# Traffigram:
# Distortion for Clarification via Isochronal Cartography

Sungsoo (Ray) Hong[1], Yeaseul Kim[1], Jong-chul Yoon[2], Cecilia R. Aragon[1]

University of Washington[1]
428 Sieg Hall, Box 352315
Seattle, WA 98195, USA
{rayhong, yeaseul.kim, aragon}@uw.edu

Kangwon National University[2]
245-711 Jungang-ro Samcheok-si,
Gangwon-do, Republic of Korea
media19@kangwon.ac.kr

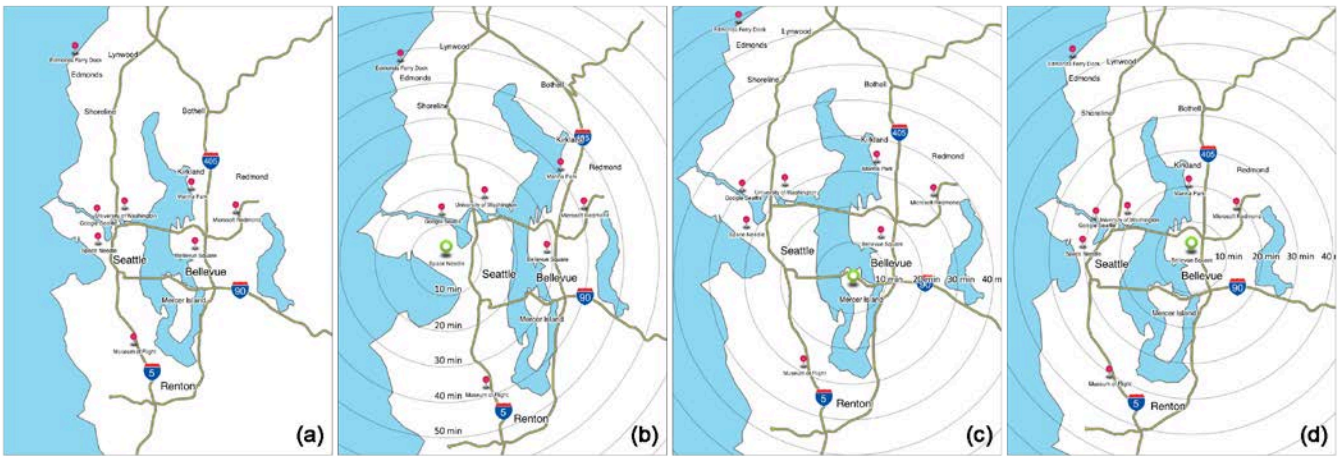


**Figure 1. Traditional map and Traffigram results warped from three different places in the Seattle area at 4:00 p.m., 26 February 2013: (a) Traditional map; (b) From the Space Needle; (c) Mercer Island; (d) Bellevue square.**

## ABSTRACT
Most geographic maps visually represent physical distance; however, travel time can in some cases be more important than distance because it directly indicates availability. The technique of creating maps from temporal data is known as isochronal cartography, and is a form of distortion for clarification. In an isochronal map, congestion expands areas, while ideal travel conditions make the map shrink in comparison to the actual distance scale of a traditional map. Although there have been many applications of this technique, detailed user studies of its efficacy remain scarce, and there are conflicting views on its practical value. To attempt to settle this issue, we utilized a user-centered design process to determine which features of isochronal cartography might be most usable in practice. We developed an interactive cartographic visualization system, Traffigram, that features a novel combination of efficient isochronal map algorithms and an interface designed to give map users a quick and seamless experience while preserving geospatial integrity and aesthetics. We validated our design choices with multiple usability studies. We present our results and discuss implications for design.


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## INTRODUCTION
Maps provide a simple, yet powerful visualization method for representing geospatial reality [9]. Many maps are constructed to representationally reflect geospatial dimensions. Since they reflect real-world geography (or attempt to reflect, as effectively as possible, the three-dimensional Earth as a two-dimensional construct), individuals can intuitively estimate the distance between two points on a map by measuring the distance between them. However, physical proximity may not always most effectively predicate accessibility. Urban travel is fraught with traffic congestion and uncertainty; the variable nature of the time between two points in urban areas regularly distresses people because geospatially representative maps may fail to represent realistic accessibility of any given point on the map.

Meanwhile, various digital map solutions and widely used devices (including mobile) have led people to use digital maps more frequently in complex contexts. Compared to traditional map usage, which is primarily focused on understanding geography, users of digital maps may wish to select a place to live based on travel times from their workplace, evaluate the traffic situation downtown at a particular time, or select a branch bank in an unfamiliar area. One critical aspect of knowledge often sought by digital map users is temporal information, because it helps users choose when and where to move during increasingly busy lives. Travel time between two points is easy to display, but it is not so obvious how to effectively present multiple travel times to a variety of potential destinations. Limitations in human working memory must be addressed [21]. Additionally, presenting travel times in a traditional "static" equidistant map is a challenging task. This is because, first, there may be an intrinsic discrepancy between spatial distance and spatial accessibility. Second, travel time information is based on specific locations (origins) and is always changing [2, 3].

Isochronal cartography is an intuitive visualization technique to represent temporal information. This cartography aligns every point on the map with isochrones, or temporally equidistant contours, from the origin. Studies have shown that humans most efficiently glean quantitative information from spatial position [14]. Thus, by using position to represent travel time from the origin, a user can directly compare travel times to multiple points. However, there are several barriers to implementing such an interface, including the difficulty of collecting, managing, and dealing with discontinuities in travel time data and presenting them in a usable interface, and the relative lack of usability studies of isochronal cartography [7].

This paper's contributions are the following:

- Traffigram, a novel web-based map visualization for users in areas of high and variable traffic congestion.
- An optimized isochronal warping algorithm and database designed to present a seamless map user experience (within a second per user query). Our database is extensible across dimensions of both time and space. We resolve the challenge of efficiently and usably presenting dynamic geotemporal information within a traditionally geospatial construct (there is a complex set of visual discontinuities that must be resolved).
- A usability study consisting of four user scenarios and one survey supporting our work's applicability in real world settings. We focus on how effectively a geotemporal cartogram aids people in recognizing temporal accessibility and present a set of design guidelines for this type of isochronal cartography.

