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Analyzing Singapore's Metro Networks: Insights for Enhancing India's Railway System

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Abstract*— The main objective of this research is to conduct an analysis of Singapore's metro networks and determine the most important stations based on various criteria. The findings from this analysis will be used to address issues within India's railway system. Additionally, the study aims to gain insights into the effective utilization of Singapore's MRT system by its residents. Several countries, including China, South Korea, the UK, and Taiwan, have adopted Singapore's transportation ideas, technology, and analytical methodologies to improve their own public transportation systems. India has also witnessed significant developments in its public transportation sector, including improved infrastructure, increased social media awareness, and higher investments. The analysis of Singapore's metro network goes beyond considering population and includes factors such as infrastructure, station connectivity, and public awareness. This study will help identify stations with extensive connectivity and important hubs. Network analysis tools will be used to evaluate the success of Singapore's metro system and provide valuable insights for enhancing public transit in India. Factors like station usage, population distribution per station, and distances between stations will play a vital role in the comprehensive analysis of Singapore's MRT system. Social network analysis metrics, such as degree, centralities, and betweenness, will be employed to draw meaningful conclusions about the effectiveness of Singapore's Metro system. The outcomes of this analysis will enable the identification of strengths and weaknesses within India's metro system and provide recommendations for improvement through various strategies.

***Index Terms*—Singapore's metro networks; Public transportation systems; Hubs.**

I. INTRODUCTION

Machine Singapore, renowned as a highly industrialized nation, has achieved remarkable progress in areas such as architecture, technology, transportation, and education. The transportation infrastructure has played a pivotal role in Singapore's rapid development. Particularly, the Mass Rapid Transit (MRT) system has been at the forefront of Singapore's metro transportation, effectively meeting the demands of urbanization.

The MRT system has not only bolstered Singapore's economy but has also gained international recognition. Many developed countries, including China, Japan, Italy, France, and the UK, have taken inspiration from Singapore when establishing their own metro systems. Singapore's commitment to using public transportation as a solution to global issues like pollution and traffic congestion caused by the increasing number of cars showcases its dedication to sustainable urban development.

The allure of Singapore's MRT system stems from its exceptional infrastructure and efficient population monitoring and analysis. The system is designed to accommodate population growth while ensuring efficient transportation services. Despite being a developed country with a growing population and significant tourism, Singapore has effectively planned and operated its MRT system. Taking cues from the experiences of Singapore's MRT system, there are valuable lessons for the Indian metro and railway system, given India's large population and high tourism rates. India faces similar challenges in meeting the transportation needs of its population and visitors. This analysis utilizes network analysis techniques to explore various aspects of Singapore's metro network and provides insights into potential developments for India's metro systems.

By treating stations as nodes and employing centrality metrics such as degree centrality and betweenness centrality, this analysis identifies the most crucial stations within Singapore's MRT network. The statistics and data collected from all stations in Singapore serve as a basis for comparison with India's metro system, offering valuable information and analysis. The objective is to identify key MRT stations in Singapore and evaluate their relevance to the Indian context. The comprehensive study of Singapore's MRT system presents a promising roadmap for enhancing India's railway system. By utilizing network analysis techniques, this study offers a comprehensive understanding of Singapore's metro network, facilitating the identification of vital stations. Such analysis can guide the evaluation and improvement of India's metro system, paving the way for more efficient and effective transportation across the country.

A. Problem Statement

Mac The current state of the Indian metro system falls short of meeting the global standards and demands in urban transportation. Despite its significance, the system exhibits

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several limitations that hinder its effectiveness, reliability, and capacity to cater to the growing population. This research endeavor aims to address these issues through a comprehensive evaluation of the strengths and weaknesses of the Indian metro system, thereby proposing necessary improvements. To achieve this objective, a rigorous comparative analysis will be undertaken, examining the metro systems of China, the United States, Singapore, and Japan. The primary focus will revolve around comprehending their achievements and challenges encountered during the development of exemplary MRT systems. Singapore and Japan emerge as compelling examples due to their well-established and extensively utilized MRT networks. These nations have effectively dealt with construction-related obstacles and implemented innovative technologies and ideas to ensure the provision of efficient transportation services.

