IMPROVING INFORMATION EXCHANGE THROUGH INTERACTIVE DATA VISUALIZATIONS

DREW LEVITT and PAUL SOHN

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APPROVED

Paul Waddell

Karen Frick

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Improving Information Exchange Through Interactive Data Visualizations

Executive Summary

Information exchange between planners and members of the public represents both a critical problem and a major opportunity. Providing clear information about complex planning projects to the public has long been a challenge, and practitioners and scholars alike criticize traditional approaches to public participation. Increasing web access and modern web technologies that facilitate interactive data visualization present the potential for planners to communicate with members of the public in new, powerful, and sophisticated ways. This project aims to explore **the role of modern data visualization and mapping tools in the process of information exchange between planners and the public**. Specifically, we are interested in whether such tools might help the public better understand transportation projects and other urban planning efforts, and whether they might help increase public support for these projects, with the caveat that whether this is an ethical goal of public participation is up for debate.

Better Market Street, a major public effort to redesign a critical corridor in San Francisco, served as a case study for this project. Based on the publicly available materials used to communicate about Better Market Street on agency websites, **we created parallel visual elements aimed at communicating identical information using interactive mapping and data visualization tools**. We created a survey to randomly assign respondents to view either the static original materials or newly created interactive materials, and then answer factual and subjective questions about the visual elements they reviewed. Survey participants were recruited through Amazon Mechanical Turk, and we received 225 responses overall, with 153 responses passing all of our quality checks.

We found that for the street cross-section and bar chart visualizations, **respondents that viewed an interactive visualization were significantly better able to answer questions about its content, compared to those that saw a static version**. This result did not hold true for two different types of maps; static and interactive materials performed similarly on these visualizations. See section 5.2 on page 27 for details on these findings.

We also found that **respondents that viewed more interactive visualizations were significantly more likely to say that they support Better Market Street**. This finding is explored in section 5.5 on page 38. These results suggest that interactive data visualization can help increase understanding of planning projects, and may also help planners generate support for their projects, though we emphasize that this second goal should only be pursued through the kinds of transparent and honest communication that interactive visualizations can facilitate.

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Acknowledgments

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1 Introduction

Information exchange between planners and members of the public represents both a critical problem and a major opportunity. When developing projects or plans that have the potential to affect a large and diverse group of people, public outreach presents a unique challenge for planners, who must present a wide range of facts to the public about current conditions, help the public understand the possible impacts of decisions, and distinguish between the implications of various alternatives. They are also often charged with the simultaneous task of collecting information from the public about its collective preferences and concerns about specific impacts or aspects of presented alternatives, which magnifies the importance of providing clear information.

The problem is that many existing approaches that planners use to share technical and analytical insights are not effective enough for this challenging task. Practitioners and scholars alike criticize traditional approaches to public participation, arguing that such approaches do not adequately engage the public, do not improve public agencies' decision-making, and may even antagonize stakeholders. (Casello et al. 2015) In cases like the public engagement efforts surrounding Plan Bay Area (2011–2013), certain groups of Bay Area residents expressed strong concern about a perceived lack of alternatives, a perception that facilitation techniques pushed participants toward preconceived ideas, and that the process was not inclusive of all views. This opposition came in spite of a concerted effort by planners to use visualization technology to help generate rich public discussion about plan alternatives. (Frick 2013)

The internet is an important medium through which planners can provide a large amount of detailed information about projects. Furthermore, the internet has the potential to meaningfully remove barriers to public access, especially given the high penetration of smartphones with internet access among low-income populations. Currently, agency web sites often provide written information and downloadable documents, such as PDF versions of plans or public hearing records, along with links to other useful information, including contextual sources and other key agencies. Modern web technologies, though, are increasingly enabling more sophisticated functionalities that agency web sites can take advantage of, including rich embedded maps, interactive data visualization and exploration, narrative storytelling using embedded images and video, and combinations of these tools that allow users to engage with planning information in a different way. While there are examples of planning and transportation agencies beginning to adopt these modern tools, these appear to be exceptions to the norm.

This project aims to explore the potential role of modern data visualization and mapping tools in the process of information exchange between planners and the public. Specifically, we are interested in whether such tools might have an effect on public participation in two ways:

1. **Can interactive data visualization help the public better understand planning/transportation projects?**
   Effectively communicating facts is a core part of public engagement. We are interested in learning how such tools can help enhance public understanding of complex planning projects.

2. **Can interactive data visualization have an effect on increasing public support for these projects?**
   Many strands of planning theory emphasize that the proper role of planners is the objective presentation of projects' characteristics. However, in professional practice, planning agencies may also be interested in gaining public support for proposed projects. Bearing in mind this duality of theory and practice, and in the spirit of academic inquiry, we sought to test whether interactive visualizations could accomplish each of these goals.

2 Literature Review

Here, we examine recent and relevant literature from three distinct fields of scholarship:

1. Public participation in the realm of transportation planning
2. Technological advances in public participation
3. Approaches to evaluating the effectiveness of data visualizations

Our work in this professional report synthesizes learnings from each of these fields.

2.1 Public participation and transportation planning

2.1.1 Legal requirements

Transportation agencies are typically required by a wide range of federal and state laws to provide avenues for input from the community for any project involving public funds. Title 23 of the United States Code, amended to reflect the public engagement requirements of the recently passed Fixing America's Surface Transportation Act (FAST Act), includes explicit requirements for participation including:

- purpose and need: "As early as practicable during the environmental review process, the lead agency shall provide an opportunity for involvement by participating agencies and the public in defining the purpose and need for a project." 23 USC § 139(f)(1)
- alternatives analysis: "As early as practicable during the environmental review process, the lead agency shall provide an opportunity for involvement by participating agencies and the public in determining the range of alternatives to be considered for a project." 23 USC § 139(f)(4)(A)
- coordination plan: "The lead agency shall establish a plan for coordinating public and agency participation in and comment on the environmental review process for a project or category of projects." 23 USC § 139(g)(1)(A)

This legislation follows in the footsteps of the previous surface transportation bill, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which required metropolitan planning organizations to "provide citizens, affected public agencies, representatives of transportation agency employees, private providers of transportation and other interested parties with a reasonable opportunity to comment" on regional transportation plans. (Young 2005; Shuster 2015)

Similarly, any project that involves environmental review under the National Environmental Policy Act (NEPA) requires public hearings. Other statutes require that public hearings be held at accessible times and locations, and that records of meetings be made promptly available to the public. Federal regulations also explicitly recommend the use of visualization in the development of state transportation plans: "To the maximum extent practicable, use visualization techniques to describe the proposed long-range statewide transportation plan and supporting studies." (23 CFR § 450.210(a)(1)(v))

Aside from legal requirements, there are many reasons why transportation agencies may want to conduct public participation processes. The U.S. Department of Transportation's guide, "Public Involvement Techniques for Transportation Decisionmaking," suggests that such a process helps achieve better representation of the wide-ranging constituencies of any project or plan, and that it can act as a forcing function for a better organized planning process. It also discusses the idea of *meaningful feedback* as distinct from merely having a public participation process; the former means that the agency actually takes public feedback into account in its decision making. (U.S. Department of Transportation 2015)

2.1.2 Scholarship on engagement

The distinction between having a public participation process at all and allowing for meaningful feedback fits neatly into the Public Participation Spectrum developed by the International Association for Public Participation (IAP2), which is cited in guidelines from the Federal Highway Administration and Federal Transit Administration. The spectrum provides a range of goals and define the public's involvement in a process. In order of the public's increasing impact on a decision, the goals are to inform, consult, involve, collaborate, and empower the public. (International Association for Public Participation 2014) The engagement principles of socially motivated research paradigms such as community-based participatory research (CBPR) point clearly toward improved understanding, rather than increased support, as the most ethically urgent goal of public engagement efforts, including new interactive visualization techniques. (Seifer 2006) In turn, CBPR builds on a rich tradition dating back to Sherry Arnstein's (1969) seminal "ladder of citizen participation."

One crucial aspect of public participation relates to the need for public agencies, as required by law and otherwise, to take into account racial/ethnic, tribal, and lower-income minority groups in their planning. Title VI of the Civil Rights Act of 1964 requires that "transportation planning and programming be non-discriminatory on the basis of race, color, national origin or disability." (Celler 1964) Later federal statutes draw explicitly on the concept of environmental justice, one principle of which is "ensuring full and fair participation by all potentially affected communities in the transportation decision-making process." The USDOT guide states that "agencies must assume responsibility for reaching out and including underserved populations in the planning decisionmaking process." (U.S. Department of Transportation 2015)

There is a wide range of techniques for engaging the public, with public meetings being perhaps the most commonly used. These meetings can take many forms, from open houses, traditional town hall-style meetings, or more formal hearings, and can be organized around information dissemination (e.g. presentation or informational open house), feedback from the public (small groups, charrette, visioning exercise), or both. (Transit Cooperative Research Program 2011) A core participation group, such as a working group, task force, or advisory committee, can provide an avenue for more intensive collaboration and feedback.

Many scholars and practitioners have criticized legally mandated public participation processes. Innes and Booher, for instance, argue that "legally required methods of public participation in government decision making in the US…do not achieve genuine participation in planning or other decisions…[and] seldom can be said to improve the decisions that agencies and public officials make…" (Innes and Booher 2004) Forester (2006) points out that despite planners' best intentions, public processes can be waylaid by inequalities of power, deep-seated distrust of public agencies, multiple stakeholders with conflicting intentions, and planners' own shortcomings as mediators and facilitators. Others have observed that public officials often find public participation processes to be more trouble than they are worth, while at the same time individual citizens have grown cynical of such processes. (Shipley and Utz 2012)

2.2 Technology and public participation

The literature indicates both opportunity and concern around technology in the planning process. Broadly speaking, the application of technology to public participation to communicate about planning outcomes includes a range of web tools, as well as spatially focused applications known as public participation geospatial information systems (PPGIS).

Mandarano and Meenar (2010) provide examples of several free internet tools that can support planning (see Table 1), and suggest that such tools can be used to build digitally mediated forms of social capital among citizens, which is "deemed a key variable facilitating collective action in planning practice." The authors note that internet tools make it easier for wide audiences to stay engaged in planning processes, and that "Web 2.0" platforms that allow for two-way information transfer (as opposed to one-way information dissemination) and PPGIS techniques offer promising ways to build digital social capital, but that more empirical study is required.

