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Evaluating Public Bus Transit Efficiency and Centrality: A Network Science Approach for Kamloops, Kelowna, Squamish and Victoria

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Abstract: As concern about climate change and its consequences continues to grow, public transportation keeps positioning even more as an essential service for urban areas, offering residents and visitors a greener and more affordable alternative form of transportation, compared to private vehicles. The aim of this study is to analyze the public bus transit network of Kamloops, Kelowna, Squamish and Victoria using network science techniques to find key points, highlight the network's strengths and suggest possible improvements. The data was retrieved from the British Columbia government data website. After properly cleaning the data, it was entered into RStudio for further analysis. Various network science metrics were calculated, including hubs, centrality, betweenness centrality, distance metrics between stops and eigenvector centrality.

Keywords: Public transportation; British Columbia; betweenness and eigenvector centrality; hubs

1. Introduction

In cities like Kamloops, Kelowna, Squamish or Victoria, where bus transportation networks are smaller compared to major metropolitan areas, it is essential to ensure that the network is as efficient as it can be and that it is able to cover the needs for all the necessary areas of the cities. These smaller networks face unique challenges, such as limited resources, uneven geographic coverage, and fluctuating demand across different regions. Moreover, the relatively smaller scale of these networks can lead to vulnerabilities, where the disruption of a single critical route or stop can significantly impact the entire system's functionality.

To address these challenges, data-driven analyses become crucial. By leveraging tools from network science and spatial analysis, we can identify critical hubs, optimize route planning, and ensure equitable service across underserved areas. These efforts are particularly important in smaller urban areas, where public transit often serves as the primary or sole mode of transportation for many individuals, including students, low-income residents, and seniors. Balancing efficiency, accessibility, and resilience in these networks are key to promoting social inclusion, reducing traffic congestion, and achieving environmental sustainability.

This report focuses on the bus transportation networks in Kelowna, Victoria, Kamloops, and Squamish as case studies, highlighting the unique challenges and opportunities faced by small to medium-sized urban transit systems. By analyzing the structural strengths and weaknesses of these networks, the study aims to provide actionable insights that can improve urban planning and transit optimization. The findings are intended to support decision-makers in ensuring that these cities' transit networks remain efficient, accessible, and resilient, meeting the needs of their diverse populations while promoting sustainable urban development.

2. Related work

A rapid literature search on the public transit system of British Columbia retrieves many results. When limiting this search to the cities of Kamloops, Kelowna, Squamish and Victoria, the number of papers reduces considerably, and limiting the scope further to bus transit decreases it even more. One of the papers selected, highlights Kamloops actual transit network, and the future action plan designed to improve its flaws [1]. Another paper, used for Kamloops, was Route Optimization: Enhancing Efficiency, Reliability, and Accessibility in Kamloops' Transit System [2]. This paper delves deeper into the challenges faced by the residents of Kamloops in accessing the Transit in Kamloops. This study complements the strategic vision outlined in the Transit future action plan and offers actionable solutions to improve network performance.

Public transportation systems in growing urban centers like Kelowna play a critical role in shaping sustainable mobility and equitable access to essential services. The Central Okanagan Integrated Transportation Strategy (CO-ITS) emphasizes the importance of aligning transit services with land use planning to address the city's unique transportation challenges. For Kelowna, specific priorities include enhancing high frequency transit corridors such as Highway 97, expanding pre-existing transportation infrastructure, and densifying urban cores through mixed use developments [3]. These measures aim to improve the accessibility and efficiency of public transit while promoting shorter trip lengths and better resource utilization. Initiatives such as the Healthy City Strategy and Community for All Action Plan further support these goals by prioritizing equitable access to transportation and enhancing livability through active transit networks and public space improvements.

Future strategies for Kelowna's transit network are also outlined in the Kelowna Transportation Master Plan (TMP). The TMP identifies key areas for transit system enhancements, such as expanding service coverage to underserved areas and increasing the reliability and frequency of bus routes. Plans for the future include introducing transit-priority measures, such as dedicated bus lanes and enhanced signal coordination, to reduce travel times and improve network efficiency. Additionally, the TMP advocates for the adoption of technology-driven solutions, including real-time tracking systems and integrated fare collection methods, to elevate the passenger experience and streamline operations [4]. These strategies aim to ensure that Kelowna's transit network is prepared to meet the demands of a growing population while supporting broader sustainability and resilience objectives. Collectively, these strategies emphasize a multi-faceted approach to improving Kelowna's transit system by addressing its existing limitations and proactively planning for future growth.

