Smart Streetcar Corridor for Greater Community Health, Equity, Livability, and Prosperity (HELP)

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Abstract: Smart city concepts identify the need for innovative transit to serve the needs of future cities, and modern streetcars have been deployed throughout the world to motivate development and provide transportation. However, research on streetcar transportation shows that while the aim of motivating development has seen results, achieving these results requires high levels of system performance. Further, research on streetcar transportation, as integrated within a smart transit corridor, is lacking. This paper describes a smart streetcar corridor concept that employs technologies including 5G wireless, 8K video, cloud data storage, cloud computing, Internet-of-things, and edge computing. This smart streetcar corridor provides a sensing and communications system to support data-gathering, operational support functions, and transportation research methodologies. The domain of application is discussed for The Hop streetcar in Milwaukee, Wisconsin, and the functional modules and analytic research methods that could be applied are identified. This discussion shows how a smart streetcar corridor could provide benefits to the community for health, equity, livability, and prosperity.

1. Introduction

As cities have changed over human history, their infrastructure has been adapted to new uses for urban land. Smart city ideas recognise this special role for urban transportation in future cities [1, 2] and for knowledge-based economies arising from densely-populated areas [3, 4]. In order to serve dense urban corridors and to make the best use of urban land [5, 6], streetcars have been identified to provide transportation and encourage development [7, 8, 9]. In the early 21st century, streetcars "are making an unprecedented resurgence across the U.S. and around the world" [10] with over 376 streetcar systems in operation or development [11].

Transportation research literature has examined how streetcars can encourage development and serve as a transit service [12]. While the aim of motivating development has seen results [13], achieving these results requires high levels of performance as a transportation system [12]. The desire to encourage building and property development along the route is a strong motivator to build a streetcar system [8, 14] and is a motivator for streetcar systems such as The Hop streetcar in Milwaukee, Wisconsin [15, 16]. However, researchers Brown and Mendez caution that the function of the streetcar system as transportation is key: “the more effective a streetcar is as a transportation service, and the more widely used it is by patrons, the more likely it is to have development effects” [17].

Despite the importance of a streetcar's transportation role, a multiple-case study of streetcar transit found that “there is remarkably little work on the streetcar’s role as a transportation service” [12]. Further, in examining the stated motivations for the streetcar, it was found that “transportation objectives were largely afterthoughts with the notable exception of Portland” [12]. However, stakeholders expect both the development benefits as well as the transportation benefits. Mendez and Brown examined the “expected transportation benefits relative to indirect benefits through economic development” and found “that approximately three-quarters of all expected benefits from streetcar projects accrue to property development with the remaining expected benefits assigned to transportation” [13].

While researchers have shown that building a streetcar for transportation is usually not a primary motivation [18], research shows [17] that improving the streetcar as a transportation mode helps development goals. A multiple case study shows the importance of this in the case of Portland which had the highest ridership and service productivity and the second-most cost-effective service that surpassed the average local bus [12]. Further, the design of Portland's streetcar within areas of high ridership potential and with frequent service integrated with other transit “reflected a view that the streetcar was not just a development tool, but that it also needed to function effectively as a transit service that catered to a broader ridership” [12].

Supporting transportation by creating a smart corridor for vehicle communication has precedents in several pilot projects. In Finland, the LuxTurrim5G project seeks to build the "world's smartest road" [19]. This project involves a 5G wireless network using "smart light poles with integrated antennas, base stations, sensors, screens and other devices" [20, 21, 22]. Similarly, the Smart Transport Corridor from Helsinki to St. Petersburg seeks to identify and address mobility problems in a corridor, exchange data, and work toward the interoperability of data and services [23]. Another example of 5G wireless services focused on transit corridors includes Japan-based operator KDDI completing the first 5G demonstration on a moving train in October 2017 [24]. The interaction along a multimodal corridor can be complex, but as Erik Josefsson, Ericsson's head of advanced industries, has said, "I think the industry has high hopes that this [5G] can help simplify complex environments" [25].

Emerging technologies such as 5G, 8K video, and cloud computing provide opportunities for improving transit support and methodologies through lower latency, higher resolution video, and an integrated communications and support network along a transit corridor.

This paper provides a discussion of a smart streetcar corridor concept and

- identifies the technologies, components, and operation of a smart streetcar corridor concept;
- describes the application of this smart corridor concept to The Hop streetcar in Milwaukee, Wisconsin and the data-gathering, support functions, and transportation research methods that can be applied; and
- describes the outcomes and impacts of this smart corridor application for the streetcar operations, community benefits, and future design, development, and research.