Table 1: Internet tools used to support planning (Mandarano and Meenar 2010)

Texting/SMS	Virtual Meetings
Blogs/Microblogs	Website
RSS	Email
Video sharing	Web-based survey
Mashups (mapping applications)	Social networking sites
Crowdsourcing	Wikis

Anttiroiko (2012) identifies many of the same web tools as the backbone of a potential transformation of the field toward "planning 2.0," a paradigm defined by knowledge sharing and emerging creativity, as opposed to traditional technocratic planning. He also argues, though, that "unless planning processes are opened up and democratised, there will be no breakthrough associated with the use of Web 2.0 tools," and that the emergence of these tools may provoke a split between citizens that are interested in embracing a citizen-centered approach to planning, and those that prefer the existing professional, representative approach.

Seltzer and Mahmoudi (2013) further identify “open innovation” practices from the business sector, which focus on gathering ideas and innovations from sources external to the firm (such as customers or the general public), as applicable to citizen participation in planning. The primary method of open innovation, crowdsourcing, allows for firms or agencies to take advantage of a large base of loosely affiliated users to generate ideas or brainstorm about solutions, with the caveat that such approaches only succeed when a problem is well-defined.

Brabham (2012) and Hosio et al. (2012) identify several positive design characteristics of digital interfaces. Hosio et al., examining a youth-oriented public platform in Oulu, Finland, note the importance of a playful design aesthetic and the power of implicit social pressure on individuals to engage with the tool. Brabham evaluated the motivation to participate among users of a 2009 Utah Transit Authority bus-stop design contest and found that “[p]articipants were driven to participate by the opportunity to advance their career, to have fun, to express themselves, to contribute to a collaborative effort, to gain peer recognition, and to learn new skills and knowledge.” Furthermore, “[a] recurring theme relating to motivation, and a theme that falls outside of the hypothesized motivational categories, was that of usability and a low perceived barrier to entry.” (Brabham 2012)

To date, much hope has been invested in the potential of technological tools to improve the public participation process. However, many scholars caution that technology is no panacea. Epstein, Newhard, and Vernon (2014) identify several barriers to effective online public engagement, including both access deficiencies (no computer; slow or no internet access) and the non-physical challenges of “motivational access” (believing that engagement with tech and planning processes is worthwhile) and the “democratic divide” (an understanding of how and where to interact with the political process itself). Mandarano and Meenar (2010) warn that a shift toward digital forms of planning engagement run the risk of alienating less wealthy and less connected citizens, though this concern is waning over time.

Aside from the benefits and drawbacks of using internet-based venues for public participation, agencies’ abilities to deliver such venues are also an important consideration. Slotterback (2011) explores the staff and technical limitations of internet-based approaches to public participation. Drawing on a survey of planning practitioners, she finds that planners most strongly agree that their organizations have the staff capacity and hardware/software to create a project website, less capability for other methods such as video streaming, virtual open houses, and online comment forms, and even less for mapping applications or other GIS-based tools.

This literature is largely focused on ways that technology can facilitate specifically two-way dialogue between planners and the public: both disseminating information to the public and receiving information back about the public’s preferences. (Forkenbrock and Schweitzer 1999; Waddell 2011) There has been limited study on the information flow from agencies to the public using data visualization itself.

2.3 Data visualization evaluation

In addition to the literature on the role of technology in public planning processes, we also turned to the literature on evaluating data visualization, outside of the context of city planning or transportation. This is a rich literature largely based in the Human-Computer Interaction (HCI) field and a growing scholarship on information visualization itself.

Lam et al. (2012) provide a framework for running empirical studies of information visualization, with the goal of helping practitioners use evaluation methods that are appropriate for the type of visualization they are using. The seven types of visualizations are:

- Scenarios for understanding data analysis:
  - understanding environments and work practices (UWP),
  - evaluating visual data analysis and reasoning (VDAR),
  - evaluating communication through visualization (CTV), and
  - evaluating collaborative data analysis (CDA).
- Scenarios for understanding visualizations:
  - evaluating user performance (UP),
  - evaluating user experience (UE), and
  - evaluating visualization algorithms (VA).

The visualizations we developed for this project fall under the "evaluating communication through visualization" (CTV) and "evaluating user performance" (UP) categories. CTV projects are intended to study how visualization can enhance communication and idea presentation; such studies are surprisingly rare. The authors find studies of this type to be designed as traditional controlled experiments, though some also use field observation methods and interviews. UP projects are much more common in the information visualization literature and focuses on how one visualization or technique compares to another in terms of human performance; this comparative element is a core part of our design. Controlled experiments are the typical study design for UP projects as well, and the authors note that because a large number of respondents are typically needed to achieve statistical significance, non-experts are often recruited. While this can lead to the need for greater abstraction in designing visualizations in such studies, non-experts are the appropriate population for our survey, given that we are hoping to test the ability for the general public to interpret visual materials.

Carpendale (2008) also reviews the advantages and disadvantages of various evaluation designs in terms of generalizability, realism, and precision. She describes the categories of "laboratory experiment," which is most precise and least realistic, and "sample survey," which is most generalizable and less precise or realistic. According to Carpendale's analysis, one of the biggest potential drawbacks of a study design similar to the one we ultimately adopted is a potential lack of realism. That is to say, people may interact with visualizations that planning or transportation agencies actually deploy about real-life projects in a very different manner than with the visuals we use for our project. Using a real case study within our controlled experiment, however, addresses concerns that many similar studies place user tasks too far outside a real-life context. (Plaisant 2004)

Qualitative methods are also common in evaluating information visualizations, using techniques such as field observation, interviews, and "think aloud" protocols. (Carpendale 2008; Lam et al. 2012) *Heuristic evaluation* is one popular and simple method that involves judging a visualization by a set of accepted criteria for what makes visualizations effective, and is usually conducted by experts. Hearst, Laskowski, and Silva (2016) argue that evaluating visualizations along a heuristic dimension along with a question-based scoring dimension is an effective way to quickly gather complementary data. This study also used a novice sample. We borrow concepts from this study by asking both fact-based questions as well as qualitative questions about respondents' confidence in their answers and how helpful they felt the visualizations were in answering the questions.

2.3.1 Survey participant recruitment

With the advent of online surveys, which can be cheaper, faster, and more flexible than traditional mail or other paper-based surveys, online recruitment methods have also become increasingly popular. Amazon Mechanical Turk is an online service that pairs "requesters" that require human intelligence to complete a task, and "workers" that complete requested tasks for a fee. Typical tasks include image or video categorization, evaluations of subjective characteristics like beauty, and text translation; these are tasks that would be difficult for a computer but relatively simple for a human to complete. Mechanical Turk is a large online market; at the time of writing, there were more than 500,000 tasks available, although individual workers are often eligible for a fraction of that total number.

Mechanical Turk has become an increasingly popular recruitment tool for academic surveys. (Behrend et al. 2011) Workers (subject to selection criteria) can take surveys for pay, as they would any other "human intelligence tasks," and researchers have a relatively low-cost source of survey respondents. Concerns about Mechanical Turk as a survey recruitment tool focus on the representativeness of the population of workers and the accuracy and reliability of survey responses.

In order to assess the representativeness of workers on Mechanical Turk, it is important to consider alternative recruitment pools. Especially for behavioral research, studies often rely on pools of undergraduates on university campuses, which are shown to be a population that is relatively unrepresentative of broader populations. (Henrich, Heine, and Norenzayan 2010) Behrend et al. (2011) find that "as compared with a traditional university participant pool, crowdsourcing respondents were older, were more ethnically diverse, and had more work experience." Buhrmester, Kwang, and Gosling (2011) also conclude that "MTurk participants were more demographically diverse than standard Internet samples and significantly more diverse than typical American college samples." Demographic diversity, especially with respect to age and ethnicity, is an attractive property of a respondent pool that is meant to be representative of the general public that is affected by and potentially involved in public sector planning decisions.

Behrend et al. (2011) find that data collected from a Mechanical Turk survey sample were at least as reliable as data from a university student sample. Kittur, Chi, and Suh (2008) also find Mechanical Turk to be promising for user tasks on the condition that tasks are objectively verifiable and build in checks to filter out inattentive or malicious responses. Some studies have specifically investigated the suitability of Mechanical Turk for assessing data visualizations. Heer and Bostock (2010) replicate previous studies on data visualizations using Mechanical Turk and find that the platform is viable for such studies while providing a large cost reduction.

One concern about Mechanical Turk is directly due to the popularity of the platform for survey research: the "growing non-naivety of participants to typical research materials." (Peer et al. 2015) This was not a major concern for our study, which we believe is a relatively novel survey instrument the effectiveness of which is not substantially altered by a respondent's experience with taking surveys or participating in behavioral studies.

3 Research Approach and Case Study

Our literature review uncovered several key points that served to inform our research design. First, public participation is an essential component of ethical and effective transportation planning. This point directed us toward a public-facing transportation project. Second, there is growing interest in the potential of technological tools to facilitate information transfer between planners and members of the public. This point motivated us to design and build our own technologically sophisticated data visualizations. Third, the substantial literature on data visualization evaluation has yet to be meaningfully applied to the city planning field. We sought to rectify this by incorporating components of heuristic evaluation into our research.

In order to better understand the extent to which data visualization can help transportation planners communicate with the public about their projects, we took a basic experimental approach. Using a survey instrument, we instructed respondents to review one of two sets of visual materials about a real transportation project: the original "static" (i.e. non-interactive) visuals, or interactive interpretations of those visuals that we created specifically for this project. We then measured two major, and significantly different, outcomes:

1. The extent to which respondents were able to correctly interpret complex information through those visuals, and
2. The extent to which respondents felt they supported the project as a whole after viewing the visual materials.

Again, it is worth noting that the ethical principles of city planning dictate that planners pursue this first outcome (information transfer) over the second (building support), especially in cases in which these two goals are in conflict.

We selected a currently active transportation project in San Francisco to use as a case study for our experiment. Better Market Street is a major project to reinvent Market Street, the city's primary civic and commercial downtown corridor. Market Street is one of San Francisco's oldest, most famous, and most important streets. From the Ferry Building in the city's historic core, it runs southwest for three miles toward the geographic center of the city before winding up into the hills beneath Twin Peaks.

