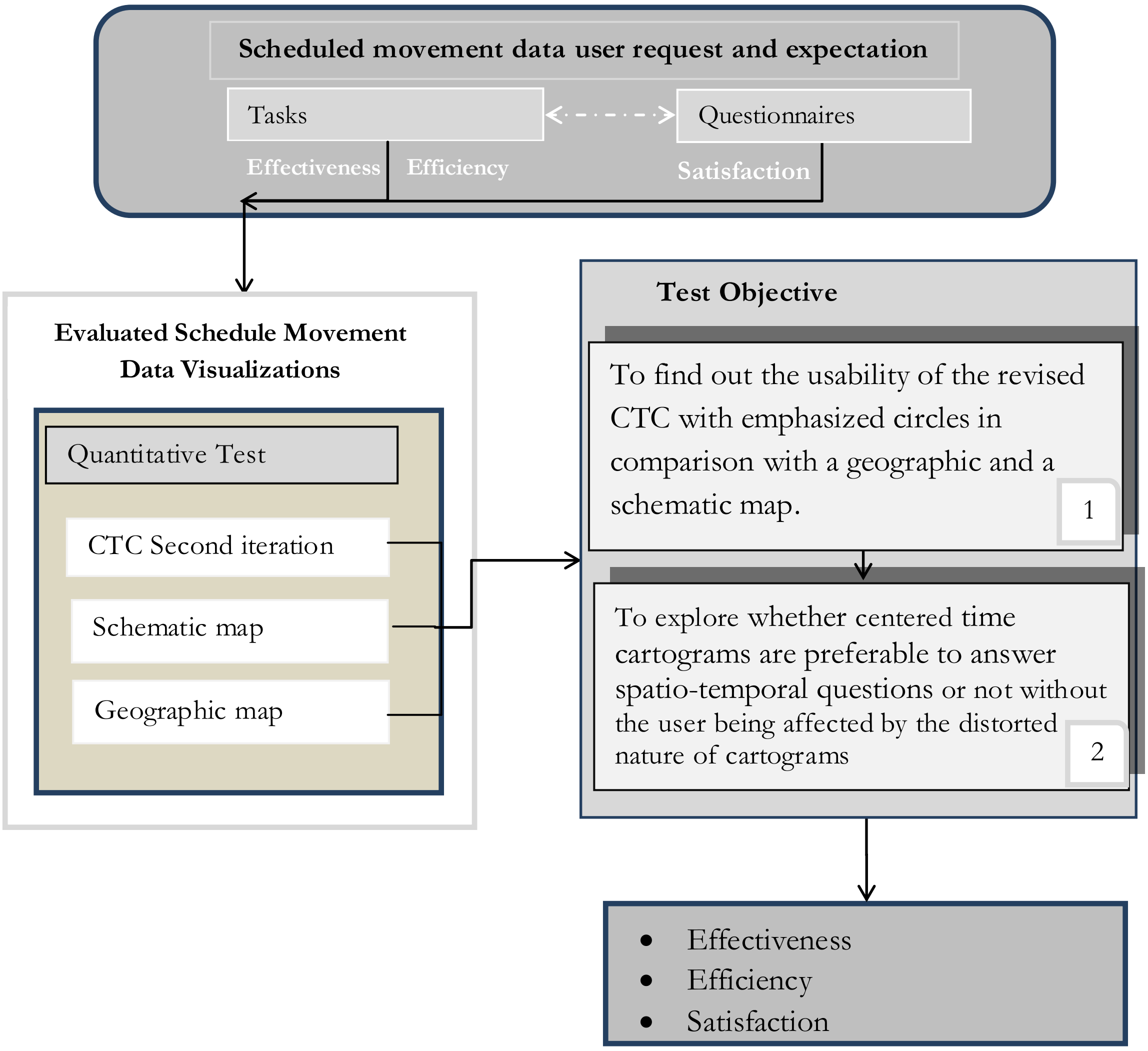


Figure 6-1: Test objectives of the quantitative evaluation

6.3. Preparations for test implementation

Similar tasks as task 1, 2, 6 and 7 (Appendix 6) of qualitative test and likert scale questionnaires (Appendix 7) that are similar with qualitative test were prepared with the three visual representations, which are made for this test implementation (Figure 4-4, 4-5 and 4-6). Tasks 1,2, 6 and 7 were presented with candidate maps Eindhoven, Utrecht, Maastricht and Schiphol respectively. In addition, a user profile questionnaires were made that helps to perform a detailed analysis (see Table 6-1) that was presented following the tasks. Also, participant's invitation letter made (Appendix 1) that was aimed to include willing and many real user representatives in the test

6.4. Test implementation

The quantitative test was implemented through an online survey from February 3 to 10, 2015. In total, 134 responses were collected among these; 82 records were valued responses, and the other 52 were incomplete responses. The respondent number was different for each map; 55 were replied task with the CTC, 11 with the geographic map and 16 were to perform the tasks with the schematic map. We think the reason for this variation was due to the order of option button presentation influence (see Figure 6-2), for example, the CTC button was in the middle. The participant group (i.e. based on with the three candidate map) consisted of various user profiles as presented in the Table. Figure 6-2 shows the test execution procedure while the participants were responding to the tasks online. The test site (see Figue 6-2) was prepared before the online survey invitation. This survey is implemented through lime-survey (open source software that used to process, record survey responses and also provides analysis) that is to record user response including the time cost. As Figure 6-2 presents the online surveys were prepared and processed based on the following four main steps:

- **Part 1:** First respondents were asked to reply about questions of user profile(Appendix 2)
- **Part 2:** It was provided three options(buttons) to be selected by user randomly that leads to the tasks related with one of the comparable maps(see Figure 4-4,4-5 and 4-6)
- **Part 3:** According to the random selected button tasks were displayed with one candidate map and user were perform four spatio-temporal tasks with this map.
- **Part 4**: finally they were requested to perform the same tasks with a map other than they worked on it. In the mean time they were requested to level the three maps according to likert scale questionnaires. Here the intentions were to compare the three candidate maps performance per task that is to analyze their performance per map type and per task later.

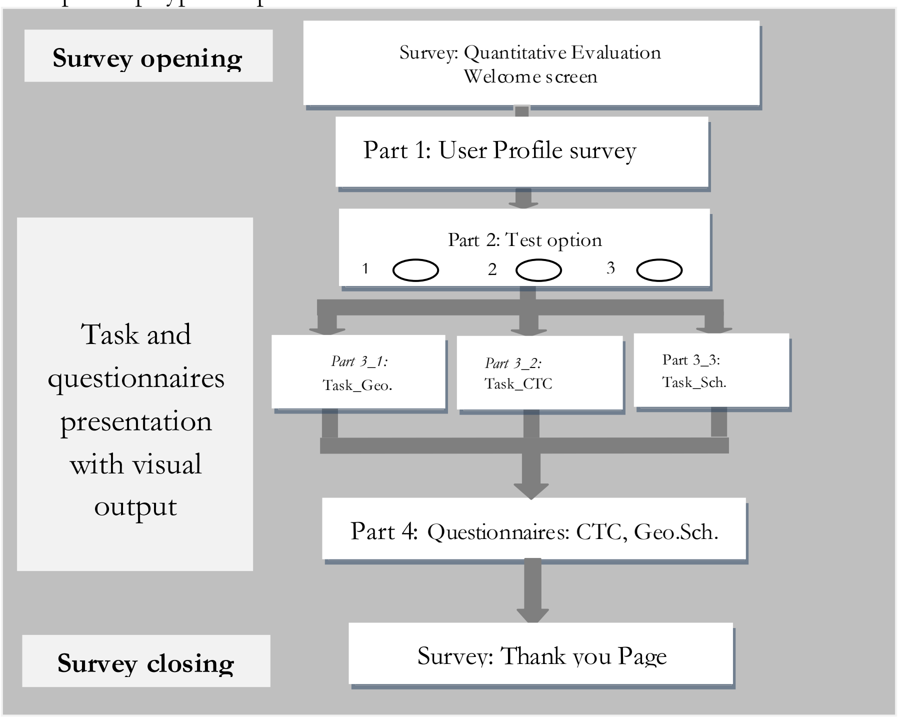


Figure 6-2: Quantitative test execution procedure through online survey

Table 6-1: Quantitative test participant user profile

User profile data type	Answer	Percentage
Gender	Male	62.35%
	Female	37.65%
Educational level	Bachelor degree	30.59%
	Master	48.24%
	PhD	17.65%
		2.26%
Educational degree	Geography, Cartography, Engineering, Computer Science, Geo-Information Science and Earth Observation	43%
		57%
Country of residence	the Netherlands	64
	Other	21
Live in Netherlands Experience	Less than 1 year	13%
	1 to 2 years	15%
	3 to 4 years	7%
	4 to 8 years	3%
	More than 8 years	26%
Travailing experience by train	Never	2.35%
	Seldom	7.06%
	Several times per year	5.88%
	Several times per month	15.29%
	Several times per week	36.47%
	Daily	32.94%
Maps make experience	static maps	48.24%
	static and interactive/dynamic maps	35.29%
	Daily	2%
Travel by train experience	3 to 4 times a week	8%
	1 to 2 times a week	7%
	2 to 3 times a month	12%
	Once a month	23%
	5 to 10 times a year	14%
	3 to 4 times a year	7%
	Once or twice a year (	12%
	Ask somebody else (e.g. at the train station)	12.94%
Ways of travelling plan	Go to the train station and consult the information boards	22.35%
	Consult a train trip planning website	72.94%
	Consult a train trip planning app on my Smartphone or tablet	51.76%
	Consult a map	28.24%
Experience about cartogram		45%
Experience about CTC		10%

6.5. Implementation results and findings

The test persons were asked to perform tasks related to spatio-temporal aspects. First they were requested to perform four tasks with a particular visual output (geographic map, CTC and schematic map) which was presented to them randomly. Then they had to reply to four questions by comparing the three stimuli. The result of these test sessions were analyzed generally and specifically. The general analysis was aimed to prove the first test objective while the specific findings were addressing the second objective of the test. In the general analysis the effectiveness efficiency and satisfaction of the scheduled movement data visualization (geographic map, CTC and schematic map) were evaluated based on the total averages: correct answers, completion time of tasks and likert scale values respectively. In the specific usability aspect analysis, the three visualizations were evaluated in terms of particular task performances for spatio-temporal map reading.