2. Smart corridor concept description

The smart corridor consists of a communication and sensor network built to support the streetcar for safe and efficient operations through data-gathering, application of methodologies, operations support, and continuous improvement and research.

2.1 Smart nodes

The communications network consists of "smart node" devices along the streetcar corridor. A single smart node would be an all-weather container enclosing equipment for 5G communications, 8K video, sensors for quantities such as air quality, a computer, and a connection to a terrestrial high-speed Internet cable to cloud-based data storage and computing. Figure 1 illustrates a smart node.

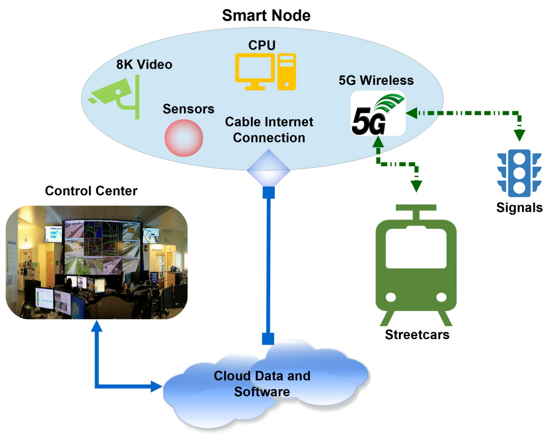

Fig. 1 *Smart Node components and communication*

The fixed nature of streetcar tracks provide known locations for line-of-site wireless communication to the streetcars and thus a good testbed for 5G communications. Most significantly, 5G provides real-time tracking through low-latency (1 millisecond) signals and possibilities for sensors in a density of up to 1 million devices per square kilometre. Current technologies for vehicle communications encounter problems where "[t]he effectiveness and efficiency of a TSP [Transit Signal Priority] implementation quickly degrades as the communication latency increases" [26]. 5G wireless would provide an advantage through much lower latency than GPS and Wi-Fi is used for vehicle location and communication [27].

The small computer in the smart nodes would serve to control the system as well as direct the 8K cameras whose data output would be too voluminous even for transmitting by terrestrial cable, but require data-reduction techniques, machine vision, and selective image and video clip upload. In this way, the smart nodes are a self-contained unit, capable of computation near the source of the wireless signals and video input as needed (edge computing).

The cable Internet connection would provide cloud-based data collection and would be accessible to a control centre for communications and commands. The cloud-based data could also be available to engineers, manufacturers of parts and systems for the streetcar, or other partners in research along the corridor.

2.2 Smart network

To form a smart network, a series of these smart nodes would be mounted on infrastructure spaced along the corridor in estimated intervals of 50 meters [22]. Wireless communication also would be made from these nodes with traffic and pedestrian signals and the streetcars. The resulting smart network would support communication among vehicles, nodes, edge computing resources, and the cloud. This communication could track the streetcars, monitor objects and events on the corridor, collect data from sensors, provide wireless communication, and send data to and from cloud-based storage and computing resources.

The network would serve as sensing and communication system for the corridor. As a collector of incident reports, statistics, and streetcar systems diagnostics, it could gather data to improve the system. For example, battery, brakes, wheels, and other systems could be monitored in real-time and statistics stored in the cloud. 8K video monitoring could continuously check for damage from vehicles or objects and be able to be directed by machine vision to identify objects striking the vehicle, for example, and their source, with redirected cameras photographing the source of objects striking the streetcar in a video buffer that would be able to "look back in time" at the activity on the route that caused the incident. High-resolution video might be transmitted to the streetcars or platforms for display on high-resolution monitors quickly, in response to conditions, route guidance, or advertising.

2.3 Data gathering

Data would be gathered on an ongoing basis to inform scientific methods or to draw conclusions that could inform procedures or public policy. The importance of continuous data-gathering cannot be overstated: conclusions could be drawn from data recorded and rates of incidents and events. Anecdotal accounts of incidents, such as observations of ride-sharing vehicles parked on the tracks, parked cars blocking the route, and other events cannot be used to make claims about the rate of these occurrences without a continuous record of observations.