The Better Market Street project involves nearly every city and county agency involved in transportation, including the San Francisco Municipal Transportation Agency (SFMTA), the San Francisco Planning Department (SF Planning), the San Francisco County Transportation Authority (SFCTA), the San Francisco Public Utilities Commission, and the San Francisco Office of Economic and Workforce Development. The impetus for the Better Market Street project began with a series of studies by the SFCTA in the 2000s; by early 2011, initial conceptual design meetings were held with members of the public. (San Francisco Planning Department 2016) SF Planning serves as the lead agency for Better Market Street and is in charge of preparing the project's Environmental Impact Report; San Francisco Public Works is the project sponsor. (San Francisco Planning Department 2016)

3.1 Better Market Street: background and goals

Better Market Street has five main goals, as described in the Notice of Preparation of an Environmental Impact Review (EIR):

> "The purpose of the Proposed Project is to:
>
> 1. Better serve transit riders by implementing transit priority improvements and increasing surface transit capacity, speed, reliability, and accessibility;
> 2. Support the City of San Francisco's planned growth and economic development by redesigning Market Street to enhance its role as the City's cultural, civic, and commercial center;
> 3. Improve pedestrian accessibility, safety, and mobility on Market Street;
> 4. Encourage ongoing growth in bicycle use by providing safer bicycle facilities along one of the primary bicycle thoroughfares in the City; and
> 5. Maintain access for taxis and paratransit and accommodate commercial vehicle deliveries within the Project corridor." (San Francisco Planning Department 2016a)

Most of the stated goals of the project involve improvements for specific travel modes; the Notice specifically discusses improvements for transit, pedestrian, and bicycle users. For transit, the critical improvement that the EIR focuses on is speed; for bicycles and pedestrians there is a shared focus on safety. These goals reinforce each other in some ways. Improvements to transit, bicycle, and pedestrian facilities work together to encourage travel by non-car modes, which is a stated goal of the City and County of San Francisco. They also involve tradeoffs with each other in some ways. In certain alternatives, bicycles must share lanes with buses, presenting a direct conflict between speed and safety. In another alternative, an exclusive cycletrack for bicycles takes space away from pedestrians.

The fifth goal is explicitly about automobiles and other private vehicles, but personal travel is not mentioned: the project serves to maintain (not improve) access for commercial vehicles. This is consistent with the City and County of San Francisco's (1973) transit-first policy, which states, "Within San Francisco, travel by public transit, by bicycle and on foot must be an attractive alternative to travel by private automobile." Nevertheless, Market Street remains an important travel corridor due to the intensive land use and important transit hubs along the corridor.

Finally, one of the five goals is not about a travel mode, but is more focused on Market Street's quality as a whole. This goal is focused on economic development and "supporting San Francisco's planned development," but also represents a more qualitative vision of Market Street as the region's premier street and the needed improvements to fulfill that vision. Official materials stress the importance of public space in the revitalization of Market Street, which appears to be most directly represented in "Streetlife Zones" that occupy portions of sidewalk space in several presented alternatives.

3.2 Project options

The project team for Better Market Street has narrowed down the possible improvements into three discrete alternatives. These three alternatives are currently being studied in the Environmental Review process, and are currently being presented online. The tentative project timeline anticipates a phased construction process beginning in 2018 and lasting for three to five years; no project budget has been announced. (San Francisco Planning Department 2016b)

The Better Market Street project is examining changes to 1.9 miles of Market Street, between the Embarcadero and Van Ness Avenue, and to 2 miles of Mission Street, in the segment paralleling the aforementioned reach of Market Street. Currently, these portions of both Market and Mission Streets include two lanes of vehicular travel in both directions. Part of Market Street has one lane reserved for transit vehicles and taxis. Bike infrastructure is limited on Market Street and nonexistent on Mission Street. Curbside parking is available along most of Mission Street and is generally unavailable along Market Street. Due to Market Street's role as the interface between San Francisco's two off-kilter street grids, intersections along Market Street are often large and irregular.

The three official alternatives, as described by the Notice of Preparation of an EIR, the official factsheet, and text on the Better Market Street website, are as follows:

- Alternative 1: Improvements to Market Street, including changes to private vehicle access
    - Design Option A: Improvements to existing shared bicycle and automobile lanes, no new cycletracks created
    - Design Option B: Cycletrack along the length of the project
- Alternative 2: Same as alternative 1 with more moderate changes to private vehicle access
- Alternative 3: Same as alternative 1, Design Option A, but with bicycle traffic moved to parallel Mission Street, and buses moved from Mission Street to Market Street

The PDFs representing the project's Conceptual Design, which were available under the "Better Market Street Design Options" section of the website[1] at the time of writing, are what we draw on for our project. The options presented in these materials, however, represent a different set of configurations than the alternatives presented in most of the official documents. The options as presented in the Conceptual Design documents are as follows:

- Option 1: Alternative 1, Design Option A, with both recommended and maximum auto restriction scenarios presented
- Option 2: Alternative 1, Design Option B, with both recommended and maximum auto restriction scenarios presented
- Option 3: Alternative 3

We conjecture that the BMS project team chose to highlight the built-environment differences between Design Options A and B rather than focusing on the different private vehicle restrictions between

[1] http://www.bettermarketstreetsf.org/about-reports-docs.html

Alternatives 1 and 2. In our survey instrument, we refer to "Options" (as distinct from "Alternatives") throughout the survey. This enables our survey to be consistent with the official materials, and also avoids confusion on nomenclature.

Proposed cross sections for Market and Mission Streets under each project "option" are presented in Appendix A.

3.3 Existing materials

The "static" visualizations we use in this project are drawn entirely from the Conceptual Design documents available on the Better Market Street website. The PDF links are accompanied with text that reads: "Download the 3 conceptual design options here. These are the 3 options the BMS project team will be studying during environmental review."

Each of the three documents is a high-quality, poster-sized PDF document that includes the following elements:

- A cross-section diagram showing the lane widths and types on either Market Street or Mission Street
- A general description of the option
- A section on "Street Life" including a graphic and text pertaining to proposed areas of the sidewalk devoted to Streetlife Hubs, street furnishing, and other amenities
- A "Bicycle" section including a map of proposed bicycle facilities, a graphic showing what one of the proposed bicycle facilities looks like, and a text description of the facilities
- A "Pedestrians" section with only a text description of proposed pedestrian facilities
- An "Auto Restrictions" section including text description and a simplified map of proposed auto restrictions
- A "Transit" section including text and a bar chart of projected transit speed improvements under different scenarios
- A full-color rendering of Market Street or Mission Street under proposed conditions

Screenshots of each relevant section of these PDF documents were used as the static visualizations in the survey instrument.

4 Methodology

4.1 Survey instrument

Based on the guidelines for "evaluating user performance" that we encountered in our literature review, we selected an experimental design for our study that aimed to compare respondents' performance on factual questions based on which visualization they viewed. Our project aims for a balance between precision, realism, and generalizability through a research design that is a hybrid of Carpendale's "laboratory experiment" and "sample survey" categories. (Carpendale 2008) Because we have created an experimental design which allows us to directly compare the effectiveness of designs in a quantitative manner, our findings are precise. We can also assess the extent to which our results might be generalizable based on the sociodemographic variables we collect.

Our survey instrument was designed to measure the added value effect of interactivity on respondents' understanding of facts presented about Better Market Street, and, secondarily, on respondents' support for the Better Market Street project in general. The survey consisted of four major sections:

1. *Introduction to Better Market Street*
   This section includes a short introduction to the Better Market Street project, and a brief explanation of each of the three options. We borrowed as much language as possible from the original Better Market Street materials themselves, including text descriptions and pictures.
2. *Demographics*
   We asked respondents to identify their age, gender, income, level of education, race/ethnicity, typical mode of transportation to work/school, and whether they have access to cars. Ordinarily, sociodemographic measurements are collected at or near the end of surveys. We chose to locate demographic questions near the beginning of the survey in case of respondent attrition later in the survey; this would allow us to better measure non-respondent bias in these cases. We anticipated that non-respondent bias might be an issue because the following sections of the survey were unusually demanding and technical. However, the rate of survey completion turned out to be very high, so attrition was not an issue in the end.
3. *Visualization Content: Cross Sections, Bicycle Routes, Auto Restrictions, Transit*
   This section was divided into four subsections, with one for each major visualization we developed. In each of these sections, respondents were randomly shown either the "static" visual materials presented in the original Better Market Street PDF documents, or interactive materials we developed to present the same information. Both types of visual materials were accompanied by text from the original materials. Respondents were then asked two or three questions about the materials they just viewed; these questions have right and wrong answers and were meant to gauge how well respondents were able to learn key information from the visual materials. Finally, respondents were asked how confident they were about their answers, and how helpful the materials were in answering the questions.
4. *Opinions and Perceptual Questions*
   In the final section, respondents were asked about their personal opinions, including their support for the Better Market Street project, and their preference for each of the three options. To gauge the extent to which individuals' opinions about urban transportation might affect their support for the project and its options, we also asked a series of perceptual questions about driving, walking, and bicycling in cities.

Incorporating visual materials into the survey was an implementation challenge. At first, we planned to include links to external materials (the PDF documents hosted on city websites, and a separate website displaying our visualizations), and assign respondents to one or the other. We solicited feedback on our survey design from Professors Karen Chapple, Karen Frick, and Paul Waddell. These researchers suggested that we randomize whether respondents see static or interactive visualizations for each question, so that each respondent sees a collection of static and interactive versions. This approach, our advisers suggested, would lead to more conclusive results about the effects of visualizations themselves over other factors (e.g. attractive and professional PDF formatting, or the overall experience of reading a document vs. a website).

The final design was implemented in the Qualtrics online survey platform, which allows embedding of custom web elements (including HTML, CSS, and JavaScript functionality). This enabled us to embed visual elements within the survey itself: as respondents click through the survey, they are shown visualizations in line with survey questions, whether in the form of static images, or interactive charts. The ability to embed these elements within the survey itself also allowed us to randomize whether respondents saw interactive or static visualizations in each section. Figure 1 below, a screenshot of our Qualtrics survey, shows an interactive visualization seamlessly integrated into the survey structure.

Our survey ultimately encompassed:

- ten demographic questions,
- eleven questions designed to assess the extent to which respondents were able to understand and make comparisons among the data presented in each visualization,
- two questions designed to check for respondents' attention to the task,
- four questions about respondents' support for BMS as a whole and for each project option,
- six measurements of respondents' attitudes, and
- two open-ended feedback questions.

We anticipated that the survey would take between 15 and 20 minutes to complete; as discussed in more detail later, the average completion time among attentive respondents was 17.45 minutes, almost exactly in the middle of our expected range.