6.5.1. Test result data organization

The data results from the participants are organized in tables, which relate to the usability measure effectiveness, efficiency and satisfaction. These tables include the response data about correctness, time costs and data about user satisfaction (Appendix 10_1, 10_2 and 10_3). Also, the time of task execution and Likert scale statistics were calculated to measure the time costs and satisfaction per task and per visual output.

6.5.2. Quantitative test analysis: general findings

The findings presentd here are related to the first objective of the quantitative test, which determines the usability of the CTC in comparison with the two other visual representations of scheduled movement data.

6.5.2.1. Effectiveness

In order to measure the effectiveness of the CTC in comparison with the other maps of the scheduled movement data representation, the averages of the correct answers to the four tasks were calculated for each map. These results are presented in the Appendix 10_1, 10_2 and 10_3. Figure 6-3 illustrates the comparison between the maps based on this result .As shown from the figure CTC have higher rank of effectiveness than the other two maps, but different nature of the four tasks, which may cause the similarity when adding up the results for effectiveness.

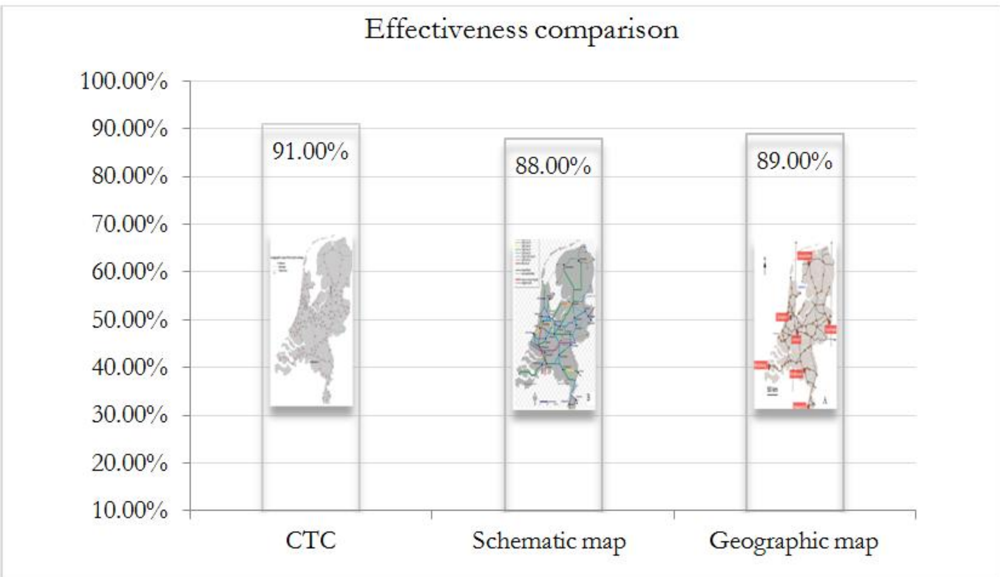


Figure 6-3: General comparison of the effectiveness of the CTC, schematic and geographic map

6.5.2.2. Efficiency

In order to measure the efficiency of the CTC in comparison with the other two scheduled movement data representations, the average time of giving a correct answer was calculated for each map. These results are presented in the Appendix 10_2. Figure 6-4 illustrates which map may help participants to perform the correct answer more quickly. As shown from the figure the CTC has a higher rank of efficiency than the other two maps.

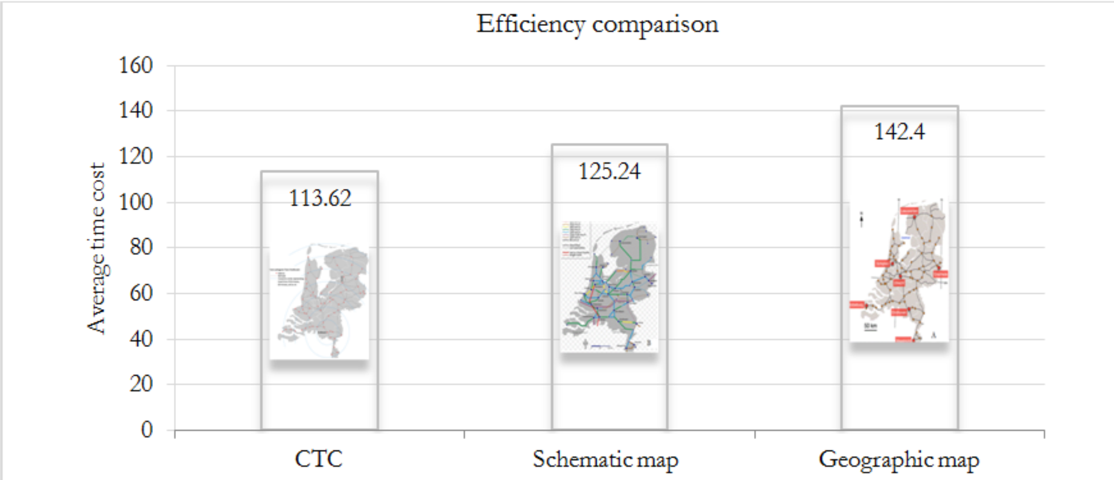


Figure 6-4: General comparison of the efficiency of CTC, schematic and geographic map

6.5.2.3. Satisfaction

In order to measure the user satisfaction of the CTC in comparison with the other scheduled movement data representations, the average satisfaction per visual representation was calculated based on Likert scale values that show the user opinion about the easy use of the maps these results are presented in the Appendix 10_3. Figure 6-5 illustrates the user satisfaction comparison. As shown in this figure the geographic map has a higher rank of satisfaction than the other two maps, but the difference with the CTC is only marginal.

.

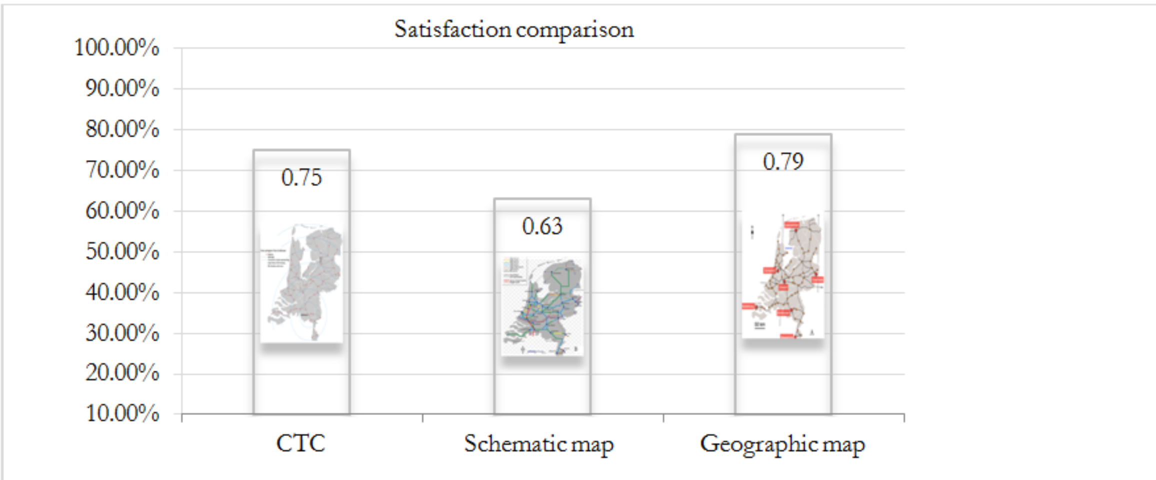


Figure 6-5: General comparison of the satisfaction with the CTC, schematic and geographic map

6.5.2.4. Summary of general findings

A summary of the general comparison between the scheduled movement data representations is shown in Table 6-1

Table 6-2: Summary of the general findings of the comparison between the CTC, geographic map and schematic map

	CTC	Schematic map	Geographic map
Effectiveness	91%	88%	89%
Efficiency	123.62	125.24	142.4
Satisfaction	75%	63%	79%

Table 6-1: shows that the CTC is more effective and efficient than the geographic and schematic map with an average correctness of 91% and a time cost of 123.62 (average time cost of correct answer in seconds). Because the four tasks were more related with temporal aspects it seems that participants who worked with this map did it well. However, the participants were less satisfied with this map than with the geographic map, with an average of 75% in satisfaction. It seems that according to the cartogram's nature, and particularly because this cartogram is a new product, it might create an uncommon look for the users. Generally, test objective one were proved with this findings.

6.5.3. Quantitative test analysis: specific findings

Here, to prove the second objective of the quantitative evaluation, the usability findings are focused on particular task performance of each visual representation, which relates the spatial and temporal task response through the three stimuli.

6.5.3.1. Effectiveness comparison per task

To compare the effectiveness of the maps for specific task performance, the average correctness of each task execution for the related maps was calculated. Figure 6-6 shows the highest effectiveness of the maps per task, accordingly the effectiveness of CTC were not better for all tasks.

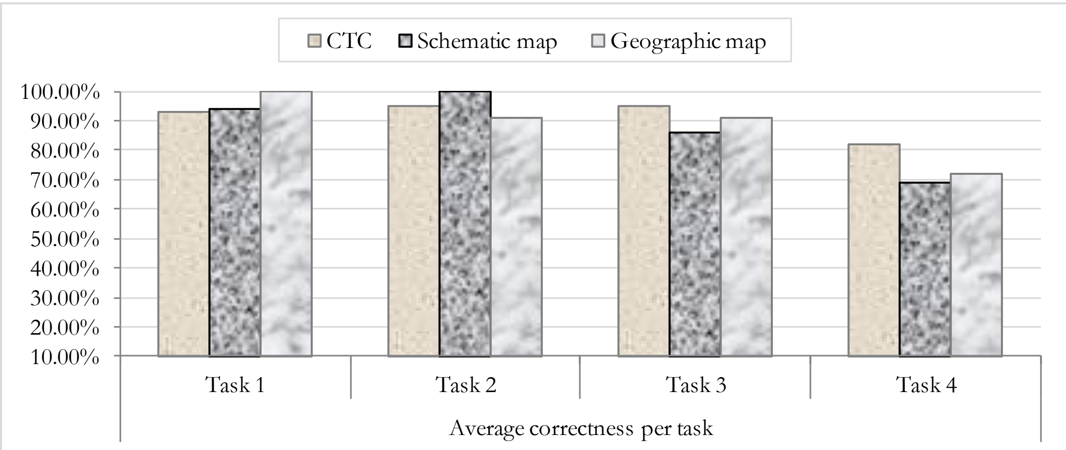


Figure 6-6: Average correctness of each map per task

Figure 6-6 illustrates task the average CTC is more effective for more temporal related tasks, like task 3 and 4, than a spatial related task like task 2. However, geographic map in task one and schematic map in task 2 has higher score that is for tasks more related with spatial aspect.

