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Lessons learned from evaluating complete streets project outcomes with emerging data sources

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ABSTRACT
Complete Streets projects can bring multifaceted benefits but before-and-after analysis regarding their mobility and accessibility outcomes is quite limited in practice. This study used emerging data sources to conduct longitudinal project outcome evaluations. Two projects from Louisiana were selected as case studies for demonstration. The two projects did not induce heavier congestion in a pilot analysis region. One project with sidewalks/bike lanes contributes to traffic calming in an urban context, while the other project consisting only of a widened shoulder marked for bicycle use may raise speeding concerns in a rural context. Both projects are likely to bring accessibility benefits as they attract more businesses and longer visits. The authors also noted data source and outcome measure challenges in different contexts. The proposed evaluation approach and identified data gaps will benefit the private sector in diversifying/improving their data products and facilitate the public sector in making more data-driven decisions.

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Introduction

Shifting transportation policy from auto-centric to multimodal balance is not entirely new but has evolved to embrace more transportation modes (e.g. walking and biking) with more detailed actions as time has passed. The Intermodal Surface Transportation Efficiency Act (ISTEA) was the first national level legislation in the U.S. emphasizing multimodal transportation upon highway transportation assets (Schweppe 2001). Succeeding national legislation continued emphasizing multimodal concepts (FHWA 2012, 2005, 1998). In 2016, the Fixing America's Surface Transportation (FAST) Act starts (1) authorizing alternative design guidelines for better pedestrian and bicyclist accommodations and (2) stating 'providing safe and adequate accommodation of all users of the surface transportation network in all phases of project planning, development, and operation' (FHWA 2016). In 2022, the Federal Highway Administration (FHWA) proposed moving to a Complete Streets design model (which is a process and approach accommodating all road users (Smart Growth America n.d.)) in its

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report to the Congress (FHWA 2022). Complete Streets facilities include a wide range of transportation infrastructure (from sidewalks and bike lanes to streetlights and signs) with an emphasis on promoting multimodal transportation (e.g. walking and biking) and context sensitive design. The report identifies improving 'measures of performance to support decision makers in addressing all transportation modes' as one of five challenges/opportunities (FHWA 2022). While Complete Streets 'output' (e.g. facility presence) measures are currently subject to data consistency and limitation issues, 'outcome' (i.e. benefits) measures need to be improved in order to assess progress made toward the policy goals (FHWA 2022).

Outcome measures are considered of great importance in tracking project performance and supporting future transportation project selection decisions. The most well-known measure perhaps is the Level of Service (LOS) from the Highway Capacity Manual (TRB 2016). Multimodal Level of Service (MMLOS) measures have also been proposed and have evolved in the last decade to address the concept from different perspectives. However, the impacts of Complete Streets projects are not restricted to their contributions to mobility but may be extended to include various benefits (e.g. access to major destinations).

In addition, even states leading multimodal (or Complete Streets) practice are facing challenges in making consistent and comparable evaluations over time and geographic regions (Jordan and Ivey 2021; Khedri, Malarkey, and Mackenzie 2022). For example, a pilot cross-sectional outcome evaluation was made on eight corridors in New York (Lenker, Maisel, and Ranahan 2016). The pilot evaluation features qualitative surveys, count and crash data, and economic and health impact metrics. The study recognized that collecting survey data is invaluable, but also that it is time-intensive and costly to do so (Lenker, Maisel, and Ranahan 2016). The Multimodal Mobility Dashboard of Washington State Department of Transportation (DOT) provides annual performance information but only on selected state-owned facilities (WSDOT 2022). Even though measuring project performance 'one year before construction and then after one year and after three years' is considered a best practice, before-and-after analysis is limited in practice (Jordan and Ivey 2021; Khedri, Malarkey, and Mackenzie 2022; Seskin, Kite, and Searfoss 2015). Overall, project outcome evaluation practice is typically restricted in its temporal span and spatial scope. Data availability may be one of the reasons preventing past studies and practices from pursuing project outcome evaluations to their best extents (Canfield, Yang, and Whitlow 2018; Mitra et al. 2015; Smart Growth America 2021).

Passively collected data (e.g. smartphone records) have the potential to expand the temporal and spatial scope of outcome evaluations (Barbeau et al. 2020). The purpose of this study is to use emerging data sources in evaluating longitudinal project outcomes. Several data sources were compared by scope and granularity on both spatial and temporal dimensions. Measures were then proposed based on data availability and past studies. Then two Complete Streets projects in Louisiana were selected as case studies to demonstrate how the proposed measures and data sources work in practice. The selected projects are in different types of areas (i.e. urban and rural) and have different types of facilities built, which facilitates data source evaluation in different contexts. The projects' longitudinal outcome evaluation results are then presented and discussed. Note that this study does not intend to make generalizable conclusions regarding outcomes gained from Complete Streets projects, but to provide an evaluation approach to practitioners. Lastly, the authors present lessons learned from conducting the case studies and point out several specific data source and outcome evaluation challenges and opportunities.

The research findings will benefit private sector stakeholders (e.g. data vendors) aiming to improve their data products, broaden their impacts in addressing more transportation issues, and assist transportation decision-making to a greater extent. The proposed outcome evaluation approach will benefit the public sector (e.g. state DOTs) in making more equitable and data-driven decisions over a long period (i.e. multiple years) and a large region (i.e. state- or nation-wide).