4.2 Visualizations

4.2.1 Cross sections

The Better Market Street materials for each option include an image displaying the cross-section of Market Street (and Mission Street for Option 3), showing the width and type of various lanes along with some renderings of vehicles, pedestrians, and other elements of the street. See Figure 2 on page 15 for an example image. Each of the three PDF documents for Better Market Street include one cross-section for that option, but in the survey, the three cross-section images are presented alongside each other for simplicity.

Some of the key pieces of information viewers should be able to answer using these visuals include:

- The widths and types of lanes included in each option
- The widths and types of lanes available to different travel modes
- The total width of lanes available to different travel modes
- Differences in lane widths available to different travel modes between options

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AUTO RESTRICTIONS
First, please take a few moments to explore the information presented below. You can zoom and pan the interactive map, examine the auto restrictions proposed in each project option using the buttons in the upper right corner, and click on each line on the map to see when private cars are permitted to travel along that street segment.

OPTION 1: MARKET STREET
Due to the shared bicycle / vehicular lane east of 8th Street, auto restrictions are recommended 7am to 7pm from Fremont Street to 8th Street to accommodate peak transit flow from the Transbay Terminal to 5th Street.

OPTION 2: MARKET STREET
Due to the shared bicycle / vehicular lane from Grant Street to 5th Street, auto restrictions are recommended 7am to 7pm from Fremont Street to 5th Street to accommodate peak transit flow on Market Street from the Transbay Terminal to 5th Street.

OPTION 3: MARKET STREET + MISSION STREET
Due to the shared bicycle / vehicular lane east of 8th Street and the rerouting of buses from Mission Street, maximum auto restrictions are recommended 7am to 7pm from Fremont Street to Van Ness Avenue. New left turns in this option help facilitate traffic crossing Market Street.

Now, we want to see how clearly these materials communicated their information. Referring back to the above materials, please answer the following questions to the best of your ability. Don't worry if the answer is not obvious. If you are not sure about an answer, just take your best guess.

Which option recommends restrictions on private cars along the greatest length of Market Street? *(If two or more options are tied, please select all that apply.)*

Option 1

Option 2

Option 3

Figure 1: Interactive data visualizations embedded in Qualtrics survey.

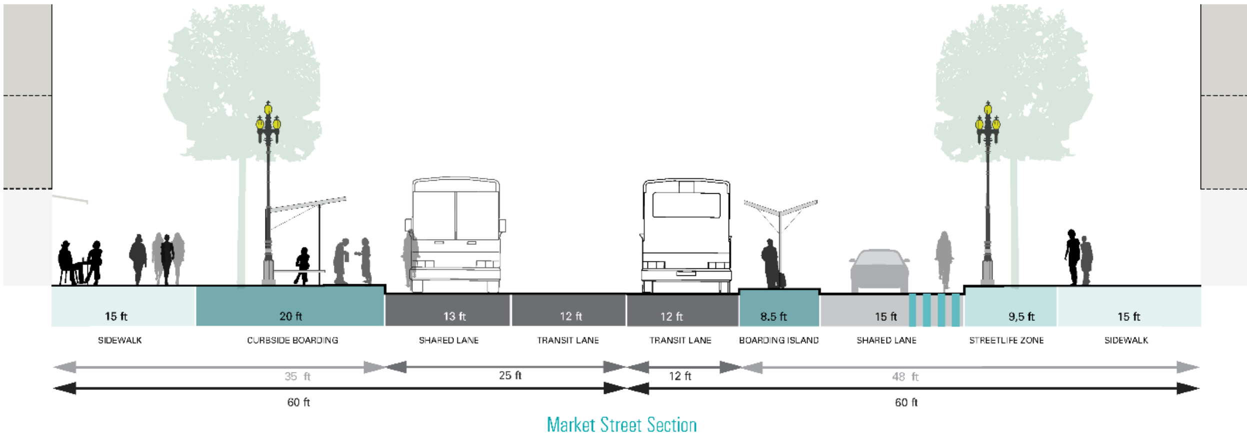

Figure 2: Option 1 cross-section (static visualization). Source: bettermarketstreetsf.org.

The interactive visualization that we developed for the cross-section included two parts. In the first section, users are given the ability to select a travel mode, and upon selecting a mode, the lanes available for that mode are highlighted in the static cross-section image. Users are only allowed to select one mode at a time, and no additional information is provided (such as a sum of lane widths). The three cross section images are presented side-by-side, and the highlighting is displayed on all three images simultaneously. Figure 3 demonstrates this functionality, showing the Option 1 cross-section with space for biking highlighted.

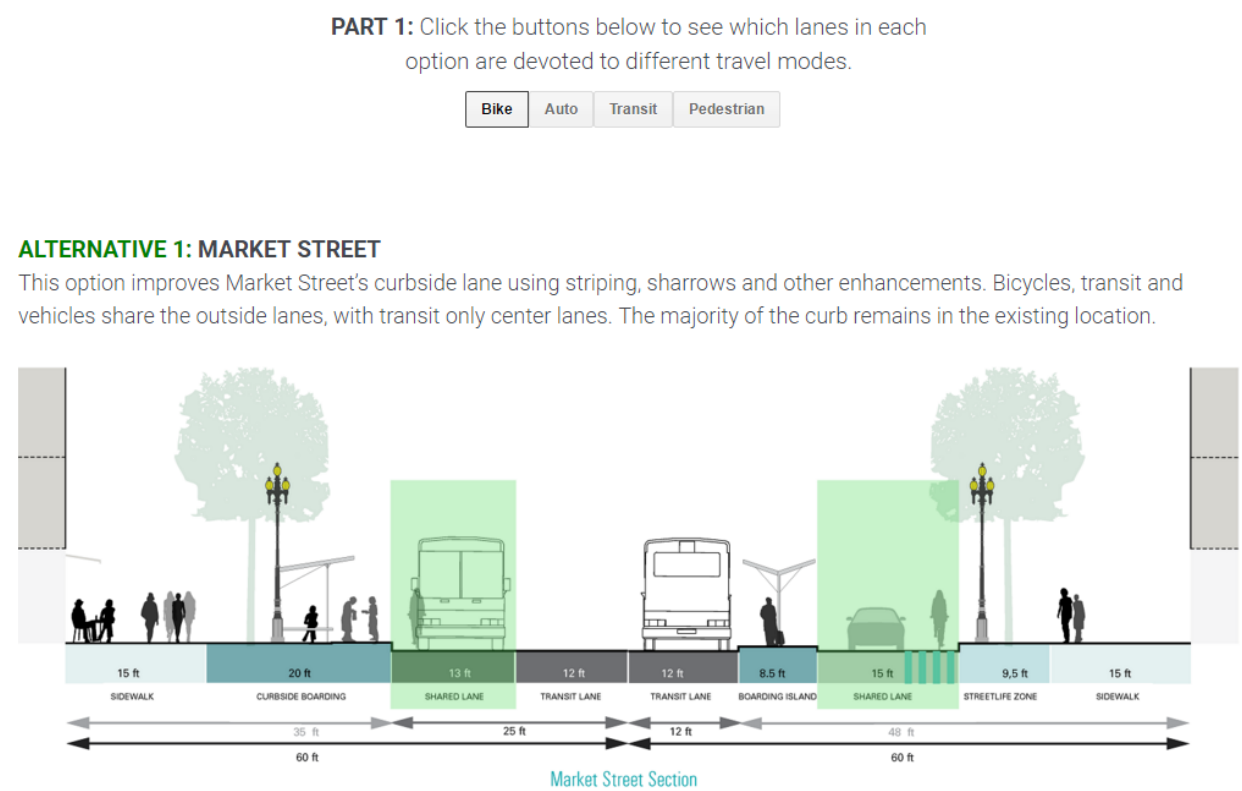

Figure 3: Cross-section (interactive visualization). Source: bettermarketstreetsf.org, modified by Paul Sohn and Drew Levitt.

The second part of the visualization is an interactive bar chart that we developed using the Highcharts.js toolkit. This bar chart displays the width of lanes available to different modes, and is a new element that does not adapt existing Better Market Street materials. The mode selection buttons that allow users to highlight the cross sections in part 1 of the interactive visualization also switch the bar charts. There are two bar charts displayed: one for Market St. and one for Mission Street. Both charts update simultaneously upon clicking on a new mode. See Figure 4 below for an example image of this second interactive visualization component.

For each selected mode, the bar chart displays:

- The width of each lane available to that mode in each option, denoted by the length of each segment in the bar
- The sum of lane widths available to that mode in each option, denoted by the total length of each bar
- The type of lanes available to each mode in each option, denoted by the color/patten or each segment in the bar
- The direction of each segment, denoted by text that says “Outbound” or “Inbound” for each segment

