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A Unified Real-Time Dashboard for Multi-City Bike-Sharing Systems

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Abstract

Bike-sharing systems have emerged as a crucial component of urban mobility infrastructure across major metropolitan areas. While these systems provide significant benefits for sustainable transportation, the disparate nature of monitoring platforms poses challenges for both users and transportation planners. In response to this, this paper presents a unified real-time dashboard that integrates multiple bike-sharing systems across major North American cities. Notably, selected bike-share systems generate 86 percent of total trips in 2023. These cities include Boston (Bluebikes), Washington, D.C. (Capital Bikeshare), Chicago (Divvy), New York City (Citi Bike), Montreal (BIXI), San Francisco (Bay Wheels), and Toronto (Bike Share).

Furthermore, our dashboard implements a scalable architecture that uses the General Bikeshare Feed Specification (GBFS) to aggregate and visualize real-time data from multiple bike-sharing networks through a single interface. The system employs a configuration-based approach that facilitates the easy integration of additional cities and bike-sharing systems. Built on a Python-based stack utilizing Panel for the user interface and Folium for interactive mapping, the dashboard provides comprehensive visualization of system status, including conventional and electric bicycle availability, docking station capacity, and operational status across all integrated networks.

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Keywords: Bike-sharing systems; urban mobility infrastructure; sustainable transportation; real-time dashboard; General Bikeshare Feed Specification

1. Introduction

Bike-sharing systems have become an integral component of urban transportation infrastructure, supporting sustainable mobility initiatives and reducing dependency on motorized vehicles. Over the past decade, cities across North

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America have adopted bike-sharing systems to address challenges such as traffic congestion, air pollution, and the demand for last-mile connectivity.

Despite their benefits, bike-sharing systems often function as independent entities with proprietary monitoring platforms. This lack of integration creates challenges for users who wish to access reliable, real-time data across multiple cities. Furthermore, transportation planners face difficulties in comparing and analyzing system performance due to the disparate data sources.

The emergence of the General Bikeshare Feed Specification (GBFS) provides a standardized framework for accessing real-time data from bike-sharing networks. Currently, more than 1,200 bike-share systems have data available according to GBFS. Hence, it would make sense to develop a uniform standard interface and structure for a dashboard.This paper focuses on the design, implementation, and evaluation of the dashboard, highlighting its scalability, real-time monitoring capabilities, and potential applications for transportation planning. For testing the performance of the proposed dashboard, we decided to apply it to seven major North American bike-sharing systems, which collectively accounted for 86% of all trips in 2023 (NACTO, 2023).

The remainder of this paper is organized as follows: In the Background section, an analysis of existing bike-share system websites is presented. Subsequently, the Data and Methodology section discusses the data structure and sources, as well as the development of the proposed dashboard system. The findings of this study are detailed in the Results and Discussion section. Finally, key findings and suggestions for future research are provided in the Conclusion and Future Work section.

2. Background

According to research by Fishman et al. (2014), the increasing adoption of bike-sharing systems has spurred the development of dashboards and platforms aimed at monitoring and managing these systems. O'brien et al. (2014) argues that these tools are critical for both users and transportation planners, as they enable real-time decision-making and operational insights. Márquez-Saldaña et al. (2025) emphasized a need for a standardized, unified data framework so that BSS comparisons can be conducted properly.

In order to analyze the current status of the bike-share systems (BSSs) in North America, seven systems that represent 86% of total annual trips in 2023 were selected. The basic statistics of these systems are shown in Table 1.

Table 1. Station Statistics

Name	Number of Stations	Total Dock Capacity	Docks per Station
Boston Bluebikes	539	9399	17
Chicago Divvy	1824	18446	10
DC Capital Bikeshare	794	13684	17
Montreal BIXI	952	21215	22
NYC Citi Bike	2233	69846	31
SF Bay Wheels	568	12562	22
Toronto Bike Share	876	16981	19

2.1. Current Dashboard Shortcomings and Feature Inconsistencies

Many existing bike-sharing dashboards are designed for single-city systems or specific regions, which create significant barriers to comprehensive analysis. Fishman (2016) highlights that most bike-sharing platforms lack the capability to integrate data from multiple networks, which hinders cross-city analysis and limits the ability of transportation planners to study the impact of bike-sharing on urban mobility on a broader scale. This fragmented approach restricts system-wide trend analysis and prevents the identification of best practices across different operational contexts.

