A-Map: Interactive Visual Exploration of Intercity Accessibility Dynamics Based on Railway Network Data

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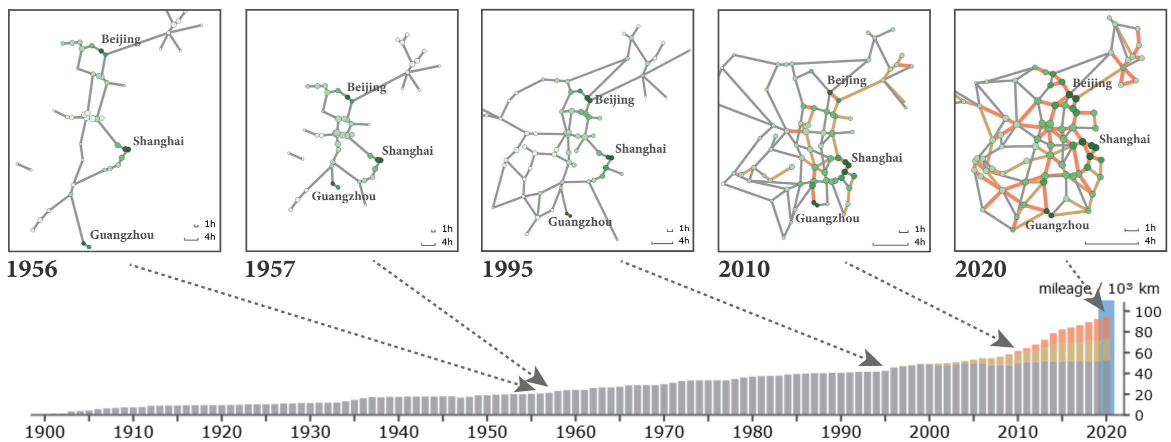

Figure 1: The snapshots of cartogram view of our system on five years. The distance between nodes in cartograms encodes the travel time between corresponding cities, the color and radius of node represent the accessibility of the city. High-speed, express and ordinary railway are discriminated by color in the timeline and cartogram. The heights of bars represent the total length of railways.

Abstract

Railway transportation is closely linked to everyday lives while also aiding domain experts in analyzing national or regional development. However, discrepancies between travel time reduced by railways and actual distance pose challenges in visualizing the accessibility. Existing methods either struggle to simultaneously depict the accessibility relationships among all cities or disregard genuine geographical positions, leading to spatial cognitive confusion. In this work, we propose a novel approach to balance between the geographical positions and travel time between cities. We construct linear cartograms to represent accessibility while preserving better local railway network structures compared with existing methods. We further propose the A-Map system, enabling users to interactively explore the extensive development of China's railway system over decades. We validate the effectiveness of our proposed layout algorithm from qualitative metric evaluation and illustrate the applicability of our system with results.

Keywords: Accessibility visualization, linear cartogram, layout optimization, transportation system

1 Introduction

Transportation infrastructure, especially the railway system, enables the flexibility of goods and people exchange between cities. Accessibility has been considered as a representative indicator to portray the connectivity level, service performance, and operational efficiency of a transportation network [12]. The development of railway systems and advances of travel modes have reduced travel times between cities, and consequently improved intercity accessibility. Transportation researchers are keen to develop an interactive visual exploration tool that supports quantitative measurement and intuitive representation of intercity accessibility. However, insufficient efforts have been conducted on intercity accessibility in the visualization community.

It is non-trivial to visualize intercity accessibility, where the challenges mainly come from two aspects. First, the analysis requirements of intercity accessibility include multiple levels, from global accessibility among cities at the country level, to local accessibility within a metropolitan coordinating region, to accessibility to a single city. Existing visualizations [7, 14] for intercity accessibility mainly focus on one certain level, either focusing on the overall accessibility at country levels or providing analyses with assigned central cities. An integrated visualization for multi-level accessibility exploration and analysis is still needed. Second, the intercity accessibility measured on railway systems typically involves complex and dynamic network analysis. The development of railway systems over time, including addition of new stations, routes, increasing speed,

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makes the analysis of intercity accessibility difficult and significantly challenges the design of visualization.