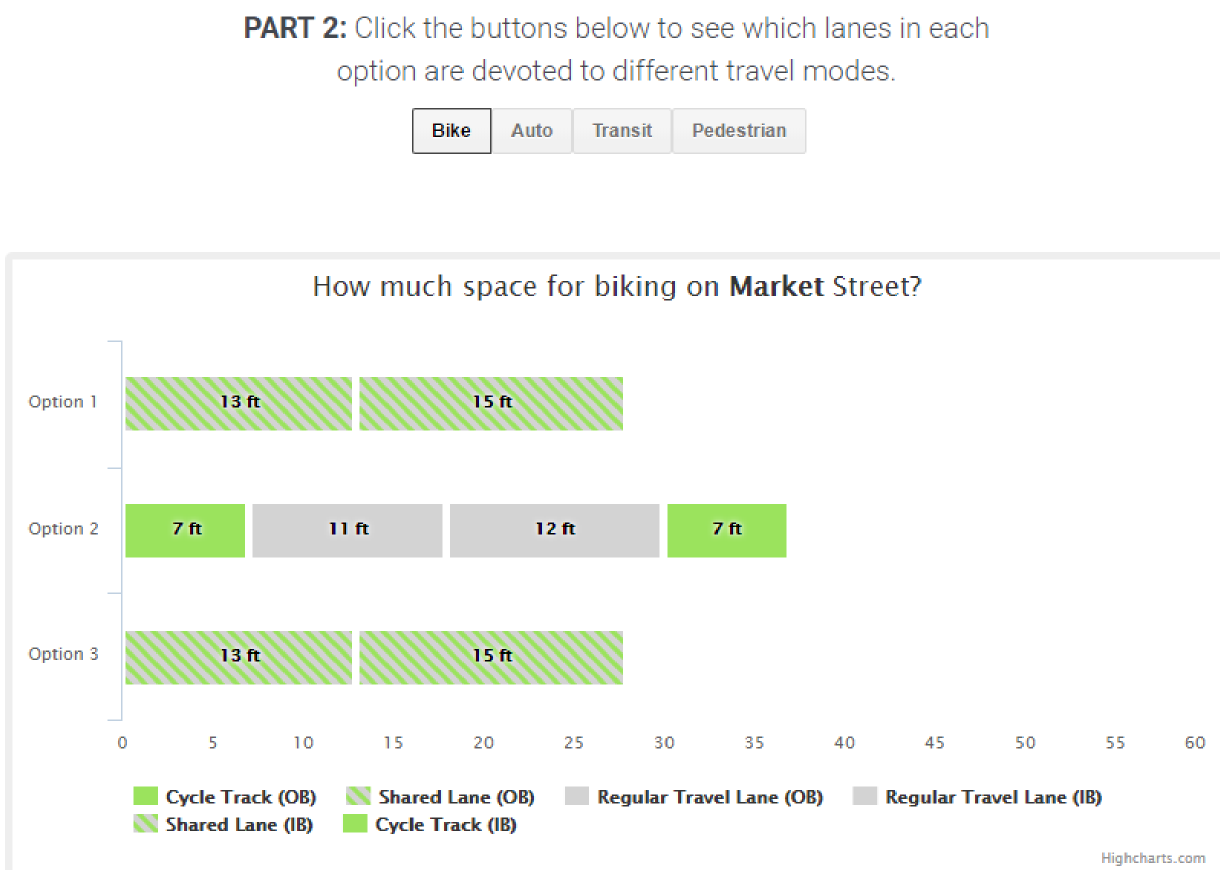

Figure 4: Part 2 of our interactive cross sections visualization.

To implement Part 1 of this visualization, a series of static images containing the original cross sections with green highlighting boxes were created in Adobe Illustrator and uploaded to a Qualtrics image library. Upon loading the page, the user's browser preloads all images. JavaScript code controls the switching of images based on user selections. Part 2 was implemented using Highcharts.js. Data were manually entered from the cross-sections into JSON format in the JavaScript code, and switching between data for different options is controlled in JavaScript based on the same user input as Part 1.

4.2.2 Bike infrastructure

The section of the Better Market Street materials devoted to bicycles present a brief narrative overview of each option's design goals, a detailed map of the location and type of bike facilities on and near Market and Mission Streets under that option, and some kind of graphical depiction of a typical bike facility. Figure 5 below shows the format and content of these materials. The maps depict three types of bike facility: shared lane, bike lane, and cycletrack.

The format of the first two components is constant across all three documents, but the bike facility image is significantly different between options:

- Option 1 displays a conceptual sketch of a shared lane
- Option 2 displays a conceptual sketch of a cycletrack
- Option 3 displays a photograph of a cycletrack in New York City

This lack of parallelism (sketches vs. photographs) and failure to provide a graphical depiction of bike lanes struck us as potentially serious shortcomings of the static bike infrastructure materials.

Information that respondents should be able to gather from these visual materials includes:

- The type of various bicycle facilities under different options
- The location (i.e. from what street, to what street) and type (i.e. cycletrack or bicycle lane) of various bicycle facilities under different options
- What the key bicycle facility under this option looks like

In our judgment, the static bike infrastructure materials are effective in several ways. In particular, presenting a clear map of the locations and types of proposed bike facilities tells a clear and compelling story. The short textual description also helps focus the reader's attention on each option's signature plan components. However, we also discerned some important limitations and weaknesses in these materials. As discussed above, the images depicting the different types of bike infrastructure lack parallelism. Furthermore, because they are primarily renderings rather than photographs, these images make it harder for a viewer to form a realistic conception of what such facilities actually look and feel like.

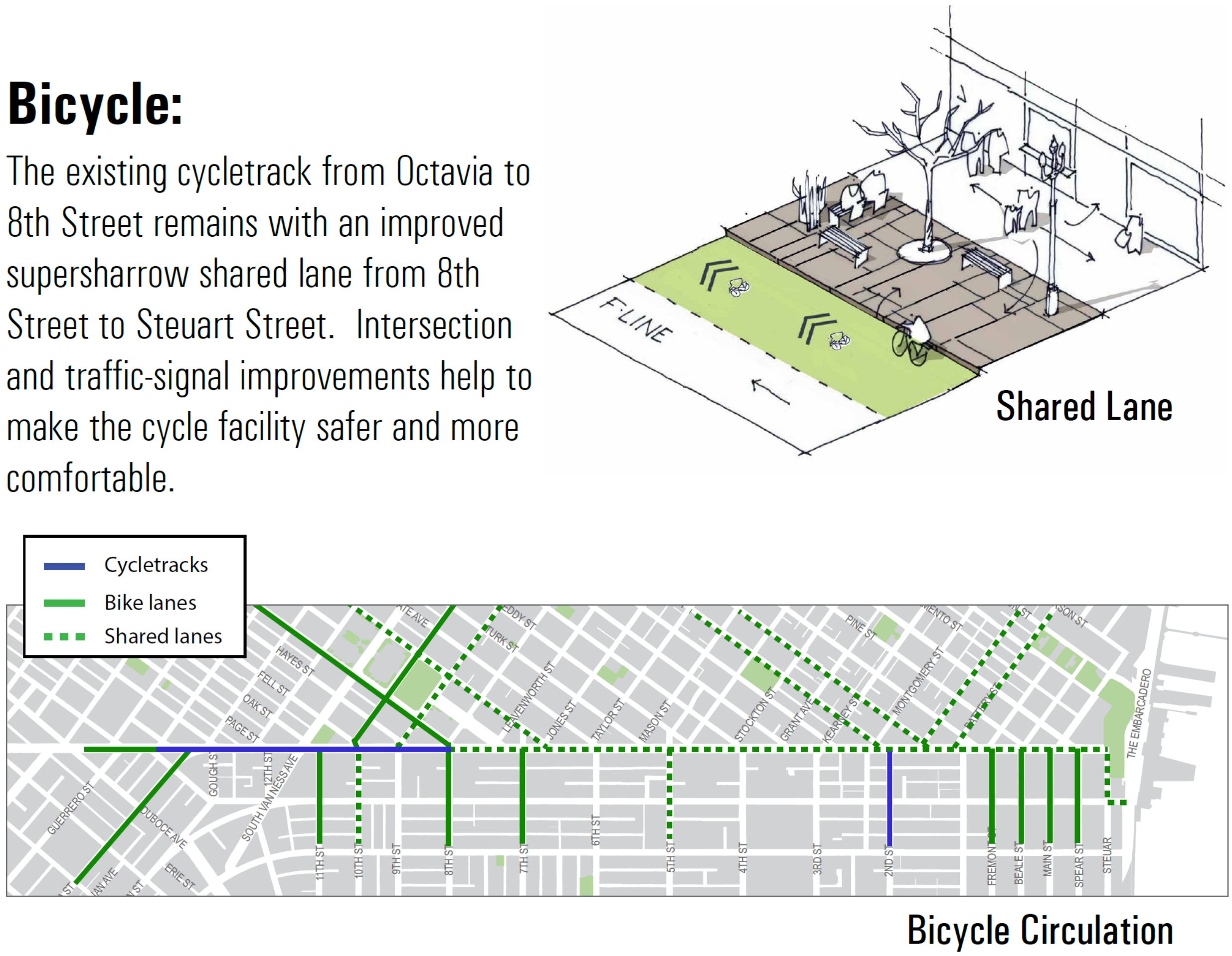

Figure 5: Example of bicycle infrastructure materials, in original static form. This image is an excerpt from the Option 1 PDF poster.

Perhaps because the static PDFs were designed for printing as large posters, much of the maps' detail, including street names, is difficult to read, especially on a computer screen. The maps are also rotated by approximately 45 degrees clockwise, allowing Market and Mission Streets to run horizontally along the rectangular viewport of the map. This design decision makes sense when the available page area is limited, but the tradeoff is that the map looks more schematic than cartographic, and the broader context of the city is lost.

Based on our review of the existing static materials, we determined that an interactive web map would be the best way to present parallel material in a useful way. Our dynamic bike infrastructure visualization is shown in Figure 6. The map displays the same bicycle infrastructure network on the map that is presented in the static materials, and provides a button for switching between options. Clicking on bicycle facilities in the map allows respondents to view an image of the type of facility they clicked on. (For maximal parallelism as well as realism, we used three example photographs, rather than sketches, of the three types of bicycle facilities.) Meanwhile, the full cartographic presentation of the data provides access to the broader context of the city.

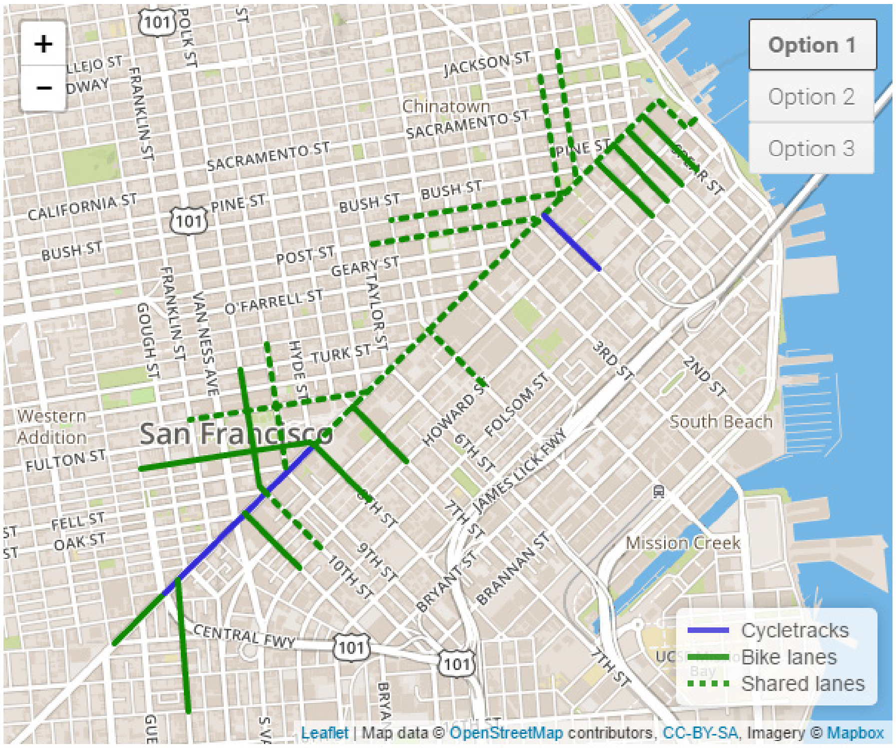

Figure 6: Bike infrastructure (interactive visualization).