For the city of **Squamish**, two papers were used as a reference. The first one, *Shifting Towards Transit in Squamish,* focuses on the strategies to improve local and interregional transit, how to support the district's rapid growth and how to address the climate goals [5]. The second paper used as reference, *Transportation in Squamish: Past Studies, Selected Case Studies, and Recommendations,* analyzes past, current and future transportation practices of Squamish, concentrating on sustainable growth and connectivity. Transportation based on resources was reviewed in this paper. Also, analyzes the challenges faced with public transit, alongside dominance by cars in infrastructure. The report presents 15 recommendations for improving Squamish transportation network by drawing from case studies and local planning documents, which include improved cycling and pedestrian networks, better connectivity, multimodal transit hubs and improved public transit services, being the last two the only ones relevant for us and our study. It emphasizes a lot on the creation of a sustainable and efficient transportation system, the balancing of community access, taking into account the economic growth of the city and the ecological goals [6].

The Victoria Transit Future Plan [7] presents a comprehensive strategy for the development of the city's transit network over the next 25 years, emphasizing the need for efficient urban mobility. The plan addresses the growing population, focusing on integrating transit alongside the expansion of the city. It highlights the need for significant investments in infrastructure, and the local and targeted transit services. Their priorities include reducing the dependency on privately owned vehicles, and to support sustainable urban growth.

Key components of the plan include the development of transit priority measures, such as exclusive transit corridors and signal coordination. These measures aim to significantly enhance transit speed and reliability by minimizing delays caused by mixed and heavy traffic, ensuring that public transit becomes a more competitive and reliable alternative to private vehicles. Moreover, the plan advocates for better customer amenities, and stronger integration of cycling and pedestrian networks with transit. The emphasis on creating a transit-supportive city aligns with local growth strategies, aiming to reduce greenhouse gas emissions by promoting walking, cycling and public transit.

No previous research related to all four cities in terms of bus transit network efficiency and sustainability using network science techniques was found.

3. Methodology

This study retrieved data from the British Columbia government data website [8].

For **Kamloops**, after retrieving the data from the .ship files found on the bc transit website, bus stops were treated as nodes while routes connecting stops were used as edges. The bus stops were geographically positioned using longitude and latitude coordinates. Routes were converted into edges with weight. The network was then visualized via ggplot2 and the stops were marked in red while the routes were marked in blue. The communities and clusters were highlighted based on centrality matrices. The data was cleaned and ready for processing.

The bus network was modeled as an undirected network, focusing on the connections rather than the route frequency. Centrality metrics, betweenness centrality, eigenvector centrality and degree centrality were computed via the igraph package to identify key hubs, bottlenecks and influential stops.

Community detection was done using the louvain algorithm, as it revealed clusters of closely connected bus stops and highlighting zones of high connectivity. Spatial mapping in R was used to achieve visualizations, with centrality metrics represented as scaled point sizes to indicate their importance.

The analysis of the **Kelowna** bus network followed a structured, step-by-step approach integrating graph theory, spatial analysis, and visualization techniques. The first step involved data collection and preprocessing. Shapefiles for bus routes and stops were obtained from local transit authorities, and all data was standardized to the WGS 84 coordinate reference system. Missing or inconsistent entries were addressed through interpolation or exclusion, and attributes such as route_id, stop_id, and geographic coordinates were cleaned and prepared for analysis.

The bus network was modeled as an undirected, unweighted graph where nodes represented bus stops and edges represented direct connections between stops derived from bus route geometries. This graph was unweighted, focusing solely on the existence of connections rather than incorporating attributes like route frequency or passenger volume. This simplified representation facilitated an analysis of the network's fundamental structural properties. To identify the importance of individual stops, three centrality metrics were calculated: degree centrality, betweenness centrality, and eigenvector centrality. Degree centrality highlighted stops with the highest number of direct connections, indicating key hubs in the network. Betweenness centrality identified critical bottlenecks by measuring the frequency with which stops appeared on the shortest paths between other stops. Eigenvector centrality captures the influence of stops by evaluating their connections to other highly connected stops. These metrics were computed using the igraph package in R and provided a comprehensive understanding of the network's most significant nodes.