Except for the Toronto bikeshare website, all the websites for the BSSs analyzed in this paper were accessed. Each website was checked to see whether it contained (a) a map of the bike stations with real-time information, (b) operational real-time statistics, and (c) how easy it is to access the information.

Most of the systems provide the map at the bottom of the webpage, so you can reach it if you scroll down. Two of the systems, NYC Citi Bike and Montreal BIXI, require clicking the ”find a bike” and ”Stations” links at the bottom of the page to access the map, respectively. Most of the systems are operated by the same company; however, the visualization of information on the map is non-standard. Hence, the lack of uniformity in using icons or displaying statistical data, such as regular bike availability, forces the user to relearn when they look at the website of another system. All of the systems that we accessed do not provide real-time system-wide statistics, even though the GBFS allows the downloading of real-time data.

Another common inefficient implementation is how the user accesses station data on a computer; they have to click the icons to open a window to view the information. This can be improved by implementing 'hover-over' functionality, allowing the user to see the station details by pointing the cursor at the station icon.

Beyond these interface inconsistencies, existing dashboards suffer from several functional deficiencies. While some platforms provide basic visualizations of bike availability and dock usage, they do not support advanced functionality. Few dashboards allow for the simultaneous comparison of multiple bike-sharing systems, which is critical for identifying best practices and operational inefficiencies. Additionally, dashboards often prioritize operational metrics over user-centric features, such as journey planning tools or personalized recommendations for finding available bikes and docks.

Moreover, issues of scalability arise as new bike-sharing systems are introduced. Dashboards built with rigid architectures struggle to integrate new networks quickly and cost-effectively. This challenge is particularly evident in large-scale systems like Citibike in New York City, which require robust data handling capabilities to process high-frequency updates from thousands of stations.

Based on the exploration of these bike-share systems (BSS), the research question of this study is: ”What design principles and technical architecture are required to create a comprehensive real-time monitoring dashboard that consolidates disparate operational and user information from multiple North American bike-sharing systems into a unified interface for enhanced decision-making and user experience?”

2.2. The Need for Unified Dashboards

The shortcomings identified in existing dashboards underscore the urgent need for a unified, scalable platform capable of aggregating and visualizing data from multiple bike-sharing systems. Such a platform would address the following critical gaps:

1. **Scalability and Integration**: A modular architecture would enable the seamless integration of additional cities and systems without significant redevelopment efforts, addressing the current challenge of incorporating new networks.
2. **Real-Time Monitoring**: Advanced error-handling and caching mechanisms would ensure consistent performance, even during network outages or high demand periods.
3. **Advanced Visualization and Analytics**: By incorporating features such as predictive modeling and cross-system comparisons, a unified dashboard could serve as a valuable tool for transportation planners and policymakers.

This work builds upon the foundational concepts explored in prior studies by Fishman (2016) and Shaheen et al. (2010), and addresses the gaps in scope and functionality that hinder the effectiveness of existing solutions. The proposed dashboard leverages the GBFS standard to create a scalable, real-time platform that bridges the inadequacies of current approaches.

3. Data and Methodology

Dashboards provide data visualization that should address the needs and preferences of the user. Data visualization systems are computer programs that use visual representations of data to help people perform tasks more efficiently (Munzner, 2014). The flowchart of the developed dashboard system is depicted in figure 1.