The accessibility can manifest itself in different ways for a transportation network. Travel time between nodes is often the most popular strategy to represent accessibility. Linear cartograms is the most desirable and effective way to encode travel time. As early as the 1960s, Tobler [17] made attempts to use the distance channel of the map to encode the travel time between cities. From then on, many researchers have tried several methods, mainly around using multidimensional scaling (MDS) to deform the map, but these cartograms suffer from uneven distortion and local structure loss. Although Shimizu and Inoue [14] pioneer proposed a generalized solution that used angle iteration and better preserved the spatial structure on Japan's railway networks. It was not satisfactory to apply it directly to the Chinese railway network which has more stations, more complex network structure and richer geographic features.

To address these challenges, we propose a three-staged hierarchical layout construction method to generate cartograms representing the accessibility using travel time between nodes. Our approach maintains the local structure according to geographic references. The successful preservation of shared geographic references enables smooth transitions between cartograms across time or different perspectives. We further develop an interactive exploration system, A-Map, to visualize the railway accessibility among the main cities of China over past decades.

2 Related Work

Cartogram is a well-known technique for showing geography-related statistical information. There are several different types of cartograms, based on the manipulation type. Area cartograms manipulate areas of geographical regions in proportion to some statistics [13], and many efficient algorithms have been proposed to construct area cartograms (*e.g.*, [5,9]). Linear cartograms or time-space maps manipulate linear distance and are more suitable for visualizing travel time. Thus, we focus on related work on linear cartograms in this work.

Transforming maps according to travel times has been investigated for several decades. Tobler [17] in his dissertation presented examples of distance distorted to represent travel times from a location. The design has been applied in visualizing travel times via subway systems in cities like New York[1] and London[2], and via railway systems [11]. Kohei Sugiura [16] designed a famous travel-time map using distance to representing shortest travel times from Tokyo. Though effective at depicting travel times, the linear cartograms introduce excessive warping to the geographical map, which may impact geographical integrity, perception, and usability [6]. To mitigate the issues, multidimensional scaling (MDS) [8] and dynamic Delaunay triangulation [3] methods have been proposed. Hong et al. further introduced thin-plate spline based warping [6], and implemented an interactive visualization system to effectively solve a series of problems centered on a single starting point [7]. Ullah and Kraak [18] incorporated vector calculus to ensure that the relative positions of the stations are maintained, which can improve map recognizability.

The studies focus on visualizing proximities (*e.g.*, travel times or costs) to a single starting location. Many applications, on the other hand, require to depict proximities among a set of locations. For instance, by comparing travel time change over decades, studies have shown the increased mobility in Europe [15], in Switzerland [2], and in Salt Lake City [1]. These methods typically employ a step-wise MDS technique to reposition the studying locations in accordance to pairwise proximities between them. However, the technique may excessively distort the locations and consequently affect the map recognizability. Shimizu and Inoue [14] formulated prior methods into a generalized solution based on the bearings of links, to better preserve spatial integrity of distance cartograms. The solution is applicable to depict proximity among locations that can be connected as a node-link graph, *e.g.*, subway and railway systems. However, these methods may heavily distort local structures of the transportation systems, which takes an extra cognitive burden for users. Our proposed method addresses this issue through hierarchical layout construction to deform the map while keeping local structure features.

[1]subway.nateparrott.com

[2]www.tom-carden.co.uk/p5/tube_map_travel_times/applet

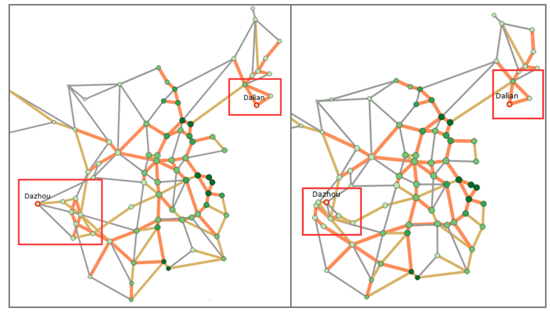


Figure 2: The comparison of layout generation by method of Shimizu and Inoue [14] (left) and our method (right). Previous work was unsatisfactory in two aspects: 1) Classic geographic features destroyed. Dalian, the most representative city on the Liaodong Peninsula has been pushed out; 2) Severe topology damage. Dazhou is supposed to be in the center of southwest China, but it is out of bound in left picture, which takes extra cognitive burden for people familiar with Chinese geography to identify and locate the city.