Continuous data-gathering is key to building a database of statistics on the operation of the streetcar. Events, incidents, or more serious incidents can be looked at in terms of their occurrences, lessons can be learned, and procedures updated. This corresponds to a historic phrase used in rail transportation safety: rules and regulations are "written in blood" [28], that is, as a result of an incident, rules are codified. A record of the conditions of incidents and events could evaluate risks associated with different procedures. Further, known events in the corridor, such as expected traffic conditions for season, time-of-day, day-of-week, and the occurrence of festivals could be gathered. Weather events and snowfall amounts that lead to blockages of the track due to parking issues could be quantified so that procedures put in place to reduce delays and reduce conflicts.

Data gathering activity could include a range of statistics:

- Telemetry on vehicle position, speed, systems status (batteries, breaks, etc), passenger count, vehicle operations, auditory data, video clips or still images, traffic events or signals, and current weather and environmental conditions could be gathered.
- Event recording on particular events of interest such as sounding the horn, braking, speed changes, delays, passenger levels, including automatic capture of video and other data could be recorded. In particular, any incident which constitutes a potential safety issue could be examined so that procedures could be developed to prevent, mitigate, or understand the situation.
- Systems operation could be recorded, particularly in conditions of interest. For example, during polar vortex conditions, the battery drain rate and status could be tracked. For delays, the cause, proximate traffic, blockages, and other factors that led to it could be examined.
- Passenger loads throughout the trip could be recorded and sent to the cloud in real-time (to possibly avoid the streetcar door count data that was lost in February-March 2019, for example [29]).
- Passenger surveys might be developed through an app to measure, at various times through their ride, the level of satisfaction or specific questions, including perhaps tracking volunteer passengers throughout their trip on and off the streetcar. This data could yield insights into passenger behaviour and satisfaction and behaviour when fares are collected.
- Maintenance events including downtime, system failures, and probabilities associated with part replacements required could be gathered comprehensively.
- Video observations along the route could be gathered in a manner that uses data reduction techniques to make use of the high-resolution video and the selective upload of video frames. Procedures for blockage detection and resolution, ahead of the streetcar's arrival at a blockage, might be developed.
- Corridor state, including traffic and parking levels, pedestrian levels and movement could be gathered continuously.

2.4 Data integration

The massive data recorded would be processed by edge computing, and then integrated in cloud-based databases and used in cloud-based software. Presented in user interfaces in a physical control centre and monitored by analysts, decision support systems and other software could be applied to support operations in real-time. Analytic methods could be applied in cloud-based software for smart signalling, decision support systems, and integrated corridor management techniques that are described by a body of transportation research.

Smart signalling, based on mathematical models, has improved the performance of transportation systems. Transit data can be analysed and provide real-time responses to problems based on vehicle position [30]. Traffic signal timing has shown to reduce streetcar travel time [31]. Smart signalling has improved the reliability of service and reduced travel delays [32], and decreased passenger travel time in Bus Rapid Transit [33].

Transportation analysis can improve managing transportation routes in emergencies. Passenger demand management techniques can estimate demand patterns of a transit route [34], and real-time information for mobile phone users can help with accurate information for transit choice [35].

Decision support systems enhance the ability to plan traffic flows in a specific time period, such as in an emergency evacuation or unusual traffic condition [36]. Critical real-time issues can be supported with advanced traveller information [37] and for dilemma-zone intersections [38].

Integrated corridor management (ICM) approaches aim to make the best use of transportation infrastructure, facilities, and equipment [39]. ICM has been applied to mitigating congestion [40] and for a diversion control model for incident management on I-94 from Milwaukee to Waukesha [41].

These methods could control signals for streetcars, automobile traffic, and pedestrian signal lights. Further methods could be developed to address operational issues such as weather, snow, route blockages, or special events or conditions.

The corridor itself could be modelled using a digital twin [42]. For example, analysis could be done to see performance for 10-minute vehicle service intervals versus 15- or 20-minute intervals for varying conditions or events. Cost analysis could be done to see the value of adding another streetcar to the route for the day or permanently to the fleet. Cost analysis could be done on expected extensions, with detailed data on how street configuration (one tracks on a street or two, street widths, car-clearance distances) affect safety and efficiency. Digital twin scenarios could be developed in a virtual model, and then tested in the real world, along with null case conditions, to test hypothesis about algorithms or procedures that are under consideration.

