
Visual Analytics for Urban Public Transport

Using visualizations to reveal the underlying movement patterns of urban public transport in Singapore

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Public transport systems (PTSS) play an important role in modern cities, such as Singapore. Vast amounts of urban public transport data have been collected automatically and pervasively, promoting more research focus on analyzing and exploring public transport data when studying PTSS. However, analyzing massive urban public transport data is a challenging task due to its high-complex, large-size, multi-mode and spatio-temporal characteristics. To get over these challenges, visual analytics show great potential as they can make the way of processing and analysis of public transport data transparent: Visual analytics can provide interactive means for transport researchers and decision makers to examine the actual processes of analyzing data instead of just the results.

This article investigates advanced visualization technologies for analyzing and exploring massive urban public transport data that consists of massive commuter RFID card data (EZLink data), transport network and transit schedule in Singapore. To address various analytical tasks raised by transport researchers, a family of novel visual analytics systems have been developed. Specifically, three scales of origin-destination (OD) information (Fig. 01), which are essential in transport modeling and analysis processes, have been extracted from the input dataset for visualization and exploration.

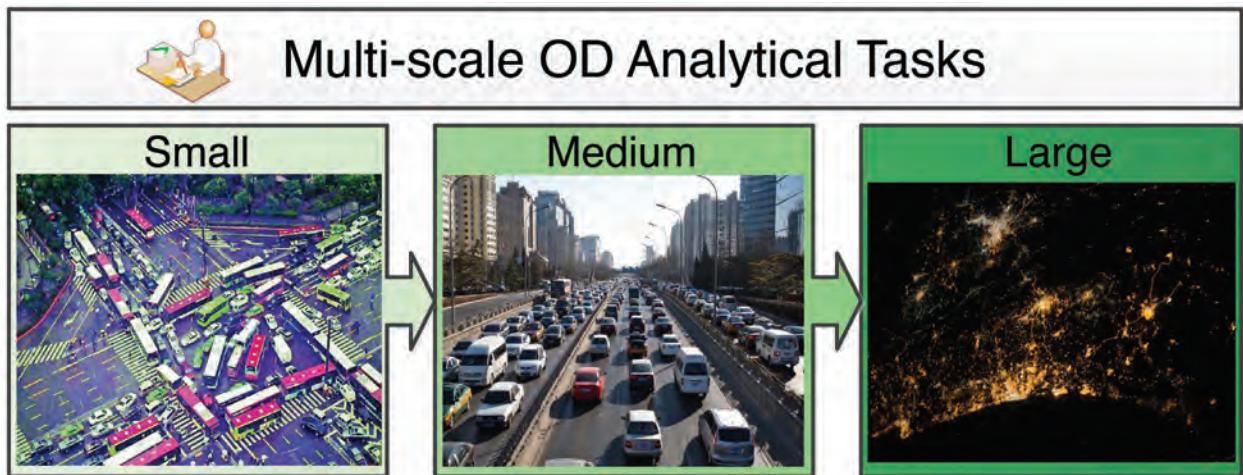


Fig. 01 Multi-scale analytical tasks of OD patterns emerged from transport domain. 1) Small-scale: analyze how moving objects redistribute themselves at junctions, e.g., crossroads, bus stops; 2) medium-scale: study origins and destinations of the trajectories successively passing through an entry and exit waypoints; and 3) large-scale: explore all reachable destinations from a starting location within certain time period.

Small-scale: Interchange Patterns

A small-scale OD pattern, which is referred to as interchange pattern in this article, describes how moving objects redistribute when entering/ passing through a junction node in the transport network. Interchange pattern is a highly valuable means not only for unveiling human movements at junctions, such as crossroads and bus stops, but also for assisting transport planning. For instance, interchange information can help reveal the road junction utilization and suggest crossroad design, e.g., adding a fork.

To support efficient visualization of interchange patterns that emerged from EZLink data, we designed a novel visual representation, namely the interchange circos diagram, for presenting the redistribution of people at junction nodes. Incorporated with various advices from domain experts, we revised and customized the circos figure (Kryzwinski et al. 2009) for presenting commuter interchange: a flyover ring to denote the junction node itself, bi-directional bundling to reduce visual cluttering, and an optimized color assignment on linkages to enhance the visual connections between neighboring interchange circos diagrams, as shown in Figure 02.