Due to the nature of Kelowna’s bus system lots of exchanges are created in the network, these are large hubs designed to allow people to access many different communities from just one simple stop. Exchange stops such as, “UBCO Exchange” and “Orchard Park Exchange” were identified using partial string matching of stop names. For each exchange individual bay specific stops (e.g. “Bay A”, “Bay B”) were grouped together to provide a more uniform representation of the exchanges as a whole rather than focusing on individual bay stops, offering a clearer image of the importance of major transit hubs. However, this approach may overlook individual variations in connectivity at the bay level, and inconsistencies in naming convention or unanticipated stop labels could lead to misclassifications. Despite these challenges, the grouping method proved effective in simplifying the analysis and highlighting the relative importance of the main exchanges in the network. Robustness was evaluated by simulating the removal of important nodes (stops) and edges (routes) to assess the impact on network connectivity. These simulations tracked the size of the largest connected component, identifying critical vulnerabilities and redundancies within the system. Additionally, static maps were generated using ggplot2 and tmap for inclusion in the report. This methodology provided a comprehensive framework for analyzing the Kelowna bus network, offering insights to enhance its efficiency, accessibility and resilience.

Squamish's public bus transit network analysis was conducted similarly to the ones done for the cities of Kamloops and Kelowna. After downloading and cleaning the data, it was used to model it as a graph, where the nodes represented the bus stops and the edges, the routes connecting these stops. To provide a more accurate analysis and representation of the Squamish transit network, geographic coordinates were incorporated, allowing us to visualize the graph as close we could to the real-world bus stops distributions, making easier to interpret the results and providing practical insights into the network.

After having the network correctly plotted, we calculated some centrality measures such as betweenness and eigenvector centrality, hub scores to be able to identify the importance and impact of each node in the network. Betweenness centrality measure was used to identify the nodes which played a crucial role in the network, acting as critical bridges and facilitating connections between different routes of the network. Eigenvector centrality revealed the stop that is most central to the most active area of the network. That node also turned to be a central hub, increasing its relevance and impact in the network. Hub score was also computed, as we wanted to measure how well-connected bus stops were to the different routes, making sure that a correct transition and mobility through the network was possible.

Distance metrics between stops was also computed as it would give us information about the network efficiency and accessibility. It also revealed how well-connected the network is spatially and how the physical layout impacts the overall transit experience. It also has implications for travel times, fuel efficiency and scheduling, which can help us optimize the network and create more efficient future action plans.

Lastly, the Louvain algorithm was used to perform a community detection analysis, to uncover clusters of closely connected stops. Each stop was assigned a community label, and the resulting clusters were visualized to identify regions of high connectivity and isolated areas. This analysis provided insights into the network's internal structure and potential underserved zones.

The analysis of **Victoria**'s public transit network followed a comprehensive methodology similar to the approaches taken for other cities, focusing on graph-based modeling and centrality analysis. The initial step was to collect the data from BC Transit's open data portal. All spatial data was then standardized for consistency. Any missing or inconsistent data were resolved through interpolation or exclusion. Relevant attributes such as Stop ID, and Route ID were also cleaned to ensure the network worked efficiently

The network was modeled as an undirected, unweighted graph, where bus stops formed the nodes, and direct connections between them served as edges. To account for transit hubs, a proximity threshold was applied to combine stops that were close geographically. This adjustment merged individual stops within transit hubs, such as "UVic Exchange", and "Douglas Street Exchange" into single nodes, representing these stops as one cohesive hub. This ensured a clearer visualization of key hubs and avoided redundancy in the graph. While this approach highlighted major hubs, it also had some limitations, such as potential misclassification of stops due to naming inconsistencies or an unanticipated stop layout.

To identify the significance of individual stops, three main centrality metrics were calculated: degree centrality, betweenness centrality, and eigenvector centrality. Degree centrality identified stops with high amounts of direct connections, indicating major hubs or popular intersections. Betweenness centrality emphasized critical stops that controlled the flow of many buses. Finally, eigenvector centrality evaluated the influence of each stop based on their connectivity to other well-connected nodes.

The Louvain algorithm was applied to detect clusters of closely connected stops, revealing distinct communities within the network. Each stop was assigned a specific cluster, which was then visualized using R's Tidyverse package to highlight areas of strong internal connectivity.