The interactive map was implemented using Leaflet.js. The bicycle facility layer was created manually in ArcMap before exporting to a GeoJSON format. Custom JavaScript enabled control layers in Leaflet to allow for toggling between options. We were also able to modify the style of popups in order to embed the image of the bicycle facility being clicked on.

4.2.3 Auto restrictions

The static materials present recommended and maximum auto restrictions for each option in a very stylized, abstract fashion (see Figure 7). The key information that viewers gain is between exactly which streets along Market Street the recommended and maximum restrictions extend.

Figure 7: Auto restrictions on Market Street (static visualization). Source: bettermarketstreetsf.org.

We chose to present auto restrictions in a positive light, drawing attention to the hours when private automobiles are permitted to travel along Market Street (as opposed to the hours when they are restricted) as well as noting explicitly that private cars may always travel along the entirety of Mission Street under all alternatives' recommended auto restrictions. This decision aligned with our selection of a Leaflet interactive web map as the medium for our dynamic data visualization: both the positive presentation of auto restrictions as well as the presence of the full, unrestricted San Francisco street network serve to emphasize that private vehicles may travel unimpeded at all hours throughout the vast majority of the city's roadways. Our interactive auto restrictions visualization is shown in Figure 8 below.

As with the bike infrastructure visualization, our dynamic materials provided substantially more information and context than the static PDF materials did. We hypothesized that this context would help survey respondents better apprehend the scale of auto restrictions being proposed. Meanwhile, we anticipated that the ability to zoom and pan the map could enable respondents to easily discern the extents of each proposed auto restriction.

As it turned out, survey participants did not benefit significantly from this dynamic visualization; this extra context and information may in fact have obfuscated the key takeaways of this section of the materials. The inclusion of a second line along Mission Street may have contributed to the poorer performance of this interactive visualization relative to the static materials, which displayed only a stylized diagram of Market Street. In some cases, it appears, less information may translate into less confusion.

Figure 8: Auto restrictions on Market and Mission Streets (interactive visualization).

Implementation for this map was very similar to using Leaflet.js. The restriction line layer was created manually in ArcMap before exporting to a GeoJSON format. Custom JavaScript enabled control layers in Leaflet to allow for toggling between options. We were also able to modify the content of popups in order to clarify when private vehicles would be permitted to travel along each road segment.

4.2.4 Transit

Finally, the original Better Market Street materials also include a bar chart displaying transit speed improvements under different scenarios for each option. The PDF for each option has a bar chart showing these improvements under recommended and maximum auto restrictions on Market Street, for rapid and local buses, and for buses boarding at the curb and buses boarding at center islands. This results in four separate categories under which transit speed data are split:

- Options (1 vs. 2 vs. 3)
- Boarding location (center vs. curb)
- Type of service (rapid vs. local bus)
- Auto restriction scenario (maximum vs. recommended)

Figure 9 shows an example of these rather complicated bar charts.

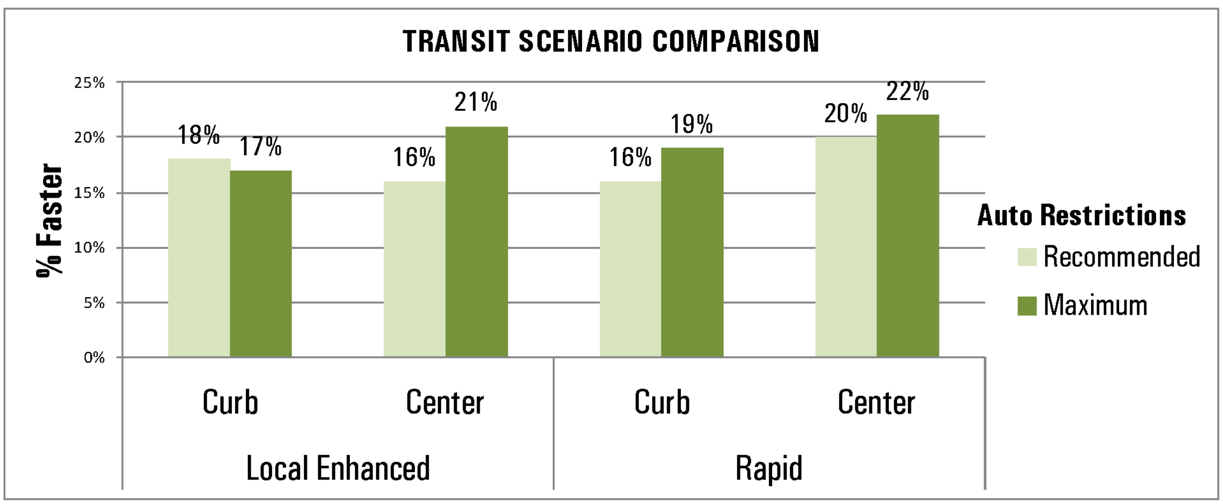

Figure 9: Transit speed improvements (static visualization; Option 1).

As with each other set of visualizations, these bar charts were presented in the PDF materials for each option separately, but were placed side-by-side in the online presentation. Some of the important information that we determined that users should be able to understand based on these visuals include:

- The absolute percentage improvement in transit speed for a given combination of categories (e.g. for Option 1, under maximum auto restrictions, for buses boarding at the center, for rapid buses)
- Comparison between percentage improvements in transit speed between different combinations of categories (e.g. Option 1 vs. Option 2 with other factors remaining equal)

The interactive version of these bar charts was developed with the goal of reducing the number of categories that were displayed at a given time. This was achieved using user interactivity. Users are given the option to choose the scenario being displayed for two of these categories: auto restrictions and boarding location. This allows the number of bars to be reduced, with a single view showing a direct comparison between options, and an indirect comparison between rapid and local bus service. Using the selection buttons, users can choose any of four combinations of auto restrictions and curb vs. center boarding.

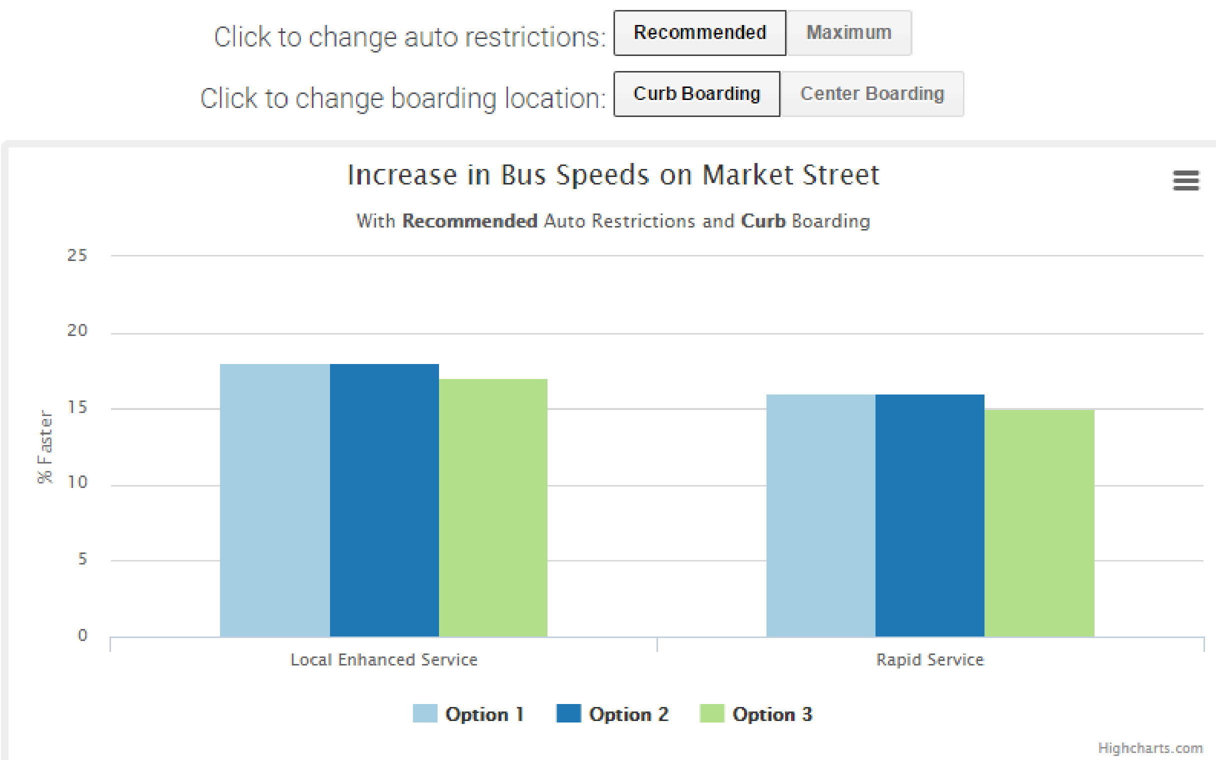

Figure 10: Transit speed improvements (interactive visualization).

Figure 10 shows the interactive transit visualization we developed. It is noteworthy that we chose to juxtapose the three options' transit performance as the clustered bars, making comparisons across options the most visually prominent component of the visualization. This interactive bar chart was implemented using Highcharts.js, and JavaScript code controls the switching of data according to user selections.

4.3 Recruitment

Survey respondents were recruited using Amazon Mechanical Turk, a popular "crowdsourcing" platform that provides a market for small online tasks. We selected this recruitment mechanism based on our review of the literature on Mechanical Turk's usefulness for social science surveys. See section 2.3.1 above for more information on Mechanical Turk's strengths and weaknesses.

Responses to our survey were collected in two batches. An initial batch of ten surveys was administered to test the rate of responses, the quality of data, and technical implementation of the survey (such as whether online visualizations appeared to work and whether respondents were randomly assigned to static and interactive visualizations). This initial batch filtered survey responses geographically using IP addresses, and only allowed those within an area code near the San Francisco Bay Area[2] to take the survey. These ten surveys were completed within about 18 hours, but our timeline required a faster data collection phase, so we opened up the second batch to respondents anywhere in California. The second batch was identical to the first batch other than this change in allowed geographic location. Table 2 provides a summary overview of the two batches we commissioned.