By drawing insights from the experiences and successes of these advanced nations, this study endeavors to identify pivotal changes that can enhance the Indian metro system. The research will delve into the exploration of cutting-edge technology adoption while emphasizing the paramount importance of public awareness regarding the benefits of a dependable metro system. Additionally, the study will underscore the imperativeness of establishing a robust infrastructure, implementing effective planning strategies, and fostering a sense of ownership and responsibility among the population. Through meticulous analysis and the provision of actionable recommendations, this research aspires to contribute to the transformation of India's metro system into a world-class transportation network. It will address specific challenges encountered by India, such as accommodating population growth and meeting global competitiveness. The research will propose pragmatic alternatives aimed at improving the system's effectiveness, reliability, and capacity. Ultimately, the objective is to drive substantial advancements in infrastructure, public engagement, and technology, thereby paving the way for the establishment of an exceptional metro system in India.

II. LITERATURE SURVEY

Muhamad Azfar Ramli proposed a novel method for predicting the distribution of passenger throughput in a metropolitan rapid transit system. This method involves calculating the normalized betweenness centrality of stations and edges in the rail network. To evaluate the effectiveness of our approach, we compare the throughput distribution with the betweenness centrality distribution using real passenger data from Singapore's rail system, which recorded over 14 million trips in a single week. Our analysis shows that removing outliers, which represent less than 10% of the stations, results in a statistically significant correlation above 0.7. Notably, these outliers correspond to stations that recently opened, indicating that travel patterns at these stations have not yet stabilized. Additionally, when examining the data for each line separately, we observe significant variations in the characteristics of each line, leading to a significant improvement in the correlation. This emphasizes the importance of considering the unique properties of individual lines. method demonstrates that transport planners can accurately predict passenger traffic by utilizing static network analysis of the transport network's structure, without relying on complex dynamic simulation techniques.[1]

Zixuan Liu has collected the Internet public opinion is a dynamic system influenced by a large number of users, with characteristics such as explosive growth and evolutionary ambiguity. Computational intelligence plays a key role in mining and analyzing textual data related to public sentiment. Using the Changchun Changsheng Vaccine Incident as an example, we analyze the evolution of network public opinion. By examining the level of interest in emergency-related keywords, we identify distinct phases and explore the geographical and topological structure of each phase using social network analysis. We segment the network public opinion into four phases: latent, spreading, control, and stable, each with unique characteristics. These findings provide insights for effective governance of network public opinion. Overall, this research examines the evolution of internet public opinion, focusing on the Changchun Changsheng Vaccine Incident, and offers valuable insights for policy measures in managing online public sentiment.[2]

Andrea Failla did two distinct research directions have emerged with the aim of enhancing representations of complex networks. The first direction focuses on high-order modeling, which examines the connectivity between sets of nodes rather than individual pairs. The second direction, known as feature-rich augmentation, incorporates external data into the network structure. This research introduces a novel toolkit called Attributed Stream Hypergraphs (ASHs), which combines high-order and feature-rich components to analyze large networks. ASHs provide a comprehensive framework for characterizing complex social processes in social network analysis. They incorporate topological, dynamic, and attributive components, enabling a wide range of studies when applied to real social interactions. These include analyzing node similarities within participating hyperedges, capturing similarities in high-order groups, and revealing temporal dynamics through routes that connect hyperedges the integration of high-order and feature-rich components in ASHs contributes to the advancement of complex network research, particularly in the field of social networks. By considering multiple aspects of network structure and dynamics, ASHs offer valuable insights into the complexities of social processes.[3]

Teferi Tolera To enhance resilience in socioecological systems (SES) amid environmental changes, effective natural resource management is crucial. Governance networks established by actors play a vital role in adapting to complex