4. Results

4.1. Kamloops

After carrying out the network science analysis on the Kelowna bus transit dataset, the stops of **Seymour at 4th Ave** and **Todd at Klahanie** have the highest eigenvector centrality. The scores are 0.116 and 0.107 respectively. Both stops are critical to the network. Both stops function as central nodes and facilitate access to the entire network. Routes originating from Seymour at 4th ave and 6th Ave at Victoria have the highest betweenness centrality. This indicates their importance in maintaining network cohesion and accessibility. Similarly, stops such as Highland and Valleyview dr.(lowest degree and betweenness centrality) and Halston Connector at Salish(Lowest eigenvector centrality) have lower centrality scores and indicate limited connectivity and accessibility.

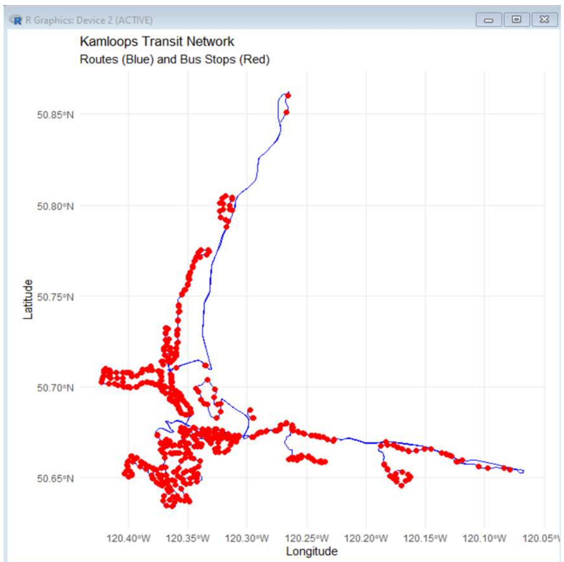

Figure 1: Kamloops Transit Network: Visualizing Routes and Bus Stops

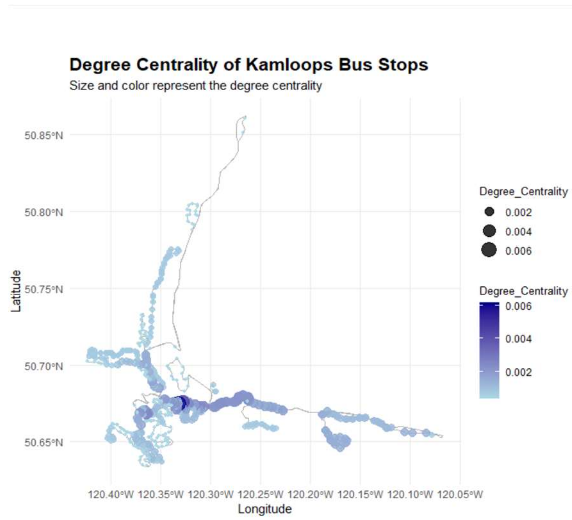

Figure 2: Degree Centrality of Kamloops Bus Stops

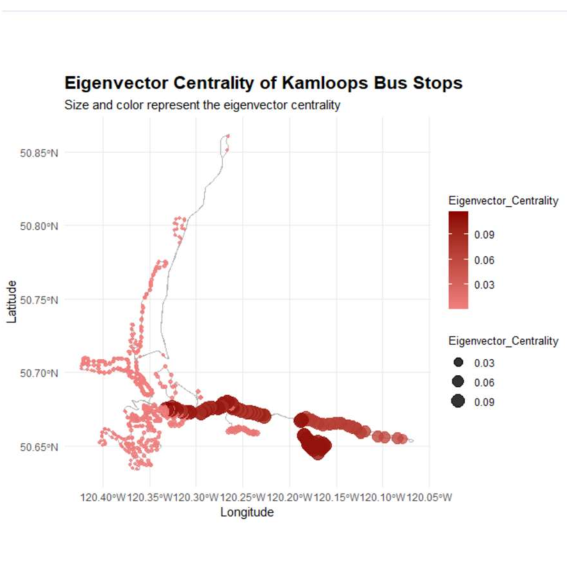

Figure 3: Eigenvector Centrality of Kamloops Bus Stops

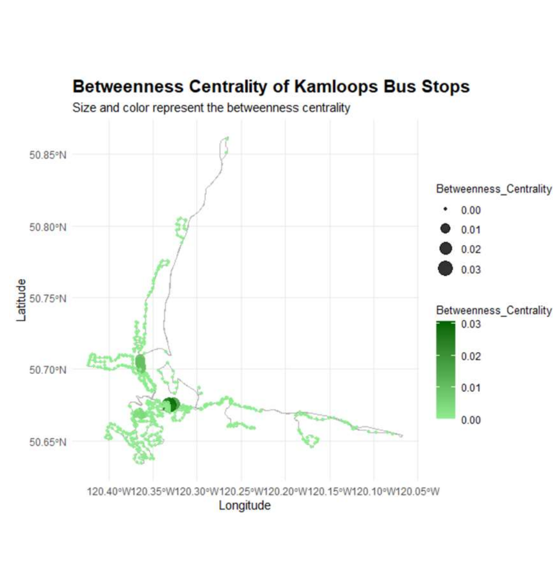

Figure 4: Betweenness Centrality of Kamloops Bus Stops

Seymour at 4th Ave was the stop with the highest degree centrality and emphasizes its role as the hub with direct connections to many other stops. 6th Ave at Victoria closely followed the Seymour at 4th Ave and also is very important in Kamloops' Transit system.

The Louvain algorithm helped me identify distinct clusters within the network, with stops like **Seymour at 4th Ave** forming the core of a major community. Peripheral stops in regions like Highland and Valleyview Dr exhibited lower centrality scores, indicating potential service gaps or limited accessibility.

4.2. Kelowna

The analysis of the Kelowna bus network utilized both grouped and ungrouped centrality measures—degree centrality, betweenness centrality, and eigenvector centrality—to gain insights into the network's key nodes.

