The Challenges of Designing Metro Maps

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Keywords: Cartography, Schematic Mapping, Transit Maps, Map Design.

Abstract: Metro maps can be regarded as a particular version of information visualization. The goal is to produce readable and effective map designs. In this paper, we combine the expertise of design experts and visualization researchers to achieve this goal. The aesthetic design of the maps should play a major role as the intention of the designer is to make them attractive for the human viewer in order to use the designs in a way that is the most efficient. The designs should invoke accurate actions by the user—in the case of a metro map, the user would be making journeys. We provide two views on metro map designs: one from a designer point of view and one from a visualization expert point of view. The focus of this work is to find a combination of both worlds from which the designer as well as the visualizer can benefit. To reach this goal we first describe the designer's work when designing metro maps, then we take a look at how a visualizer measures performance from an end user perspective by tracking people's eyes when working with the formerly designed maps while answering a route finding task.

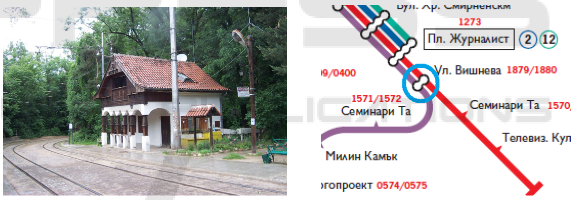
1 INTRODUCTION

Stop! I want to get off... Not an unreasonable request. But where?

Cartographers face many challenges, not least of which is how to represent the physical world in as true a form as possible. Public transport mapping is no different. Leaving aside the long-standing debate about schematics, one of the challenges the map designer encounters is the requirement to provide maps to customers in the travel and publishing industry where page size is everything. Here, schematic maps work very well indeed.

We first go back to the basics, i.e., to good old-fashioned fieldwork. On surface-based networks, such as Amsterdam, Budapest, or Pisa, walking the streets plotting each of the routes and stops had to be done. And in 1990, when we (second author and his company) first started doing this, there was no internet, which meant that pre-departure information was very limited. We would not necessarily have known how many lines there were and over how much ground. That meant guessing the time required to do the job and that in turn meant either a long or short stay or a short stay with long hours.

There was no technical aid like digital cameras for recording tram and bus stop names in those early days. Everything was handwritten. The arrival of digital cameras, at prices making ownership a reasonable proposition, was certainly a boon. It has made fieldwork so much easier, particularly where the Latin alphabet is not used in signage, i.e., in Athens, Belgrade, Sofia, and St Petersburg, for example. We now have a library with more than 48,000 photos of every single station or stop name on every line in every city we cover, together with an assortment of other interesting subjects, objects, artifacts, and oddities. Figure 1 shows a typical example of a photo of a stop and the associated map.



(a) (b)

Figure 1: (a) One of the charming little stops in the middle of a park in Sofia. A direct line from the city center goes here. (b) A section of the corresponding map. The stop labeled 1879/1880 is the one in the photo on the left.

A decision as to which lines to incorporate and which to leave out must be made and that always depends on the type of system. Mindful that the end-

Burch, M., Woods, R., Netzel, R. and Weiskopf, D.
The Challenges of Designing Metro Maps.
DOI: 10.5220/0005679601950202
In *Proceedings of the 11th Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2016) - Volume 2: IVAPP*, pages 197-204
ISBN: 978-989-758-175-5

user is a tourist who may not have much time to get to grips with the complexity of the network, we generally first select the fixed route types, such as tram, trolleybus, or metro and then bus if there is either space or the book author specifically mentions a particular point of interest only reachable by bus.

Naturally, if the system is predominantly bus, like Pisa, or in the case of Venice, waterbus, then we choose a selection of routes that properly cover the most important points of interests first, and then include others to complement those where space and time allow.

Fixed routes are good to map for tourists—it is easy for them to locate lines visually at street-level—either overhead catenary in the case of trolleybus, or tracks and catenary, in the case of trams. Getting lost is no problem; exploring the city you will eventually come across a route somewhere. It is a simple case of following the line in either direction until you come across a stop, note the name (or number), look at your schematic map, and off you go, or on you get!

In fact, perhaps to the wrath of other cartographers, we would argue that getting lost and exploring somewhere without a street map is absolutely fine and very enjoyable—armed with your transport map you will always get back to where you want.