3 Background and Design Requirement

We worked closely with transportation experts (TEs) specialized in rail transport for six months. TEs are interested in the developement of intercity railway accessibility in China. They need a visualization supporting accessibility analysis. We decided to use travel time as the primary characteristic for intercity accessibility. We tried the potentially most suitable method proposed by Shimizu and Inoue [14]. We showed generated cartograms as Fig. 2-left. TEs appreciated the idea of a linear cartogram but also pointed out the layout by [14] distorts geographical features heavily. The misalignment between the cartogram and geographical commonsense hinders TEs' analysis. Nevertheless, we reach agreement to continue use cartogram for intuition and effectiveness. Furthermore, we conducted semi-structured interviews to elicit and understand their requirements. In general, TEs required a visualization system that supports the exploration of intercity accessibility from a global perspective at the national level, as well as local accessibility from a regional or city levels. TEs would also like to analyze improvements of intercity accessibility brought by the development of railway networks.

To this end, we compile a set of design requirements as following:

- **RQ1: Multiple level accessibility analysis**: For TEs, their workflow contains analytic iterations over different levels, the nation, region, and city level.
- **RQ2: Preserve local structure**: Geographic information are involved in accessibility analysis. The cartogram should preserve more local geographical structures to facilitate the analysis by leveraging knowledge of the geographical railway network.
- **RQ3: Show accessibility evolution**: To reveal the benefits of railway network development, transportation researchers would like to examine the evolution of intercity accessibility at national, regional, and city levels over decades.

4 METHOD

As the mentioned in Sect. 2 and Sect. 3, existing cartogram algorithms do not meet our requirements to show global accessibility over continuous decades. In this section, we propose a hierarchical layout algorithm to generate a linear cartogram and report a quantitative evaluation on our algorithm.

4.1 Hierarchical Layout Algorithm

To improve the cartogram maintaining local structure while proximating distances to travel time, we propose a three-staged algorithm as shown in Fig. 3. We divide all points into several intersecting groups in first stage, then establish hierarchical relationships between these groups, finally in a bottom-up manner, SGD is used to calculate the layout of higher-level groups through the layout of the lower-level groups (**RQ 2**).

We first give formal definitions to the problem. The problem gives an undirected graph $G=(V,E)$ and a matrix T, where V, as vertices, is the set of main cities we are interested in, E, as edges, is the set of railways segments connecting city pairs, and T is the travel time matrix where t_{ij} equals to the travel time by railway between city i and j. Our goal is to design an algorithm $\mathscr{A}$, which can efficiently calculate positions of vertices, $L=\{(x_i,y_i)|i\in V\}$ by $L=\mathscr{A}(G,T,L_{\text{geo}})$, where L_{geo} is the cities' geographic location. The goal to manipulate the distances to reflect travel time is formulated as a nonlinear least squares problem like Equation 1, and Shimizu and Inoue [14] rewrite it as Equation 2 (slightly modified for uniform format).

$$\min_{x,y}\sum_{i,j\in V}(t_{ij}-\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}) \tag{1}$$

$$\min_{x,y}\sum_{i,j\in V}[\{t_{ij}\sin\theta_{ij}^{'}-(x_j-x_i)\}^2+\{t_{ij}\cos\theta_{ij}^{'}-(y_j-y_i)\}^2] \tag{2}$$

Group Partition. Since we want to keep local features, it is necessary to define what is a local structure and how to divide it. Most fundamentally, a reasonable division method should have the following properties:

- ***Inter-Group***: The travel time and geographical distance between two cities in the same group should be near.
- ***Inner-Group***: The travel time or geographical distance between two cities in different group should be far.
- ***Connectivity***: The cities in the same group g should be connected directly or indirectly through the edge set $E^{'}$, where $E^{'}=\{(u,v)|u,v\in g,(u,v)\in E\}$

Moreover, through our experiments, we find that the feature of a point or an edge differs when it belongs to different groups, and all these features are reasonable and should be considered. Therefore, the groups that we want to maintain local features should intersect. Moreover, on the one hand, to minimize the missing local structure, we want to create as many groups as possible and the union of all groups should cover all points in V. On the other hand, we should premise that each pair of groups is not too similar because it will waste calculation time. From our experiments, ensuring that every pair of points is covered is not noticeably better than only ensuring every point is covered in terms of structure retention. Therefore, our approach to group partition is as follows:

We define $U(x,r)=\{p|t_{xp}\le r\}$, and *threshold_set* is adjustable parameters, in this paper we take $threshold\_set=\{k,\frac{1}{2}k,\frac{1}{4}k\}$, where $k=\frac{1}{5}D$, D is the furthest distance between city-pairs.