For the project, we utilized real-time traffic data from the Seattle metropolitan area. This region includes areas of heavy traffic, bridges, and a large number of corporate businesses including Microsoft, Boeing, Amazon, Starbucks, and others. Fig. 1 depicts an example Traffigram screenshot. On the left is (a) the traditional cartographic representation. The three visualizations on the right show the Traffigram result on February 26, 2013 at 4:00 p.m. from three separate origins: from left to right, (b) the Space Needle, (c) Mercer Island, and (d) Bellevue Square. In Fig. 1(b) it is easy to see the easterly/westerly expansion of the landmass just north of Seattle indicating the slower roads and increased traffic in that direction at that time of day coming from the Space Needle; at the same time, Fig. 1(b) reveals an east/west narrowing in Bellevue, indicating easy access in that direction coming from the Space Needle.

## RELATED WORK

### Simplification and Abstraction in Map Design

For many years, researchers have attempted to understand how mapmakers can produce effective, visually esthetic, cognitive, and communicative visual designs. This is a challenging problem because the associated data is complex and has many dimensions. Even with meaningful information, the expression of these data is a difficult task. To manage these data, it is best to capitalize on the human faculty for processing visual information, thereby improving comprehension, memory, and inference. [1]. Designers put considerable effort into the selection of data to represent in their visualization and how to visualize it in order to aid human perception [12]. Harry Beck's map of the London Underground is a stellar example of such design practice. He introduced the pivotal idea of mapping by simplification when he reduced the complex London subway system to the renowned representational London Subway Map of 1933. This visualization did not reflect geographical reality, but it helped people in London use the complex subway with ease and comfort. Kopf et al. [10] also used simplification to abridge complex route information thereby aiding users' cognition on understanding routes to their destinations through a cartographic visualization. Traffigram builds on these visualizations by reducing the complexity of a traditional map to isochrones. Thus by sacrificing the accurate representation of geographical reality and by focusing on the selective representation of information, users gain a greater understanding of temporal accessibility.

### Time-space Maps and Isochronal Cartography

Adding temporal information to maps has been investigated for several decades [11], and time-space maps or isochronal cartography has been developed as one solution. Shimizu's approach is one of the earliest time-space cartography examples [17]. He proposed the term "time-space map", and cartographically represented a major Japanese city with elapsed train travel time. Shimizu minimized the discrepancy between travel time and actual distance between connected points by using optimization to preserve spatial integrity [18, 19]. His approach does not include a user origin or isochrones, so the user may have difficulty in extracting exact travel time from one point to another. Lightfoot and Steinberg's travel-time map of Great Britain utilized colored isochrones to represent train travel time [13]. This work successfully preserved travel time without distorting geography by using color, but multi-layered color along with other information can render this solution illegible in some cases. Karlin redesigned the London underground map around the time it takes to travel between specific points [8]. Inspired by this work, Carden created an interactive web application of Karlin's London underground map [20]. This application uses an interlaced circular background to represent travel times. Bies upgraded the time-space map to a more user-centric formulation via triangulation [2]. Her approach lets users select an origin and shows the travel time to other areas of the map. Chen proposed subjective cartography to present various contexts including travel time [3]. Despite the multiplicity of approaches to time-space cartography, few usability studies have been conducted [21], and Kaiser pointed out that further usability studies are needed to verify the effectiveness of this technique [7]. Many of these approaches focused on entities with scheduled temporal patterns, such as trains. However, automobile traffic conditions are unscheduled. To address this situation, Traffigram utilizes a traffic anticipation model which will be described in more detail in the Algorithm section.

### Quantitative Presentation in Cartogram: Linear vs. Area
For anyone who has explored the many different projections of the Earth, it is easy to understand the difficulty of the cartographer's task of reducing three dimensions to two [6]. While there are challenges associated with people realizing that the landscape is not "accurate" as represented on a traditional map, it is important to realize that cartographers have been wrangling with this issue perhaps since Anaximander the ancient Greek cartographer, who first scribed such representations over 2500 years ago. With these efforts, many researchers have attempted unique geo-visualization methodologies to convey more insightful context to people and to enhance human perception and cognition. Linear and area cartogram methods have both advantages and limitations. Linear cartograms use position to present quantitative data. As Mackinlay noted [14], position is the most powerful method to present quantitative information; thus it is generally used to represent travel time or positional relationships in cartograms. Beck's [1] and Carden's [20] London underground maps are examples of linear cartograms. Area is not as visually effective for presenting quantitative data than position, but it is frequently used in cartography when time or distance is already represented by linear position because people's background knowledge of the map's contour and position help them to understand the secondary information. Worldmapper [5] is a geo-visualization system that presents statistical data such as national population and wealth around the world by using a value-by-area technique. Newman's work with election maps also uses an area cartogram technique to reveal real voting power that might be obscured by geographic area data [15]. In general, linear cartograms are effective at visualizing quantitative metrics, but excessive warping may impact geographical integrity, perception, and usability.

## TRAFFIGRAM

### Algorithm
To address the issues mentioned above, we developed a novel combination of warping and shortest-path algorithms to display isochronal maps interactively. Traffic information has two important characteristics; it is direction-dependent and ever-changing. These aspects require two user inputs to our system; an origin (initial user position) and a specific time of day/date. With these inputs, we describe the four steps of the Traffigram algorithm: traffic network construction [Fig. 2(a)], real traffic data acquisition [Fig. 2(b)], isochronal contour generation based on shortest path analysis [Fig. 2(c)], and thin-plate spline (TPS) based warping [Fig. 2(d)].