In this paper, we illustrate some challenges when designing metro maps from a designer's point of view but also from a visualizer's point of view. Both have different goals in mind, but in the end they also share some common goals, i.e., generating readable and useful metro maps helping travelers find their ways in a foreign city.

2 RELATED WORK

From a visualization perspective, metro maps fall into the category of relational data, i.e., they should be an efficient means to display graphs (Battista et al., 1999). The difference to abstract graph data comes from the fact that the vertices already have some kind of spatial information attached which stems from the inherent topographic dimension in the data. Therefore, we are not allowed to freely choose a standard graph layout algorithm from a given repertoire (Fruchterman and Reingold, 1991; Kamada and Kawai, 1989; Sugiyama et al., 1981) following aesthetic graph drawing criteria (Ware et al., 2002).

'Metro map' is a commonly used term aiming to describe a schematic map, i.e., a diagrammatic representation of some kind of geospatial data which was epitomized by Henry Charles Beck (Garland, 1994). There is an ongoing debate by commentators and historians about the real origin of the metro map as it is known today. One version is to suppose that Beck himself had a significant influence by George Dow, who designed, among other ideas, a carriage diagram for the London & North Eastern Railway company (LNER). In Andrew Dow's book "Telling the Passenger Where to Get Off" (Dow, 2005), we can find a fascinating perspective on the evolution of diagrammatic railway maps and the work of someone who, although nowhere near as famous as Beck, made a number of pioneering designs preceding Beck. These map designs are already some kind of information visualization since their common goal was to graphically depict data in a sense to make them understandable and readable in a rapid manner. The difference to today's map design is that the map creators in these early days had to do map research without the help of computers and the pre-knowledge acquired on the internet.

Today the term metro map is widely used but maybe the term public transport map may be the better choice since there is a variety of transportation modes and systems combined in a single map like tubes, metro lines, buses, water buses, and so on. Although such combined maps are beneficial, they easily produce an information overload resulting in visual clutter (Rosenholtz et al., 2005). This high degree of complexity may lead to the assumption that some commentators and aficionados would argue that they are not even maps at all and should be referred to as diagrams (Horne, 2012).

For example, the London Underground map has been known, at different times during its history, to refer to itself exactly as a diagram of lines. In any case, it no longer portrays purely a metro system either now. The most recent editions include suburban surface rail (the so-called London Overground), light rail (Docklands), and even a cable car (so-called Emirates Air Line) across the Thames river. In an extensive collection of maps, Ovenden brings together examples from around the world (Ovenden, 2005).

To really understand the usability and readability aspects in metro map systems, i.e., graphical depictions of transportation system data, user studies have been conducted. Eye tracking can be used as one tool (Burch et al., 2014b; Yarbus, 1967) to analyze where and when visual attention is paid (Kurzhals et al., 2014) to a map and which visual task solution strategies (Burch et al., 2013; Netzel et al., 2014) are applied to perform a route finding task. From a graph visualization perspective, such route or wayfinding tasks have already been explored (Huang, 2007) with the main result that people tend to follow the geodesic path tendency (Huang et al., 2009). This tendency is also present in metro maps (Burch et al., 2014a) but here, the original task is subdivided into subtasks between the interchange points. Each subtask is performed by following the geodesic path and finally cross checking the answer for correctness. Moreover, it was found out that the map complexity has an influence on task completion times.

3 DESIGNING METRO MAPS

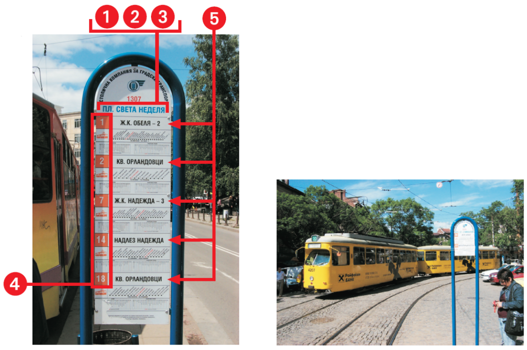
Designing metro maps is a challenging task since the designer must be aware of two major aspects: the design in the sense of beauty and art making a map aesthetically appealing to a traveler and second, the design in the sense of readability making the map useful as a means to effectively and safely travel in a foreign city (Burch, 2015).

3.1 The Designer's Perspective

Let us take a look at an example after the completion of ground research. Figure 4 shows a section of the Communicarta Style45® map for the city of Sofia.