Literature review

The current study is a continuation to the author's previous study, which reviewed Complete Streets practice and performance metrics in general (Bian and Tolford 2022). The current study proceeds to exemplify promising data sources that can be used in recurring evaluations in practice and identify possible data gaps for further improvements. The first subsection reviews emerging data sources and how they are being used to solve different transportation issues, especially those that are related to biking, walking, and taking transit (which are the travel needs Complete Streets aim to accommodate). The second subsection reviews how mobility and accessibility were measured in past studies and what data sources could be used to conduct longitudinal project outcome evaluations.

Emerging data sources in solving transportation issues

With the development of data collection technologies (e.g. advanced sensors, connected/autonomous vehicles, Laser, and LiDAR), several emerging data sources are utilized to better understand traffic patterns and improve transportation system management. In general, emerging data sources in modern transportation systems include Connected Travelers Data, Connected Vehicle Data, and Connected Infrastructure Data (Gettman et al. 2016). In the last few decades, emerging big data sources have been used in transportation planning, modeling, and management. For example, Wang, Sylvia, and Leung (2018) reviewed the progress of using mobile phone data in travel behavior research. Mobile phone data show great potential in advancing human travel behavior studies due to its unprecedented coverage of population and geographic area, continuous and sufficiently long data collection periods, and detailed and accurate location and motion information. Wang, Sylvia, and Leung (2018) also discussed the major challenges of using mobile phone data (e.g. restrictions of data access, storage, and management) and identifying travel patterns (e.g. sampling bias and limited travel information). Zannat and Choudhury (2019) conducted a systematic review of emerging big data sources (e.g. smart cards, detailed vehicle location data, mobile phone traces, and social media) for public transportation planning. Applications of these big data in transportation research include travel pattern analysis, public transportation modeling, and performance assessment. They acknowledged the usefulness of big data in public transportation planning, while identifying challenges in data evaluation and validation (e.g.

discontinuity in the location data, errors/missing information due to user privacy, and sampling bias from various apps). They also suggested future research focus on developing more novel applications of big data and more advanced techniques for model validation. Lee and Sener (2020) reviewed current emerging data collected through mobile devices for pedestrian and bicyclist monitoring. For mode-unspecified emerging data that is not generated from a method targeted at only pedestrians and bicyclists but rather generated from the general population carrying mobile devices, one of the challenges is to accurately extract walking and bicycling trips from 'messy and muddled' raw datasets. While mode-specified emerging data (e.g. bicycle-tracking app, fitness-tracking app, and bike-share program) have been vigorously applied in bicycle studies, applications for pedestrians are few due to the high uncertainty and variability of walking trips. Though challenges remain, the research highlights promising opportunities to take advantage of the emerging data for pedestrian and bicyclist monitoring.

Complete streets outcome measures and data sources

As an integral part of transportation planning and management, performance measurement is important for transportation operators and authorities to ensure system service quality. Several studies have already reviewed typical outcome measures for evaluating Complete Streets projects (Bian and Tolford 2022; Hui et al. 2018; Jordan and Ivey 2021; Ranahan, Lanaker, and Maisel 2014). This section focuses on comparing different data sources for practical outcome evaluations at the project level over a long-time span (i.e. multiple years) and across a large geographic region (i.e. state-wide).

Understanding the policy goals and objectives is the first step in evaluating project outcomes (Seskin, Kite, and Searfoss 2015). The three major goals of Complete Streets policies include safety, mobility, and accessibility (Bian and Tolford 2022). Safety measures are mentioned frequently and have more uniform data sources and analytic approaches than the other outcome measures. Typical safety measures include the frequency, type, and severity of crashes for motorists, pedestrians, and cyclists; compliance with speed limit (e.g. the percentage of drivers exceeding the speed limit); and crash modification/reduction factors (Broward MPO 2015; Florida Health and Hillsborough MPO 2017; Hanson 2017; Lenker, Maisel, and Ranahan 2016; Mitra et al. 2015; Ranahan, Lanaker, and Maisel 2014; Smart Growth America 2021). Crash records kept by public agencies are the main data source for safety evaluations. Therefore, this section focuses on mobility and accessibility measures, which are mentioned less frequently than safety measures and tend to be less standardized.

Measuring mobility

Typical mobility measures include mode share (e.g. pedestrian counts and transit ridership), vehicle miles traveled (VMT), efficiency in parking/loading, trip consistency (e.g. travel time by mode, travel time reliability, and the percentage of person-hour change in delay), level of service by mode, and MMLOS (Broward MPO 2015; Liu et al. 2020; Mitra et al. 2015; Stevanovic et al. 2020). Data sources mentioned in past studies include field observations and traffic simulation models (Liu et al. 2020; Stevanovic et al. 2020). Table 1 lists potential data sources for evaluating mobility. Among the identified sources, Regional Integrated Transportation Information System (RITIS) provides data of the

Table 1. Potential data sources for mobility measures.