Once each of the batches were active, the survey task was displayed to Mechanical Turk workers as shown in Figure 11 below. The task was titled "Answer questions about city planning data visualizations (San Francisco Bay Area only) – 20 minutes," with the geographic area changed to "California only" for the second batch. Workers were paid $2.00 for completion of the survey, and were allowed to take the survey as long as they had a high approval rate (above 95%) for task completion. (Requesters on Mechanical Turk are allowed to reject completed tasks if they do not meet certain criteria; a 95% approval rate is relatively high but not uncommon among Mechanical Turk workers.) All workers were approved and paid for our project.

Table 2: Overview of two Mechanical Turk data collection batches.

Batch	Number of Tasks Requested	Geographic Area	Rate	Completion Time	Average responses per hour
1	10	San Francisco Bay Area	$2.00	17.6 hours	0.568
2	200	California	$2.00	89.4 hours	2.237

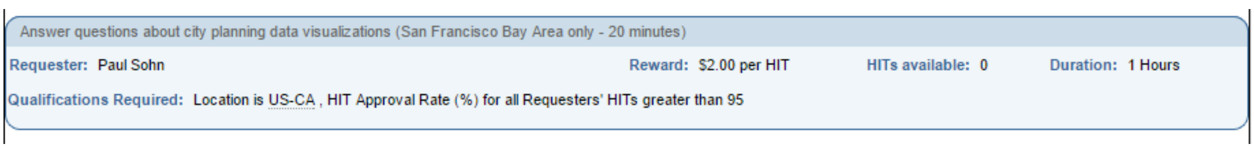

Figure 11: Display of Amazon Mechanical Turk task description.

Several measures were implemented to make sure that Mechanical Turk survey responses were reliable and valid:

- Respondents were not allowed to take the survey more than once
- Two "attention check" questions were added to the survey. These are questions that are disguised to look like real questions but direct the respondent to pick a certain answer, and are meant to identify respondents that may be taking the survey quickly without reading instructions. See Table 3 for details.

[2] The permitted area codes were 415, 707, 925, 510, 650, and 408.

- The survey included a feature to record how much time respondents spent on each page in the survey. This enables us to identify respondents that may have quickly skimmed the survey rather than interacting with the materials as intended.
- A unique code was generated in Qualtrics for each respondent and displayed on the last page of the survey; respondents were then instructed to enter the code back into the Mechanical Turk interface in order to receive credit for finishing the survey.

Table 3: Attention check questions.

Section	Question Text
Bicycle	Under Option 3, beginning at the Embarcadero and traveling toward South Van Ness Avenue, where does the shared lane first change to a cycletrack? Please select "8th Street."
Transit	Under Option 2's recommended auto restrictions, which type of service experiences the greatest increase in speed? Please select the fourth option.

While all respondents had their task under Mechanical Turk approved and paid for, the above measures allow us to filter out final responses that were likely to have been inattentive or otherwise unsuitable for analysis. As discussed below, 68.4% of survey respondents correctly answered both attention checks.

5 Analysis and Results

Once we had acquired a sufficiently large sample via Mechanical Turk and Qualtrics, we downloaded the Qualtrics survey responses as a comma-separated values (CSV) file. We manually coded the two open-ended questions (see section 5.7) in the CSV. We then conducted extensive quantitative analysis in Python, using the Pandas library to manage data, SciPy to run statistical tests, and Matplotlib to create graphics.

For all the analyses that follow, we examined statistical significance at a 95% confidence level (i.e. $\alpha = 0.05$).

5.1 Sample size

Using Amazon Mechanical Turk, we sought to acquire 210 completed responses, and received 138 responses that passed all of our quality checks. We received more than 210 responses to the survey, which we attribute to user error on the part of Mechanical Turk workers (i.e. individuals that took the survey and did not complete their Mechanical Turk task to get paid). There was also a small proportion of survey respondents that dropped out very near the end of the survey after having completed most or all of its critical sections. It is unclear why these respondents dropped out at this late stage; they may have run into the Mechanical Turk task's one-hour limit, although this would not end the Qualtrics survey. We ultimately obtained a sample of 225 responses. This sample size reflects the number of respondents who saw and completed at least all four visualization sections. For these respondents, it is at least feasible to examine the relationship between exposure to interactive vs. static visualizations and the number of questions correct for each visualization.

5.1.1 Quality check: inattentiveness

We needed to select a subset of our total response pool for quantitative analysis. Our first selection criterion was whether each respondent correctly answered the two "attention check" questions we included in the survey. Because the attention check questions explicitly directed survey participants on how to respond, we felt that all answers provided by participants who did not correctly answer these two questions must be considered suspect and should be excluded from analysis. Of the 225 respondents who saw all four visualizations, 208 correctly responded to the first attention check question (located on the bike infrastructure visualization page, which was the second of four visualizations presented) and 159 correctly responded to the second attention check (located on the transit visualization page, the last of four visualizations presented). Taken together, 154 respondents (68.4 percent of the full sample) correctly answered both attention check questions and were therefore included in some of our analyses, depending on further quality checks.

Figure 12 and Figure 13 below provide graphical justification for our decision to filter our responses to only those who correctly answered both attention checks: both in terms of total time spent and total questions answered correctly, respondents who passed the attention checks demonstrated substantially greater engagement and performance on the survey as a whole. The mean survey response time for respondents who passed the attention checks was 17.45 minutes, compared with only 12.78 minutes for respondents who did not (p-value = 0.001). Similarly, respondents who passed the attention checks correctly answered an average of 6.9 assessment questions, compared with 5.0 questions correct for respondents who did not (p-value = 0.000).

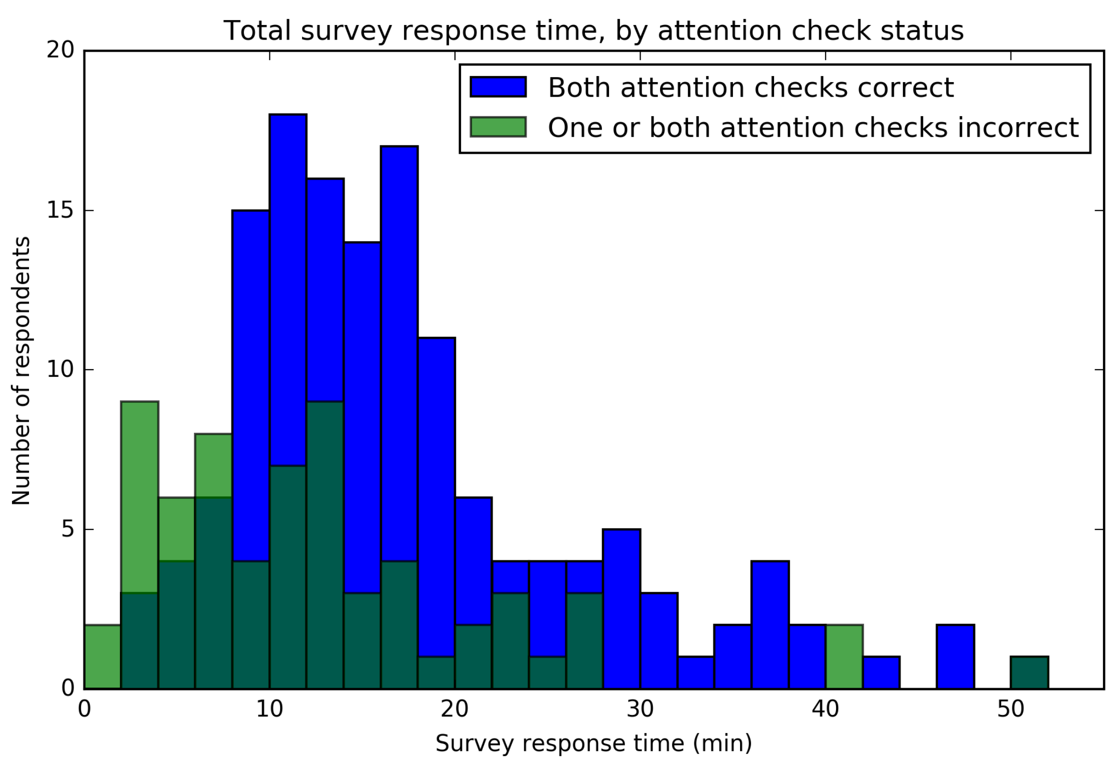

Figure 12: Total survey response time, by attention check status.

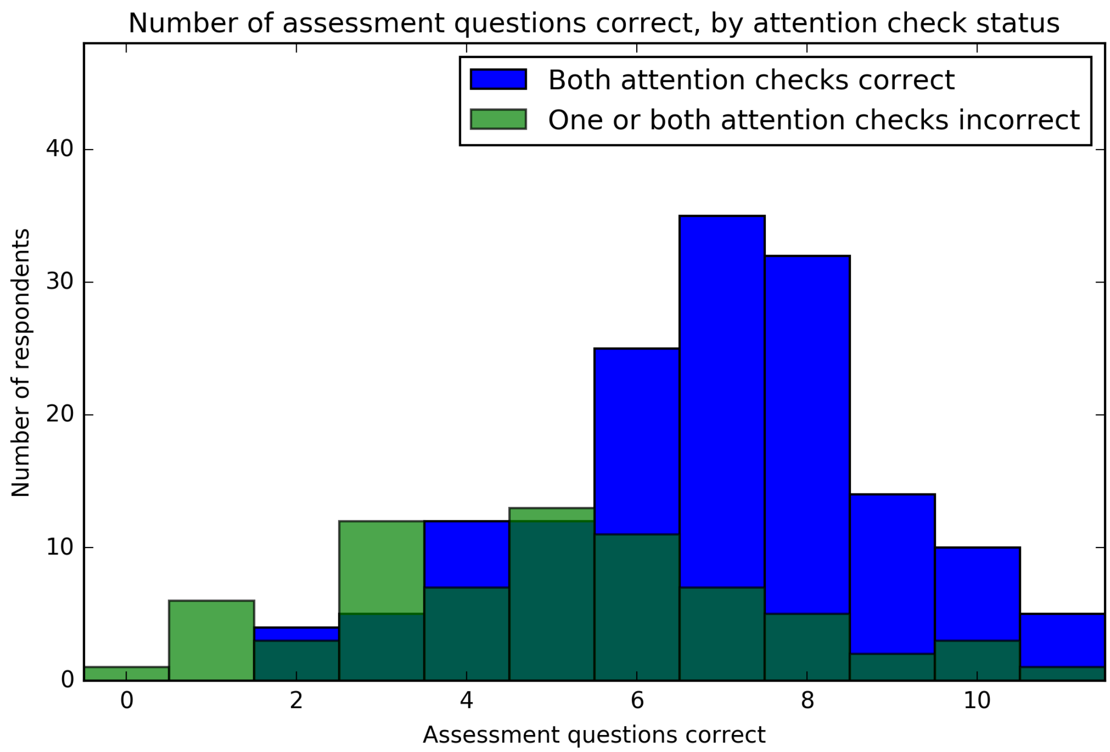

Figure 13: Number of assessment questions correct, by attention check status.