6.5.3.2. Efficiency comparison per task

To compare the efficiency of the maps for the specific task performance, the average time for correctly answering each task for the related maps was calculated. Again, as shown in Figure 6-7, it can be understood that the average time execution result of the CTC varies per task. In the line plot below the y axis represents average time cost.

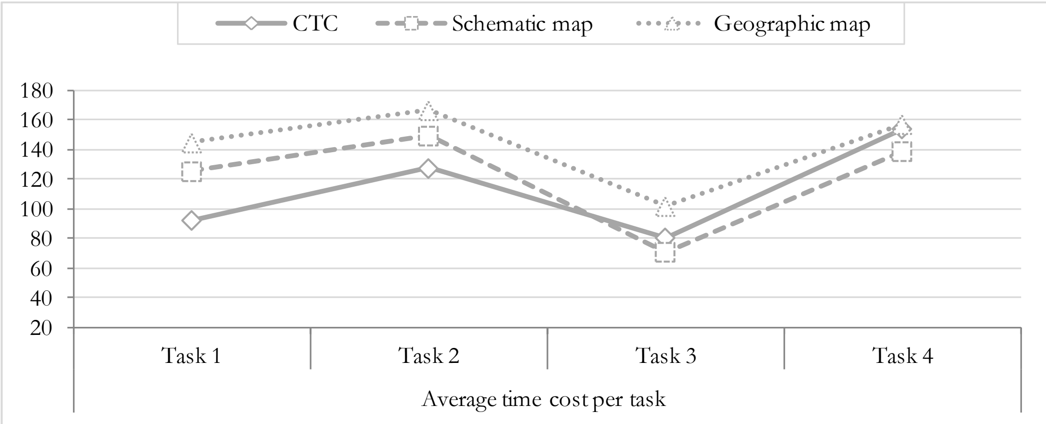


Figure 6-7: Average time cost of each map per task

Figure 6-7 illustrates that, users were consumed more time to perform the tasks using geographic map for all tasks. This is also happen for schematic map, but its user performed with less time for task 3. However, TP were faster to perform the assigned for tasks with CTC. The reason is in line with effectiveness.

6.5.3.3. Satisfaction comparison per task

To compare the satisfaction with the maps for specific task performance, the average satisfaction is calculated based on the Likert scale values of each task for the related map. The reaction of the participants who compared the three maps after they had performed particular tasks shows that their preference level of higher satisfaction for CTC varies per task and according to the group.

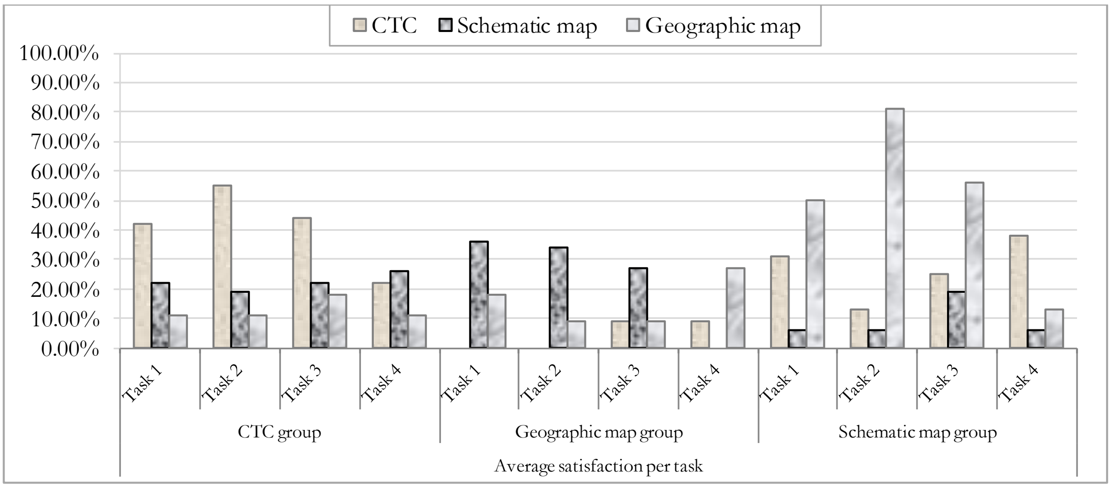


Table 6-3: Average satisfaction of each map per task

It can be identify from the Figure 6-8 that user were satisfied with particular map they worked on(as test execution procedure) the first for tasks and they provide the response mostly related with that map.

Accordingly in each group the result of satisfaction were towered their group map exceptionally for task four.

6.6. Conclusion and outlooks

The quantitative evaluation was applied with spatio-temporal tasks and questions to access scheduled movement data through the CTC, geographic map and schematic map. This chapter presented a comparison result between the three stimuli. The usability aspects of the evaluated maps were defined based on the quantitative test with 82 participants. The general and specific or task based effectiveness, efficiency and satisfaction comparison of each map were discussed to address the test objectives.

As the general and specific findings result shows CTC is more effective than the other maps regarding temporal aspects such as in task 3 and 4. It could also examine that CTC was not time consuming for all tasks performance. However, task 1 was performed better with geographic map and task 2 was replied with a schematic map, but less performance of temporal related tasks. Also, TPs' could not examine the temporal tasks with these two maps easily and quickly.

The overall result indicates that, the CTC is a more effective and efficient representation than the other two maps. However, the satisfaction result and the specific task based findings show that this difference depends on the type of task. Again, as indicated in Chapter 5 with the detail qualitative findings, the test participants could execute well some tasks related to temporal aspects with the CTC, but they had problems to execute all spatio-temporal tasks with the CTC with the higher satisfaction. This indicates that the task based presentation of this cartogram can be improved by presenting through an interactive environment. Generally, it could be useful if an interactive environment to be created in which some questions can be answered with the CTC, some with the geographic map and some with a schematic map.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The main objective of this MSc research was to analyse and evaluate the usability of the centred time cartogram for scheduled movement data visualization. This objective was divided into four sub-objectives that were achieved during the different periods of this research. This section summarizes how the specific objectives were achieved by answering the research questions.

1. **Who are the users of scheduled movement data? What are their characteristics?**
   In the second chapter of this research, in the section on use and user contexts, the appropriate comparables for representing scheduled movement data were identified. Then a theory was defined about alternative time cartogram design solutions including two other representations of scheduled movement data: the geographic map and the schematic map. Potential users of scheduled movement data representations were identified through with limited user profile surveys, preceding the qualitative and quantitative tests described in Chapters 5 and 6. In both experiment user profiles were surveyed with thirteen critical criteria's that is to experiment with the representative of the prospective users of the CTC. In order to apply the CTC evaluations with real user representatives, the collected user characteristics were put again the anticipated user profiles. Generally, the experiments were inconsideration of CTC potential users, but it was not with inclusive user profile of all type of users.

2. **What spatio-temporal questions do users have? In which use contexts do users want to have answers to their spatio-temporal questions (e.g. behind the desktop, in the field with a mobile device or by other means)?**
   In Chapter 5 a few users were requested and suggested to accesses time related information with maps on mobile devices, particularly their suggestion related to maps used in transport systems. In addition, they indicated the importance of interactive environment in CTC with features zoom in/out and pan.
3. **How can scheduled movement data be visualized?**
   In Chapter 2, an intensive discussion about the theory and characteristics of comparable maps was done, based on the research review, to show which visual representations are theoretically the most suitable choices for representing scheduled movement data. Accordingly, a centred time cartogram, a geographic map and a schematic map were selected to be prepared and implemented with the case study dataset (the Netherlands 2010 railroad network data), as described in Chapter 4.

4. **Can the CTC provide effective answers to the spatio-temporal questions of users??**
   The qualitative and quantitative usability evaluation of the time cartogram was discussed in Chapters 5 and 6. It was measured in the three aspects effectiveness (the average number of correct responses to the tasks), efficiency (the average time cost for correct answers) and satisfaction (values scores on Likert scale questionnaires), and it was implemented in two phases. First, a qualitative comparison of four alternative design solutions of the CTC was implemented in the usability laboratory. It was done by using a combination of use and user research techniques: eye tracking, thinking aloud, video recording and questionnaires. The qualitative test was the first evaluation phase that was executed by 40 participants in four groups. Each group of 10 participants with evenly distributed user profiles was working with one of the alternative design solutions of the CTC. The test implementation results were discussed and presented with illustrations followed by summary and detailed findings. The evaluation results were analyzed based on the formulated test objectives, and hypotheses were proved. On the one hand, the summary findings aimed at a usability comparison between the alternative CTC design solutions for performing the overall tasks. On the other hand, the detailed findings have shown the

usability aspects of CTCs' in performing each individual spatio-temporal task. As a result, the CTC with emphasized railroads got the highest effectiveness among the four alternative solutions in the general comparison. However, this result was not true for performing all types of tasks; particularly spatial related tasks were answered incorrectly.

In the second phase evaluation, the selected CTC (design with emphasized railroads) was prepared to be compared with a geographic and a schematic map through a quantitative test. In the implementation of this test, 82 responses were collected through an online survey. Participants randomly executed tasks with one map type; as a result, 55 participants worked with the CTC, 11 with the geographic map and 16 with the schematic map. To compare the usability of these maps, the test implementation results were analyzed generally and specifically, which resulted in general and specific findings. Similar to the qualitative test analysis, the results were analyzed based on the test objectives. The general findings compare the maps overall effectiveness, efficiency and satisfaction as the whole task performance. But, the specific finding shows the usability comparison in terms of particular task performance. As a result TPs' were prefer CTC to execute the temporal related task easily, where as the geographic and schematic map were preferable more of for spatial aspect. Schematic map were also provided quick response for some temporal related tasks.