Data source	Spatial range	Spatial unit	Temporal range	Temporal unit	Measuring …
Regional Integrated Transportation Information System (RITIS)	Nation	Route (to segment)	Since 2010 (*)	Hour	Compliance with speed limit; traffic volume; travel delay; travel time reliability
National Transit Database (NTD) (FTA 2022)	Nation	Agency	Since 1997	Year (**)	Passenger miles; Unlinked passenger trips; Average trip length; Average cost per trip
General Transit Feed Specification (GTFS) (gtfs.org 2022)	Nation	Transit route	(Up-to-date)	(Real time)	Transit service frequency

Note: (*) the dataset has improved geographic coverage since 2017 and continues to be regularly improved. (**) some transit agencies did not begin to submit monthly ridership to NTD until 2002.

best resolution for project-level mobility evaluations. Most state DOTs in the U.S. have subscribed to its service and can access historical INRIX traffic data from the platform. The traffic data are collected by agencies and third parties from various roadway sensors (RITIS 2022). Traffic data (e.g. travel speed and time) on interstates and major arterials in the U.S. can be traced back to 2010 with specific time stamps.

It should be noted that the above-mentioned data sources fit outcome evaluations for road segments but not for spot locations (e.g. intersections), which is a potential data and measurement gap. In current practice, a good source to get a one-time mobility evaluation for spot locations is from traffic studies. In addition, congestion at intersections is typically focused on autos, without any measure of pedestrian and bicyclist accommodation or delay. The Highway Capacity Manual included methodologies for calculating a bicycle level of service (BLOS) and pedestrian level of service (PLOS) at signalized intersections (TRB 2016). However, the BLOS and PLOS measures are not sensitive to delay (Huff and Liggett 2014). Consequently, any traffic signal improvements will not be reflected through these measures. In addition, BLOS and PLOS tend to be more focused on the user experience/comfort instead of safety. Measuring pedestrian and bicyclist delay is important for safety concerns because undue delay results in pedestrians and bicyclists disregarding traffic signals. The National Cooperative Highway Research Program (NCHRP) recently published a report including pedestrian and bicyclist delay as vital performance measures for intersections (NASEM 2022). Treatments reducing pedestrian and bicycle delay are also included in the report (NASEM 2022).

Measuring accessibility

A thorough review of accessibility measures could be found from the study by Geurs and van Wee, which categorizes accessibility measures into infrastructure-based, location-based, person-based, or utility-based (Geurs and van Wee 2004). Some past studies include mobility measures (i.e. the number of trips by different mode) or connectivity measures (i.e. closing network gaps or level of traffic stress (Furth 2022)) in evaluating accessibility (Seskin, Kite, and Searfoss 2015). In this study, accessibility refers to connections with major destinations (Seskin, Kite, and Searfoss 2015). Convenient access to commercial destinations (e.g. restaurants and grocery stores) and outdoor destinations (e.g. playgrounds and parks) can contribute to economic growth and public health improvements. Thus, this study identifies and incorporates potential measures for these two relevant benefits and their data sources.

The economic benefits of Complete Streets projects include increased consumer spending, increased property values, higher business occupancy rates, higher employment rate, individual transportation cost savings, and positive perceptions from businesses and residents (Broward MPO 2015; Canfield, Yang, and Whitlow 2018; Lenker, Maisel, and Ranahan 2016; Mitra et al. 2015; NYCDOT 2014; Perk, Hymowitz, and Catala 2015; Prieger 2014; Seskin, Kite, and Searfoss 2015; Smart Growth America 2021). Data sources mentioned in past studies include county/parish property tax databases, sales tax receipts, and surveys of business owners (Broward MPO 2015; NYCDOT 2014; Perk, Hymowitz, and Catala 2015; Ranahan, Lanaker, and Maisel 2014). Sales tax receipts are considered to provide the strongest and the most direct data for business vitality evaluation (NYCDOT 2014). However, confidentiality of the data source restricts widespread use in practice. Employment information is considered a moderate indicator but does not fit evaluation at a finer scale (e.g. community or project level) (NYCDOT 2014).

Typical public health measures include health records (e.g. asthma, diabetes, chronic disease, and obesity cases), physical activity duration and frequency, and exposure to heat/heat-related illness (Florida Health and Hillsborough MPO 2017; Lenker, Maisel, and Ranahan 2016; Mitra et al. 2015; Ranahan, Lanaker, and Maisel 2014; Smart Growth America 2021). Data sources include hospital records, self-reported physical activity, household surveys, field data collection, and databases of health-related state/local agencies (Lenker, Maisel, and Ranahan 2016; Ranahan, Lanaker, and Maisel 2014).

Table 2 lists potential data sources for evaluating accessibility benefits. Among the identified sources, SafeGraph provides data of the best resolution for project-level evaluations. This large-scale data is passively and anonymously collected from mobile devices

Table 2. Potential data sources for accessibility measures.

Data source	Spatial range	Spatial unit	Temporal range	Temporal unit	Measuring …
SafeGraph	Nation	Longitude/ Latitude	Since 2018	Month	Accessibility to major destinations; Number of new businesses; Activity durations at commercial destinations; Activity durations at outdoor destinations
National Center for Education Statistics	Nation	Address	(*)	(*)	Accessibility to schools and colleges
Census: County Business Pattern (CBP)	Nation	Zone (to zip code)	Since 1994	Year	Accessibility to employment centers; Number of new businesses and employment
Longitudinal Employer-Household Dynamics	Nation	Zone (to census blocks)	Since 2002	Year	Accessibility to employment centers; Number of new businesses and employment
CDC National Environmental Public Health Tracking	Nation	Zone (to parish)	Since 2000	Year	Rates of obesity, asthma, diabetes, etc.
CDC PLACES (CDC 2022)	Nation	Zone (to census tract)	Since 2021	Year	Health in 29 different indicators

Note: (*) is based on the time of data collection.

year-round since January 2018. Specifically, the dataset presents how often millions of points of interests (POIs) were visited by people in the U.S. each month. SafeGraph's POIs are places that fall in categories recorded in the North American Industry Classification System (NAICS). The most recent product updates attach transaction data to each POI, which would benefit longitudinal economic impact analysis in the future.