Hierarchical Dependency Establishment. We then establish the dependency set D for each group in *Groups* to help the high-level group h construct a bottom-up layout L_h based on L_g of all $g\in D_h$ and its initial layout $L_h^{'}$.

The initial value of the dependency set of g is $D_g=\{g_i|g_i\subseteq g,\ g_i\in Groups\}$. To reduce redundant dependencies, we drop the value c from D_a if there $\exists b,c\in D_b,c\in D_a,b\in D_a$, because when we use D_a to generate the layout L_a of a, the information of c has been already encoded into $D_b,b\in D_a$. Here also shows the advantage that we build the *threshold_set* by halving the next element each time. It ensures that for each low-level group, there is always an upper layer that will depend on it, so every local structure can be effectively utilized in building global structures.

Algorithm 1 Intersecting Group Partition

Input: *threshold_set*; Graph $G=(V,E)$;
Output: A list *Groups* contains all ;
  $Groups\leftarrow EmptyList[]$
  for each *thres* in *threshold_set* **do**
    $covered\_set\leftarrow\emptyset$
    $S\leftarrow\emptyset$
    while $covered\_set\neq V$ **do**
      $x\leftarrow$ the point which the closest distance to all points in S is furthest
      $covered\_set\leftarrow covered\_set\cup U(x,thres)$
      $S\leftarrow S\cup\{x\}$
      $Groups\leftarrow Groups+\{U(x,thres)\}$
    end while
  end for

Bottom Layout Construction. Inspired by the optimization objective from Equation 2 and optimization method from Zheng et al. [20], we propose an SGD optimization on weighted angle-preserving equations. Specifically, we first rewrite the equation as follows:

$$\min_{x,y}\sum_{i=1}^{M}Q_i^1(x,y), \tag{3}$$

$$Q_i^1(x,y)=w_i((X_i-(x_{v_i}-x_{u_i}))^2+(Y_i-(y_{v_i}-y_{u_i}))^2) \tag{4}$$

Here we convert every item in Equation 1 into a constraint Q^1, where u_i and v_i are two ends of an edge, $X_i=t_{u_iv_i}\cos\theta_{u_iv_i}$, $Y_i=t_{u_iv_i}\sin\theta_{u_iv_i}$, w_i is the weight of the constraints. We assign w_i to $\frac{1}{X_i^2+Y_i^2}$ after empirical assessment. The total number of constraints is M. In our work, we add the constraints between each two vertices in each most bottom group.

In each term, we pick the constraints in random order and then relax it. As shown in Fig. 4(a), for each relaxation, we let $\Delta x=\frac{\mu_i(X_i-(x_{v_i}-x_{u_i}))}{2}$, then add or subtract it from x_{u_i} and x_{v_i}, and do the same operation to y_{u_i} and y_{v_i}. Here $\mu_i=\min(\eta w_i,1)$ and η is a step size with a exponential annealing follows $\eta=\eta_{\max}e^{-\lambda t}$. We can see that $Q_i^1(x,y)$ will become 0 after relaxation if $\mu_i=1$, as μ_i decreases, the degree of adjustment to $Q_i^1(x,y)$ will become weaker and weaker.

The inner loop is completed after T terms. By using this method, only $O(TM)$ is required in an angle iteration. The outer angle iteration will terminate until the change in angle of each edge after two adjacent iterations is less than a specified value.