5. **Can the CTC provide efficient answers to the spatio-temporal questions of users?**
   Efficiency of CTC was also determined based on the findings in chapter five and six. The overall result shows that CTC is more efficient than geographic and schematic map concerning temporal aspect. Again this result is from general perspectives, the efficiency were also varies based on task types as its effectiveness.

6. **Is the visualization of a CTC can provide satisfactory answers to the spatio-temporal questions of users**
   Again, the question about the satisfaction with the CTC was answered in Chapters 5 and 6: but the users did not give a higher satisfaction value for the CTC. According to the collected user profile, in one hand, most participants were not familiarized about cartograms. In the other hand they were user or producer of the common transport network map; schematic map and the traditional map; geographic map. Therefore, CTC was not familiarized representation for most participants to score higher satisfaction. In addition, concerned with the particular design of CTC some suggestions were identified in qualitative test like colouring.

7. **Which scheduled movement data visualization can be recommended? For what type of users? For what type of spatio-temporal questions?**
   In Chapter 6 the specific findings show that the usability scores of each candidate map were different based on the type of tasks. Accordingly, recommendations were identified according to scheduled movement data user requests. If users need to access temporal information only, the CTC and schematic map are more advisable. If the user needs to access spatial information, only the geographic map is suitable.

8. **What improvements can be suggested with respect to the CTC visualization?**
   In Chapter 5, based on the qualitative test findings some drawbacks of the CTC first iteration were recognized and provided to the CTC producer for redesigning the cartogram, which includes labelling, legend and colour composition. As the finding in chapter 5 and 6 summarized, it is suggested to combine the CTC with the schematic map and the geographic map in a dynamic and interactive environment in order to be able to address the different spatio-temporal questions of the users.

7.2. Recommendations

- The CTC visualization can be accustomed by putting it in an interactive environment and combining it with the availability of a schematic and a geographic map. Thiscould answer more user requests in spatio-temporal perspectives according to its purpose.

- Much more use and user research is required specifically to expose the completeness of the CTC in comparison with other relative cartogram types that are already in use.

LIST OF REFERENCES

Andrienko, G., Andrienko, N., Bak, P., Keim, D., Kisilevich, S., & Wrobel, S. (2011). A conceptual framework and taxonomy of techniques for analyzing movement. *Journal of Visual Languages & Computing*, *22*(3), 213–232. doi:10.1016/j.jvlc.2011.02.003

Andrienko, G., & Augustin, S. (2006). Visual Analytics Tools for Analysis of Movement Data. *ACM SIGKDD Explorations Newsletter*, *9*(2), 38–46. doi:10.1145/1345448.1345455

Andrienko, N., Andrienko, G., & Pelekis, N. (2005). Basic concepts of movement data. *Link.springer.com*, 1–26. doi:10.1007/978-3-540-75177-9_2

Antonius, K., & Verbeek, B. (2012). Algorithms for Cartographic Visualization. Retrieved September 23, 2014, from http://www.win.tue.nl/algo/phd-theses/Thesis-Verbeek.pdf

Barnard, Y. F., & Sandberg, J. A. C. (1994). *THE THINK ALOUD METHOD A practical guide to modelling cognitive processes*. Retrieved September 23, 2014, from http://echo.iat.sfu.ca/library/vanSomeren_94_think_aloud_method.pdf

Barnicle, K. (2000). Usability testing with screen reading technology in a Windows environment. *Proceedings on the 2000 Conference on Universal Usability - CUU '00*, 102–109. doi:10.1145/355460.355543

Bevand, N. (1994). "DRAFT IN INTERNATIONAL ISO 9241-11 STANDARD." Retrieved December 07, 2014, from https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-1:v1:en

Bhatt, L. M. (2006). Data, Investigating the Appropriateness of Gastner-Newman's Cartogram Versus Conventional Maps in Visual Representation and Modeling of Health. Retrieved July 07, 2014, from http://books.google.nl/books/about/Investigating_the_Appropriateness_of_Gas.html?id=stBsAimpDKMC&redir_esc=y

Bies, S., & Kreveld, M. Van. (2013). Time-Space Maps from Triangulations. *20th International Symposium, GD 2012, Redmond, WA, USA, September 19-21, 2012, Revised Selected Papers*, 511–516. doi:10.1007/978-3-642-36763-2_45

Blok, C. A. (2005). *Dynamic visualization variables in animation to support monitoring* (p. 188). igitur-archive.library.uu.nl. Retrieved September 25, 2014, from file:///C:/Users/GOD_27/Desktop/blok.pdf

Buchin, K., Goethem, A. Van, Hoffmann, M., Kreveld, M. Van, & Speckmann, B. (2014). Travel-time Maps : Linear Cartograms with Fixed Vertex Locations. Retrieved July 07, 2014, from http://link.springer.com/chapter/10.1007/978-3-319-11593-1_2#page-1

Coltekin, A., Heil, B., Garlandini, S., & Fabrikant, S. I. (2009). Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating Usability Metrics with Eye-movement Analysis. *Cartography and Geographic Information Science*, *36*(1), 5–17. doi:10.1559/152304009787340197

Dorling, D. (1996). Concepts and Techniques in Modern Geography Area Cartograms: Their Use and Creation LISTING OF CATMOGS IN PRINT. Retrieved from http://www.dannydorling.org/wp-content/files/dannydorling_publication_id1448.pdf

Fabrikant, S. I., Hespanha, S. R., Andrienko, N., Andrienko, G., & Montello, D. R. (2008). Novel Method to Measure Inference Affordance in Static Small-Multiple Map Displays Representing Dynamic Processes. *Cartographic Journal, The*, 201–215. doi:10.1179/000870408X311396

Fabrikant, S. I., Hespanha, S. R., & Montello, D. R. (2008). A visual analytics approach to evaluate inference affordance from animated map displays, 1–7. Retrieved September 23, 2014, from http://geoanalytics.net/GeoVisualAnalytics08/a15.pdf

Freksa, C., Moratz, R., & Barkowsky, T. (2000). *Schematic maps for robot navigation*. *www.springerlink.com* (pp. 100–114).

Gero, J. S., Tversky, B., & Knight, T. (2004). Visual and Spatial Reasoning in Design III. Retrieved September 23, 2014, from http://mason.gmu.edu/~jgero/publications/books/VR04Proceedings.pdf

Higerstrand, T. (1970). WHAT ABOUT PEOPLE IN REGIONAL SCIENCE? by Torsten H / igerstrand *. Retrieved December 27, 2014, from http://booksc.org/g/Torsten H%C3%A4gerstrand

Johnson, H., & Nelson, E. S. (2013). Using flow maps to visualize time-series data: Comparing the effectiveness of a paper map series, a computer map series, and animation. *Cartographicperspectives.org*, 47–63. doi:10.14714/CP30.663

Kaiser, C., Walsh, F., & Farmer, C. J. Q. (2010). User-centric time-distance representation of road networks. *Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 85–99. doi:10.1007/978-3-642-15300-6_7

Kaiser, C., Walsh, F., Farmer, C. J. Q., & Pozdnoukhov, A. (2010). User-Centric Time-Distance Representation of Road Networks. *Springer Link*, 85–99. doi:10.1007/978-3-642-15300-6_7

Kaspar, S., Fabrikant, S. I., & Freckmann, P. (2011). EMPIRICAL STUDY OF CARTOGRAMS. Retrieved from http://www.geo.uzh.ch/~sara/pubs/kaspar_fabrikant_freckmann_ica11.pdf

Keim, D. A., North, S. C., Panse, C., & Schneidewind, J. (2002). Efficient cartogram generation: a comparison. *IEEE Symposium on Information Visualization, 2002. INFOVIS 2002.*, *2002*, 33–36. doi:10.1109/INFVIS.2002.1173144

Keim, D., Andrienko, G., Fekete, J. D., Görg, C., Kohlhammer, J., & Melançon, G. (2008). Visual Analytics: Definition , Process , and Challenges, 154–175. doi:10.1007/978-3-540-70956-5_7

Kocmoud, C. J. (1997). Constructing Continuous Cartograms: A Constraint-Based Approach. Retrieved June 24, 2014, from http://www.nuim.ie/staff/dpringle/gis/koc98.pdf

Kraak, M. J. (2003). The Space-Time Cube Revisited from a Geovisualization Perspective. *21st International Cartographic Conference ICC*, (August), 10–16. doi:0-958-46093-0

Kraak, M. J. (2014). Integrated Time and Distance Line Cartogram:a Schematic Approach to Understand the Narrative of Movements. *Cartographic Perspectives*, (77), 35–44. doi:10.14714/CP77.1234

Li, X., & Kraak, M. J. (2010). The time wave in time space:a visual exploration environment for spatio - temporal data. *University of Twente Faculty of Geo-Information and Earth Observation (ITC)*. doi:10.1179/000870408X311387

Liamputtong, P. (2010). Focus Group Methodology : Introduction and History. *Oxford University Press*, 1–14. doi:9781446209776

MacEachren, A. M., Hardisty, F., & Gahegan, M. (1998). Supporting visual integration and analysis of geospatially-referenced data through web-deployable , cross-platform tools. Retrieved November 07, 2014, from http://www.geovista.psu.edu/publications/Dgla01/DG01_AMM_PSU.pdf

Mercurio, P., Riley, M., & Sokolov, J. (2008). Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating Usability Metrics with Eye-Movement Analysis. *Geo-Spatial Information Science*, (December), 215–220. doi:10.1007/s11806-008-0090-z

Miller, H. J. (2004). A measurement theory for time geography. *Wiley Online Library*, 17–45. doi:0.1111/j.1538-4632.2005.00575

Moore, A. B., Whigham, P., Holt, A., Aldridge, C., & Hodge, K. (2013). *A Time Geography Approach to the Visualisation of Sport*. *citeseerx.ist.psu.edu* (pp. 1–13).