Methodology

This section presents how to use the identified data sources to measure mobility and accessibility outcomes. Figure 1 provides an overview regarding what Complete Streets project outcomes were measured in this study, including data sources, metrics, and measures.

Measuring mobility with RITIS data

The proposed measures were calculated based on traffic speed data from RITIS (RITIS 2022). First, traffic calming is frequently identified as one of the benefits of implementing Complete Streets (NYCDOT 2015; Smart Growth America 2021). Speeding (or speed limit non-compliance rate) was calculated as the percentage of times that the measured travel speed is greater than the posted speed limit in this study.

Second, congestion reduction is another priority of state DOTs. Reducing the number/width of travel lanes and using the space to accommodate pedestrians and bicyclists may raise the concern of increased congestion for motorists (FHWA 2022). RITIS data can help inform mobility evaluations for road segments. Congestion is measured in different manners in practice (Afrin and Yodo 2020). This study used the speed reduction factor defined by Texas A&M Transportation Institute (TTI) (Schrank et al. 2021). TTI applies the congestion measure in its nation-wide Urban Mobility Report, which is published each year (Texas A&M Transportation Institute 2022). RITIS also applies TTI's definition in their system as they calculate travel delay. This study replicated TTI's congestion measure by using the same equation (as shown below) and the same dataset (i.e.

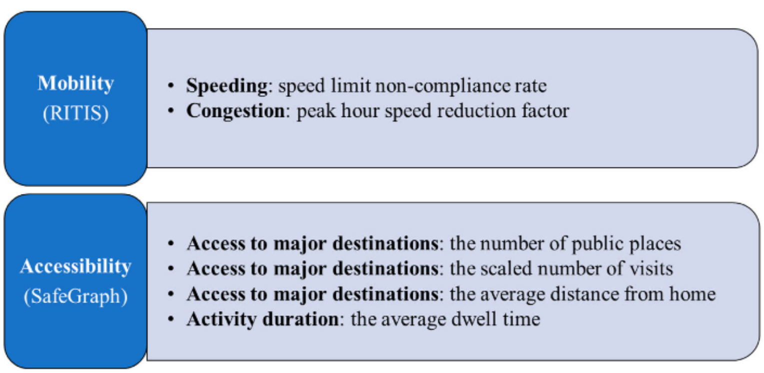


Figure 1. Complete Streets project outcomes measured in this study.

RITIS/INRIX) in evaluating mobility outcomes achieved from Complete Streets projects (Schrank et al. 2021). As defined, morning peak period is from 6 am to 10 am, while evening peak period is from 3 pm to 7 pm For non-freeways, speed reduction factors ranging from 80% to 100% is considered no to low congestion; ranging from 65% to 80% is considered moderate congestion; and less than 65% is considered severe congestion (Schrank et al. 2021). The case studies presented in the next section discuss how well the congestion measure works in evaluating mobility outcomes from Complete Streets projects.

$$\text{Speed reduction factor}(\%) = \left(\frac{\text{Average Peak Period Speed}}{\text{Free flow speed}}\right) * 100\% \qquad (1)$$

Measuring accessibility with SafeGraph data

The proposed measures were calculated based on SafeGraph data. In this study, accessibility was measured by the number of public places covered within 0.2 miles (i.e. 1000 feet) to the center line of road segments under evaluation. This threshold was selected to ensure that all POIs which would typically be accessed via the study corridor were included, while excluding locations on parallel routes. Future evaluation studies may want to adjust this distance threshold to fit their specific evaluation cases, as this threshold may vary depending on land use and intersection density. In addition, the dataset also provides average travel distance from home to public places. Observing the longitudinal variation of travel distances can help determine whether short-distance trips increase after project completion, which is likely to indicate improved accessibility to nearby destinations and may contribute to area-wide congestion alleviation, as shorter trips are more likely to be taken by non-motorized travel modes.

The number of visits is likely to be affected by the number of devices counted in SafeGraph's data. Table 3 shows the number of devices counted by SafeGraph each year. The number of visits reported in the following case studies was scaled by dividing the increment factor (shown in the second column on the right-hand-side) to normalize the data for use in longitudinal evaluation.

Case study results and discussions

This section presents how the outcome measures and data sources work in actual project evaluations. Although Complete Streets include a wide variety of components, here the authors focus on construction projects that have sidewalks, bike lanes, multi-use paths, or

Table 3. The number of devices counted for all the U.S. states.