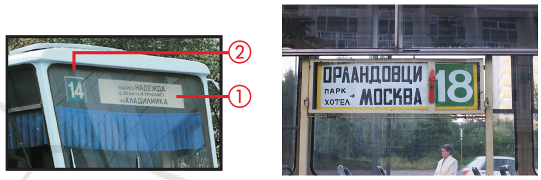
Generally, in transport mapping we must be aware of the information a traveler needs to make successful journeys. There is a bare minimum and, for some strange and unknown reason, not all transport authorities deem this part important. That perhaps, is for another discussion. For now, however, we can agree that a traveler will need at least three pieces of information for stress-free wayfinding that are at ground level, on and inside the vehicle, and on the map (see Figures 2, 3, and 4):

- **At Ground Level (Figure 2): If people walk around in a city, the most important aspect when using public transportation is the easy recognition of the metro, tube, and bus stops. Without them, the metro map is useless even if it is well-designed.**
  1. **Boarding Point:** The name of the stop should ideally be written on the stop sign and should be the same as in the metro map to avoid misinterpretations (Figure 2 (a), (1)).
  2. **Interchange Point:** If the stop is an interchange point, this should be already indicated on the stop sign. Again, ideally the name of the stop should be written on the stop sign (Figure 2 (a), (2)).
  3. **Where to Alight:** For passengers, it is very important to directly see where a metro line is going to. This gives them the information in which coarse direction they will be going even if the destination stop is not indicated (Figure 2 (a), (3)).
  4. **The Lines or Service Identifiers:** Numbers, names, letters, or symbols of routes for each of the intended journey(s) should be clearly indicated. A certain unique color for each metro line should be used since color can easily be perceived and mentally mapped to a certain metro line (Figure 2 (a), (4)).
  5. **The Direction of Travel:** The 'towards' or 'destination' of the services so as to select (a), the correct platform, and (b), the right vehicle traveling in the desired direction is also very important (Figure 2 (a), (5)).



(a) (b)

Figure 2: At ground level: (a) A multi-route nameboard: Note the red number (1307) above the stop name, which is unique for this platform. Each platform has its own unique number. (b) Central Sofia: Typical tram stop and nameboard position.



(a) (b)

Figure 3: On and inside a tram: (a) Front of a tram displaying route number (in this example route 14), the service identifier, and destination names. The destination name of both ends of the line are shown. Ideally, only the actual direction the vehicle is traveling in should be shown. (b) The inside signboard of a tram where the red arrow shows the 'direction' the tram is going.

- **On and Inside the Vehicle (Figure 3): Once entered a tram, we are dependent on this first decision. Are we right? Is it going to the correct direction? Do we have to change lines and after how many stations do we have to do that?**
  1. **Destination:** The 'towards' or direction of travel should be clearly indicated on the front

Figure 4: Information about the public transport system in an easy-to-read and intuitive format: the Communicarta Style45® map. Note that all stops have both the names and individual unique platform numbers.

of a tram, train, or metro (Figure 3 (a), (1)).

2. **Service Identifier:** Also the service identifier, i.e., which line or route the train operates should be given to the passenger before entering the vehicle (Figure 3 (a), (2)).
3. **Inside the Vehicle:** Clear announcements before each stop would be great, in addition, next stop indicators in visual format would be fabulous. Without these last two items, it is not impossible to get around it is just rather annoying (Figure 3 (b)).

- **On the Map (Figure 4): Having a metro map in hand, a traveler is well-equipped to get not lost in a foreign city—assumed the map is well-designed and the visual encodings and designs inside the map correspond to those given at ground level and also on the vehicle.**

1. **Linking between the Stations:** An easy-to-read format has to be used for the visual encoding of the linking of individual stations. From a graph visualization perspective, a node-link visual metaphor is suitable. Also laymen are able to directly understand the principle of connectedness when links in the form of straight colored lines are used.
2. **Topography:** In many situations—even if travelers are not familiar with a city—they already know some points of interest like sights, the airport, the main station, or a river. This topographical information is important to rapidly find stations in a map.
3. **Individual Lines:** Color coding is typically used to visually encode individual metro lines. Keeping the same color coding for the lines is important since map users build some kind of mental map which helps them directly manage the many map details.
4. **Interchange Points:** Traveling long routes in a city oftentimes demands for changing lines, i.e., passengers have to identify suitable stations where they could change trains without wasting time or making the journey unnecessarily unpleasant.