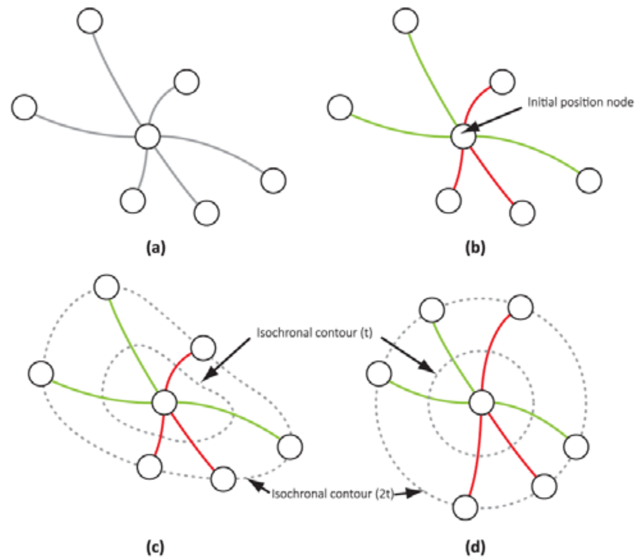


**Figure 2. Traffigram algorithm: (a) Traffic network construction; (b) Traffic data acquisition; (c) Isochronal contour generation; (d) TPS warping**

*Traffic Network Construction*
The first step in the construction of Traffigram is developing a directional network structure (i.e. directionally-weighted graph) that reflects an existing road infrastructure in the Seattle area. This task is accomplished by overlaying a network structure onto a traditional spatial-based map. The traffic network functions as a skeleton; this structure must accurately represent the real road infrastructure and general traffic information. In our system, every node represents a geographical point; node data includes longitude and latitude. In practice, we have two types of nodes: one, a crossroad with geographic significance and above a certain threshold of traffic. The other type is a point on a highway related to an entrance, exit, or fork. Every edge represents a road that connects two nodes; the presence of an edge means two nodes are geographically adjacent and physically connected. Our system contains crossroad/crossroad edges, highway/crossroad edges (highway exit), crossroad/highway edges (highway entrance) and highway/highway edges. Fig. 3(a)

depicts the traffic network structure of Traffigram applied to the Seattle area. The challenge of structuring this network lies in applying the following factors: occasional one-way traffic, numerous highway entrances/exits, and complex connections related to inter-highway junctions. As a result, we simplified the metropolitan Seattle area road infrastructure by representing it with 107 nodes and 435 edges. We considered the following aspects when sampling for traffic network construction. First, we evenly distributed every node and edge in our coverage area considering population and traffic issues. Second, we represented existing routes to preserve geospatial realism. Third, we focused on building an interactive warping and construction system to provide a faster, more responsive user interface.

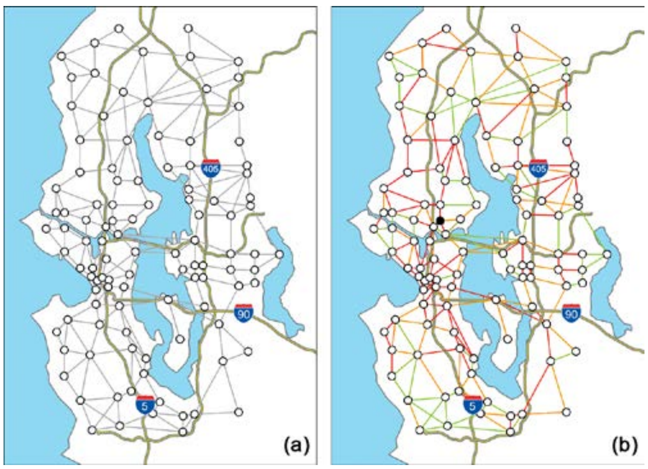


**Figure 3. Network construction and data acquisition: (a) Traffic network structure; (b) Congestion factor from black node: green $C_{ij}$=1, yellow 1< $C_{ij}$ <2 and red 2≤ $C_{ij}$**

*Real Traffic Data Acquisition*

The second phase involves the gathering of information on traffic conditions. In our optimized traffic network structure, we weighted every edge with real travel time. Different types of temporal traffic information are available; data might be aggregated from individuals (i.e. observed on a highway) or collected from a public data center. We chose to use the Bing map API and data since publicly-available sources in the Seattle area currently only address primary arterial routes. Traffigram gathers travel time data every 30 minutes. Upon user request with a specific time and origin, Traffigram fetches weekly periodic data and presents the weighted mean value to the user. Utilizing periodic traffic data to estimate traffic flow is a classic and broadly-adopted technique and with this approach, the database delivers a meaningful and concrete estimation model to a user. We then calculated a congestion factor for every edge by dividing the actual travel time (with traffic) by the baseline time (without traffic). Fig. 3(b) illustrates one snapshot of our data. The roads depicted in red show congestion while those in green are clear or uncongested. Fig. 3(b) depicts a visualization of the congestion factor of the network. The congestion factor $C_{ij}$ from node $i$ to $j$ is encoded as edge color in this figure. A value of 1 is green, 1< $C_{ij}$ <2 yellow and 2 ≤ $C_{ij}$ red.

*Isochronous Contour Generation*

Traffigram then calculates every node's shortest route from the origin via Dijkstra's shortest path algorithm [4]. In our network, the system automatically generates one virtual edge if the user's chosen origin is not the same as the representative, predefined node; the virtual edge links the user-selected origin and the "adjacent node" that has a minimum geospatial Euclidean distance from the origin. Based on the shortest path analysis, Traffigram creates isochrones by connecting all points that are equitemporally distant from the origin; i.e. all points on a given contour are an equal amount of time away from the origin. Fig. 4 depicts this process. With the shortest path analysis, Traffigram gathers travel time information [Fig. 4(a)]. In Fig. 4(b), we can see the disparity of several contour intervals by comparing the three double-headed arrows. For each arrow, a traveler spends the same amount of time to traverse the varying distances. Thus, the lengths of these arrows are inversely proportional to the degree of congestion. The route through downtown Seattle is highly congested (the shortest arrow), Bellevue (to the right of the bay) is less congested, and Northgate (north of the center contour) is the least congested.