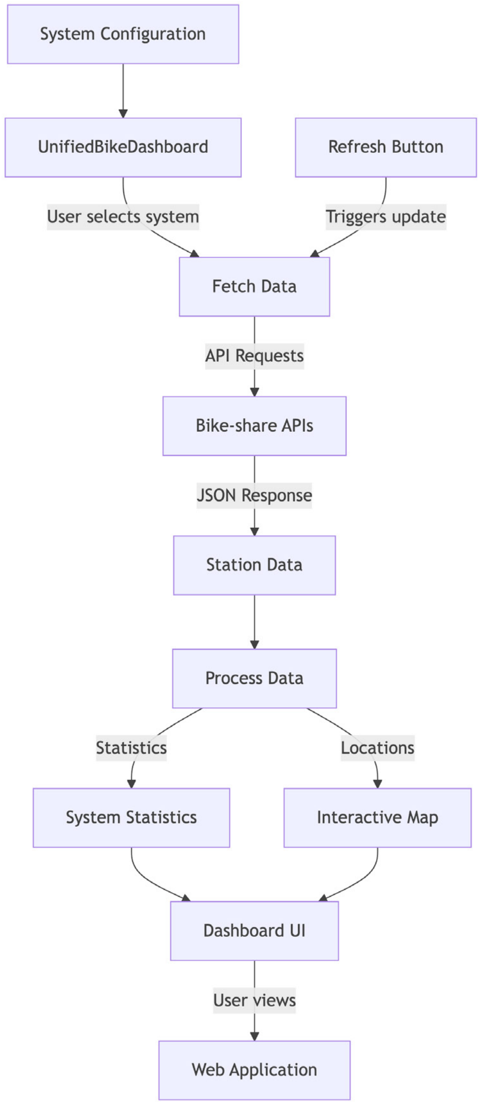

Fig. 1. Dashboard System Flowchart

3.1. System Architecture

The unified dashboard employs a modular architecture designed for scalability and extensibility. Each integrated bike-sharing system is defined through a configuration file specifying parameters such as:

- API endpoints for GBFS feeds.
- Geographical boundaries and time zones.
- Visual styling elements for the user interface.

Python version 3.10.10 is used, along with the following modules: os, requests, pandas, folium, panel, datetime, and pytz. The complete source code is publicly available Kunt (2025).

The map view in the dashboard was created using open-source tools OpenStreetMap and Leaflet.js for their fast response time when zooming in and out.

3.2. Data Processing Pipeline

The system uses a Python-based data processing pipeline to fetch and process GBFS feeds as depicted in Figure 1. Key components include:

1. **Data Aggregation**: Real-time data is fetched from the GBFS endpoints of each system.
2. **Data Transformation**: The raw data are normalized to a consistent format for visualization.
3. **Error Handling**: Intelligent error detection and reporting mechanisms ensure system stability even when individual feeds experience issues.

3.3. User Interface Design

The dashboard interface is built using the Panel library for interactivity and Folium for dynamic mapping. Key features include:

- A city selection dropdown for switching between different networks. Boston Bluebikes is the default BSS when the dashboard starts.
- Current local time when the data was uploaded for the selected system.
- Refresh button is used for real-time updates of bicycle availability and docking capacity.
- The success/failure of the data refresh is also printed on the dashboard
- System-wide station bike availability statistics are provided
- Dynamic maps displaying station locations and statuses.

3.4. System Integration and Scalability

The dashboard's ability to integrate data from various sources is key to its effectiveness in managing a bike-share system. Currently, the platform relies on the General Bikeshare Feed Specification (GBFS) as the primary data source for extracting real-time information about bike availability, station status, and system performance. GBFS provides a standardized format, ensuring consistent and reliable data extraction across multiple bike-share systems.

3.4.1. Color coding of markers

Three colors were employed for the markers to visually convey the condition at each station. Green signifies that all docks are full, blue indicates the availability of regular or electric bikes, and red denotes that no bikes are available at the station.

3.4.2. Hover-over Features

When the user hovers over the icon at any station, a pop-up window displays the following information:

- Cross street names of the station
- Bike availability text (Available/No Bikes available)
- Regular bike count
- E-bike count
- Available dock count

3.5. Dashboard Visualization

Figures 2 and 3 represent the system-wide statistics and the map of the stations, respectively.