The interchange circos diagram has been customized to analyze the interchange patterns at train stations of the Singapore MRT system. As shown in Figure 03, we can pick a train station and visualize its interchange

pattern for a user-selected time interval, which is 08:00 - 10:00 in this case. By examining these four interchange circos diagrams, we can see the relative flow volumes for different possible routes at these train stations, e.g., the major movement directions at each station as well as the relative flow volumes among the four stations. Since the selected time interval is in the morning, we can observe unbalanced flow volumes in the bundled ribbons as well as in the node-connecting links.

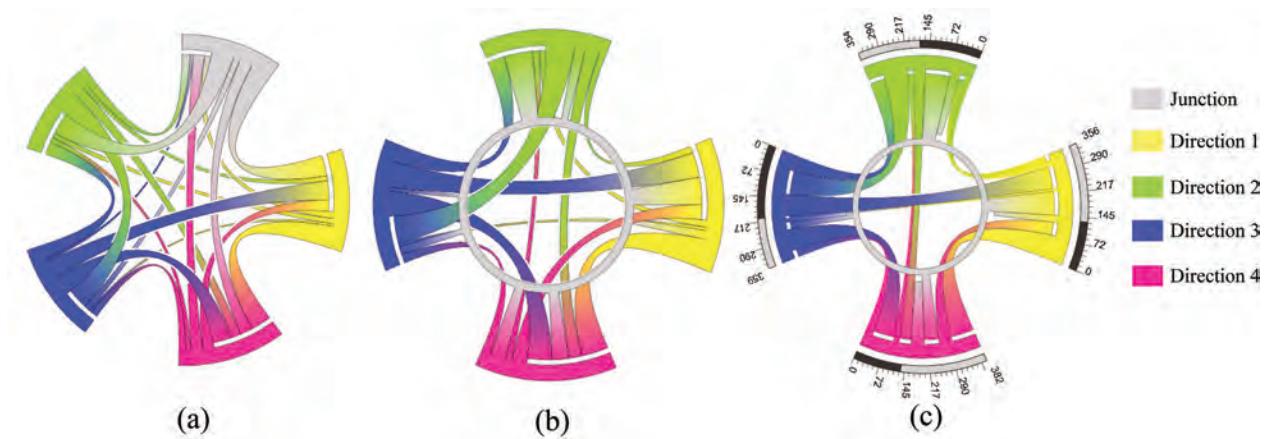


Fig. 02 Developing the interchange circos diagram from the original circos figure: (a) the initial design; (b) use a gray-colored flyover ring (like a source/sink) for the junction itself; (c) bundle pairs of bi-directional ribbons to reduce the visual cluttering.