Nielsen, J. (1994). Estimating the number of subjects needed for a thinking aloud test. *Www.sciencedirect.com*, 385–397. doi:10.1006/ijhc.1994.1065

Nielsen, J. (1997). The Use and Misuse of Focus Groups. *IEEE Software*, *14*. doi:10.1109/52.566434

Norman, D. N. (1988). The design of everythings. Retrieved December 07, 2014, from http://itu.dk/people/miguel/DesignReadings/Readings/!other readings/The Design of Everyday Things - Don Norman.pdf

Ormeling, F. (2009). *scenarios for national atlas use*. *avn.geo.uu.nl*. Retrieved September 23, 2014,from http://avn.geo.uu.nl/docs/Scenarios for national atlas use.pdf

Panse, C. (2004). Visualizing Geo-Related Data Using Cartograms. Retrieved September 23, 2014,from http://kops.ub.uni-konstanz.de/bitstream/handle/urn:nbn:de:bsz:352-opus-16364/Panse.pdf?sequence=1

Peuquet, D. J. (2006). A CONCEPTUAL FRAMEWORK AND COMPARISON OF SPATIAL DATA MODELS. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 66–113. doi:10.3138/D794-N214-221R-23R5

Razeghi, R. (2010). Usability of Eye Tracking as a User Research Technique in Geo-information Processing and Dissemination. Retrieved January 07, 2015, from http://www.itc.nl/library/papers_2010/msc/gfm/razeghi.pdf

Schwandl, R. (2006). Urbanrail.nel. Retrieved September 23, 2014, from http://www.urbanrail.net/about.htm

Shimizu, E., & Inoue, R. (2009). A new algorithm for distance cartogram construction. *International Journal of Geographical Information Science*, *23*(11), 1453–1470. doi:10.1080/13658810802186882

Spiekermann, K., & Wegener, M. (2004). The shrinking Continent:Accessibility,Competitiveness,and Cohesion. Retrieved July 24, 2014, from http://spiekermann-wegener.de/pub/pdf/KSMW_Shrinking_continent_120308.pdf
Street, N. (2006). TimeContours: Using isochrone visualisation to describe transport network travel cost. Retrieved September 07, 2014, from http://www.doc.ic.ac.uk/teaching/projects/Distinguished06/nicholasstreet.pdf
Sun, H., & Li, Z. (2010). Effectiveness of Cartogram for the Representation of Spatial Data. *Cartographic Journal, The*, *47*(1), 12–21. doi:10.1179/000870409X12525737905169
Tobler, W. (2003). *Geographical Movement* (pp. 1–25). www.geog.ucsb.edu. Retrieved September 23, 2014,from http://www.geog.ucsb.edu/~tobler/presentations/index.html
Tong, Y. (2014). the visual narrative of events using alternative timeline representations. Retrieved July 01, 2014, from http://www.itc.nl/Pub/Home/library/Academic_output/AcademicOutput.html?p=9&y=14&l=20
Ullah, R., & Kraak, M.-J. (2014). An alternative method to constructing time cartograms for the visual representation of scheduled movement data. *Journal of Maps*, (July 2014), 1–14. doi:10.1080/17445647.2014.935502
Van Elzakker, C. P. J. M. (1999). Thinking aloud about exploratory cartography. Retrieved July 21, 2014, from http://ezproxy.utwente.nl:2980/papers/1999/conf/vanelzakker_thi.pdf
Van Elzakker, C. P. J. M. (2004). Map Use Tasks in Regional Exploratory Studies. Retrieved July 21, 2014, from http://icaci.org/files/documents/ICC_proceedings/ICC2001/icc2001/file/f16002.pdf
Van Elzakker, C. P. J. M., & Wealands, K. (2007). Use and Users of Multimedia Cartography. *Www.springerlink.com*, 487–504. doi:10.1007/978-3-540-36651-5_34
Van Elzakker, C. P. J. M. van. (2004). *The use of maps in the exploration of geographic data* (p. 208). Retrieved July 21, 2014, from http://www.itc.nl/library/Papers_2004/phd/vanelzakker.pdf
Vlag, D. E. van de. (2006). Modeling and visualizing dynamic landscape objects and their qualities. *Wageningen Universiteit*, : 200. doi:9085043840
Ware, J. K., Taylor, G. E., Anand, C., & Thomas, N. (2006). Automated Production of Schematic Maps for Mobile Applications. *Transactions in GIS*, *10*(1), 25–42. doi:10.1111/j.1467-9671.2006.00242.x
Weihua Dong, Qingsheng Guo, J. L. (2008). Schematic road network map progressive generalization based on multiple constraints. *Geo-Spatial Information Science*, *11*, 215–220. doi:10.1007/s11806-008-0090-z
Weisbrod, R. (2011). The Geography of Transport Systems. *Journal of Urban Technolo*, 99–101. doi:10.1080/10630732.2011.603579
Wikipedia. (2015). Provinces of the Netherlands. Retrieved February 14, 2015, from http://en.wikipedia.org/wiki/Provinces_of_the_Netherlands
Wu, Y.-H., & Hung, M.-C. (2010). Non-Connective Linear Cartograms for Mapping Traffic Conditions. *Cartographic Perspectives*, 65. doi:10.14714/CP65.128

URL1. http://www.tobii.com/eye-tracking-research/global/products/software/tobii-studio-analysis-software/

URL2. https://www.surveymonkey.com/

URL3. https://doodle.com/dashboard

URL4. https://www.limesurvey.org/en/

APPENDIX 1

Test Person invitation letter

Dear ITC staff /student,

I am an MSc student in the Department of Geo-Information Processing. I am working on a user evaluation of CTCs for the visual representation of scheduled movement data under the supervision of Crone van Leaker and Menno-Jan Kraal.

As part of my research, I am doing a usability survey to compare four alternative visualizations of CTCs to find out which one of these provides the most effective and efficient visual representation of scheduled movement data.

As a case study, we are working with CTCs of part of the Dutch railway network. The target user of these cartograms is any person who may want to travel by train in the Netherlands. Therefore, you are a potential user of the cartograms and I would like to invite you to take part in a user test that will be held soon in the usability lab of the GIP Department (1-066).

If you are willing to participate, I would like to ask you first to complete an online survey in which you will be asked questions about your background. This information is required to allocate you to particular test groups. Be informed that in reporting the research results your name and identity will never be revealed and you will remain anonymous.

Please complete the online survey, if you are willing to participate in my user tests.
Click the link below to start the survey:
https://www.surveymonkey.com/s/VF7TXQ5

Please complete this survey on or before 31 October 2014. After that date you will receive a separate invitation to participate in the actual user test, which will only last some 25 minutes and which will take place in the first two weeks of November (on the date and time that suits you best).

Thank you in advance for your time and consideration.
I highly appreciate your participation!

With best regards,

-Eskedar-

APPENDIX 2

User Profile Questions

In order to be able to invite you for the actual user test, we need your name and email address. Please specify below:
Name: Email address:

1. What is your gender?
   a. Male
   b. Female
2. What is your class of age?
   a. Younger than 20
   b. From 20 to 25
   c. From 26 to 30
   d. From 31 to 35
   e. From 36 to 40
   f. From 41 to 45
   g. From 46 to 50
   h. Older than 50
3. What is your country of origin? Please indicate.
   ____
4. What is your highest educational degree?
   a. Bachelor
   b. Master
   c. PhD
   d. Other (please specify): ___________________
5. What was your field of studies in the highest educational degree you have obtained so far?
   a. Geography
   b. Cartography
   c. Engineering
   d. Computer Science
   e. Geo-Information Science and Earth Observation
   f. Education
   g. Humanities and Arts
   h. Social Sciences, Business and Law
   i. Other (please specify): ___________________
6. What is your current occupation?
   a. UT/ITC staff (go to Q7)
   b. PhD candidate (go to Q7)
   c. UT/ITC MSc student (go to Q8)
   d. UT/ITC Master student (go to Q8)
   e. Other (please specify): (go to Q7)
7. In which UT/ITC department do you work?
   a. Geo-information Processing (GIP)
   b. Earth Observation Science (EOS)
   c. Earth Systems Analysis (ESA)
   d. Natural Resources (NRS)
   e. Urban and Regional Planning and Geo-Information Management (PGM)
   f. Water Resources (WRS)
   g. Other (please specify):
8. In which course domain are you studying?
   a. Geo-informatics
   b. Water Resources and Environmental Management
   c. Engineering Geology and Geological Remote Sensing
   d. Urban Planning and Management
   e. Land Administration
   f. Natural Resources & Environment
   g. Other (please specify):
9. In daily life, how often do you use maps?
   a. Never
   b. Seldom
   c. Several times per year

d. Several times per month
e. Several times per week
f. Daily

10. Did you ever make maps yourself?
    a. No
    b. Yes, but only static maps
    c. Yes, both static and interactive/dynamic maps
11. How long have you been in the Netherlands?
    a. Less than 1 year
    b. 1 to 2 years
    c. 3 to 4 years
    d. 4 to 8 years
    e. More than 8 years
12. How often do you travel using Dutch trains (on average)?
    a. Daily
    b. 3 to 4 times a week
    c. 1 to 2 times a week
    d. 2 to 3 times a month
    e. Once a month
    f. 5 to 10 times a year
    g. 3 to 4 times a year
    h. Once or twice a year
    i. Never (go to end of survey).
13. Which routes do you take when travelling by train? (multiple answers possible)
    a. Often / always the same route from one station to another. Please specify those stations:
    b. Different routes. Please specify the station of origin and examples of the most frequent destination stations:
14. If you have to travel a new route by train how do you normally plan your trip? (multiple answers possible)
    a. Ask somebody else (e.g. at the train station)
    b. Go to the train station and consult the information boards
    c. Consult a train trip planning website
    d. Consult a train trip planning app on my Smartphone or tablet
    e. Consult a map
15. Do you know what a cartogram is?
    a. No
    b. Yes. Please specify how you would define a cartogram:

Your responses have been recorded.

Thank you in advance for your time and consideration.
You will soon receive a separate invitation to participate in the actual user test, which will only last for some 25 minutes and which will take place in the first two weeks of November (on the date and time that suits you best).
If you have any questions, you can contact me via e.z.mengistu@student.utwente.nl.