Upper Layout Construction. For a high-level group g, we first use the method in the above section to construct an initial layout. However, as we mentioned before, this result will lose some local features, so we need a method to embed many sub-graph layouts into the initial layout. The Laplacian Constrained Distance Embedding (LCDE) algorithm has been proposed by Yuan [19] to solve a similar problem. We add such idea of an angle-based objective function to it as follows:

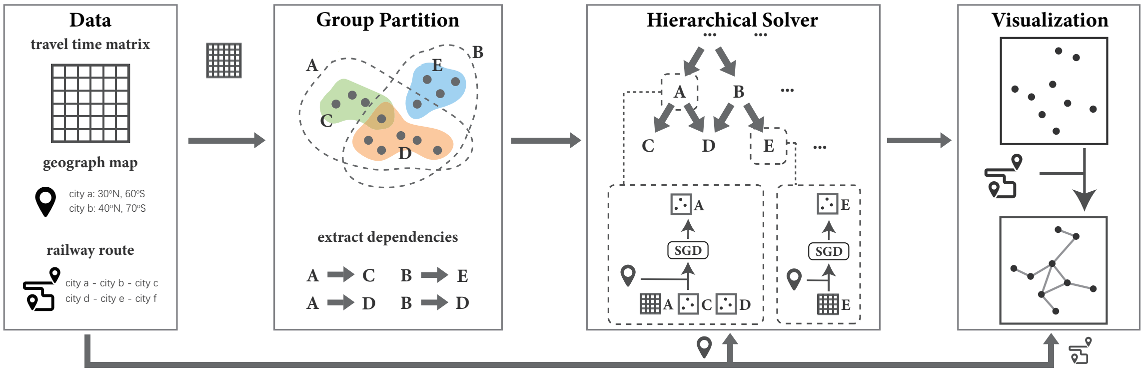
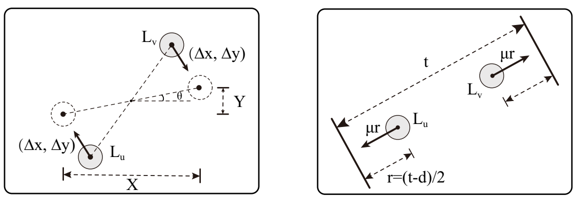


Figure 3: Processing of the cartogram view. We first divide the entire graph into several variable-size intersectable groups based on the travel time matrix and establish dependencies between them to make them into a directed acyclic graph and move redundancy. Then we use it to reconstruct the layout for each group according to the geography location as supporting information based on SGD from the bottom up. Finally, the railway route are used to link the nodes on the cartogram.



(a) (b)

Figure 4: Relaxation for Q^1 constraint (a) and for Q^3 constraint (b).

$$\begin{aligned}\min_{x,y} & \sum_{i,j\in g} w_{ij}^g\{[X_{ij}^g-(x_j-x_i)\}^2+\{Y_{ij}^g-(y_j-y_i)]^2\}+\\ & \alpha\sum_{h\in D_g}\sum_{i,j\in h} w_{ij}^h[\{X_{ij}^h-(x_j-x_i)\}^2+\{Y_{ij}^h-(y_j-y_i)\}^2]\end{aligned} \tag{5}$$

Here X_{ij}^f represents the value of $x_j - x_i$ in layout L_f, so do Y_{ij}^f. $\alpha = \alpha' c$, where α' is a parameter set to 1 in this work and c is a coefficient balancing the initial layout and sub-graph layouts. If we assume $M_1 = \frac{|g|(|g|-1)}{2}$, $M_2 = \sum_{h\in D_g}\frac{|h|(|h|-1)}{2}$, it should have $c = \frac{M_1}{M_2}$. Then we can also rewrite the equation into constraint form which is available for SGD, where the w, X, Y has a different definition from above but the strategy of relaxation is similar:

$$\min_{x,y}\sum_{i=1}^{M_1+M_2} Q_i^2(x,y), \tag{6}$$

Specified Origin Layout. Sometimes a user would like to focus on the travel time from a specified origin precisely. We deform the map while ensuring the distances from the specified origin to other nodes are accurate (**RQ 1**). We can also express it in a constraint form and then use the same framework as the above method to solve it. Suppose the user specified a node c, the objective function can be written as follows:

$$\begin{aligned}&\min_{x,y}\sum_{i=1}^{|V|-1} Q_i^3(x,y)+\sum_{i=1}^{M} Q_i^1(x,y)\\ &Q_i^3(x,y)=\beta w_{cu_i}(t_{cu_i}-\sqrt{(x_c-x_{u_i})^2+(y_c-y_{u_i})^2})^2\end{aligned} \tag{7}$$