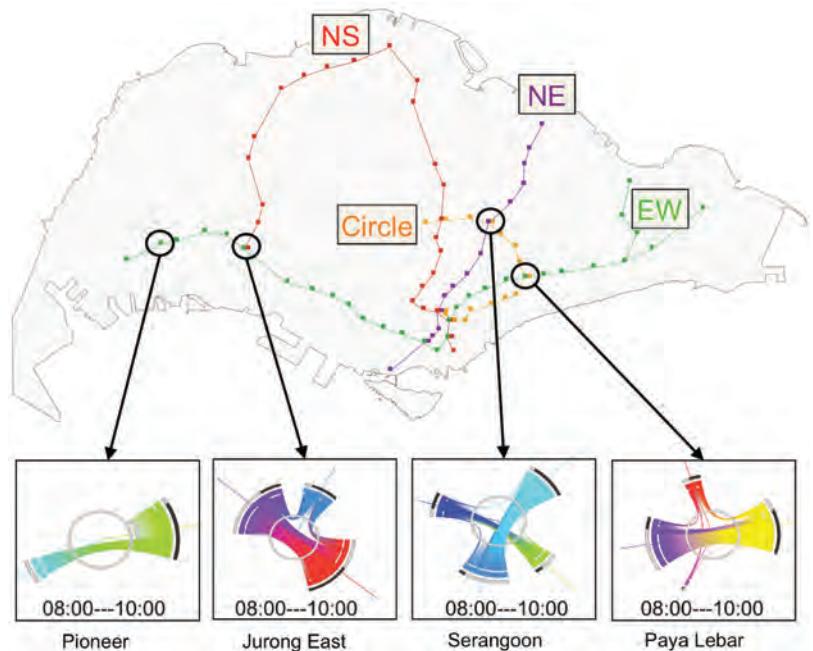


Fig. 03 Interchange patterns at different train stations in the Singapore Metro system.

Medium-scale: Waypoints-constrained OD Patterns

A medium-scale OD pattern, which is referred as waypoints-constrained OD pattern, associates with trajectories that successively pass through entry and exit waypoints in the transport network. Such aspect has not been explored in previous visualization research, and has practical value in transport. For instance, the study by Wang et al. (2012) showed that only a few (less than 2%) of the road segments in urban areas give rise to congestions. This motivates us to study OD patterns subject to specific locations/paths rather than to the en-tire city.

To address such waypoints-constrained OD analytical tasks, we elaborated a set of design principles and rules, and then developed a novel unified visual representation, called the waypoints-constrained OD view, by carefully considering the OD flow presentation, the temporal variation, spatial layout, and user interaction. The waypoints-constrained OD view has three main components: in-flow view, OD-flow temporal view, and out-flow view, as shown in Figure O4. These components work together to support the analytical tasks.

The visualization has been applied to explore the daily pendulum movement patterns in the Singapore MRT data on a normal working day. In transportation, pendulum movements describe an obligatory urban mobility pattern that is highly predictable and recurring on a regular basis (Rodrigue et al. 2013): Employees who commute from residential to working areas contribute to the A.M. peak flow; when they return home, they contribute to the P.M. peak flow. By comparing Figure O5(a) & (b), we can easily observe the pendulum movements pattern. First, both waypoints-constrained OD views identify nearly the same set of major origins and destinations, but with swapped roles, e.g., in the morning, many trajectories end at EW23, EW21, and EW15, while in the evening, many trajectories start from these stations. Second, we can see that the flow volumes between the same OD pair in A.M. & P.M. with reversed directions are almost the same, e.g., flow volume from NS stations to EW23 in Figure O5(a) and that from EW23 to NS stations in Figure O5(b) are nearly equal.

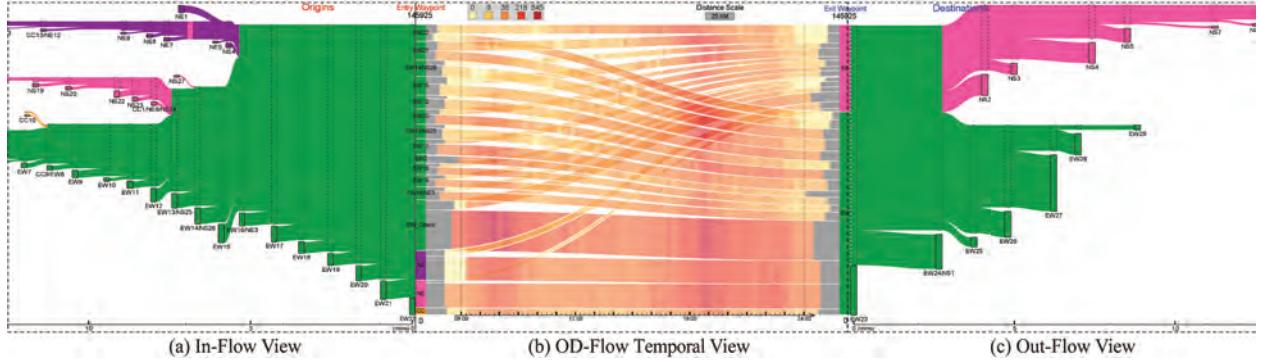


Fig. 04 An example waypoints-constrained OD view with three components: (left) in-flow view, (middle) OD-flow temporal view, and (right) out-flow view, as an integrated and coordinated solution to support the waypoint-constrained OD visual analytical tasks.