Having pre-purchased a street map, printed it in black and white for easy mark-up, we can commence fieldwork; to begin we need to establish the types of transport and if possible highlight the routes on our street map. Visiting the transport information office, we are sometimes able to obtain some information about the routes. Now at least we may know the types and extent.

3.2 The Visualizer's Perspective

From a visualization expert's perspective, metro maps can be considered as node-link diagrams representing stations as nodes and metro lines between stations as links. There is additional data attached to the stations and metro lines, e.g., categorical data expressing the direction of travel under certain conditions or the time periods a link (a metro line) is active. Additional information is placed on a metro map to guide a spectator through the city or serve as a mental aid, i.e., the mental map. This is important in graph visualization but also generally in all visual depictions of data, in order to find and observe visual patterns, relocate them, and finally compare them with others to derive meaning and knowledge by remapping them to the underlying data, i.e., the metro map system.

Interpreting a schematic map reliably and effortlessly is important to make it a useful guide for a traveler in a foreign city. If there is only the metro map with its lines and stations, it may be readable and understandable, but the information it provides is not enough to be really useful for the traveler. The map designer has to outweigh the benefits and drawbacks of the design being sure to not end up at either end of the design space, i.e., information overload is as worse as information sparsity.

To fully understand how the end user of schematic maps behaves we need user studies comparing different map designs with each other. Although we can measure accuracies and response times of the study participants, we also investigate the applicability of eye tracking techniques to explore the visual task solution strategies, visual attention, and visual behavior of people when working with the map. Consequently, the map designer generates questions that the visualization expert tries to answer.

From a visualization perspective, comparative user studies are highly appreciated (Lam et al., 2012). In the best case, recording the time-varying visual attention paid to a metro map stimulus is very interesting but such spatio-temporal eye movement data is difficult to analyze. The inherent space and time dimensions in the data build another dependent variable in a user experiment in addition to the traditional ones like error rates and response times.

By inspecting eye movement data visually, e.g., by visual analytics techniques (Andrienko et al., 2012), we might be able to analyze the map designs for design flaws, reading difficulties, or missing visual support like labels or legends. These evaluations can support the map designer in improving the maps or chosen design.

4 SOFIA: A METRO MAP DESIGN—REAL-WORLD USE

In public transport mapping, we must be aware of the information a traveler needs to navigate around a system. Here, in these illustrations, we can see how the designed map links to the real-world situation, i.e., what the map user will see in the city. There is a bare minimum and, we can agree that a traveler will need these pieces of information for wayfinding (Figure 2 illustrates such a scenario at ground level): boarding point, interchange point, where to alight, the line or service identifiers, and the direction of travel. Note that the last two points are particularly important for stops or stations where multiple routes operate from the same platform, as in this example here in Sofia.

Sofia has good coverage by trams with the majority of platforms having signboards with both a name and unique number. Those facts, combined with our digital camera, proves very useful in saving time annotating the street map markup because, as all the names are in Cyrillic, we do not actually have to write the names down merely the numbers.

The signboards also show service identifiers together with the destination stations of each route. Not only that, there are also timetables for each route, a line diagram with each of the stop names in end-to-end order and, highlighted in red, the name of the actual stop where the sign is located. This is a perfect scenario. All very good information for the user and for us is present to build a great map.

The service identifiers and destination names also appear on the front and sides of most of the trams. Even if they were not, so long as you have the map and have noted the name at the end of the route in the direction you wish to travel, you merely need stand on the correct platform to make the journey.

Given all this information and in possession of a well-designed and thoroughly researched Style45® transport map, it is truly a synch to get around and enjoy the city, its suburbs and the surrounding countryside—even if you do not read Cyrillic.

Strangely, despite providing all this really useful navigational information on the ground, it is amazing why some transport authorities around the world (actually quite a lot) choose to issue the most useless map information to their customers.

Back in the office after 5 full days of research and having obtained all the photographic evidence, plotted the stops and lines, it is time to complete the job. We import the marked-up street map (Figure 5), overdraw the geographic layout of each of the routes on a 'trace' layer, then draw each of the individual routes, typeset the stop names, straighten the lines, stylize with 45 degree angles, add station symbols and service identifier numbers.

In Figure 5, we can see all the individual tram routes overlaying the street map we used for the research, i.e., the network of interconnected tunnels, lines, and stations. This 'hardware' is essentially invisible to passengers' eyes. What we mean is that, without good and clear map information there can be no perception or indeed, comprehension on the part of the customer as to where the network goes and how to navigate their way around.