Based on the framework provided by this smart corridor, modules could be developed to support the functional needs of a particular streetcar system. Figure 2 shows an overview illustration of these functions which could include:

- an integrated payments system, including transit fares, parking charges, bicycle sharing, shared vehicles, or congestion charges;
- traveller information including pre-trip information, travel guidance, location-based interest, advertising and promotions, demand forecast, or demand control;
- integrated corridor management issues including transit-oriented development; pedestrian-friendly street design, multimodal design and management, or facility management;
- smart signal functions including V2I (vehicle-to-infrastructure), transit signal priority, or adaptive signal control;
- smart vehicle functions including V2V (vehicle-to-vehicle), collision avoidance, and V2X (vehicle-to-anything); and
- safety and emergency management functions such as surveillance, traffic regulations, emergency notifications, emergency vehicle and pedestrian management.

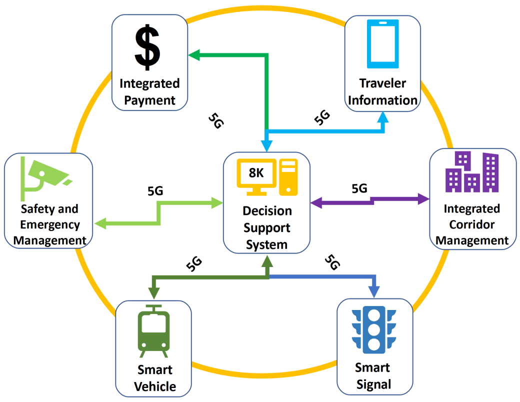

Fig. 2 *Functional Modules*

3. Smart corridor concept application

The domain of application of the smart corridor concept is described here for The Hop streetcar in Milwaukee, Wisconsin. The Hop uses modern streetcars and operates in a city with a history of past streetcar use and with a completed (2018) Main Line corridor of 3.4 km.

Electric streetcar service in the City of Milwaukee, Wisconsin operated from 1890 under the Milwaukee Street Railway Company through its successor companies, The Milwaukee Electric Railway & Light Company and The Milwaukee Electric Railway and Transport Company, until 1958

[9]. The extent of the system through the city of Milwaukee grew to as much as 289 km of track and an estimated streetcar fleet of approximately over 400 streetcars around the year 1930 [9, 43].

On November 2, 2018, Milwaukee's modern streetcar system, “The Hop,” opened in the downtown area with a Main Line corridor and five Brookville Liberty Modern streetcars capable of running off-wire on batteries using an onboard energy storage system [7]. The Hop's Main Line connects 18 boarding areas of various configurations [16]. Extensions of this system include the Lakefront Line (partly built) and lines planned to the Bronzeville [44] and Walker's Point [45] neighbourhoods. The City's vision is a streetcar system that could serve many neighbourhoods with transit-oriented development and with emissions-free (at street-level) vehicles [46]. The streetcar and passengers interact with Milwaukee's existing multi-modal transportation choices along its route which is a setting for commerce, housing, tourism, entertainment, and economic development [15, 47]. The Hop is new enough so that the operators may be eager to see ways to measure performance, and is small enough that placing a smart network on its entire corridor might be feasible; it also displays a diversity of street configurations and interactions with a variety of neighbourhoods. Therefore, the Hop in Milwaukee was identified as a pilot project of the smart streetcar corridor concept. Figure 3 illustrates the Hop's Main Line with smart node placement.

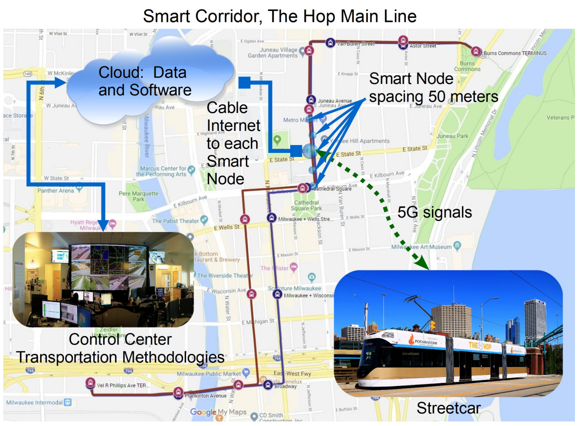

Fig. 3 *Smart Corridor Illustration on The Hop's Main Line*

The local needs of The Hop include providing transportation, motivating development, and supporting community goals. The City of Milwaukee sees The Hop as one component of environmentally-sustainable systems. The Milwaukee Environmental Collaboration Office recognises The Hop as an important choice in multi-modal, ecologically-sound transportation modes [48].