Year	The total number of devices seen in the year	Number of days	The average of devices seen per day	Increment in relative to 2018	Increment in relative to the previous year
2018	5,934,391,271	365	16,258,606	1.00	na
2019	6,606,080,908	365	18,098,852	1.11	1.11
2020	6,327,538,728	366	17,288,357	1.06	0.96
2021	5,740,700,020	365	15,727,945	0.97	0.91

Note: 'na' means not available.

paved shoulder, etc. built during the project time because (1) these components are more likely to improve multimodal accommodation, (2) the study area (i.e. Louisiana) has a clear design guideline for the above-mentioned Complete Streets components, and (3) Louisiana's existing Complete Streets Policy does not include clear guidance for how to incorporate a Complete Streets approach into signage, signal, or other operation-focused projects. After reviewing projects funded by Louisiana DOT (or DOTD) between 2011 and 2020, two projects were selected for demonstration purposes in considering data availability. The two projects are located in different contexts and have varying characteristics, though both included elements intended to improve conditions for people walking and/or bicycling. In addition, data were also collected for control groups with similar characteristics (in considering distance proximity, land use, and roadway layout) where no Complete Streets interventions were implemented for comparison (NYCDOT 2014).

Case study 1: a corridor improvement project in the capital city

The project is in Downtown/Mid City of Baton Rouge. The horizontal line in the center of Figure 2 shows its location. The project built four miles of bike lanes (4.5′-5′) and sidewalks (4′-12′) on Government St., which is classified as a minor arterial. The project also involved a 'road diet' concept, converting a four-lane roadway to three lanes. The project was started in early 2018 and marked as complete by the end of 2021. It should be noted that the majority of construction was already completed in early 2021. The evaluation period is from one year before the project starts to the latest date for which data is

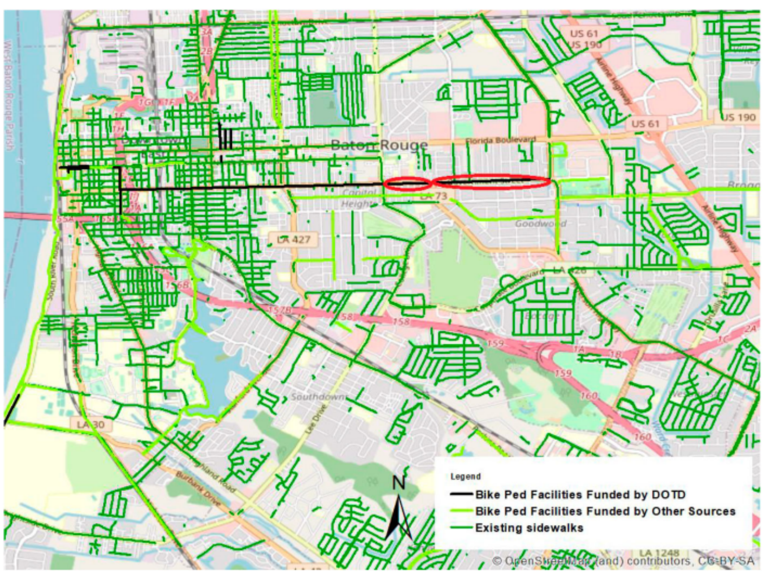


Figure 2. Complete Streets projects in Downtown/Mid City of Baton Rouge.

available. The road segments selected as its control group for comparison are on a parallel route (i.e. Florida Blvd; classified as a major arterial) that is about half a mile to the north of Government St.

Mobility: speeding and congestion

The posted speed limit on all segments of this corridor within the study area is 40 mph. According to the design guidance of National Association of City Transportation Officials (NACTO), unprotected bike lanes are generally considered inadequate for road segments with such a posted speed limit to accommodate bicyclists of different ages and abilities (NACTO 2017). Table 4 presents the speed limit non-compliance rate by direction. The speed limit non-compliance rate drops from around 2.6% to 1.4% after project completion. As a comparison, the speed limit non-compliance rate of its control group (i.e. Florida Blvd) maintains around 10% during this time period (except in 2020 as explained below). In addition, the speed limit non-compliance rate on Government St increases to 2.8% in 2020 (i.e. the year of pandemic outbreak), while the increment is more dramatic (i.e. 19%) on Florida Blvd. Overall, the scale of changes indicates that the Government St project contributes to traffic calming since its completion. If we look at individual segments on Government St, the speed limit non-compliance rate is relatively higher on the segments between Jefferson Hwy and Lobdell Ave (i.e. segments in the right-hand-side circle in Figure 2) than other segments.

Table 4 also presents average travel speed and speed reduction factor by direction in peak hours. Free flow speed was extracted from RITIS, which defines it as 'the 95th percentile of the speeds between 10 PM and 5 AM over a 6-month period' (RITIS 2022). As shown in Table 4, free flow speed is slightly higher than the speed limit on these road segments. The congestion measure reveals that the corridor (including Government St and Florida Blvd) generally sees severe congestion (speed reduction factor < 65%) in peak hours on both directions before and after the project completion. The speed reduction factor drops from around 60% to 55% during the time period on Government

Table 4. Mobility status on Government St.