When calculating degree centrality, Queensway Exchange emerged as the most connected stop with the highest degree of 12, making it a critical hub. Rutland Exchange (degree 7) and Harvey Ave at Cooper Stn - Orchard Park (degree 5) were also significant in connecting different regions. For betweenness centrality indicated in **Figure. 5.** The Queensway Exchange again played a central role with a score of 6, followed by Harvey Ave at Cooper Stn - Orchard Park, also with a score of 6. These findings highlight the importance of these stops in facilitating passenger flow across the network. Other stops, such as Rutland Exchange and Kelowna General Hospital, acted as secondary connectors. In **Figure. 6.** Eigenvector centrality showed that Harvey Ave at Cooper Stn - Orchard Park had the highest score of 1.0, reflecting its connection to other highly central stops. Other stops, such as Kelowna General Hospital, South Pandosy Exchange, UBCO Exchange, and Westbank Exchange, had lower scores, indicating weaker connections to other influential stops in the network.

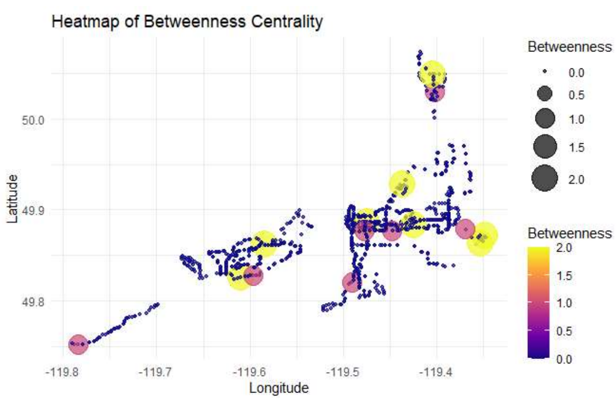

Figure 5 : Heatmap of Betweenness Centrality. This map displays betweenness centrality, with larger, darker points representing bus stops critical for connectivity across the network

Figure 6: Eigenvector Centrality of Bus Stops in Kelowna. This map shows bus stops colored by their eigenvector centrality, with larger points indicating higher centrality values.

Both grouped and ungrouped calculations were performed for stops, particularly focusing on exchange stops like Orchard Park Exchange and Queensway Exchange. The grouped approach, which combined bay-specific stops, provided a more unified view of the significance of these hubs in the network. However, it may overlook variations in connectivity at the individual bay level, and naming inconsistencies could lead to misclassifications. Despite this, the grouping method proved effective in identifying key hubs and understanding the broader structure of the network. Orchard Park Exchange and Queensway Exchange are central to the Kelowna bus network. Ensuring the reliability and accessibility of these major hubs, along with stops with high betweenness centrality, such as Rutland Exchange and Harvey Ave at Cooper Stn - Orchard Park, could significantly improve the network's efficiency and connectivity.