Large-scale: Mobility Patterns

A large-scale OD pattern explores all reachable destinations from a starting location within certain time period, which considers the mobility in the entire transport system. Mobility measures a transport system's ability to move goods and people to their destinations based on the quantity and quality of physical travel (Handy 2002). Traditional transport planning aims at improving the mobility of transport systems. Thus, studying the mobility of a transport system is highly beneficial to both individuals as well as an entire city as a whole.

However, developing visual analytics methods to meet this goal is a highly challenging task: First, public trans-portation systems are increasingly complex. Second, existing works in visualizing public transportation net- works mostly employ network visualization methods and focus on presenting the network topology across stops. Lastly, the mobility-related factors vary dynamically with both time and space, and could also exhibit round-the-clock patterns. To address the above issues, we developed a visual analytics framework to visualize and explore mobility-related factors in a public transportation system with three visualization modules:

- Isochrones map view (Fig. 06), which presents geographical regions accessible from a given starting location within certain duration;
- Isotime flow map view (Fig. 07, left), a novel strategy that linearizes a flow map in a parallel isotime fashion, enabling visualization and exploration of various mobility-related factors; and
- OD-pair journey view (Fig. 07, right), which enables interactive exploration of various mobility-related factors, and their temporal variations, along the origin-destination journeys.

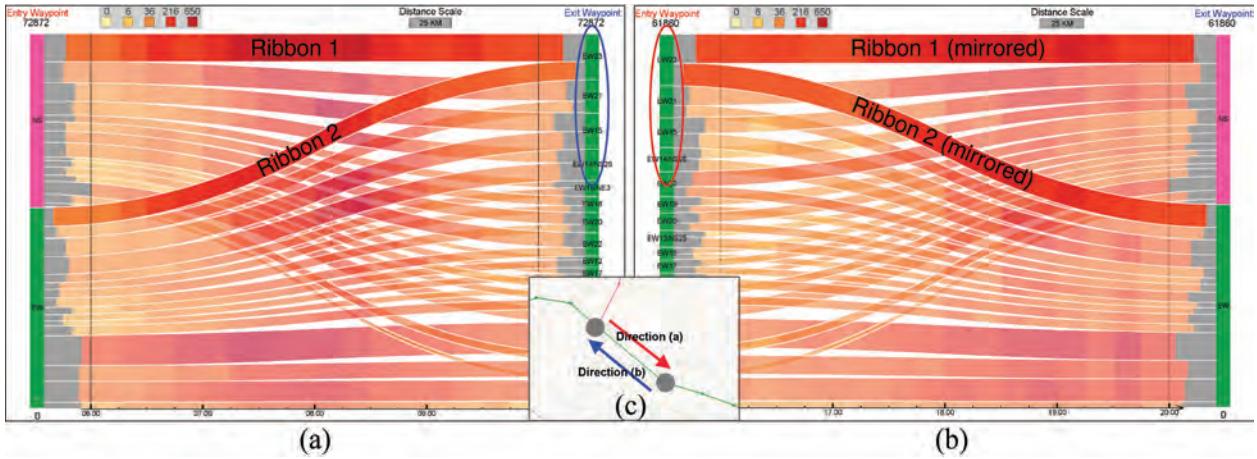


Fig. 05 Daily pendulum movement exploration. (a) & (b) present an interesting pendulum movement pattern, which illustrates home-to-work movements through the red arrow in (c) in the morning (6:00-10:00), and work-to-home movements through the blue arrow in (c) in the evening (16:00-20:00).

The visualization can facilitate the exploration of PTS mobility over different locations in a city. Figure 06 presents the isochrone map views related to two different locations on the map: Changi airport (left) and Boon Lay (right). Though the starting time for both visualizations is 8 A.M., the isochrone map views reveal very different sizes of reachable dominions from the two locations. From the isochrone map view on the right, we can clearly see the reachable regions are much larger, since Boon Lay is an important interchange center in the Singapore MRT system, while Changi airport is located far away from the city.