Direction	2017 (before)	2018 (during)	2019 (during)	2020 (during)	2021 (after)
Westbound					
Speed limit non-compliance rate	2.9%	2.7%	2.3%	2.9%	1.5%
Free flow speed (mph)	45	43	43	43	43
Morning peak hour average speed (mph)	27	25	26	27	25
Morning peak hour speed reduction factor	63%	60%	61%	64%	58%
Afternoon peak hour average speed (mph)	24	24	24	25	22
Afternoon peak hour speed reduction factor	57%	57%	56%	59%	52%
Eastbound					
Speed limit non-compliance rate	2.2%	1.9%	2.3%	2.7%	1.3%
Free flow speed (mph)	43	43	43	43	43
Morning peak hour average speed (mph)	25	25	25	27	25
Morning peak hour speed reduction factor	60%	59%	59%	64%	59%
Afternoon peak hour average speed (mph)	24	23	23	26	22
Afternoon peak hour speed reduction factor	57%	55%	54%	61%	53%

St, which means the traffic speed reduces. However, the parallel route (i.e. its control group Florida Blvd) does not become more congested with potential traffic diversion during the time period as its speed reduction factor remains almost the same as before. If we look at individual segments, the most congested segments are between South Foster Dr and Jefferson Hwy (i.e. segments in the left-hand-side circle in Figure 2).

Accessibility

Table 5 shows that the total number of public places and the average dwell time generally increases from year to year and jumped significantly in 2021. The scaled number of visits significantly drops in 2020 and bounces back in 2021, which is likely due to the pandemic as the same pattern occurs on Florida Blvd (i.e. its control group). The average travel distance from home also increases in 2021, which means public places near Government St attracts more long-distance trips. Overall, this project is associated with attracting more businesses and longer visits (in both time and distance) after its completion.

The top place category is 'Restaurants and Other Eating Places' due to its leading numbers and attracted visits. This suggests that the project has potentially resulted in economic benefits. In addition, the project provides convenient access to existing health-related businesses (e.g. 'Offices of Dentists' listed in Table 5) and attracts new health-related businesses (e.g. three 'Offices of Physicians' opened in 2021), which potentially provides public health benefits.

Table 5. Public places near Government St.

Place category	2018 (during)	2019 (during)	2020 (during)	2021 (after)
The number of public places				
TOTAL	212	211	228	253
Restaurants and Other Eating Places	48	48	48	53
Offices of Dentists	14	14	14	14
Personal Care Services	16	16	16	14
Religious Organizations	10	10	13	12
Child Day Care Services	9	9	9	9
The scaled number of visits to public places				
TOTAL	420,925	456,788	374,217	456,266
Restaurants and Other Eating Places	135,975	150,759	125,810	154,145
Offices of Dentists	6864	7637	5422	4724
Personal Care Services	6076	5937	4657	4246
Religious Organizations	26,494	29,982	19,675	20,178
Child Day Care Services	7831	6125	4596	4812
The average dwell time (in minutes)				
AVERAGE	76	64	72	86
Restaurants and Other Eating Places	60	62	67	61
Offices of Dentists	147	155	169	109
Personal Care Services	109	124	118	115
Religious Organizations	63	64	74	83
Child Day Care Services	110	69	68	55
The average distance from home to public places (in miles)				
AVERAGE	6.4	6.6	6.5	8.4
Restaurants and Other Eating Places	5.9	6.4	6.3	7.3
Personal Care Services	6.7	6.6	7.0	7.8
Offices of Dentists	6.7	6.9	7.4	9.9
Religious Organizations	6.2	6.7	7.7	8.5
Child Day Care Services	5.3	6.8	7.2	7.5

Note: SafeGraph data is available since 2018. The table only lists the top five place categories.

Case study 2: a shoulder expansion project in a small town

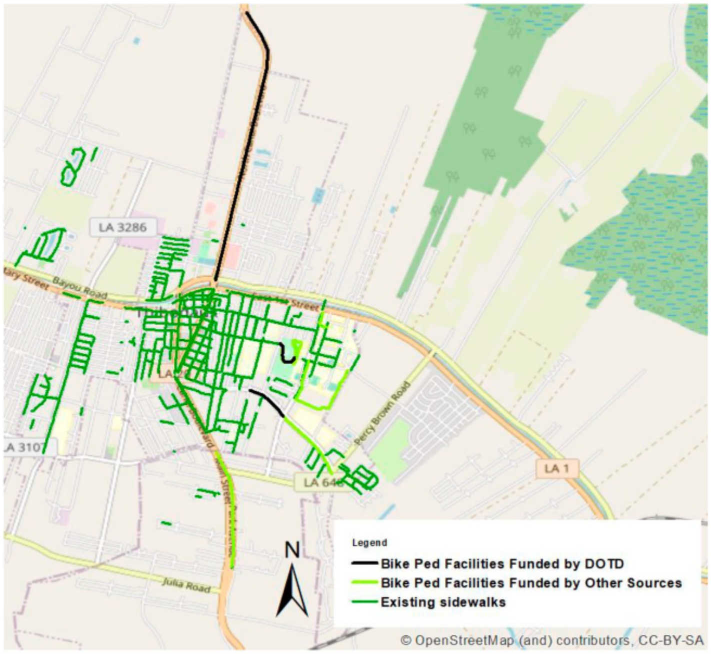
This case study evaluates outcomes from building expanded paved roadway shoulders, which may be considered adequate Complete Streets accommodation for pedestrians and bicyclists in rural contexts, such as under Louisiana's current Complete Streets design guidance. Figure 3 shows the project stretching out from the center of Thibodaux, which is the parish seat of Lafourche Parish. The 2.67-mile project built 8′ shoulders (which may vary to 4′ or 10′ at some places) and has bike lane markers to indicate that this is a designated bicycle route. The project was started in 2015 and marked as complete in 2017. The evaluation period is from one year before the project starts to the latest date for which data was available. The road segments selected as its control group for comparison are on LA24, which is a major arterial as well. LA24 connects with LA20 but the selected LA24 segments are about two miles to the south of the LA20 segments under evaluation.