4.3. Squamish

After carrying out the network science analysis on the Squamish bus transit dataset, we have obtained that the stops with the highest Eigein vector centrality are ***Brennan Park*** and ***Cleveland at Victoria,*** with a score of 1 and 0.9186 respectively. These results position Brennan Park as one of the most important stops in the Squamish bus transit network, as not only it is well-connected itself, it is also connected to other influential stops. As shown in **Figure 7** it acts as a central hub, suggesting that it likely serves as an interchange or frequently accessed stop. Cleveland at Victoria also has a high score, indicating its importance in connecting passengers to the central routes. As both stops are key for Squamish transit network, the infrastructure at these stops must be adequate to handle high passenger volumes. Moreover, ensuring service reliability at these stops should be a priority, as incidents could cause undesirable effects throughout the network. **Figure 7** shows eigenvector values for every bus stop in the network.

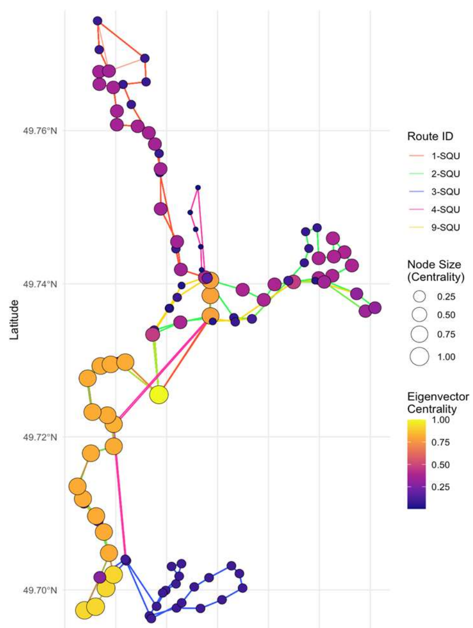

Figure 7, Visualization of Eigenvector centrality scores

For the betweenness centrality analysis, we obtained that, **41000 Blk Government Rd** has the highest betweenness centrality with a normalized score of 0.2398, followed by **Westway at Juniper** with a 0.1465 score. As we can observe in **Figure 8**, the Squamish transportation network's low betweenness centrality scores are a reflection of its size, composition and geographic limitations. Because it is a medium-sized system with reasonably direct routes, the network disperses connectivity across stops more fairly, lowering the need for individual nodes as vital linkages.

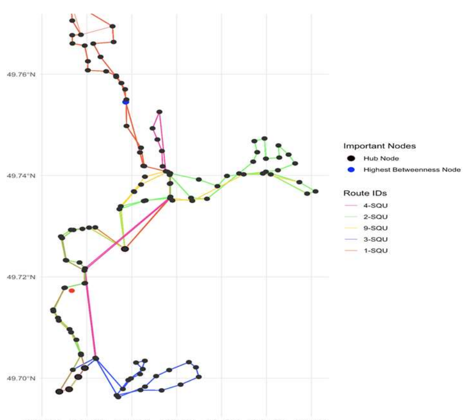

Figure 8, Visualization of Squamish transit network, highlighting hubs

4.4 Victoria

Our analysis of the transit routes of Victoria allowed us to identify several key points, and potential weaknesses in the network. The main metrics used to determine this was the degree centrality, betweenness centrality, and eigenvector centrality. The stop with the highest degree centrality was "Royal Oak Exchange" with a degree centrality of 14. This means that this stop is the largest hub in the network with the most amount of other stops connecting to it. This is the result we would expect as "Royal Oak Exchange" is a hub in close proximity to downtown Victoria. "Lampson Street at Old Esquimalt Rd" had the highest betweenness centrality of 0.5. And "Central Saanich Rd at Keating X Rd This means that this stop is a key node, and is essential in controlling traffic throughout the city, and that putting extra effort to ensure that it is always running is required. We also identified 49 communities in the network (see fig 9). The communities represent a closely connected group of nodes. This means that the transit network of Victoria is relatively fragmented, with distinct clusters of stops that are more interconnected within their community than with the rest of the network. These most likely correspond to specific neighborhoods. Understanding these clusters will help us optimize scheduling and determine which areas are higher in demand.