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challenges and promoting SES resilience. These networks enable diverse perspectives, knowledge, and values to be exchanged, fostering collaboration and innovative solutions for rangeland issues. However, the structural patterns of collaborative linkages among actors significantly influence behavior and governance effectiveness. Using social network analysis (SNA), this study identifies structural gaps in the Borana rangelands. Quantitative SNA reveals a low network density, indicating limited interactions and linkages among actors horizontally and vertically within the governance system. This lack of connectivity hampers information, experience, and resource flow, hindering the development of shared values and collective action. The study also highlights the absence of network heterogeneity and closure in the rangelands governance system, impeding collaborative problem-solving and efficient resource utilization. Therefore, a policy environment that fosters cooperation, strengthens actor connections, builds trust and social capital, and enables effective collective initiatives is necessary. By addressing these gaps, the resilience of the Borana rangelands can be enhanced, promoting sustainable resource governance.[4]

Jian Gang Jin This research study introduces a unique approach to examining disruptions in network systems, with a specific focus on a multi-modal transportation network that integrates bus and metro services. The goal is to enhance the resilience of the metro network by capitalizing on the improved connectivity and redundancies offered by the integrated system. Instead of creating an entirely new bus network, the research emphasizes the importance of targeted integration with existing bus services to achieve the desired level of resilience. The study represents the integrated metro and bus system using a network model. A two-stage stochastic programming model is developed to evaluate the inherent resilience of the metro network and optimize its localized integration with bus services. A case study based on the public transit system in Singapore, utilizing real travel demand data, demonstrates the significant enhancement in metro network resilience achieved through the targeted integration with public bus services.[5]

III. IMPLEMENTATION OF SYSTEM

The current state of the Indian metro system does not meet the standards required in the global competitive environment. To address this, we conducted an independent study to evaluate the strengths and weaknesses of our Indian Metro System and identify areas in need of improvement. In our analysis, we made comparisons with well-developed countries such as China, the United States, Singapore, and Japan. Our intention was to go beyond a simple examination and delve deeper into the subject matter. Through our extensive research, we examined the current state of the Indian metro system, identified existing issues, and proposed potential solutions based on the experiences of highly developed nations that have successfully built their own MRT systems. Notably, Japan and Singapore emerged as countries with the highest utilization of public transportation, including MRT, among developed nations. These countries have implemented advanced MRT networks and introduced innovative solutions to overcome challenges encountered during their journey towards becoming leading MRT system countries.

Singapore, in particular, became a key reference point for our analysis due to its early development of the MRT system when India was in the initial stages of implementation. By studying Singapore's progress, we aimed to gain valuable insights into the significant adjustments required in our system. Additionally, we emphasized the importance of incorporating cutting-edge technology and fostering public awareness about the benefits and effective utilization of the metro system. Our research provides a comprehensive roadmap for enhancing the Indian metro system to make it globally competitive and on par with the best networks worldwide. By drawing upon the experiences of these developed nations, we can pinpoint the necessary procedures and strategies required to establish a world-class metro system in India.

To accomplish our research objectives, we utilize a comparative approach to analyze the metro systems of several developed countries. Our investigation focuses on the successes and challenges encountered during the development of their MRT systems, with particular emphasis on prominent examples like Singapore and Japan. Through a detailed examination of technological innovations, infrastructure development, and public engagement strategies, we aim to identify effective practices that can be implemented in the Indian metro system. By employing a comparative methodology, we thoroughly examine the metro systems of various industrialized nations to fulfill our research goals. This analysis allows us to gain valuable insights into the achievements and difficulties experienced during the establishment of their Mass Rapid Transit (MRT) systems. Notably, we highlight Singapore and Japan as exemplary cases due to their significant accomplishments in this field.

Our investigation primarily focuses on the technological advancements integrated into the metro networks of these nations. This includes exploring cutting-edge signaling systems, automated train control, and intelligent infrastructure solutions that have enhanced the efficiency and reliability of their MRT networks. Through the examination of these innovations, our aim is to identify adaptable practices that can enhance the performance and operational capabilities of the Indian metro system. Furthermore, we thoroughly scrutinize infrastructure development as a crucial aspect of our research. We delve into the planning, design, and construction strategies employed by Singapore and Japan to establish their extensive metro networks. This encompasses the integration of underground, elevated, and at-grade sections, as well as the efficient utilization of limited

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urban space. By analyzing these strategies, we aim to identify approaches that can guide the expansion and development of the Indian metro system, considering factors such as cost-effectiveness, construction timelines, and minimizing disruptions to existing urban areas.