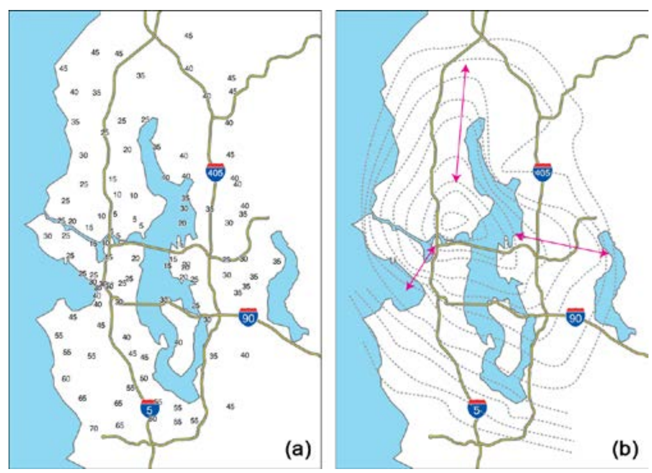


**Figure 4. Isochrone generation: (a) Shortest path analysis; (b) Isochrone construction; length of double headed arrows represents congestion**

*TPS Warping*

For the final step, we warped the equidistant map to generate an isochronal cartogram, using thin-plate spline warping (TPS). TPS is a well-known algorithm that has been widely used as a non-rigid transformation model in image alignment and shape matching [23]. TPS was chosen since it has two important merits. First, the algorithm provides closed-form solutions for interactive warping and thus enables fast computation. This feature fits well with the goal of Traffigram since the system should generate an isochronal map within a second to provide a seamless map usage experience to a user. Furthermore, TPS can generate smooth map results while preserving the source among several smoothing techniques; TPS is known as one of the most robust-toward-outlier solutions [23]. We begin by generating a sparse vector map [Fig. 5(a)] that illustrates the displacements necessary to align isochronous nodes into circular shapes. The red and blue vectors visualize the gap between geospatial accessibility and actual geography. With this sparse vector map, we interpolate a TPS surface and apply it to create a final result. Fig. 5(b) shows a warped map; note that the landmass located west of the bay (downtown Seattle and the University District) is largely expanded while the landmass located east of the bay (Bellevue/Newcastle) is condensed compared with Fig. 5(a).

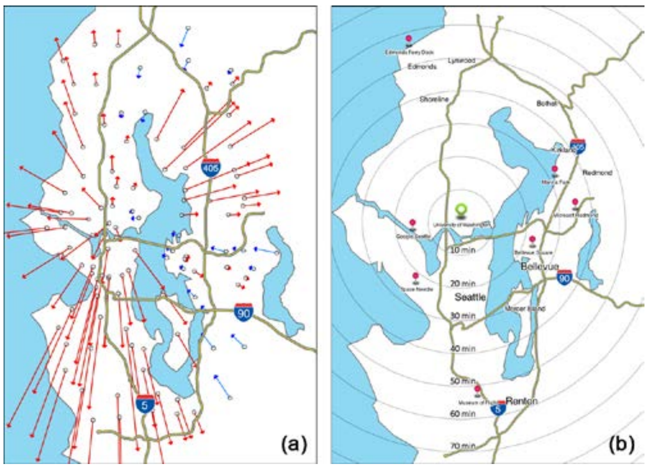


**Fig. 5. TPS warping: (a) Sparse vector map, red vectors denote expansion (congestion) while blue indicates shrink (nearly ideal condition); (b) Warped Traffigram result**

### Design Variations

Even though the algorithm created an efficient isochronal cartogram, the result needs to be visually recognizable to users to allow them to rapidly obtain the actual information they want. During our ideation phase, we considered the following questions: What are the cognitive processes involved with "consuming" the information presented on a map? What roles do maps play in embodied experience? How do cartographers convey physical constructs to a map user and how might a distorted map advance this conveyance? After the development of numerous low-fidelity prototypes, we produced a set of what we believed were functionally useful, cognitively efficient, and aesthetically appealing results based on Mackinlay's graphical representation theory [14]. We evaluated them via a usability study, which will be described in more detail in the user research method section. Fig. 6(a) shows the basic warping result without additional visual cues. Fig. 6(b) was designed to maximize the power of "position" in Mackinlay's theory by placing 10-minute band circular isochrones. We combined color information in an interlaced manner in 6(c) to enhance the recognizability of each band, as used in Carden's visualization [20]. In figure 6(d) and 6(e), we offered a grid and city boundary respectively in order to present users with a sense of geographical spatiality by utilizing "area". The grid gives users a visual cue for physical distance; each grid has 1.5-mile length and height. 6(e) gives users geographical information via city boundaries, often used in area cartograms. This visualization is useful if excessive warping is present. We also added a color scheme in figure 6(e) for each city we covered. Seattle shows the most congestion. Cities adjacent to Seattle, such as Shoreline, Bellevue, Kirkland, Burien and Edmond have a congestion factor between 1.00 and 2.00. The other cities have minimal traffic issues. In Fig. 6(f), we added vectors whose lengths represent expansion or shrinking based on the current traffic situation.

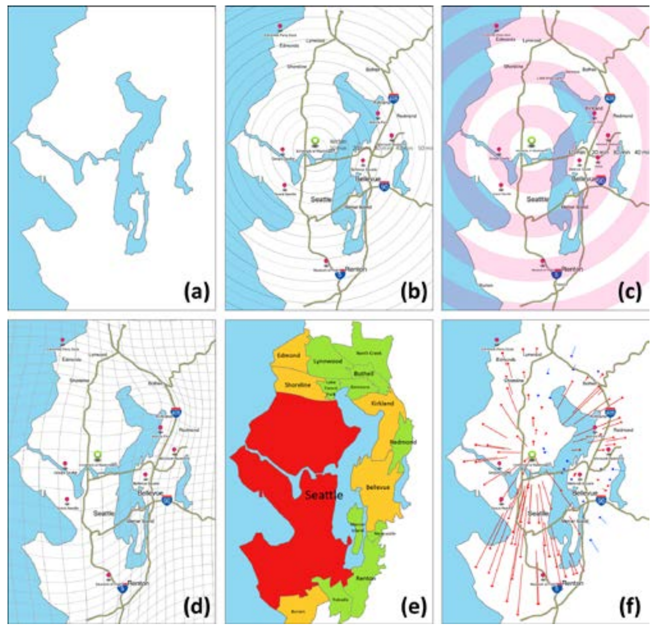


**Figure 6. Design Variations: (a) Warped map; (b) Concentric circular view; (c) Color-interlaced concentric circular view; (d) Grid view; (e) City view; (f) Vector view**