Mobility: speeding and congestion

The posted speed limit is 55 mph. Table 6 presents the speed limit non-compliance rate by direction. It should be noted that the RITIS segment (of about 6 miles) is much longer than the road segments under evaluation (of about 3 miles). The data shows speed limit non-compliance rate increases from around 2% to 3% after the project completion in 2017. Northbound traffic heading out of the town has a higher speeding rate than southbound traffic. As a comparison, the speed limit non-compliance rate of its control group

Table 6. Mobility Status on LA 20 road segments under evaluation.

Direction	2014 (before)	2015 (during)	2016 (during)	2017 (during)	2018 (after)	2019 (after)	2020 (after)	2021 (after)
Northbound								
Speed limit non-compliance rate	2.0%	2.5%	2.0%	1.9%	3.1%	2.4%	2.9%	3.5%
Free flow speed (mph)	59	59	60	60	60	60	60	60
Morning peak hour average speed (mph)	33	33	33	37	38	37	38	39
Morning peak hour speed reduction factor	55%	56%	55%	62%	64%	61%	63%	65%
Afternoon peak hour average speed (mph)	28	30	29	31	32	31	32	36
Afternoon peak hour speed reduction factor	48%	50%	49%	51%	53%	51%	53%	60%
Southbound								
Speed limit non-compliance rate	2.2%	1.4%	1.6%	1.4%	2.5%	1.9%	1.9%	2.0%
Free flow speed (mph)	58	58	59	59	59	59	59	59
Morning peak hour average speed (mph)	34	33	32	35	38	37	38	40
Morning peak hour speed reduction factor	58%	57%	55%	59%	64%	63%	64%	69%
Afternoon peak hour average speed (mph)	29	29	30	30	33	31	32	35
Afternoon peak hour speed reduction factor	50%	50%	50%	51%	56%	52%	54%	59%



(a) Project location

(b) Bike lane markings (Image source: Google Street View)

Figure 3. A project with shoulder expansion in Thibodaux, LA. (a) Project location. (b) Bike lane markings (Image source: Google Street View).

(i.e. LA24) increases from around 15% to 23% during the time period. Overall, this result indicates that the LA20 project does not positively contribute to traffic calming since its completion. However, the built facilities might prevent speeding issues from getting even worse like its control group.

Table 6 also presents the average travel speed and speed reduction factor by direction in peak hours. First, congestion during afternoon peak hours is more severe than that during morning peak hours for both directions. Second, speed reduction factors during peak hours increase from around 53% to 60% since the project completion in 2017. As a comparison, speed reduction factors of its control group increase from around 61% to 67%. The similar increment suggests that the LA20 project may have limited contributions to congestion alleviation on the corridor. The traffic improvement may be due to other improvements made in this region.

Accessibility

SafeGraph data do not cover years before the project start/completion, but the data provide an overview regarding how the project has made an impact one year and three years after completion and beyond. Table 7 shows that 10 new businesses are

Table 7. Public places near LA 20 road segments under evaluation.

Place category	2018 (after)	2019 (after)	2020 (after)	2021 (after)
The number of public places				
TOTAL	101	100	103	111
Restaurants and Other Eating Places	33	33	32	35
Health and Personal Care Stores	5	5	6	8
Depository Credit Intermediation	7	7	7	6
Gasoline Stations	4	4	5	5
General Merchandise Stores, including Warehouse Clubs and Supercenters	4	4	4	4
The scaled number of visits to public places				
TOTAL	494,878	637,816	714,563	946,482
Restaurants and Other Eating Places	144,667	194,447	228,449	278,019
Health and Personal Care Stores	25,055	31,333	37,378	42,204
Depository Credit Intermediation	2692	3859	3976	5397
Gasoline Stations	19,517	21,753	32,108	52,369
General Merchandise Stores, including Warehouse Clubs and Supercenters	85,662	110,796	117,199	111,385
The average dwell time (in minutes)				
AVERAGE	50	58	63	57
Restaurants and Other Eating Places	32	26	21	18
Health and Personal Care Stores	29	31	15	20
Depository Credit Intermediation	16	24	64	17
Gasoline Stations	8	10	10	14
General Merchandise Stores, including Warehouse Clubs and Supercenters	21	20	19	17
The average distance from home to public places (in miles)				
AVERAGE	7.3	7.3	6.2	6.4
Restaurants and Other Eating Places	5.1	5.2	5.5	6.1
Health and Personal Care Stores	4.4	5.0	4.6	4.5
Depository Credit Intermediation	4.0	4.4	4.7	5.1
Gasoline Stations	4.7	4.5	4.2	4.7
General Merchandise Stores, including Warehouse Clubs and Supercenters	4.7	5.0	5.1	6.6

Note: The table only lists the top five place categories. Shaded cells represent unusual variations (i.e. ± 40% and beyond) from the previous year. 'Depository Credit Intermediation' refers to places like banks and mortgage companies.

open on LA20 during this time period with an increase of 450,000 visits. As a comparison, five new businesses are open on LA24 with an increase of 50,000 visits. The average dwell time increases and reaches a peak on LA20 in 2020. The average travel distance from home slightly drops, which means short-distance trips may be increasing in the study area.