Public engagement holds great significance in the successful implementation of metro systems. Therefore, we investigate the strategies employed by Singapore and Japan to involve the public in decision-making processes, gain public support, and address concerns and feedback. This includes analyzing public consultations, information campaigns, and community outreach initiatives. By understanding these strategies, we strive to identify effective methods of engaging the Indian public in the development and operation of the metro system, ensuring that it aligns with their needs and aspirations. Through our comprehensive analysis of metro systems in multiple developed countries, with a specific focus on Singapore and Japan, we aim to derive best practices that can be applied to the Indian metro system. By incorporating successful strategies in technological innovation, infrastructure development, and public engagement, our goal is to contribute to the enhancement and advancement of the Indian metro network. Ultimately, our research endeavors to improve urban mobility and facilitate sustainable urban development in India.

The objective of this research paper is to systematically analyze and visualize the Singapore MRT network. The methodology begins with the installation and loading of essential packages, specifically "rvest," "igraph," and "plyr," which facilitate web scraping, network analysis, and data manipulation. Utilizing the "rvest" package, web scraping techniques are employed to extract relevant information about MRT stations from the HTML content of the "List of Singapore MRT stations" Wikipedia page. The extracted data then undergoes subsequent preprocessing steps, including column selection, renaming, row elimination, and value modifications.

To represent the MRT network as a graph, distinct edge lists are created for each MRT line (NSL, EWL, CAL, NEL, CCL, DTL) by filtering the data based on line codes and generating source and target lists. These individual edge lists are merged into a consolidated data frame called "mrt_edgelist," which incorporates additional rows to capture connections between specific stations. The resulting graph is loaded into the "igraph" package for analysis, with a specific focus on identifying and eliminating multiple edges between nodes to ensure the accuracy of the data.

Descriptive statistics are computed to gain insights into the overall characteristics of the MRT network, including measurements such as network size, density, diameter, average path length, and distances between nodes. Additionally, various attributes of the graph nodes, such as degree, betweenness centrality, closeness centrality, coreness, and eigenvector centrality, are calculated to evaluate the significance and connectivity of individual stations. The graph visualization stage employs various layouts and node attributes, considering factors such as degree, closeness centrality, betweenness centrality, and eigenvector centrality. Adjustments are made to attributes such as edge color, width, curve, vertex size, and labeling to enhance the clarity and interpretability of the graph representation.

Basic statistical analysis is performed on the graph attributes, generating frequency tables for degree, coreness, betweenness centrality, closeness centrality, and eigenvector centrality to examine their distributions and variations within the MRT network. This research paper aims to contribute to a comprehensive understanding of the Singapore MRT network through a systematic approach involving analysis and visualization. The outcomes and insights derived from this research have the potential to inform decision-making processes, identify areas for improvement, and provide support for future studies related to urban transportation systems.

IV. RESULTS AND DISCUSSION

This analysis report distinguishes itself by adopting a broader perspective that encompasses multiple countries, rather than focusing exclusively on the pros and cons of a single country. To gain insights into Singapore's MRT system, it employs concepts from Social Networking such as degree, betweenness centrality, eigen centrality, and closeness. By utilizing these social networking concepts, it becomes possible to analyze the stations and uncover the interrelationships among them. These relationships play a pivotal role in evaluating the stations in comparison to one another, leading to conclusions that can guide the development of the Indian MRT system.

An important aspect of this analysis is its departure from overreliance on population as the primary criterion for analysis, which is commonly observed in other reports. Instead, this analysis provides explanations based on its own findings, taking into account factors like technological advancements, citizen awareness, and the complexity of the networking involved. Furthermore, it emphasizes the significance of station degree, indicating that Singapore's government has achieved remarkable success in creating an exceptional and advanced MRT system by prioritizing these key areas.