### Traffigram User Interface

We recorded users' comments and opinions about their needs and expectations of isochronal cartography, that is, if the service might be helpful in their daily lives. Specifically, we gathered feedback about which functionalities they found helpful, and which interfaces they preferred. We discuss this further in the user research section. Fig. 7 presents a Traffigram screenshot. Users can input their origin as text (i.e. address), or can drag and drop the cursor in the map display area. Equidistant and isochronal maps are presented simultaneously and are synchronized as the user pans. (Zoom in/out is not available in this version.) At the bottom, a user can select time. Drop box input allows the user to select from Monday to Sunday, or "now". If users select one day of the week, the time setting is enabled, and users may choose a specific time. In that case, the average travel time for that specific timeframe is retrieved from the database and the isochronal map is updated.

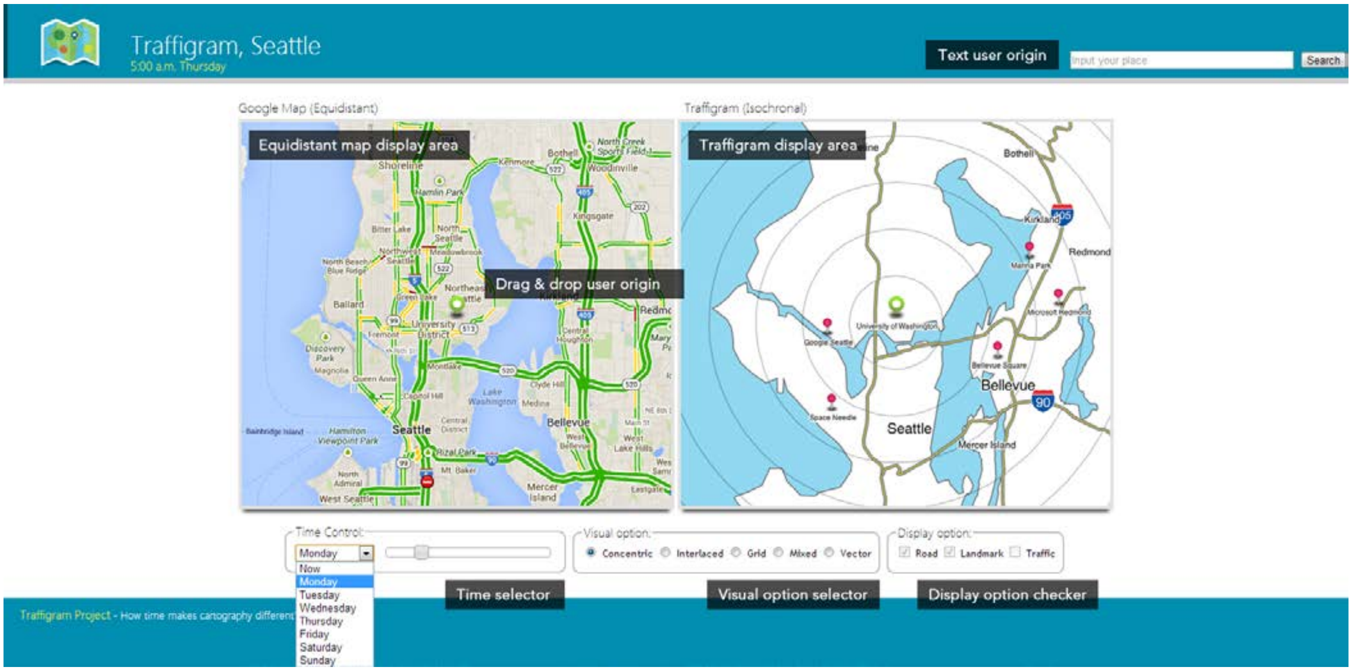


**Figure 7. Traffigram User Interface**

If user selects the "now" option, the system fetches the most recent travel time information. As we described, the database automatically gathers the travel time information every 30 minutes. Users can select design variations via a radio button interface, and also can select visual components (i.e. road, landmark, or traffic information).

## USER RESEARCH

We conducted a usability test to evaluate how Traffigram might be perceived and used in daily life. We recruited 25 participants (19 male), 12 in the USA and 13 in South Korea, via e-mail to student mailing lists. All participants were university students. Prior to each session, we briefly explained Traffigram to participants verbally. After participants felt comfortable with the main purpose of Traffigram, we conducted the session. Participants completed four tasks and one design preference survey. After the survey, we inquired about their perceptions of the Traffigram user interface. Participants were tested with several visualizations generated by Traffigram via a think-aloud protocol. All images used in the study were displayed on a computer monitor. Twelve subjects lived in the Seattle area were familiar with the area that Traffigram covers. In contrast, the 13 participants from South Korea had never been in Seattle and had little knowledge of the area. None of the subjects dropped out throughout the tasks and analysis was performed on all responses (n=25). The orders of every comparative analysis (i.e. task 2 and task 4) were generated using a Latin square to counterbalance carryover effect.