What brings the invisible to light? What makes the wonderful network—all the hardware of overhead wires, rails, tunnels, stations and vehicles—the brilliant engineering and the careful attention to safety and good materials, actually of use to the traveling public? The answer is a brilliant map. The kind of design that brings (carto)graphic reality to the user. The map brings confidence and connection to the user. It is this graphic representation with all the careful skill of design and attention to detail that makes the difference.

In Figure 6, all that was effectively hidden is now revealed in all its glory. This is one of the key elements in customer information and whether it is delivered to customers on a website or as a paper give-away, or indeed on digital devices like a smart phone, the net effect is that the network makes sense, is visible, and gives customers the opportunity to travel with knowledge and confidence.

Maps are constantly being referred to. We have all seen customers looking at maps and trying to make sense of what they see. And indeed, the most important consideration when commissioning a map designer is to make sure they have an understanding of what works and what does not.

Working with visualization experts, the map designer can gain deeper knowledge and insight of how the end-user interprets the information and so can design more effective maps leading to better use of the transport systems.

Aesthetics plays a major role in the design of

Figure 5: Research markup for Sofia showing the post research 'trace' of the individual lines. The background map is artificially blurred for illustration purposes.

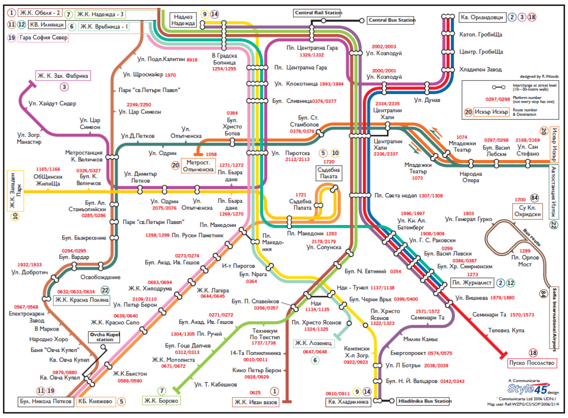


Figure 6: The final transport map of the city of Sofia in the Style45 as designed for Thomas Cook City Spot guidebook.

metro maps. Without careful attention to detail and careful design, the maps would be useless. Communicarta employs many of the 'Good Design Principles' (Ovenden, 2008), and more. Chief among those being the horizontal placement of station names, ensuring names do not cross over lines, smooth curves as opposed to right-angles which aid, what we like to call, the 'flow' of the designs, and services separated out into their individual routes as required.

As we also now know from our experience in wayfinding and research, the direction of travel-'towards' names and line or service identifiers play a major role in the users' ability to navigate the system. Emphasis on these aspects are important elements in the design.

And of course, famously, we use the 45 degree angle for the diagonal lines which we have found work very well for guidebook size pages which has been the majority of the use of the maps.

Space is everything. This helps both the flow and the way that users are able to read the maps. Not only does the correct spacing help the user the designs also look and feel better.

5 CHALLENGES AND OPEN ISSUES

There are many problems, limitations, challenges, and open issues which could not be addressed in the context of this paper. These aspects can be found on both sides, i.e., either for the map designer but also for the visualization expert.

5.1 Interactive Maps

Interactive maps are much more difficult to design since an infrastructure is required in the form of software and data bases updating the displayed information on user's demand. However, interactive maps—those on digital devices or computers—are a topic worthy of note. They build the basis for a separate subject altogether in the sense that the type of eye-tracking study would need to be different from that of a static kind of map.

That begins to open the topic up to a far greater study realm since it would involve other areas such as user interface and user interpretation of information—actually something we should be very interested in, specifically in regards to public transport, i.e., not just maps but wayfinding in general, also in the areas of timetables, ticketing, vehicle design (for example, where and what types of information are placed on-board and outside) and even subjects such as 'how to use the system'.

5.2 Scalability and Visual Clutter

A real problem for both—the map designer and the visualization expert—are growing datasets. For the map designer much more work on recording data, taking pictures, or traveling has to be done until the final map is ready for print. For the visualization expert, larger datasets cause visual, perceptual, and also algorithmic scalability problems, i.e., the question comes up if the visual design can still keep pace with the growing number of metro stations, lines, and additional information.