Q^1 is the same as what we have discussed, representing the constraint of relative angular positions. By contrast, Q^3 only focuses on the distance between a node pair. β is a parameter that should be $+\infty$ in theory, but in our experiments, $\beta = 10^3$ is enough to generate a layout following the rules while keeping the information of Q^1 from being overwhelmed. The method of using SGD to solve Q^3 is straightforward and is shown as Fig. 4(b). We abstract it in $Q_i^3(x,y) = w_i(d_i - t_i)^2$, and in each step of each term, we first calculate $d_i = \sqrt{(x_c - x_{u_i})^2 + (y_c - y_{u_i})^2}$ and μ_i as mentioned before, then adjust the coordinates of the two nodes along the direction of the vector between $P_c = (x_c, y_c)$ and $P_{u_i} = (x_{u_i}, y_{u_i})$. Let $\vec{v} = P_c - P_{u_i}$, then $P_{u_i} += \frac{\mu_i(d_i - t_i)}{2d_i}\vec{v}$ and P_c is the opposite. This process is similar to and compatible with Q^1. In the actual implementation, we choose the $|V| - 1 + M$ constraint in random order together and then do the relaxation.

Merge Connected Blocks. In the early stage of railway construction, due to the disconnection of the entire railway network, the elements in the travel-time matrix T will be $+\infty$, which will affect the layout of the linear cartogram. To avoid the internal structural relations of several connected blocks being compressed due to disconnection between blocks, we use the following method:

Suppose the set of all connected blocks $S = \{C_1, C_2, ..., C_n\}$. For each C_i, we first separately apply the hierarchical layout construction approach as we mentioned before on it, and obtain the position L_u for each $u \in C_i$. Then, by calculating the center of the geography layout and our layout of C_i, we can approximately know the bias between them. Let $(len\_geo\_x_i, len\_geo\_y_i)$, $(len\_con\_x_i, len\_con\_y_i)$ be the side length of the bounding box of the geography and constructed layout of C_i. The zoom ratio of the original map is determined by $r = \max_i(\max(\frac{len\_con\_x_i}{len\_geo\_x_i}, \frac{len\_con\_y_i}{len\_geo\_y_i}))$ to prevent the bounding box which is square in the real geographic layout from becoming wider or higher after reconstruction, thus extending it beyond its original extent and covering other cities. Finally, we obtain the position of each node by $L_u' = L_u + \text{bias}_i$ for $u \in C_i$, where $\text{bias}_i = r\frac{1}{|C_i|}\sum_{v\in C_i} L_{\text{geo}_v} - \frac{1}{|C_i|}\sum_{v\in C_i} L_v$.

4.2 Evaluation

As we discussed before, our method only need $O(TM)$ in an angle iteration. By contrast, Shimizu and Inoue [14] used LU decomposition which requires $O(M^2)$. Through our experiment, the method will converge at $T = 30$ on our dataset even if we let the the bottom group $g = V$. This improvement of efficiency is the base of our hierarchical layout algorithm and allow us to perform layout calculations for more groups.

The comparison in visual effect between the two method is shown in Fig. 2. More precisely, we use Stress-I, Stress-II [10] and normalized raw stress [4] to evaluate the distortion effect, and measure the degree of change in local structure according to the average angle change compared to the real world. We both evaluate previous method [14] as a baseline, our approach with different α and the geography location after suitable scaling in Table 1.

	Baseline	$\alpha = 1$	$\alpha = 2$	$\alpha = 10$	$\alpha = 10^4$	Geo
Stress-I	0.122	0.132	0.139	0.158	0.168	0.262
Stress-II	0.214	0.231	0.244	0.277	0.294	0.460
Raw Stress	0.015	0.018	0.021	0.028	0.032	0.075
Crossing	21	16	12	10	9	9
Angle-all	10.42	7.45	6.41	4.77	4.35	0.00
Angle-10	25.80	17.60	14.74	10.80	9.62	0.00

Table 1: The result of evaluation. "Cross" represent the number of link crossings in the cartogram, "Angle-all" is the change in angle between any two points compared to the real geographic location, in units of degrees, and "Angle-10" just considers the change in angle to the 10 closest cities. With the increasing of α, the angle maintenance becomes progressively better and the additional crossings in the graph are fewer and fewer.