### Task 1: Landmark Matching

We designed this task to understand the effect of distortion on map recognizability. We presented two images to participants on the same screen. One of the images showed a non-distorted map containing area, district, and freeway information with seven different landmarks. The other image showed a distorted Traffigram visualization with the same seven landmarks. Participants were asked to move seven pin icons in the distorted map to where they thought each landmark belonged. There is a possibility that geotemporal disparities (such as a congested route or speed limits) may cause the isochrones to contort in a highly eccentric manner; in this case, the distortion will obviously break spatial integrity. For more realistic applicability however, Traffigram must provide information without hampering readability. We used one of the most distorted results to make the experiment more challenging and to account for this possibility. Figure 9 shows the test result. The average time on the task was 66.7 sec. (SD = 31.0). Fig. 8 depicts a result of this task. Magenta circles represent a 1.5-mile spatial radius for each landmark. To analyze task error, we used average Euclidian distance of discrepancy between user's selected point and actual point. In this task, we hoped to avoid the issue that smaller less-congested grid areas might be harder to identify with their icons. Interestingly, we found that this was not the case, since we observed the highest user errors for the Museum of Flight, which was only the fifth most congested area out of seven spots, which in part, seems to dismiss our rationale. These errors may be due to the fact that there are very few visual references (coastlines, crossings, bridges, etc.) by the museum. In contrast, Bellevue Square has the second smallest grid area, but none of the participants identified the place incorrectly. The proximity of the city name may also have helped in this case.

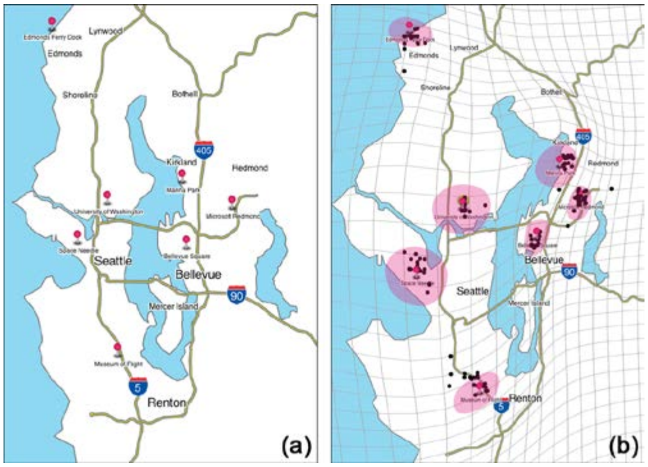


**Figure 8. Landmark matching: (a) Reference map; (b) Landmark matching result**

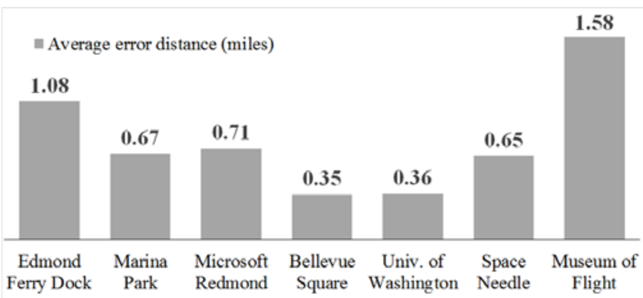


**Figure 9. Average error distance on Task 1**

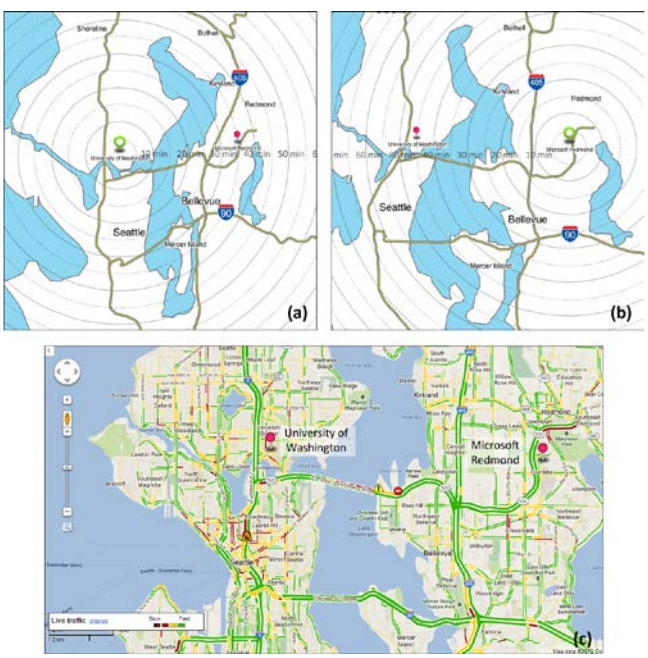


**Figure 10. Where do we meet?: (a) Warped from University of Washington; (b) Warped from Microsoft Redmond; (c) Google map traffic visualization**

### Task 2: Where do we meet?

In task 2, we studied how efficiently Traffigram provides directions when two or more people have different initial positions, yet want to know the traffic situation for a given time. Our hypothesis was that users would recognize traffic situations more easily with Traffigram than with a traditional map utilizing a traffic color metaphor. The scenario was presented to the subject as follows: one person is at the University of Washington, and one person is at Microsoft in Redmond, and they want to meet on Wednesday at 4:00 p.m. at whichever place is closest (temporally) to the other. We then presented two Traffigram visualizations with origins at, respectively, the University of Washington [Fig. 10(a)] and Microsoft Redmond [Fig. 10(b)] and Google Maps' traffic view [Fig. 10(c)] in rotation. Google Maps depicts an asymmetric traffic condition; the bridge connecting the two areas has different amounts of congestion depending on the direction of travel. Participants were asked to determine which commute was shorter based on time and relevant traffic issues. This task illustrated the degree to which Traffigram aided the correct decision (meeting in Redmond) and how efficiently it led to understanding compared to the use of a traditional traffic visualization. Table 1 relays the experiment results. Time-on-task between Google Maps and Traffigram were significantly different ($t=-3.06$, $p<0.05$) and the correct answer ratio of Traffigram (96%) was also higher than Google Maps (72%). The time on Google Maps and Traffigram between American and Korean was not significant ($F(1,23) = 1.46$, n.s.) The participants understood the concept of Traffigram as they counted rings on the map or estimated length between two places to answer quickly. However, it may have been burdensome for the user in that Traffigram uses two images while Google Maps uses only one.

| Tool | Average time on task | Correct Answer Ratio |
|---|---|---|
| Google Maps | 25.3 sec. | 72% |
| Traffigram | 14.3 sec. | 96% |

**Table 1. Time on task and correct answer ratio on Task 2**

### Task 3: When should I head home?

Even when the origin does not change, traffic is a time-dependent metric. The third experiment was devised to evaluate whether Traffigram could enable people to understand ever-changing traffic information. In this experiment, participants were asked to decide when they would like to return home from work. On a computer screen, we presented one traditional map [Fig. 11(a)] and three Traffigram visualizations centered on their fictional work location of Google Seattle in Fremont from 4:30 p.m., 4:45 p.m., and 5:00 p.m. [Fig. 11(b-d)]. We then asked participants which departure time minimizes their time on the road. 23 out of 25 participants (92%) provided the correct answer of 4:30 p.m.