5.3 Progress of Transportation Systems

Public transportation systems are typically growing with the increasing population in a city, requiring adapted infrastructures to the novel situation. Stations have to be added or new lines have to be designed making a journey through a city more efficient and more pleasant to the passengers. The map designers have to keep pace with the steady growing or change of the transportation system in order to provide informative and up-to-date traveling information to the tourists. The map designer should be aware of possible changes in a transportation system, otherwise the maps soon get obsolete.

5.4 Evaluation of Real-World Scenarios

In real life, passengers sometimes do not have enough time to read a map very carefully. Typically, they are in a hurry to catch the next train or metro which brings them to the airport for example. This more realistic scenario demands for another kind of user evaluation. The question arises if maps in a certain design are still useful in such situations where the traveler is under time pressure.

5.5 Hazards of Map Research

As a public transport map researcher, we have to carry a rucksack with all the equipment and reference material. Spare cameras, spare batteries, spare memory chips for the cameras, at least two sets of clip boards, markup pens in a multitude of different colors, highlighters, torch for when it gets dark, all the street maps that have been printed out in large A2 and A1 sizes of various sections of the city to actually do the markups on, wet weather gear where necessary, sun blocker as necessary, drinking water, hand hygiene and a space to store hats, scarves and gloves as necessary. Basically anything you would need for an expedition.

The life of a public transport map researcher is not always plain sailing either. No, from freezing climates of -17°C on one occasion in Berlin and Oslo to the searing sun and humid highs of +50°C in places like Dubai to torrential rain and flash floods of Tunis and the fog of Milan, the researcher has to deal with it all and still get the job done in the time allocated.

Sometimes the seemingly ridiculous (but true) occasion of getting stuck in the Castelletto-Portello lift in Genoa and having to be rescued, amazingly by another lift in the opposite lift shaft—in case you were wondering, are set alongside the more serious situations of being threatened with arrest in Rome (for taking pictures in the metro) or being chased by hoodlums in San Francisco and losing a day's work in the process, yes our researchers go through it all.

(a) (b)

Figure 7: A couple of amusing photo's that aptly illustrate what some of the hazards of map research are in some cities.

In other cases, it is just plain frustrating whilst trying to get the job done. Like having to avoid peak hours in cities like Beijing for example when researching the trolleybuses, or being asked to delete photo's from the camera by security guards in Madrid whilst working on line 12. We know there is a risk of this, so we exchange the memory chip for a fresh one every 2–3 hours so there is only that much loss if this happens.

Weather, of course, plays a major part in our frustrations. Rain being one of the biggest threats to productivity. In these situations if we have both metro and surface systems to research we can choose to do the metro first and then go on to the surface system when it has cleared up. Otherwise, it is a case of ducking for cover and marking up the map without it getting wet. All of this prolongs the time to complete.

In some instances, we wonder if we would ever be able to complete the job before the system crumbles apart in front of us. St Petersburg tram system is an example of this where you can see the state of the tracks. In some cities, the state of the infrastructure means we have to keep a look down instead of up. Sofia is a great example of where not looking down could cause more than just an embarrassment (see illustrations in Figure 7). At other times, we have had to contend with strikes and vehicle breakdowns.

6 CONCLUSION AND FUTURE WORK

In this paper, we discussed and explained the art of designing metro maps. We looked at this challenge from two different perspectives, i.e., the one from the map designer and the one from a visualization expert. We identified different subgoals such as aesthetics, understandability, intuitiveness, and readability in the sense of user performance. A combination of these goals can result in advanced metro maps serving as good means to convey data but also to make metro maps attractive to the eye and aesthetically appealing, two major goals typically standing in a trade-off behavior. We illustrated the design of metro maps in a real use case showing its design for the city of Sofia. From a visualization perspective, user studies are performed to measure the performance of people trying to answer route finding tasks which depends on the complexities of the maps that can lead to tremendous design problems for the map designer, in particular when many transportation systems like bus, metro, or tube have to be displayed together.

For future work, we plan to collaborate, i.e., the map designer raises questions that he is not able to answer where the visualization expert designs user studies with the goal to get hints about user performance problems or even reading problems which can be analyzed by applying eye tracking techniques for recording and measuring time-varying visual attention paid to metro map stimuli. This is challenging for static maps printed on a sheet of paper but becomes even more challenging for dynamic and interactive metro maps—maybe also on small displays like smart phones.

ACKNOWLEDGEMENTS

We would like to thank the German Research Foundation (DFG) for financial support within project B01 of SFB/Transregio 161.

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