Conclusion

This article has presented three intuitive and informative visual analytics tools developed to depict the knowledge emerged from the input EZLink data. The ultimate goal is to facilitate transport researchers' exploration and analysis of the data, such that to help them manage the traffic flow and improve the PTS design. These works were published recently in prestigious visualization research journals IEEE Transactions on Visualization and Computer Graphics (IEEE TVCG) (Zeng et al. 2014) and Computer Graphics Forum (CGF) (Zeng et al. 2013) & (Zeng et al. 2015). We have also contributed our source code to URA for their further tool development.



Fig. 06 The isochrone map views present spatial-reachability regions from 8 A.M. at origin (red icons) Changi Airport (left) and Boon Lay (right), by contour lines and areas over the geographical map. Dark blue and light blue indicate [0, 30] and (30, 60] minutes, respectively.

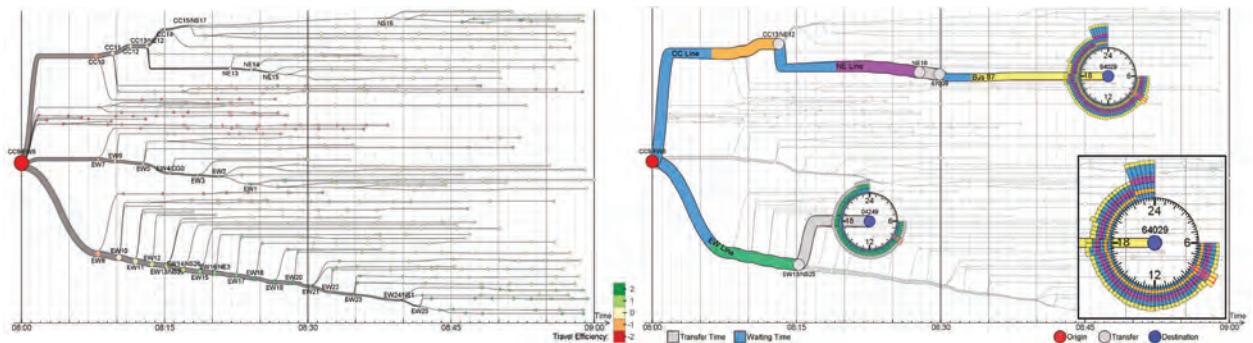


Fig. 07 Left: the isotime flow map view overviews time-efficient routes from a source location in a parallel isotime fashion. Right: the OD-pair journey view enables us to explore temporal variations of mobility-related factors for specific time-efficient routes.

References

Handy, Susan (2002) 'Accessibility-vs. mobility-enhancing strategies for addressing automobile dependence in the US'. *European Conference of Ministers of Transport*.

Krzywinski, Martin, Jacqueline Schein, Inanc Birol, Joseph Connors, Randy Gascogne, Doug Horsman, Steven J. Jones and Marco A. Marra (2009) 'Circos: an information aesthetic for comparative genomics'. *Genome Research*, 19:1639-1645.

Rodrigue, Jean-Paul, Claude Comtois and Brian Slack (2013) *The Geography of Transport Systems*. New York, Routledge.

Zeng, Wei, Chi-Wing Fu, Stefan Müller Arisona, Alexander Erath and Huamin Qu (2014) 'Visualizing Mobility of Public Transportation System'. *IEEE Transactions on Visualization and Computer Graphics (IEEE TVCG)* (*IEEE VAST*), 20(12):1833-1842.

Zeng, Wei, Chi-Wing Fu, Stefan Müller Arisona, Alexander Erath and Huamin Qu (2015) 'Visualizing Waypoints-Constrained Origin-Destination Patterns for Massive Transportation Data'. *Computer Graphics Forum*, second round review.

Zeng, Wei, Chi-Wing Fu, Stefan Müller Arisona, and Huamin Qu (2013) 'Visualizing Interchange Patterns in Massive Movement Data'. *Computer Graphics Forum*, 32(3pt2): 271-280.

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