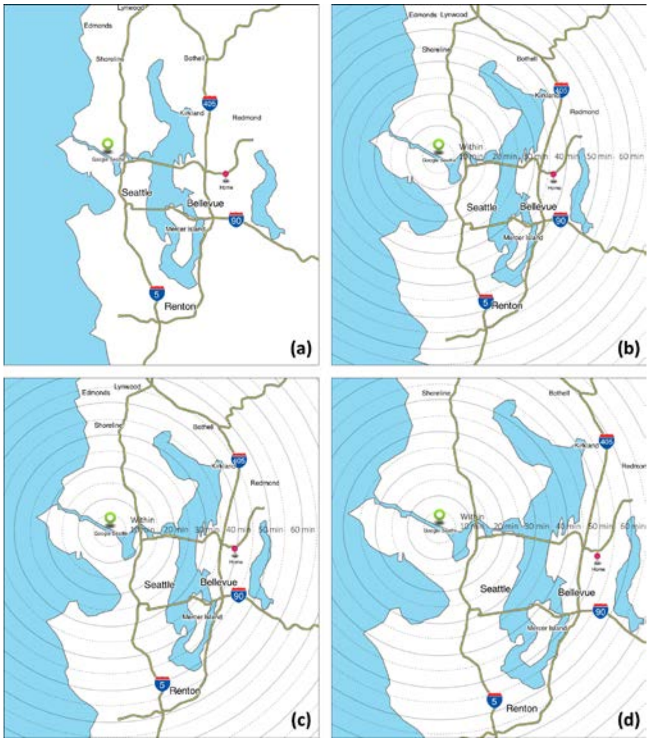

**Figure 11. When should I head home? (a) Equidistant map; (b) Warped at 4:30 p.m.; (c) Warped at 4:45 p.m.; (d) Warped at 5:00 p.m.**

The difference between American and Korean was not significant (F(1,23) = 1.92, n.s.). We evaluated the learnability of Traffigram through this task as well, as the average time-on-task decreased 38% compared to Task 2, even though this task involved an additional image. (On the previous task, participants spent on average 14.3 seconds, and for this task, 8.9 seconds.) 24% of the participants chose their answer within 6 seconds. 52% of participants stated they found this task the most useful among all the tasks they had conducted.

### Task 4: Pizza delivery

In this experiment, our main purpose was to understand Traffigram's utility when a user is considering multiple potential destinations. A fictional pizza restaurant owner runs a delivery service near the University of Washington. He has to decide which pizzas to make first since his customers are spread out across the Seattle area and he has a 40 minute delivery policy. In order to make sure he meets the deadline, he queues his orders appropriately. In practice, this task is somewhat artificial since an algorithm could easily sort the orders. However, we wanted to test the situation where users were selecting from among multiple destinations visually. (A better task, and one to be studied in future work, would be to select from multiple rental homes assuming a fixed work location. In that case, the context of each location is important and a list would be insufficient.) After explaining the scenario, we asked participants to sort pizza orders from longest to shortest travel time using two different visualizations; Traffigram map [Fig. 12(left)], and list view with address [Fig. 12(right)]. The difference between the task times presented in Table 2 is statistically significant (p < 0.0001). The time difference between American and Korean participants was not significant (F(1,23) = 0.03, n.s.). Participants completed the task 1.7 times faster with Traffigram. We also asked the participants how stressed they were during each sub-task using a Likert scale from no stress to highly stressed and 88% of participants answered Traffigram was less stressful. Even though Traffigram lacked the capacity to inform users of the exact travel time, participants still felt less stressed completing the task with the visualization. Thus Traffigram could potentially be a useful solution when user is located in one spot and (s)he has multiple choices of destination.

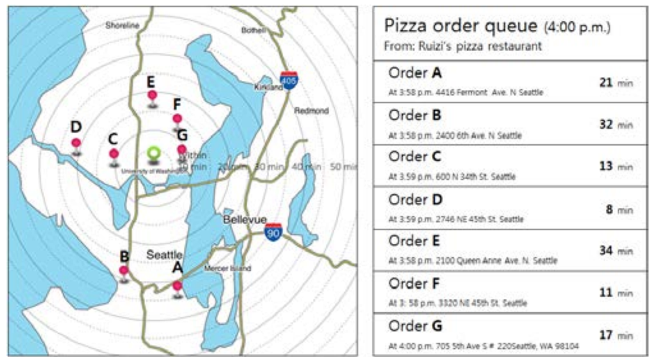


**Figure 12. Perception test. Traffigram pizza order result (left); List view of pizza order (right)**

| Tool | Average time on task | Correct Answer Ratio |
|---|---|---|
| List View | 36.7 sec. | 92% |
| Traffigram | 21.9 sec. | 96% |