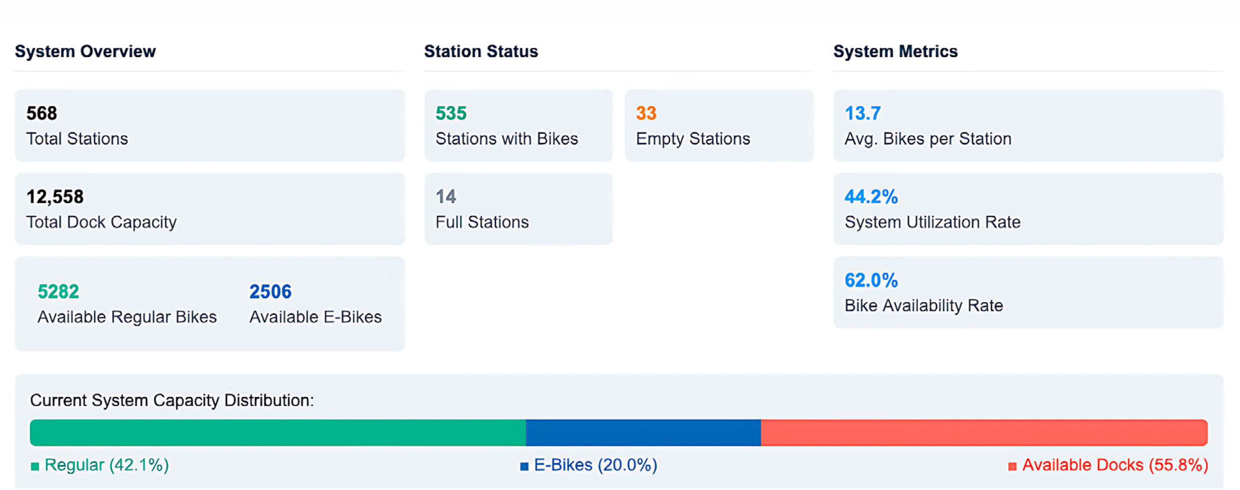

Fig. 2. System-wide statistics for SF Bay Wheels

3.5.1. Real-Time Statistics

The dashboard provides real-time updates on station-level metrics under three categories, **System Overview**, **Station Status** and **System Metrics** (Figure 2):

- Availability of conventional and electric bicycles.
- Docking station capacity and operational status.
- Number of docks available.

4. Results and Discussion

Based on the shortcomings and inconsistent implementation of bike-share data on existing websites for seven North American bike-share systems, a generic dashboard has been developed using the Panel module in Python. This research-oriented platform leverages standardized GBFS data feeds to provide comprehensive analytical capabilities for transportation research and operational management.

4.1. Data Structure and Analytical Framework

The dashboard synthesizes GBFS data into three indicator categories. Station-status feeds provide operational metrics that track real-time occupancy levels, bike availability, docking capacity, and service alerts across the network. Station-information feeds supply spatial characteristics, including network topology, station capacity, and the geographic positioning of bike-share infrastructure. System-hours and system-calendar feeds contribute temporal parameters that define when services run and how these schedules influence rider demand patterns.

The integration of GBFS and meteorological datasets enables the derivation of advanced analytical variables that enhance research capabilities beyond individual data sources. Weather-adjusted usage metrics normalize operational data against climatic variations, facilitating accurate cross-temporal and cross-regional comparative analysis. Climate-sensitive performance indicators quantify system resilience under varying environmental conditions, while complex spatiotemporal pattern variables emerge from the synthesis of operational, spatial, and temporal data streams.

4.2. Data Size and Performance

System performance was evaluated across different network sizes, ranging from smaller systems like Boston Bluebikes to large-scale systems like NYC Citi Bike. The basic statistics on these systems were discussed earlier and