Compared to the difference between the scaling geographic location and the baseline, the damage of our algorithm to the deformation effectiveness is slight. On the other hand, we can see our approach does preserve the local structural features better.

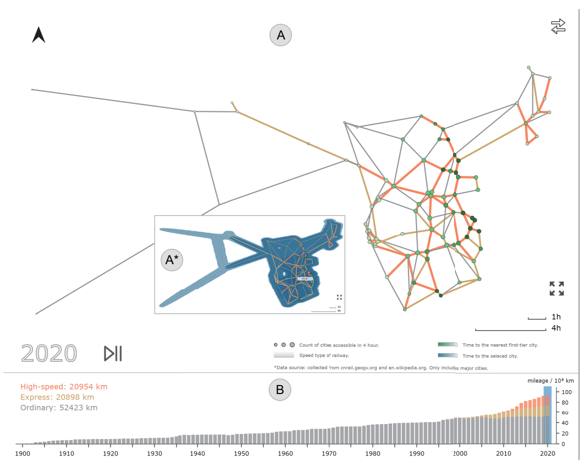


Figure 5: The user interface of A-Map consists of: (A) a main view in the upper left, (B) timeline. The travel time contours (A*) will be shown when user hovers on certain city nodes.

5 Visualization System

Based on the proposed method, we further develop an interactive system, A-Map, to meet the design requirements. We provide two views, including a linear cartogram view which deforms the map according to travel time between all pairs of cities with continuous animation over time, and a timeline that allows users to interactively select their interested time periods.

5.1 Data

We work closely with domain experts and collect the China railway data from 1900 to 2020, and load this data into our system. The main sources of railway line information are online searching and reference materials issued by the national railway department (including construction documents and railway maps). With helps from experts, we generate the operating speed of each railway from 1900 to 2020, overcoming the uncertainty and vacancies on the operation speed of ordinary railways in the early years. Due to the large number of total stations, we select a set of representative stations, remaining only provincial capitals and the departure and terminal stations of each railway. The selection results in a total of 86 stations and 249 railway lines in the data collection, which consists of the accelerations of ordinary railways, the start point of running a new type of train, and the construction events of high-speed railways.

5.2 Timeline

We start from the timeline to introduce our system, A-Map. To reflect global accessibility from an intuitive perspective (**RQ 3**), we demonstrate accessibility in one aspect through the history of railway development. The bottom left part of the interface provides a playable timeline with a stacked bar chart. The bar heights encode the total length of main railways passing in the corresponding year. Railways types are distinguished by colors.

According to the temporal dataset we collected, the timeline spans from 1900 to 2020, accurate to one year as a unit. In the play mode, the time will automatically advance to drive changes in other views to show the dynamic changes in the accessibility of other aspects of the railway network. Users can pause and drag the button to select a specified year, then interact and explore to analyze the details.

5.3 Cartogram

In this view, we show the cartogram in selected period and with selected central city. We also encode two crucial indicators advised by TEs and the travel time contours on the cartogram.

The first indicator is the X-hour transport circle, which stands for the number of cities reachable from the origin city in X-hour travel by railway. Therefore, we encode the number of cities accessible in 4 hours into the size channel of every node in a logarithmic function $r = 1.5 + (5 - 1.5) * \frac{\log_2 N}{\log_2 20}$. Another indicator is the closeness of the first-tier city, which is measured by the travel time to the nearest first-tier city. We select three traditional first-tier cities of Beijing, Shanghai, and Guangzhou, and then color each city by the least travel time to them with 1h, 2h, 4h, 12h as the classification, which reveals whether a city is located in a metropolitan area.

As shown in Fig. 5(A), our system shows travel time contours when users hover on a certain city. While the layout algorithm sometimes compromises to preserve local structure, the mapping between distance and travel time is not accurate. Then the travel time contours can compensate for this. The contours apply similar X-hour classification to demonstrate the cities and areas where people can arrive from certain cities within the time.

Users can switch the cartogram between the global layout and the mode centered on a single origin city by clicking on the city points. New cartograms will be generated according to the selected point to allow specified origin layout analysis (**RQ 1**).

6 Result

In this section, we report two analysis cases on national and city levels to demonstrate our system.