The Hop's main line (and eventually, extensions) could be covered by a smart node network. The LuxTurrim5G project places smart poles about every 50 meters along the route [22]. The smart nodes might be placed on infrastructure, such as city-owned light poles or streetcar infrastructure supporting the catenary cables. The Hop's Main Line includes track segments along adjacent streets, North Broadway and North Milwaukee Street, that are separated by about 96 meters. These segments are about 820 meters long. This would give a total distance to cover for the Main Line with smart nodes of 4.32 km. Based on the estimate of 50 meters separation of the smart nodes, The Hop's Main Line might be covered with approximately 87 smart nodes to form the smart network. Wireless connections and communication could be made to corridor traffic signals for automotive and bicycle traffic, streetcar, and pedestrian signals.

The goals of safety and efficiency can be supported through empirical research that can inform and shape procedures. Algorithms and decision-support could be developed for bridge openings or temporary closures (the Main Line crosses the Milwaukee River at St Paul Avenue), special events requiring special traffic flows in the Third Ward neighbourhood (such as Summerfest) or along the route (Veteran's Day Parade) based on observed statistics and performance goals. The aim of the smart streetcar corridor concept is to build a smart network to measure, model, and research the operations of the streetcar and the environment through which it travels.

Once implemented, the data-gathering and data-integration activities, including transportation methodologies, described in the previous concept description section could be implemented for The Hop's corridor. The cameras could be used to identify blockages to the streetcar's tracks, in advance of the streetcar arriving at the blockage. Resolution of the blockage, by towing or dispatching parking enforcement, could take place and reduce delay times or perhaps eliminate them. Cameras could also scan for immediate danger due to open car doors or other sudden blockages to the route and send messages to the streetcar operator. Smart signalling could be also optimised, so as to create faster travel times for the streetcar through the corridor.

At the heart of this concept is data-gathering that can measure how business, the environment, and residential life is impacted and to use this data for improving the network. The data collection and research could inform and justify public policies that support the harmonious operation of the streetcar with other traffic and transportation in a fair and equitable way. Application of transportation methodologies for smart signals would seek ways to reduce streetcar travel time [31], improve the reliability of service and reduce travel delays [32], and decrease passenger travel time [33]. Real-time information for mobile phone users could help with transit choice [35], and real-time issues could be addressed with advanced traveller information [37] and for dilemma-zone intersections [38].

4. Smart corridor outcomes and impact

The aim of the smart streetcar corridor is to improve the transit performance of the streetcar and, ultimately, improve the quality of life in the city. The areas of quality improvement are presented here with the abbreviation HELP meaning Health, Equity, Livability, and Prosperity.

4.1 Health

The smart streetcar corridor improves health by supporting emissions-free vehicles and reinforcing walkable urban places. The electric-powered nature of the streetcar vehicle makes it emissions-free in operation. Some streetcar systems, such as Nottingham Trams Ltd in England, buy power for electric trams from 100% "green [renewables] electricity" [49]. Advances in implementing renewable-energy production sources or special programs could increase the streetcar's green electricity use.

The streetcar systems reinforce a healthy activity, walking, by connecting neighborhoods with high walk scores [50], and thus gives people the opportunity and motivation to move within these areas to access resources in close proximity. The nature of streetcar transportation requires walking to and from stations and destinations. The walkshed distance of 400 meters from the streetcar stops takes in a wide range of features and activities to motivate walking, including fitness, parks, and health-related destinations [47].

The sensors along the corridor in the smart nodes could be used with air quality monitoring [22]. Other sensors and the 8K video could identify crash risks by all forms of traffic on the corridor, not just streetcars, so that the causes of injuries and deaths by automobile crashes might be identified or reduced.

4.2 Equity

By creating a smart corridor through which vehicles designed and built for all can operate and reducing the demand for single-vehicle trips, the streetcar supports the goal to increase equity. The smart streetcar corridor creates a framework for measuring the implementation of plans, bolsters business formation through the availability of 5G wireless, and works to make sure that the operations of the streetcar are safe, efficient, and harmonious with the goals for the communities. The smart network could maintain the accountability of the streetcar system to assure stakeholders that the best practices will be pursued, data will be collected for learning from incidents, and continuous improvement will be followed. In this way, the smart streetcar corridor works to garner trust from citizens and decision- makers.