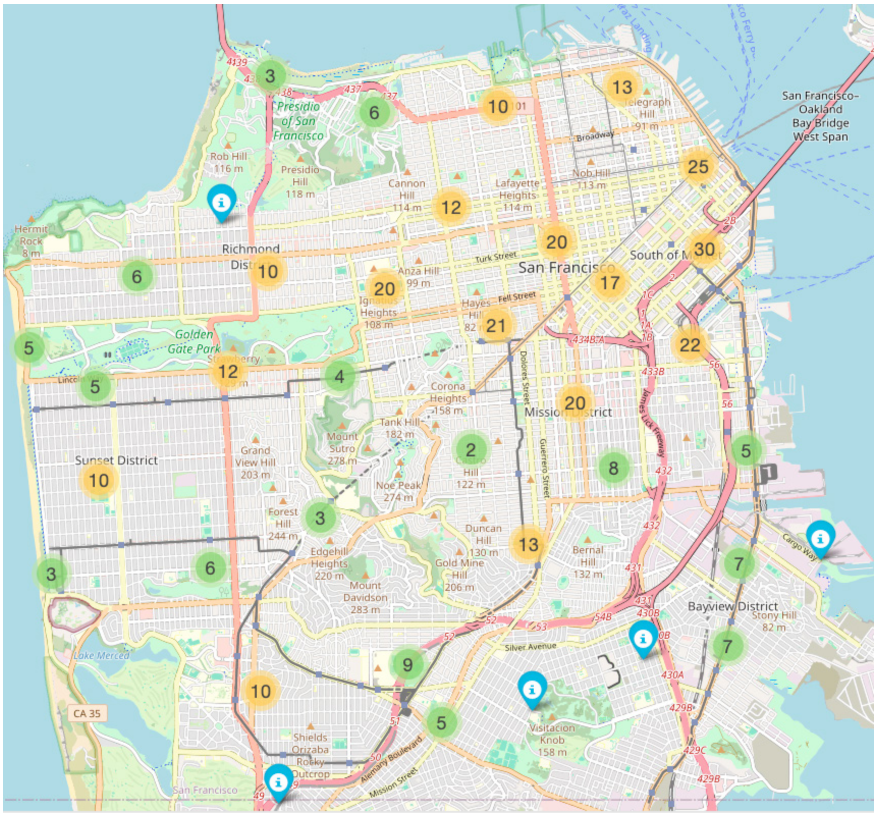

Fig. 3. Dashboard map with station locations for SF Bay Wheels

depicted in Table 1. The dashboard maintained consistent response times and demonstrated robust error handling under varying conditions.

4.2.1. Future Integration

Looking ahead, the dashboard is designed with future integrations in mind. Planned enhancements include incorporating data from the National Oceanic and Atmospheric Administration (NOAA) to provide weather-related insights, such as temperature, precipitation, and wind forecasts. Meteorological data integration through NOAA weather stations will provide standardized environmental variables that serve as critical explanatory variables for understanding usage variability and developing predictive models that account for environmental influences on cycling behavior and system performance.

This data can be used to optimize bike re-balancing and predict bike usage patterns based on weather conditions. Additionally, integrating local transit data sources will enable the dashboard to offer a more comprehensive view of urban mobility, helping operators align bike-share services with bus, train, or other public transportation schedules.

To ensure seamless integration, the dashboard leverages a modular API-driven architecture. This approach allows for easy addition of new data sources while maintaining compatibility with existing systems. By adhering to industry standards and designing for scalability, the system can handle increasing data volumes and accommodate new features, such as advanced analytics and predictive modeling, as the bike-share program evolves.

Ultimately, the integration of multiple data streams—starting with GBFS and expanding to NOAA and transit systems—ensures that the dashboard remains a robust and adaptable tool for both operational management and academic research in an ever-changing urban mobility landscape.

5. Conclusion and Future Work

This paper presents a unified real-time dashboard for monitoring bike-sharing systems across multiple cities through standardized GBFS data integration. The system demonstrates significant contributions by enabling real-time monitoring of seven major North American bike-sharing systems through a single platform, addressing the inconsistent implementation found in existing websites. The dashboard architecture maintains consistent response times regardless of system size, ensuring scalable performance from smaller systems like Boston Bluebikes to large-scale networks like Citi Bike NYC.

The modular API-driven architecture facilitates seamless integration of additional systems and data sources, providing a flexible foundation for future expansion. The dashboard serves bike-share customers, operational staff, and transportation researchers by delivering comprehensive system status and detailed station-level information. Enhanced visualization through an independent marker system provides immediate visual feedback regarding bike and docking space availability across networks.

The platform benefits operational personnel by providing system-wide status insights for bike rebalancing activities while offering transportation planners cross-city performance comparisons, e-bike adoption analysis, and service gap identification through spatiotemporal analysis.

The research framework establishes three analytical indicator categories: operational indicators from real-time feeds, spatial indicators defining network topology, and temporal indicators capturing service patterns. GBFS integration with planned meteorological datasets enables advanced analytical variables, including weather-adjusted usage metrics and climate-sensitive performance indicators.

Future work should focus on implementing NOAA weather data integration for environmental analysis, expanding compatibility to international networks, and developing predictive analytics for demand forecasting. The system's scalability ensures accommodation of advanced analytics while maintaining its role as both an operational management tool and a platform for urban mobility research.

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