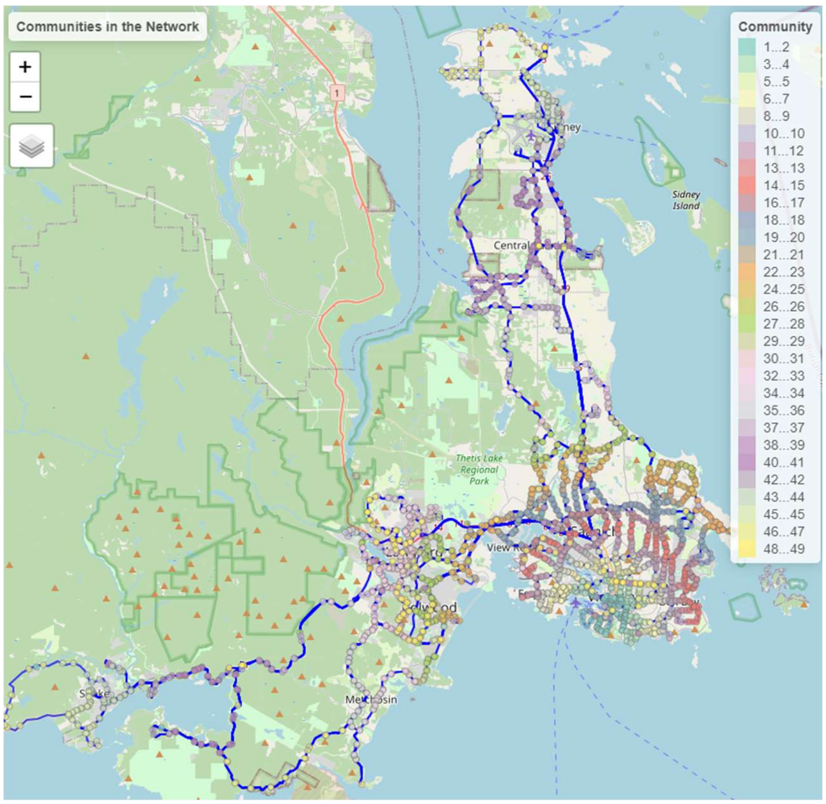

Figure 9 Visualization of the transit network communities in Victoria, highlighting clusters of interconnected bus stops identified through the Louvain community detection algorithm.

5. Discussion

Public transport is an important means of transportation for many people in urban cities and can have a big impact on some people's daily life. The different centrality and distance measures that have been calculated and analyzed in this study play an important role in the decision-making for the improvement of the public transit network, which is of use to a large quantity of people from different ages, neighborhoods and social-economic situations.

Our study sought to develop an understanding of the bus transit networks of the cities of Kamloops, Kelowna, Squamish and Victoria, remarking its strengths and ways to improve them in case they had considerable flaws. Through the use of centrality measures such as degree centrality, betweenness centrality, and eigenvector centrality, we were able to identify key nodes within the networks and determine which areas of the transit systems are most important for improvement.

The results showed that major hubs, such as Kamloops' Seymour at 4th Ave., Queensway Exchange in Kelowna, Squamish's Downtown and residential areas, and Victoria's Royal Oak Exchange, exhibited high levels of centrality, indicating their role as key connectors within each network. These hubs serve as essential transfer points for passengers and play a significant role in ensuring the networks operate smoothly. However, in areas such as Kamloops, Kelowna, and Squamish, we also identified several transit bottlenecks, where high betweenness centrality values highlighted critical stops. These bottlenecks can lead to delays and reduce the overall efficiency of the transit system, suggesting that improvements in these areas, such as creating direct connections and optimizing transfer points, are needed.

6. Conclusion

This study provides a comprehensive analysis of the public bus transit network in Kamloops, Kelowna, Squamish and Victoria, leveraging network science techniques to identify strengths, vulnerabilities and opportunities for improvement. The findings reveal that major transit hubs such as Kamloops' Seymour at 4th Ave., Queensway Exchange in Kelowna, Squamish's Downtown and residential areas, and Victoria's Royal Oak Exchange play crucial roles in maintaining the efficiency and connectivity of their respective networks. However, ears with high betweenness centrality such as specific stops in Kamloops and Squamish highlight potential bottlenecks that could impede overall performance.

The centrality metrics such as, degree, betweenness and eigenvector were crucial in identifying key nodes and assessing the structural robustness of these transit systems. Community detection further identified clusters within the network providing insights into areas that are either well connected or underserved.

Future enhancements to these networks should focus on improving the infrastructure of critical hubs and ensuring equitable coverage especially in underserved areas. Introduction of technological solutions like real time tracking or dynamic scheduling could further enhance efficiency and user satisfaction. By addressing the identified bottlenecks and leveraging these findings, city planners and public transit authorities can improve the accessibility, sustainability and resilience of the public transit system in these urban regions.

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