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A Weighted Centrality-Based Approach to Assessing Station Importance in the Tokyo Metro Network

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Extended Abstract

Urban metro systems are critical components of mass transit, where maintaining reliability, safety, and resilience requires a realistic understanding of station importance. Complex network theory (CNT) enables the identification of critical nodes through centrality analysis and has been applied to aviation [1], railways [2], multimodal transport systems [3], and metro systems [4]. However, most metro-related studies still rely primarily on pure topological representations of the network and thus overlook key operational factors such as passenger volume and travel time. This study addresses this gap by developing a weighted network framework for the Tokyo Metro that integrates empirical passenger data and detailed travel-time components, and by examining how these enhanced centrality measures relate to the surrounding urban environment.

The first objective is to redefine traditional centrality metrics, namely strength degree, betweenness, and closeness, by incorporating passenger volumes and comprehensive travel time. The Tokyo Metro is modelled as a weighted graph where nodes represent stations and edges represent rail links. Edge weights reflect generalized travel impedance derived from in-train travel time, in-station pedestrian movement, transfer penalties, and waiting time, capturing passenger behaviour that is specific to Tokyo's dense and highly interconnected network. In parallel, passenger volumes at each station are used to adjust node weights, so that centrality not only reflects structural position but also actual usage intensity.

The second objective is to evaluate how these redefined centralities alter the perceived hierarchy of stations compared with conventional topology-based measures. For each centrality type, rankings obtained from the traditional and the redefined models are compared to quantify ranking changes. Results show that the incorporation of passenger volumes and realistic travel times substantially reshapes the list of top-ranked stations. For example, major interchange and commercial hubs such as Shibuya and Shinjuku move up in strength-based rankings when empirical demand is considered, while some structurally central but less frequented stations lose prominence. Nevertheless, certain stations such as Otemachi remain consistently highly ranked across both approaches, confirming their critical role within the network.

The third objective is to link network importance to the surrounding urban context through points-of-interest (POI) data. POI data for the Tokyo metropolitan area were obtained from the Foursquare OS Places Map, yielding approximately 1.2 million records associated with a predefined set of ten functional categories. For entries without category labels, we employed a two-stage classifier that first applies high-precision rule-based matching on POI names and then uses a linear SVM trained on TF-IDF character n-gram features to predict the missing categories. The final ten categories include, but are not limited to, retail, dining and drinking, business and professional services, and community and government. POIs are aggregated within a 1 km buffer around each station to obtain category-specific and total POI counts. Correlation analysis is then conducted between POI indicators, passenger volumes, and both traditional and redefined centralities. The results indicate that centralities are positively associated with POI density, with closeness centrality exhibiting the strongest relationships, while betweenness shows weak or negligible correlations. Importantly, when passenger volume and travel-time information are embedded in the centrality definitions, the correlations with POI counts become stronger than for the purely topological metrics, suggesting that the proposed framework captures station importance in a way that is more aligned with actual urban functions and activity patterns.

Overall, this study demonstrates that integrating operational data and realistic travel behaviour into CNT-based analyses significantly improves the interpretation of metro station importance and its relationship with the built environment. The proposed methodology offers a more robust evidence base for prioritising investment, enhancing service reliability, and supporting transit-oriented development in large metropolitan rail systems such as Tokyo Metro.

References

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