-Eskedar-

APPENDIX 3

Test Scenario

1. Before the test start
   - ✓ Before an hour early of the test person arrive at the usability laboratory, open the class and refresh , switched on the desktop and eye tracker, turn on sound recorder.
   - ✓ Put the hardcopies on the table, which are group list that categorized based on user profile questionnaire, introduction notes of CTC (CTC) alternative solutions, and introduction of test procedure.
   - ✓ put the hard copy of warm-up tasks on the table
   - ✓ put the hard copy of list of task and questionnaires on the table
   - ✓ open and minimize sample video from pilot test in the usability test desktop
   - ✓ open and minimize Tobias studio and check connection of the eye tracker

2. Test person welcome and introduction:
   - ✓ Thank you test person 'x name' for coming and welcome, Please take a seat.
   - ✓ First, this is the hard copy introduction of CTC you will work on it.
   - ✓ Second, i will introduce about the CTC based on the hard copy on your hand and about the test procedure. (7 minutes)
   - ✓ Then, i will show you short demo from pilot test about the whole test procedure. (4 minutes)
   - ✓ If you don't have any question, you can read and try to familiarize yourself with the cartogram from printed hard copy and let me wait your questions. (5 minutes)
   - ✓ After that, please, this three warm-up tasks without recording that is using preview display.
   - ✓ Finally, we can start the test now based on the list of tasks and question as i introduced.
   - ✓ Do you have any question? Is everything clear to proceed like this? Don't worry I can answer question in between, if there are.

3. During the test:
   - ✓ Maximize the Tobbi studio software and open the project , participant ID and recording file
   - ✓ Start eye calibration of test person by adjusting their seat. Please, focus on the screen and follow the red dot. And, now the video recording is starting.
   - ✓ First, Read the instruction displayed on the screen and then read task on the hard copy . Press any key to answer the task using the cartogram. Then start answering each tasks after finding the answer from the displayed cartogram. During and after reading each task please speak loudly about how you are working to find out the answer, about things you find confusion, and how you reached to the final answer. If you feel you finished the answer of one task press "any key" other than 'Esc' button and continue to the next task.
   - ✓ Second, in between each task i request you a few minutes related with each tasks about your opinion towards the cartogram.
   - ✓ Therefore, for each ten task and questions the test procedure will continue like this.
   - ✓ After finishing all task press "Esc" button.

4. After the test:
   - ✓ Finally, now it is the time to have the response about the different design or alternative solutions of CTC based on the questionnaire on your hand. It has also a space for your suggestion and comment, if there exists. This will finalize the whole test.

5. Thanks for the test person

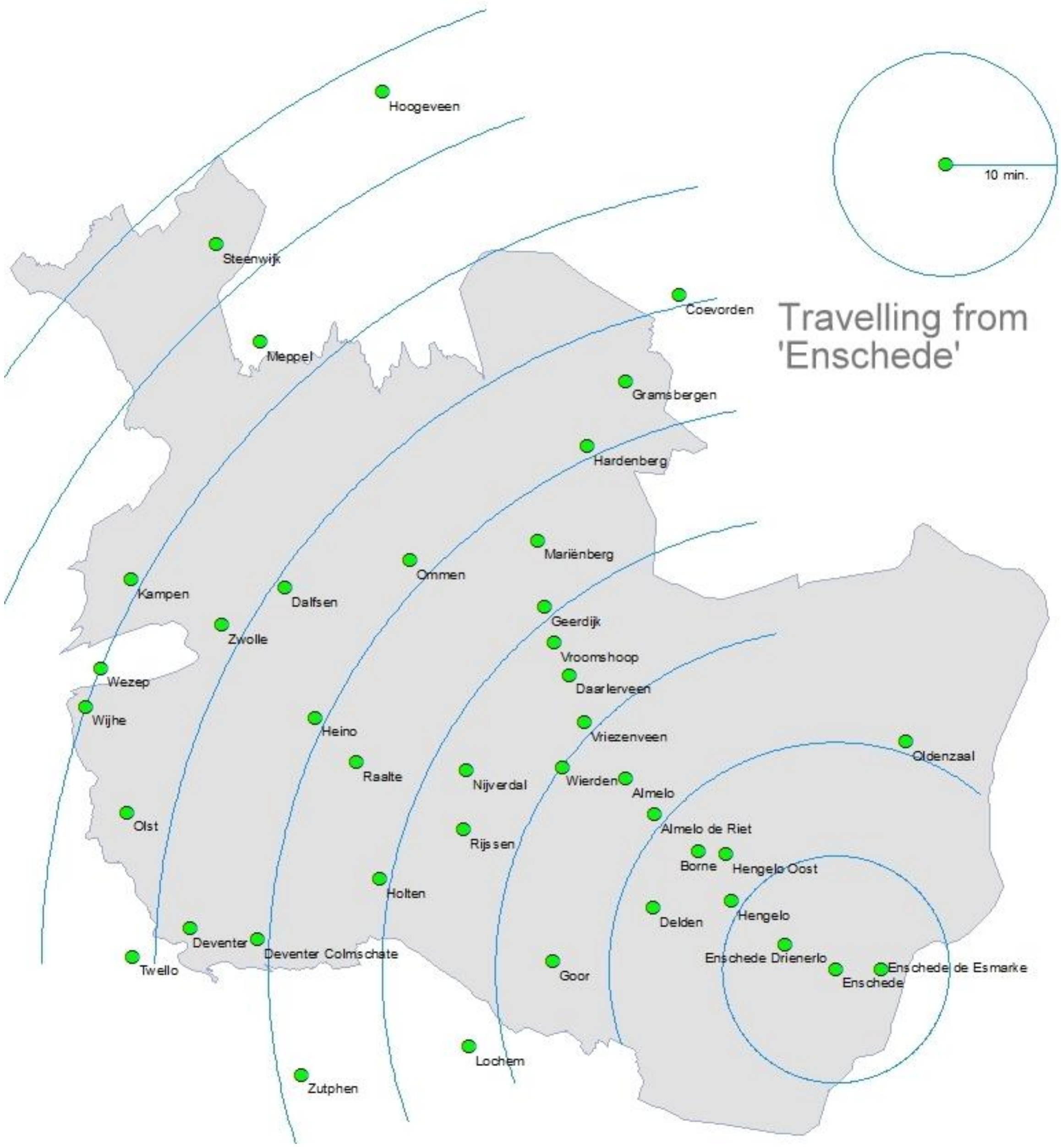
   Thank you very much for your time and patience for the work today
   You are really cooperative!
   I hope you got some knowledge and also you enjoyed it.

APPENDIX 4

1. Introduction to the CTC (CTC) without railroad

A CTC is a visual representation of a time related variable, which shows the traveling time from a specific starting location to any other location. This cartogram contains points and concentric circles, which visualize railway stations and the time interval respectively. In addition, it can contain lines that represent railroad network.

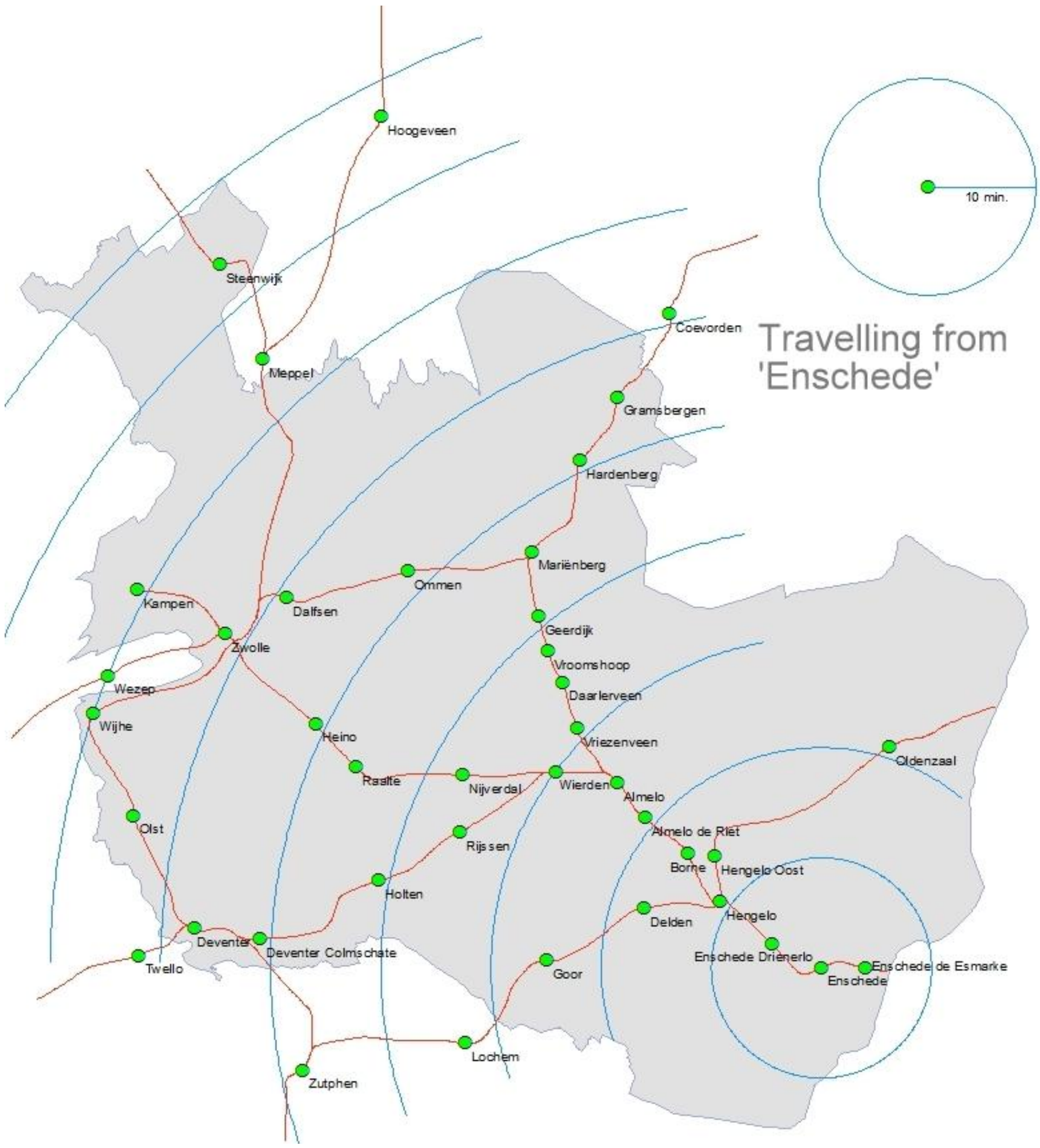
The Figure below shows an example of a CTC(without railroad) with Enschede as the starting station. As shown in the figure, the blue concentric circles represent a 10 minutes (based on legend circled in the left side) time interval between each circle. The circled green dots represent the railway stations in the Overijssel railroad network. The closer a station is to the starting station (in this example Enschede) the shorter the time the train requires to reach it. According to nature of cartograms, in this map geographical reality is distorted. In other words, the location of some stations or the lengths of the railroad segments and the shape of the railway network may not represent reality precisely.