In addition to recognizing the efforts and commitment of the Indian government in establishing metro networks, this analysis suggests that further enhancements to the Indian MRT system can be achieved through increased efforts, greater utilization of research and development, and allocating additional resources to this department.

By adopting a comparative approach and leveraging social networking concepts, this analysis offers a comprehensive understanding of MRT systems across various countries,

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with a particular focus on Singapore. It not only identifies best practices but also highlights areas where improvements can be made within the context of the Indian MRT system.

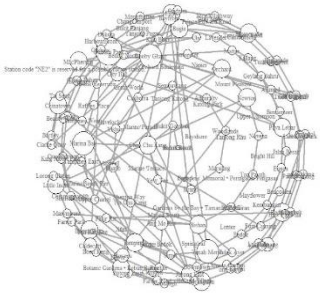

Fig. 1. graph Layout

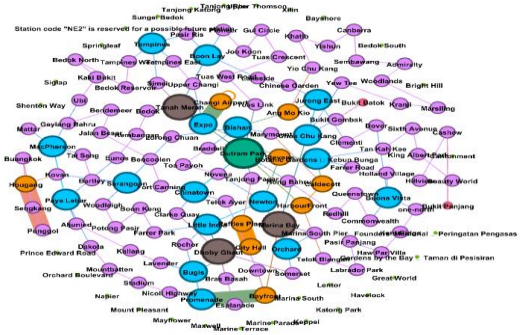

Fig. 2. Converting the graph Layout into Fruchterman Reingold Layout

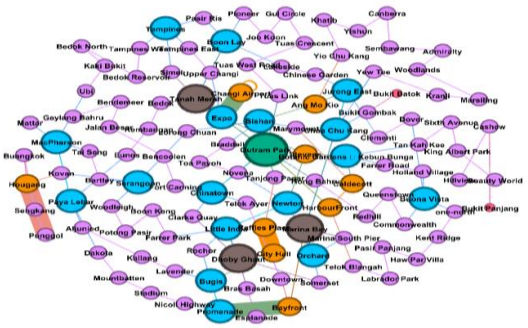

Fig. 3. After Removing Zero Degree Nodes

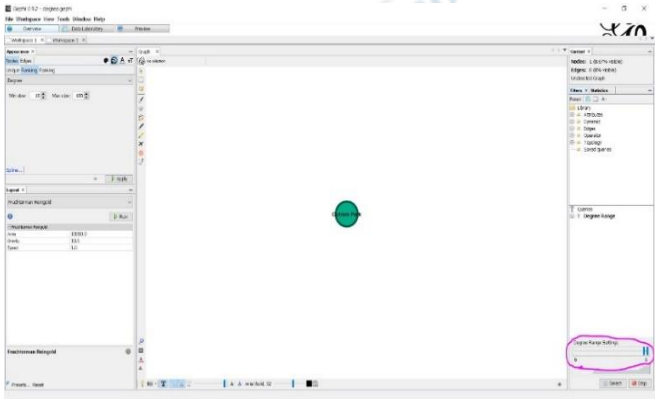

Fig. 4. Highest Degree Node

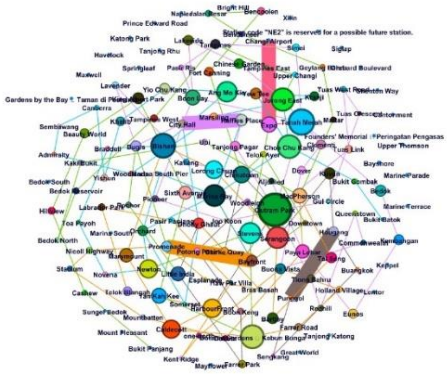

Fig. 5. Betweenness

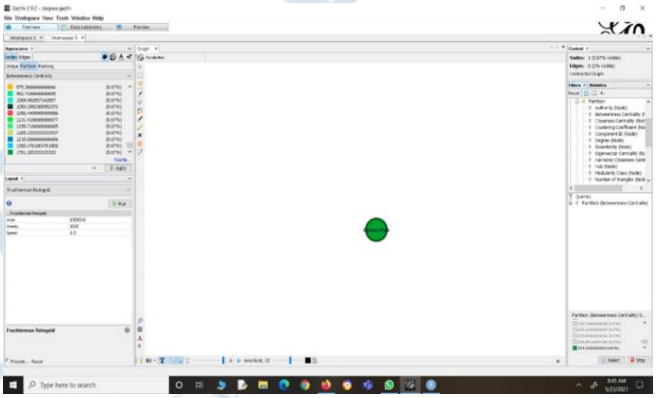

Fig. 6. Highest Betweenness Among Other Nodes

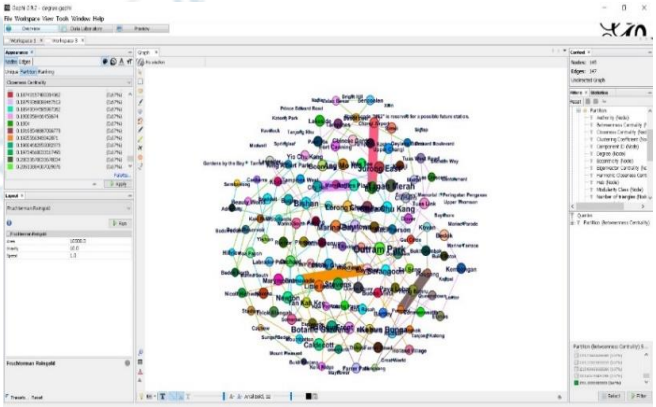

Fig. 7. Closeness

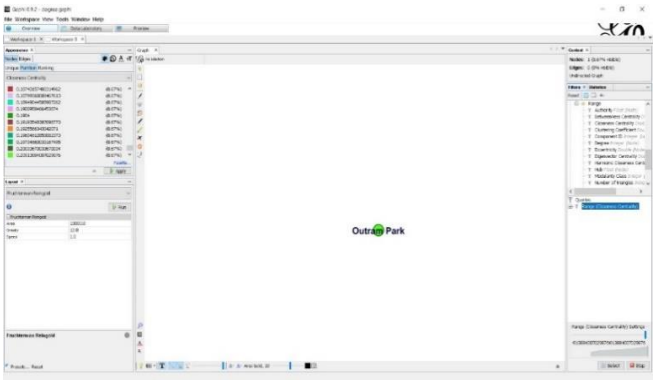

Fig. 8. Highest Closeness

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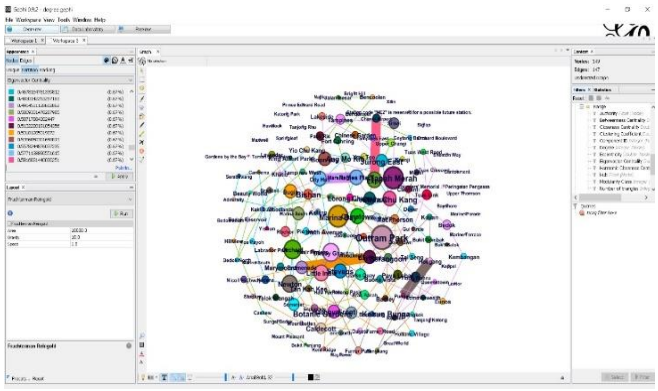