Development of China Railway System. We use our system to review the development history of the China railway network. At the early stage of railway construction, though the number of edges in the cartogram is increasing, the overall scaling remains almost constant. This is also consistent with the objective fact that the early stage of railway paving within the country was based primarily on expansion without regard to speed increases. Between 1956 and 1957, as shown in Fig. 1, a major change can be identified as a significant contraction in the north-south direction due to the completion of the Beijing-Guangzhou Railway. This completion drastically brought the distance between the three top cities (*i.e.*Beijing, Shanghai, Guangzhou) closer. The circles representating cities also get larger and greener obviously.

By 1995, the railroad network had covered most of China's major cities, and then with the seven major speed increases and the construction of high-speed railways, cities began to rapidly converge on each other. As shown in the Fig. 1, there is a nearly 2x difference between the scales of cartogram in 1995 and 2020. We can also find at the initial phase of high-speed rail construction like 2010, compared to the rapid contraction to the interior of the southeast, especially around the Yangtze River Delta, southwestern China has been in a more inflated due to the late construction of high-speed railway as a result of topographical and economic reasons. And after a decade of construction, this imbalance has been visibly reduced.

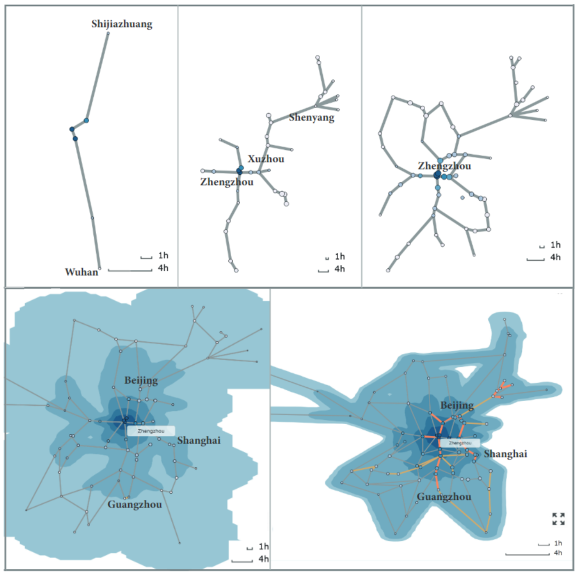


Figure 6: From left to right and top to bottom, The cartogram views Zhengzhou as the center in 1906, 1936, 1958, 1996, and 2012. As time progresses, every city gradually becomes larger, bluer, and closer to Zhengzhou.

Process of Becoming Transportation Center. By calculating the travel time matrix in 2020, we find Zhengzhou has the shortest time to the sum of the remaining major cities. Therefore, we can say Zhengzhou has the best accessibility in one aspect and is the transportation center of China now, however, we are also curious about the process of it becoming a transportation center.

Fig. 6 shows the cartogram centered on Zhengzhou. At first, Zhengzhou was only a passing station on the railway from Shijiazhuang to Wuhan. It didn't play an important role until the construction of the railway to Guangzhou was completed in 1936, after which it became one of several crossings in the railway network at that time, although its importance was not as great as Xuzhou. With the completion of the east-west Longhai Railway in 1953 and the north-south Beijing-Guangzhou Railway in 1957, other cities quickly moved toward Zhengzhou. Zhengzhou became a vital city from the south to the north and from the east to the west of China, establishing its significant position in the railroad network.

This development didn't stop there, as almost every new railway was built to bring a city to Zhengzhou. After the completion of the Beijing-Kowloon Railway in 1996, Guangzhou, the furthest of the three first-tier cities, was close to entering its 12-hour metropolitan coordinating region. After that, the high-speed railway(HSR) took the accessibility to another level, with the completion of the Beijing-Shanghai HSR bringing Zhengzhou into the 4-hour metropolitan coordinating region of Shanghai in 2011, and then the two HSRs with Shijiazhuang as the endpoint made Beijing as the closest first-tier city to Zhengzhou.

7 Conclusion

We have presented an interactive visualization system, A-Map, for exploring intercity accessibility dynamics based on railway network data. In particular, we have proposed a new layout algorithm for linear cartogram construction, which better preserves local structure. Our method can produce cartogram better supporting analytical tasks including to depict the development of a railway network, to identify transportation center, and to reveal the formation of megalopolis.

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