2. **Introduction to the CTC (CTC) with railroad**

A CTC is a visual representation of a time related variable, which shows the traveling time from a specific starting location to any other location. This cartogram contains points and concentric circles, which visualize railway stations and the time interval respectivily. In addition, it can contain lines that represent railroad network.

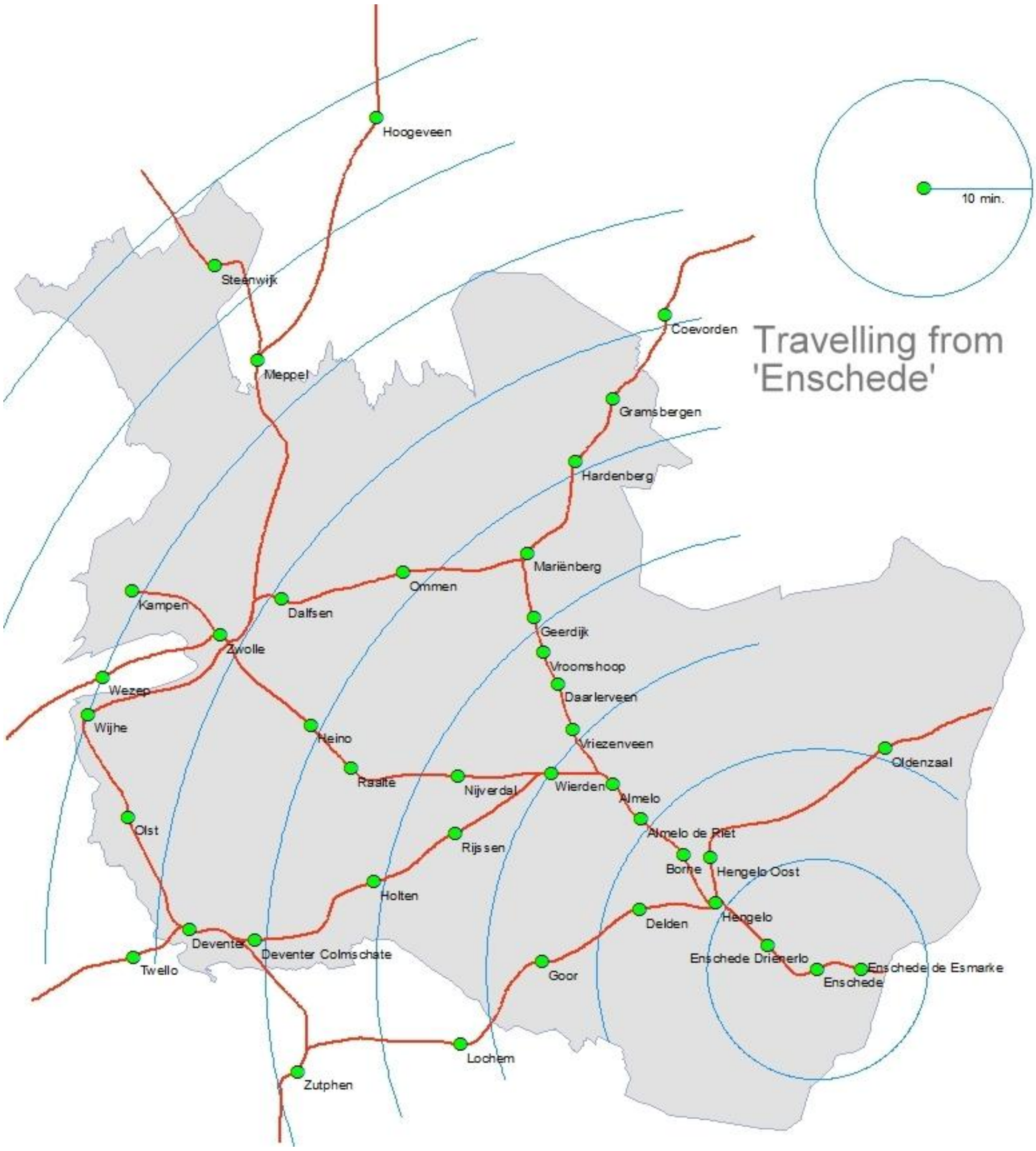
The Figure below shows an example of a CTC with Enschede as the starting station. As shown in the figure, the blue concentric circles represent a 10 minutes (based on legend circled in the left side) time interval between each circle. The red lines represent the railroad network of the province of Overijssel. The circled green dots represent the railway stations in the Overijssel railroad network. The closer a station is to the starting station (in this example Enschede) the shorter the time the train requires to reach it. According to nature of cartograms, in this map geographical reality is distorted. In other words, the location of some stations or the lengths of the railroad segments and the shape of the railway network may not represent reality precisely.



3. **Introduction to the CTC (CTC)**

A CTC is a visual representation of a time related variable, which shows the travelling time from a specific starting location to any other location. This cartogram contains points and concentric circles, which visualize railway stations and the time interval respectively. In addition, it can contain lines that represent railroad network.

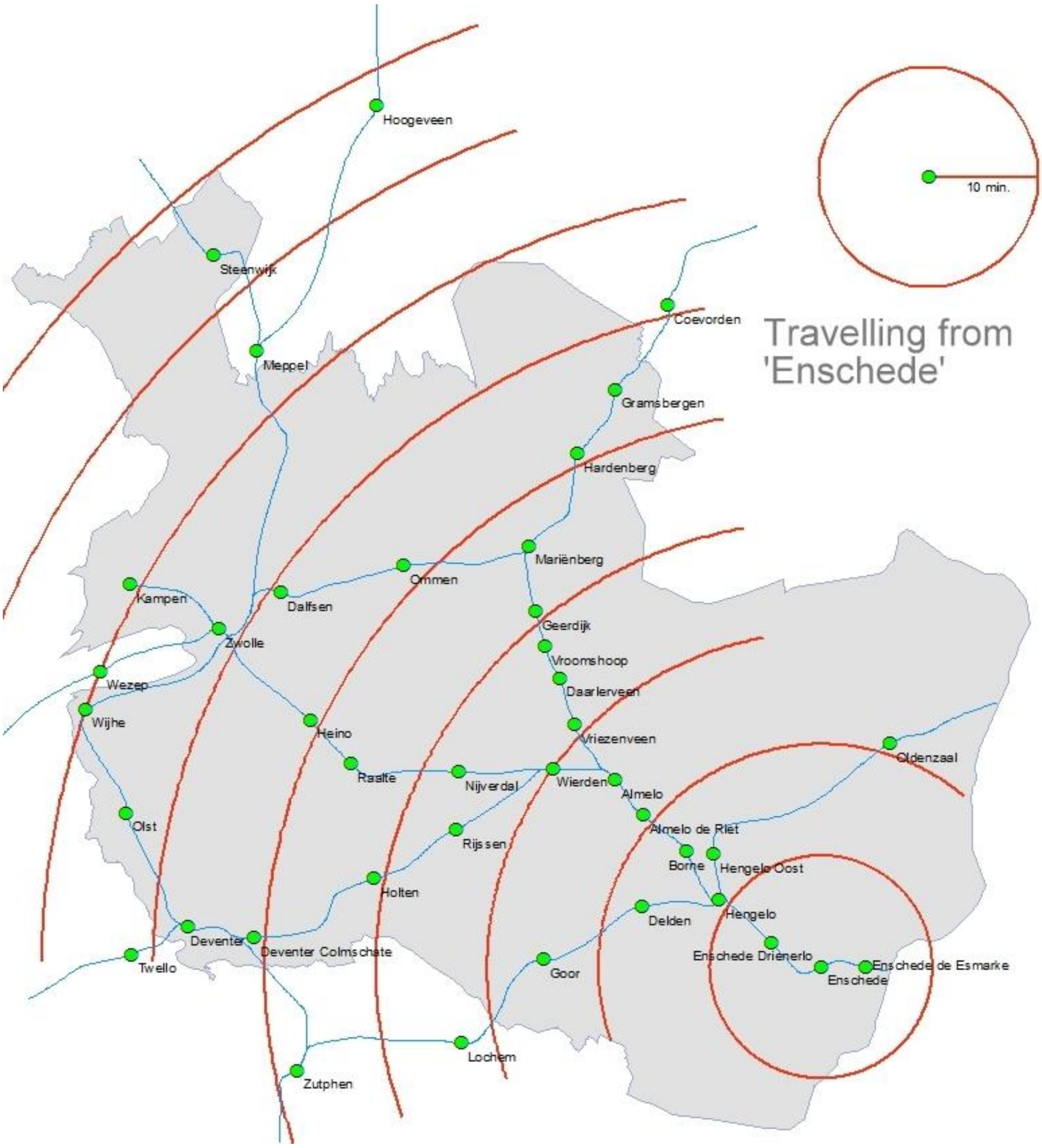
The Figure below shows an example of a CTC with Enschede as the starting station. As shown in the figure, the blue concentric circles represent a 10 minutes (based on legend circled in the left side) time interval between each circle. The red lines represent the railroad network of the province of Overijssel. The circled green dots represent the railway stations in the Overijssel railroad network. In addition, the railroads have more highlighted representation. The closer a station is to the starting station (in this example Enschede) the shorter the time the train requires to reach it. According to nature of cartograms, in this map geographical reality is distorted. In other words, the location of some stations or the lengths of the railroad segments and the shape of the railway network may not represent reality precisely.



4. Introduction to the CTC (CTC)

A CTC is a visual representation of a time related variable, which shows the traveling time from a specific starting location to any other location. This cartogram contains points and concentric circles, which visualize railway stations and the time interval respectivily. In addition, it can contain lines that represent railroad network.

The Figure below shows an example of a CTC with Enschede as the starting station. As shown in the figure, the Red concentric circles represent a 10 minutes (based on legend circled in the left side) time interval between each circle. The Blue lines represent the railroad network of the province of Overijssel. The circled green dots represent the railway stations in the Overijssel railroad network. In addition, the time circles have more highlighted representation. The closer a station is to the starting station (in this example Enschede) the shorter the time the train requires to reach it. According to nature of cartograms, in this map geographical reality is distorted. In other words, the location of some stations or the lengths of the railroad segments and the shape of the railway network may not represent reality precisely.