Fig. 9. Eigen Vector

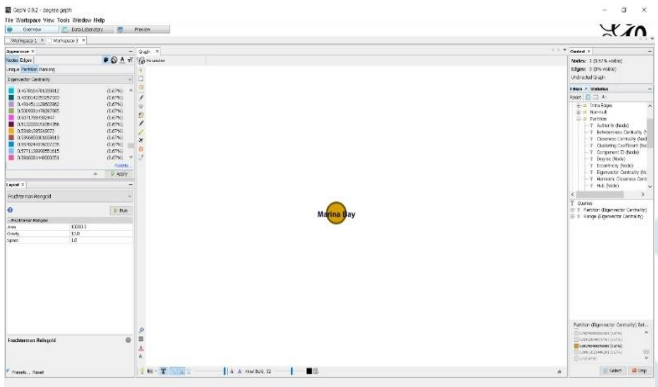

Fig. 10. Highest Eigen Vector

A small proportion of stations within the Singapore Metro System have no connections to other stations, indicating a degree of zero. In contrast, the majority of stations in the system are interconnected. OUTRAM PARK stands out among these stations with a degree of 6, underscoring its prominence and significance as it is surrounded by six adjacent stations, Moreover, OUTRAM PARK demonstrates the highest betweenness centrality within the Singapore Metro system. This highlights its pivotal role as a crucial hub through which a significant number of passengers travel, resulting in reduced transportation costs compared to using personal vehicles. The station's high degree of betweenness centrality contributes to its popularity among passengers.

Another interesting discovery is that OUTRAM PARK boasts the highest closeness centrality in the Singapore Metro system. This indicates its strong influence on neighboring stations and the broader network. The operations and activities at OUTRAM PARK have a substantial impact on the prospering businesses, diligent residents, and visiting tourists in Singapore. In our examination of stations within the Singapore Metro system, eigen centrality assumes a noteworthy role, setting it apart from other social network analysis measures. Notably, MARINA BAY exhibits the highest eigen centrality, distinguishing it from other centrality metrics where OUTRAM PARK ranks highest. This suggests that MARINA BAY holds considerable significance, albeit in a different manner than OUTRAM PARK.

V. CONCLUSION

Singapore has gained international recognition for its advancements in science, education, and transportation, as well as the hardworking nature of its population. The MRT system in Singapore is highly regarded worldwide for its technological innovations and effective regulations. The Singaporean government has made significant investments in networking, infrastructure, and scientific developments, which have been crucial to the country's success. An extensive analysis of the MRT system in Singapore reveals the impressive networking efforts undertaken to meet the needs of residents and the growing tourism industry. The focus is on establishing strategic connections between stations, emphasizing the importance of a well-balanced network rather than relying solely on one station.

The MRT system demonstrates exemplary networking strategies, evident from the fact that the maximum station degree is 6. Each station has been strategically located to minimize commuting time and expenses for the population. Singapore places a strong emphasis on short-distance travel and provides ample networking options to cater to the demands of the business community.

The analysis incorporates essential social network concepts such as degrees, betweenness centralities, closeness centralities, and eigen centralities to provide a fundamental understanding of Singapore's MRT system. The findings indicate that all stations have short distances between trains, high train frequency, and significant daily passenger flow. Singapore effectively manages its large population through well-developed infrastructure and robust enforcement of laws. The government's commitment to equitable service provision is evident in the consistent betweenness and closeness centralities observed across stations, taking into account factors such as revenue, population, and business requirements. This approach allows citizens to choose stations based on their individual needs rather than being limited to a restricted set of stations. Stations with extensive connections to neighboring stations, such as OUTRAM PARK and MARINA BAY, are considered vital. As the government plans for additional stations to accommodate the growing population, networking efforts are carried out with great care and supervision. The success of Singapore's MRT system is further attributed to the presence of advanced metro systems, with substantial government investments playing a pivotal role.

In contrast, India's MRT system falls short in comparison. Despite government efforts, the public perception of India's railway system is less favorable due to a lack of awareness and limited public usage. However, the situation is gradually improving as the government invests in cutting-edge technology, infrastructure, and awareness campaigns. Nevertheless, India's railway network has yet to match the level of development seen in Singapore. Operations, community engagement, and infrastructure in India tend to

revolve around a small number of key stations, resulting in various challenges. This concentration of activity at a few stations negatively impacts revenue generation for other stations nationwide. As a result, individuals may opt for personal transportation to avoid congestion and delays at major stations. The high concentration of passengers at specific stations hampers progress and upgrades, disrupting commuters' schedules. To address these issues, each station needs to be given priority, and networking should address the problem of overcrowding. This approach will facilitate infrastructure improvements, allowing for the replacement of outdated railways with modern metros and high-speed bullet trains, ultimately accommodating a larger number of Indian residents and tourists and enhancing the railway system.

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