Using transit to support community understanding and equity has a precedent, and the smart corridor may serve as a way to advance understanding among diverse communities. A project on Israel's public transit light rail system, Dissolving Boundaries, seeks to foster dialogue and understanding between Israeli and Palestinian residents. This project shows how "In a city full of contested spaces, Jerusalem’s light rail can function as a neutral ground" [51].

4.3 Livability

The next aim of the smart corridor is to support livability through urban-specific and human-centered design. Transit Oriented Development (TOD) seeks to make the best use of space around transit stops [52, 44, 45]. As the plans for streetcar extensions describe [46], transit-oriented development leverages the utility of locations that the streetcar establishes. Dense housing and transit, as described by architect Peter Calthorpe, seeks “to reinvent the old streetcar suburb, where you had fabulous downtowns and you had walkable suburbs, and they were linked by transit” [53]. The Hop's smart corridor, by providing a backbone of technology, can serve to unify information-sharing and data-gathering among not just the streetcar, but organizations involved in increasing the quality of life goals of TOD.

A case study analysis of a TOD development in New Jersey has shown that “...communities have been able to add populations, ...expand the variety of its housing stock, and create locations where residents can satisfy their needs without personal vehicles” [54]. TOD has been recognized as a way to capture the demand for housing near transit through development. Chris Persons, CEO of Capitol Hill [Seattle] Housing says, “The more we can locate affordable housing around transit, the better it is for the low-income individuals [and] the better it is for the resilience of our environment” [55].

4.4 Prosperity

The transportation support that the smart corridor provides aims to motivate development of property along the corridor and ridership of the streetcar. As Brown and Mendez [17] point out, the effectiveness of a streetcar as transit improves the chances for development effects along the route to take place. Further, in multiple-case-study investigation of streetcars, this relation is stated more strongly: “[C]ities that approach streetcars with transit service objectives in mind are likely to have better ridership and performance results, all else being equal.” [12]

The smart streetcar corridor would also support density by serving concentrations of residents, jobs, and visitors that lead to increased economic productivity. As observed [3, 4], the density of jobs and residences increases productivity, encouraging more jobs and growth. Density fosters specialization, knowledge spillovers, competition, efficiency, larger labor markets, and economies of scale [3]. Density is important for “enhancing economic productivity, encouraging more sustainable patterns of travel... and increasing occupational densities to support a more productive workforce” [53].

The introduction of 5G wireless service along the corridor could create a “smart zone” that motivates technology or entertainment companies or other enterprises to establish businesses. A 5G zone near the Fiserv Forum arena might be very helpful for entertainment options and major conventions. The Hop's introduction has taken place at a time of major developments in downtown Milwaukee, and the smart corridor can serve not only the streetcar, but function as a network supporting innovative technologies and services that can utilize the smart nodes and network.

4.5 Research and development

In addition to the HELP outcomes described, research and development opportunities could become available through the implementation of the smart corridor. Manufacturers of streetcar vehicles, equipment, systems, components for the smart nodes and smart network, and developers of parts, batteries [56], software, and services may benefit by cloud-based monitoring of their products as used on the streetcar corridor.

The digital twin model could be used for analysis of operations, testing designs of future expansions, or testing hypothesis regarding signaling or decision support systems algorithms. Digital twin modeling could be done to test a concept of a “virtual right of way” to examine how smart signals and traffic control could provide efficient transit through an urban area. Continuous gathering of data along the route would model the streetcar corridor and set probabilities and parameters in the digital twin for conditions such as traffic, weather, obstructions, people, activities, and special events. Development of concepts on the digital twin and measurements on the real-world system could work to continuously improve the system.

5. Conclusion

This paper described the concept of a smart corridor for streetcar operations, support, and analysis. Application of this smart corridor to The Hop streetcar in Milwaukee, Wisconsin, was discussed and its potential impact and benefits for improving the streetcar's transit capability and supporting community goals for health, equity, livability, and prosperity.

The proposed framework could help the unique community of Milwaukee through smart transportation. While focused on The Hop for deployment, the smart corridor concept might be used on some of the 376 streetcar systems around the world and those in development [11]. Many such proposed or operating systems face scrutiny. The benefit of a smart corridor would be safe, efficient, and harmonious operations that support business incubation and attraction, advancement of transportation research, and opportunities to improve the health, equity, livability, and prosperity along the smart corridor. Stakeholders may benefit greatly by the promise and operation of this "streetcar operating system," ready to work toward corridor-based continuous improvement of the system and benefits to the community.

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