APPENDIX 5

Introduction to the test procedure

This test is qualitative test consists of two parts, the first part is tasks that will be respond through thinking aloud, and eye tracking and video observation usability test methods, then following by questionnaires.
In the first session the alternative solutions of CTC (CTC) that visualizes train trip time or scheduled movement data will be shown. Simultaneously, you will be asked 10 tasks and subsequent questions will follow, which is about your opinion of the CTC. The questions are aimed to identify whether you could understand the cartogram or not and responded easily the tasks through each representations or not. We are expecting your answer of tasks and questions based on the cartograms' interpretation. It is also expected from you to think aloud (speak loudly) while performing each tasks.
Therefore, in the test process it is expected you to speak load whatever you thought during each task mean, it can be starting from reading of the tasks. For example you can start your speaking by saying "I am starting task 1", then now "I am looking the cartogram displayed on the screen" , "I am continuing searching the answer of this task",...it is easy or difficult to find .... Finally "I think this is the answer or i am sure this is the answer"...etc.
If you feel you find the answer you can select or write your answer on the lists of tasks paper. Instantly, it is expected from you to answer the questions about your opinion related with the cartogram you will be worked on it.
In this stage, in one hand tasks and related questions about your opinion are answered, in the other hand the first session test (thinking aloud, eye tracking and video observation) is finished. Secondly, questionnaires related to your comfort when you perform whole tasks with the alternative solution of CTC will be goes after. This questions will be like: Do you like...?, What do you think...? What is your suggestion...? and so on.
Note that, if you feel tired let me know we can take a break, and you can continue the tasks from the point you stopped.

APPENDIX 6

List of Tasks: Related with only one staring station for each task

Task 1: related to traveling from Enschede

Mark is a new graduate student at ITC in Enschede. This Monday he wants to go to the IND in Zwolle to collect his residence permit. The documents collection timings are from 11:30 to 12:30. At what time should he leave from Enschede to reach Zwolle around 11:00 with some minutes spare to reach the IND on time?

a) 08:30
b) 09:00
c) 09:30
d) 10:00
e) Cannot be answered with the provided cartogram

How well did the provided cartogram assist you in answering this question?

○ Very Good ○ Good ○ Average ○ Poor ○ Very Poor

Press any key to continue with next task

Task 2: related to traveling from Steenwijk

Robert is in Steenwijk to attend a 3-days workshop at Regionaal Opleidingen Centrum Drenthe College. The workshop runs from 09:00 to 17:00 daily. As he has never been in the Netherlands before, on one of the workshop days he wants to visit another place that is close to Steenwijk. Could you please list all cities to Robert that are reachable by train within 20 minutes from Steenwijk?

a) List:____
b) Cannot be answered with the provided cartogram

Task 3: related to traveling from Enschede

Which station is closer to Enschede in time?

a) Oldenzaal
b) Almelo

How well did the provided cartogram assist you in answering this question??

○ Very Good ○ Good ○ Average ○ Poor ○ Very Poor

Task 4: related to traveling from Deventer

Which path takes the longest distance to reach Mariënberg from Deventer?

a) via Zwolle
b) via Almelo
c) Cannot be answered with the provided cartogram

How well did the provided cartogram assist you in answering this question?

○ Very Good ○ Good ○ Average ○ Poor ○ Very Poor

Press any key to continue with next task

Task 5: related to traveling from Gramsbergen

What is the number of possible paths (backtracking is not allowed or you cannot visit a station twice) to reach Wierden from Gramsbergen?

a) **1,** namely: through Hardenberg, Marienberg, Geerdijk, Vroomshoop, Daarlerveen,Vriezenveen and Almelo
b) **2,** namely: through Hardenberg, Marienberg, Geerdijk, Vroomshoop, Daarlerveen,Vriezenveen and Almelo **or** Hardenberg, Marienberg, Ommen, Dalfsen, Zwolle, Heino,

Raalte and Nijverdal

c) 3 or more, namely: through Hardenberg, Marienberg, Geerdijk, Vroomshoop,Daarlerveen, Vriezenveen and Almelo or Hardenberg, Marienberg, Ommen, Dalfsen, Zwolle, Wijhe, Raalte and Nijverdal or
Hardenberg, Marienberg, Ommen, Dalfsen,
Zwolle, Wijhe, Olst, Deventer, Deventer Colmschate, Holten and Rijssen **or more**

d) Cannot be answered with the provided cartogram

Task 6: related to traveling from Raalte

List the intermediate stations while traveling (via the shortest path in time) from Raalte to Holten:

a) List:____
b) Cannot be answered with the provided cartogram

How well did the provided cartogram assist you in answering this question?

○ Very Good ○ Good ○ Average ○ Poor ○ Very Poor

Press any key to continue with next task

Task 7: related to traveling from Enschede and traveling from Zwolle

Mr. Smith needs to travel frequently between Enschede and Zwolle for his job assignments. Where should he rent an apartment so that he is time-wise evenly close to both places?

a) City: _______________
b) Cannot be answered with the provided cartogram

How well did the provided cartogram assist you in answering this question?

○ Very Good ○ Good ○ Average ○ Poor ○ Very Poor

Task 8: related to traveling from Raalte

CTC can represent time information of railroad trip through four alternative solutions**.**

Given the four alternative visualizations of the Centered Time Cartogram with different designs, which alternative would youprefer to use to perform the task below?

○ 1 ○ 2 ○ 3 ○ 4

List the intermediate stations while travelling (via shortest path in time) from Raalte to Holten?
List: ____

How well did the cartogram you choose assist you in answering this question?

○ Very Good ○ Good ○ Average ○ Poor ○ Very Poor

Press any key to continue with next questionnaire

APPENDIX 7

Questionnaire

1. Do you agree that the CTC you worked with it pleasant to see?

- ○ Strongly disagree
- ○ Disagree
- ○ Moderate
- ○ Agree
- ○ Strongly agree

2. Do you agree that the CTC you worked with is easily understandable?

- ○ Strongly disagree
- ○ Disagree
- ○ Moderate
- ○ Agree
- ○ Strongly agree

3. Do you agree that the CTC you worked with helped you to answer the tasks without confusion?

- ○ Strongly disagree
- ○ Disagree
- ○ Moderate
- ○ Agree
- ○ Strongly agree

4. What are your suggestions or comments related to the CTC you worked with?

- ○ I have comments or suggestion, Please, speak out loudly
- ○ I have no comments or suggestions

APPENDIX 8

Check list of the test execution

Item or condition	**Availability check**
Tasks and question form	
worm-up question form	
Hardcopy of test procedure introduction	
Hardcopy of test CTC introduction	
Note paper, pen, pencil, eraser	
Desktop switched on	
Eye tracker and video recorder switched on ,	
Note paper	
Scenario of the procedure hard copy	
Hard copy of Group list	

APPENDIX 9

Warm-up tasks (with the Enschede cartogram)

1. How many time intervals do you count in the cartogram displayed on the screen?
   Answer: ___________________

2. What are the map elements that are visualized in the cartogram that is displayed on the screen?
   - ☐ Points (stations)
   - ☐ Lines (railroads)
   - ☐ Area (Province of Overijssel in the Netherlands)
   - ☐ Concentric circles (time intervals)

3. What is the travelling-time from Enschede to Steenwijk?
   Answer:___________________

APPENDIX 10_1

CTC group success of task execution

Task / Successes of task	Task 1	Task 2	Task 3	Task 4
Correct	51	52	52	45
Non Correct	4	3	3	10
Average correctness per task in %	93%	95%	95%	82 %
Average correctness per Visual output in %			200/220=0.91*100 =91%	

Geographic map group success of task execution

Task / Successes of task	Task 1	Task 2	Task 3	Task 4
Correct	11	10	10	8
Non Correct	0	1	1	3
Average correctness per task in %	100%	91%	91%	72%
Average correctness per Visual output in %			39/44=0.89*100 =89%	

Schematic map group success of task execution

Task / Successes of task	Task 1	Task 2	Task 3	Task 4
Correct	15	16	14	11
Non orrect	1	0	2	5
Average correctness per task	94%	100%	86%	69%
Average correctness per Visual output			56/64=0.88*100 =88%	

APPENDIX 10_2

CTC group time cost, Unit: second

Task / Time cost	Task 1	Task 2	Task 3	Task 4
Correct	5081.54	7005.18	4435.08	8474.54
Non Correct	6030.88	686.22	221.23	1223.24
Average time per task	92.39	127.37	80.64	154.08
Average correctness time per Visual output			24996.34/220 =113.62	

Geographic map group time cost, Unit: second

Task / Time cost	Task 1	Task 2	Task 3	Task 4
Correct	1590.0	1829.6	1119.0	1727.0
Non Correct	0	4786.3	122.1	73.4
Average time per task	144.55	166.33	101.73	157.0
Average correctness time per Visual output			6265.6/44 =142.4	

Schematic map group time cost, Unit: second

Task / Time cost	Task 1	Task 2	Task 3	Task 4
Correct	8015.36	2388.2	1135.4	2220.53
Non Correct	1310.98	913.6	424.9	955.65
Average time per task	125.24	149.26	70.96	138.78

APPENDIX 12_1

CTC group Likert scale statistic

	Schematic Map				Geographic Map				Center Time Cartogram			
Task / TP ID	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4
Average per	22%	19%	22%	26%	11%	11%	18%	11%	42%	55%	44%	22%
Average per Map	22%				13%				42%			

Geographic map group Likert scale statistic table

	Center Time Cartogram				Schematic Map				Geographic Map			
Task / **TP ID**	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4
Average per task	-	-	9%	9%	36%	34%	27%	-	18%	9%	9%	27%
Average per Map	6%				32%				16%			

Schematic map group Likert scale statistic table

	Geographic Map				Center Time Cartogram				Schematic Map			
Task / TP ID	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4	Task 1	Task 2	Task 3	Task 4
Average per task	50%	81%	56%	13%	31%	13%	25%	38%	6%	6%	19%	6%
Average per Map	50%				27%				9%			

Likert scale statistics table: the values in the table indicate; 5: Very good, 4: Good, 3: Average, 2: Poor and 1: Very poor, the average values calculated accordingly