'Restaurants and Other Eating Places' is the top place category in this case as well. The number of restaurants and the number of attracted visits are both the highest among all the place categories. The project also connects local communities to existing health-related businesses (e.g. offices of dentists and physicians) but it did not attract any new health-related businesses. Thus, the project has the potential to contribute to economic and public health benefits by supporting business growth and facilitating improved access to businesses, including for people traveling by active modes.

Lessons learned and conclusions

This study used passively collected data for longitudinal performance evaluations at the project level. Proxy measures where needed were proposed to assess outcomes that were previously found challenging to measure without distributing survey questionnaires or raising privacy concerns. The data sources are already being used by many agencies for other applications, so the study approach is highly replicable. Two pilot case studies with different facilities and covering different areas were conducted to demonstrate the potential applications of these data sources for routine evaluation that goes beyond simply assessing the number and severity of crashes. This section summarized data limitations and challenges came across in completing the case studies as well as issues that need future studies' attention.

Mobility analysis

RITIS data do provide valuable input to mobility evaluations. However, as an emerging data source, RITIS currently has its limitations and needs future improvements. First, urban areas generally have better data coverage in scope (i.e. covering more places) and granularity (i.e. more RITIS segments in smaller pieces), while most rural areas are generally in an information desert. A RITIS segment in rural area is often longer than a road segment under performance evaluation. This inequity in data availability and the potential of inducing misrepresentation issues due to spatial mismatch could leave rural communities without sufficient data supports and make them less competitive in securing funding. In addition, RITIS segment IDs currently do not directly link with state DOTs' Linear Referencing System (LRS) used in Highway Performance Monitoring System (HPMS). Additional geo-information or an identification table is needed to join data from the two sources (i.e. RITIS and state DOTs) (RITIS 2022).

RITIS provides longitudinal traffic data for road segments but there is no traffic data for recurring/longitudinal mobility evaluations at intersections. The absence of data leaves intersection evaluation without a convenient, network-wide data support. In addition, the current practice does not consider delay for bicyclists and pedestrians at intersections. The recently published NCHRP report proposes pedestrian and bicycle delay as performance measures and discusses treatments reducing pedestrian and bicycle delays (NASEM 2022). State DOTs may want to consider including travel delay for pedestrians and bicyclists in evaluating intersection performance to keep their practice up to date.

There are various congestion measures for road segments and each of them has their own merits and restrictions. TTI's speed reduction factor may be the most widespread congestion measure. However, the calculated speed reduction factor value could be counterproductive if free flow speed is much higher than the posted speed limit (especially in rural areas), and/or higher than the operating speed that is safe for all road users in a Complete Streets context. If such free flow speed is used in calculations, the results lead to a finding of severe 'congestion' in such cases, while speeding is the actual issue that needs to be addressed. Overall, free flow speed, average speed during peak hours, and speed reduction factors should all be reported to help practitioners gain a full picture.

The two projects evaluated as case studies found that modifications to improve safety, mobility, and accessibility for people walking and bicycling did not induce heavier congestion in the region. In addition, the project with sidewalks/bike lanes contributed to traffic calming in an urban context. The shoulder expansion project with marked bicycle route designation may raise concerns about speeding issues in a rural context, indicating a need for in-depth safety analysis in the future.

Accessibility analysis

First, the number of devices counted in SafeGraph affects reporting the number of visits. Without scaling, the number of visits could increase significantly (more than 40%) from year to year in some cases. The following are two relevant suggestions. The first suggestion is for future outcome evaluation studies and practices: scaling factors of finer spatial scale should be applied to address regional disparity concerns and to improve evaluation accuracy. For example, the current study found the ratio between the number of devices seen in 2021 and that in 2020 is 0.91 at the national level (see the first column on the right-hand side in Table 3). After looking into the data by state, the ratio for Louisiana in the same time period is 0.99. SafeGraph started providing the number of devices seen by state in July 2020 so future studies have better opportunities to apply state-level scaling factors. The second suggestion is for data providers: regional disparities may also exist within a state (e.g. urban vs. rural). When data privacy allows, providing scaling factors in even finer spatial scale should benefit outcome evaluations to be made in different contexts.

Second, the scaled number of visits should be reported along with other accessibility measures (e.g. dwell time) to keep stakeholders aware of the data quality. This operation should facilitate unbiased result interpretations. For example, there were outstanding dwell time variations for activities at banks and mortgage companies in the second case study. However, such unusual variations are more likely due to small samples (see the scaled number of visits to 'Depository Credit Intermediation' in Table 7) instead of travel behavioral changes.

Study limitations

This study provides a practical project outcome evaluation method that can be used by other states in the U.S. (and even other countries where data are available). The following are a few study limitations with future research/practice directions. First, this study intended to illustrate feasibility of the method and data sources in making longitudinal project outcome evaluations. Future studies with different purposes may want to evaluate more projects in different states and regions to provide more generalizable conclusions of Complete Streets project outcomes. Second, this study applied 'neighborhood' strategy in selecting control groups for comparison (NYCDOT 2014). Future studies may want to introduce more control groups to study impacts from external factors (e.g. the pandemic and regional investment) more thoroughly. Third, converting accessibility benefits into specific economic and public health benefits might be of interest. For example, economic benefits in dollar values could be derived based on place categories (e.g. different commercial businesses), the number of visits, visit durations, and transaction data.

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