**Table 2. Time on task and correct answer ratio on Task 4**

### Post-task survey

After completing four experiments, we surveyed participants' design preference from among variations Fig. 6(b) - Fig. 6(f). We asked participants to choose one or two design variations that were visually intriguing. After that, we asked them to select the most practical design variation. The result of this preference survey and some of their insights are listed in Table 3. Fig. 6(c) received the highest number of votes for both criteria; several subjects mentioned that 6(c) clearly explains travel time and is easy to recognize. Furthermore, many subjects mentioned that they found 6(c) to be aesthetically beautiful. Meanwhile, many participants responded negatively to design variations 6(e) and 6(f). Responses included: 6(e) is not detailed; difficult to recognize the difference between normal maps. One subject mentioned that he couldn't find any information he wanted to know in 6(e). Three participants remarked they didn't prefer 6(f) because it was visually too busy. For the aesthetic criterion, survey results depicted participants' varied preferences compared to the practical criterion; many people had difficulty deciding among 6(b) through 6(d). From the aesthetic perspective, people mentioned that colored circles are clear, easy to perceive, and more attractive than interlaced thick and thin lines. Some people remarked that 6(d) has potential because it supports their need for a sense of distance. For the practical criterion, more than 50% of participants chose 6(c). Many remarked that the power of Traffigram lay in enabling people to understand the variation in travel time from their place of origin to their destination. Participants felt that concentric circles (i.e. isochrones) helped achieve this goal. Interestingly, in both groups, participants suggested a new design variation; combining 6(c) and 6(d), so that users can perceive travel time and distance concurrently.

| | **6(b)** | **6(c)** | **6(d)** | **6(e)** | **6(f)** |
|---|---|---|---|---|---|
| Aesthetic | 17% | 39% | 28% | 11% | 4% |
| Practical | 20% | 52% | 20% | 0% | 8% |

**Table 3. Design preference (Voting portion)**

## DISCUSSION

### Implications for Design

Based on our experience, we suggest the following usability principles for developers of isochronal cartography:

- *Present equidistant map and isochronal map simultaneously*: Seven participants mentioned that Traffigram would be more useful if an equidistant map is placed next to the isochronal map so that the user has a sense of both distance and time, and two subjects mentioned their worry about the possibility of illegibility caused by severe distortion. We believe this design decision could relieve that problem.
- *Provide easy-to-use time and origin setting*: Five subjects mentioned preferences for inputting position or time. Two of them proposed a specific user interface. To accommodate these needs, Traffigram provides text based input (i.e. address) and drag-and-drop based input in map display area for origin setting, and day selection dropbox and time setting slider bar for time selection. In the day selection dropbox, users can select the day from Monday to Sunday, or select "now". They also can modify the time that they want to see with a slider bar.
- *Interactivity and seamless experience*: Five subjects were concerned about the loading time and interactivity of the map if they were to frequently change user origin and time information. Our algorithm (including TPS and database design to gather travel time information), displays results within a second, which appears to be acceptable for map usage [16].
- *Consider aesthetics and practicality*: Users preferred 6(b): concentric circular view, 6(c): color-interlaced concentric circular view and 6(d): grid view. Table 3 shows the sums of 85% for aesthetic and 92% for practical reasons in the post-task survey.
- *Present proper complexity in isochronal cartograms*: One of the participants said that "Google Maps gives me too much information while showing routes. It makes me think too much." Three subjects described the visual complexity of maps they ordinarily use; this is a very important issue in map design [10]. Providing too much information on a distorted map (including visual cues) may disrupt understanding. Thus, Traffigram provides minimal, user-selectable information on top of isochronal cartography, including the main roads, city name, landmarks, and visual cues.

### Real-World Applicability of Traffigram

According to an annual study of national driving patterns, US residents have wasted $121 billion due to traffic congestion in 2011, and this number is rising. We believe that a tool for understanding traffic patterns could have a positive impact on sustainability. Our user study focused on the potential applicability of Traffigram in real life situations. Participants stated Traffigram could be a practical tool when users want to choose departure time or location based on traffic conditions. The variable nature of the time between urban locations regularly frustrates travelers. Traffigram could assist in clarifying this traffic uncertainty. Traffigram could be especially useful when users have to select one destination from among multiple choices; for example, recently-hired employees looking for a place to live in their new community or people selecting a restaurant during rush hour. Commonly-used maps utilizing equidistant cartography are not optimal for presenting multiple destinations and travel times simultaneously.

Additionally, our study suggests that isochronal cartography might offer an improvement over the traditional stoplight-colored (red/yellow/green) traffic presentation. The method is used in major digital map services such as Google, Bing Maps and government services such as WSDOT (Washington State Dept. of Transportation). It has two main characteristics; it uses two lines to present directional traffic information and utilizes colors for traffic flow. In the context of understanding temporal information, this method has the following problems. First, the method indicates direction by using two lines, but some people have difficulty detecting which line denotes which direction. During our user study, many subjects did recognize the asymmetric traffic flow by focusing on color, but they had difficulty determining the direction, and we believe this frequently happens in ordinary life for many users. Second, color can represent a sense of temporal information, but fails to present the actual travel time. Thus, an auxiliary user step, such as inputting the destination, is needed to get an accurate and usable travel time from the origin to the destination. Lastly, this scheme is not suitable for colorblind users [22].

Finally, our method is not limited to human automobile traffic. It could be applied to any geographically-based map where travel time is potentially variable, including applications as diverse as air traffic, cargo shipping, network routing, packet switching, or any other situation where entities must travel between multiple discrete points.

## CONCLUSIONS AND FUTURE WORK

Although the initial implementation of Traffigram appears to be successful, there is much more room for additional features and improvements. First, more precise traffic network construction is needed. Realistic (un-simplified) traffic networks entailing millions of nodes and edges would provide greater real-time complexity to our experiment. Due to this complexity, sampling is required. Traffigram would benefit from a more robust network construction algorithm that seamlessly yields real time results that represent geospatial reality evenly by minimizing the difference between actual travel time and the shortest path analysis. Second, Traffigram needs more coverage and scalability. Current digital map users zoom in and zoom out, and systems powered by AJAX provide results within a very short amount of time. This scalability lets users browse the world – literally – very easily. We intend to implement these techniques in Traffigram by expanding the hierarchical traffic network structure. Additionally, further usability studies of isochronal cartography are needed. Broader coverage may eventually compromise geographic integrity [2], and there are few studies on how impaired geospatial integrity affects the recognizability of isochronal cartography. We intend to continue developing Traffigram to reach these goals.

In one of the first studies investigating the usability of isochronal cartograms, we developed a novel traffic visualization system, Traffigram, and validated our design with usability tests. Our research led to several principles for developing usable isochronal maps. Isochronal cartography appears to be a practical technique that may have many future applications and uses.

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