5.1.2 Quality check: excessively fast responses

The nature of Mechanical Turk, in which workers are paid a fixed fee in exchange for work that can be completed in a variable amount of time, means that some respondents will move excessively rapidly through the survey instrument, declining to pay full attention to the task at hand. Because we are interested in examining the effect of interactive and static data visualizations on respondents' understanding of factual data, we chose to further subset our sample to eliminate those individuals who were likeliest to be rushing through each section. We examined respondents' completion time in each of the four visualization sections of the survey instrument, using a sensitivity test to determine the optimal cutoff time. Within each visualization, we constrained our sample for analysis to include only responses in the upper 90th percentile of completion time (see Table 5). Because respondents' attention may differ from visualization to visualization, this subsetting of the sample was independent for each of the four visualizations. That is, a respondent may be included in the analysis for one visualization but not for another. This operation reduced the sample size for analysis of each visualization to 138 observations.

For our analysis of respondents' support for the Better Market Street project and each of its alternatives, we further limited our sample to individuals who completed the entire survey. This was necessary because the questions that measure these dependent variables are near the end of the survey, and key explanatory variables including respondents' attitudes are also collected near the very end of the survey flow. We did not use respondents' completion time for the sociodemographics, support, or attitudinal sections of the survey to further refine our sample, because the participant burden for these sections is much lower than the intricate requirements of the visualization assessments. As such, we had no reason to believe that participant inattention would be a critical problem in these sections. This final narrowing of the sample left us with 153 observations. Table 4 summarizes all the subsets of our sample that we examined.

Table 4: Different measures of sample size.

Respondent sample	**Analysis using sample**	**N**
Total number of responses	-	225
Responses with first attention check correct	-	208
Responses with second attention check correct	-	159
Responses with both attention checks correct	Demographic analysis	154
Responses with both attention checks correct who finished the entire survey	Analysis of support for Better Market Street project	153
Responses with both attention checks correct who were in the upper 90th percentile of time spent on visualization pages (sample varies for each visualization)	Analysis of performance on visualization assessment questions	138

Table 5: Time cutoffs for each visualization.

Visualization	**10th percentile of time spent on page**	**N**
Cross sections	88.7 seconds	138
Bike infrastructure	95.5 seconds	138
Auto restrictions	68.0 seconds	138
Transit	53.8 seconds	138

5.2 Key findings: assessed performance of interactive vs. static visualizations

One primary output of our survey methodology is a set of three measures of the effectiveness of our interactive data visualizations, compared with the static materials for the Better Market Street project. These three measures are:

1. The average number of assessment questions that respondents got correct
2. Respondents' ratings of their confidence in their answers
3. Respondents' ratings of the usefulness of the provided materials

For each of these three measures, we conducted two-sample t-tests of means to identify statistically significant differences between respondents who saw the interactive materials and those who viewed the static materials. Table 6 below shows the average number of assessment questions correctly answered by respondents who worked with the interactive and/or static data visualizations.

Table 6: Average number of assessment questions correct, by visualization section and type (interactive/static).

Visualization	N	Maximum score	Average number of questions correct *Interactive*	*Static*	t-statistic	p-value
Cross sections	138	3	1.438	0.692	4.741	0.000
Bike infrastructure	138	3	2.060	2.000	0.427	0.670
Auto restrictions	138	3	2.507	2.592	−0.689	0.492
Transit	138	2	1.568	1.172	4.208	0.000

For each of the four visualizations, we asked respondents to rate how confident they were in their answers to the assessment questions, and how useful the provided materials were in helping them answer the questions. The results of these heuristic questions are summarized in Tables X and Y below. Both of these ratings were on a scale from 1 to 5, where 1 stood for "Not at all [useful|confident]," 3 stood for "Neutral," and 5 stood for "Very [useful|confident]."

Table 7: Respondents' rating of their confidence in their answers, by visualization section and type (interactive/static).

Visualization	N	Average confidence rating (out of 5) *Interactive*	*Static*	t-statistic	p-value
Cross sections	138	4.055	3.585	3.159	0.002
Bike infrastructure	138	3.791	3.930	−0.826	0.410
Auto restrictions	138	3.910	3.887	0.140	0.889
Transit	138	3.541	2.766	4.111	0.000

Table 8: Respondents' rating of the usefulness of the provided materials, by visualization section and type (interactive/static).

Visualization	N	Average usefulness rating (out of 5) *Interactive*	*Static*	t-statistic	p-value
Cross sections	138	4.452	4.246	1.451	0.149
Bike infrastructure	138	4.194	4.296	−0.699	0.486
Auto restrictions	138	4.269	4.225	0.286	0.775
Transit	138	3.959	3.281	3.976	0.000

These findings indicate that two of our four interactive visualizations – cross sections and transit – statistically significantly outperformed their static counterparts, measured in terms of the number of assessment questions respondents answered correctly. We considered this the key metric, because the stated goal of our visualizations was to improve participants' ability to extract and compare data about project alternatives. For the other two visualizations (bike infrastructure and auto restrictions), respondents' performance on the assessment questions was not statistically significantly different across participants who engaged with the interactive vs. static materials.

The heuristic questions shed further light on these results. For the two visualizations on which there was no significant difference in objective performance (bike infrastructure and auto restrictions), there were also no statistically significant differences in participants' ratings of confidence or usefulness. However, for the other two visualizations (cross sections and transit), there were significant and meaningful differences. For the transit visualization, respondents exposed to the interactive materials reported a significantly higher degree of confidence in their answers, and rated the materials significantly more useful, compared to those shown the static transit materials. This result holds true even as all respondents expressed the lowest ratings of confidence and usefulness for the transit pair of visualizations. (Of all the heuristic questions, the only question and subgroup for which the average value was negative – i.e. below 3, or "neutral" – was the confidence rating reported by viewers of the static transit materials.)

Perhaps most interesting is to note that while the difference in objective performance across interactive vs. static visualizations for the cross sections was highly statistically significant, and respondents reported significantly higher confidence in their answers if they saw the interactive materials, there was not a statistically significant difference in respondents' ratings of the usefulness of the cross sections materials. This lack of significance flies in the face of the actual observed performance. The cross sections had the largest gap in performance between those who reviewed the interactive materials and those who saw the static materials: the interactive group got more than twice as many assessment questions correct. Nevertheless, both groups rated their materials equally useful. This finding suggests that it is difficult for members of the public to accurately estimate the true usefulness of a given data visualization, and reinforces the need for planning agencies to conduct rigorous assessment and validation of public-facing data displays.

Figure 14 below concisely summarizes the three preceding tables in one scatter plot. For each of the four visualization types, a star and square pair displays the mean percent of assessment questions correct and mean heuristic question score for respondents who saw the interactive and static materials, respectively. The absence of significant differences in accuracy or evaluation for the bike infrastructure and auto restrictions visualizations is displayed in the close proximity of these sections' static and interactive coordinates; the significant improvement in accuracy for cross sections and transit, and the particularly substantial increase in heuristic rating of the transit interactive visualization, are also clearly visible. One of the implications of this scatter plot is that the bike infrastructure and auto restrictions sections had less "head room" for improvement in performance on the assessment questions than the cross sections or transit visualizations. It is possible that more challenging questions on these higher-scoring sections could have decreased the mean number of correct answers, increasing variance and potentially allowing for the emergence of a statistically significant difference in performance between respondents who saw the interactive vs. static materials.

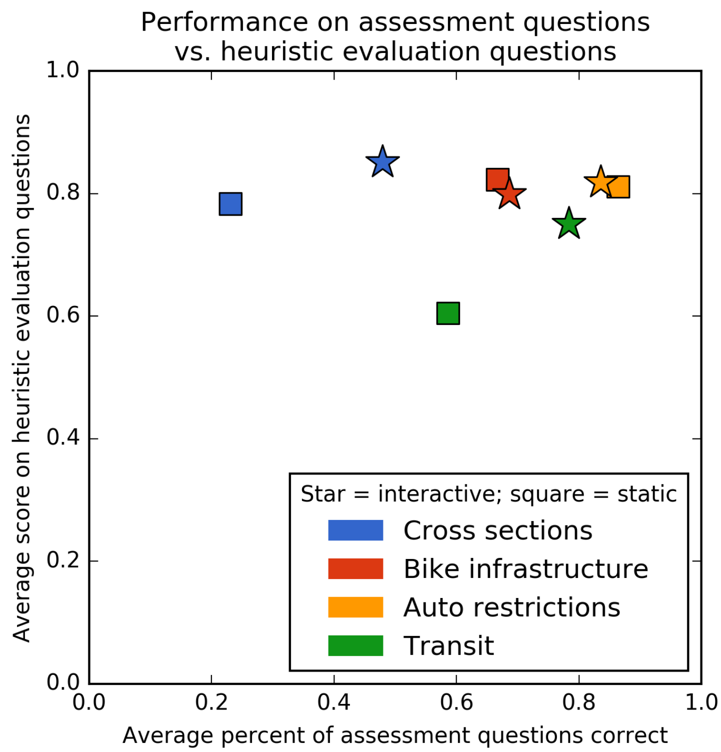

Figure 14: Scatter plot of respondents' performance on assessment questions in each survey section vs. respondents' average heuristic score of the materials, for interactive vs. static materials.

5.3 Explanatory consideration: time spent per visualization

Table 9 explores the relationship between visualization category, visualization type, and time spent interacting with the provided materials. Respondents spent significantly more time with the interactive materials in the cross sections and bike infrastructure survey sections; the differences in time spent on the other two sections are not statistically significant.

Table 9: Average time spent in each visualization section, by visualization type.

		Average time spent (minutes)			
Visualization	**N**	***Interactive***	***Static***	**t-statistic**	**p-value**
Cross sections	138	6.197	4.217	3.238	0.002
Bike infrastructure	138	5.010	3.544	2.876	0.005
Auto restrictions	138	3.387	2.832	1.788	0.076
Transit	138	3.577	4.103	−1.100	0.273

Several features of Table 9 merit closer consideration. First, respondents in general spent the most time on the cross sections. This may be due to any of several factors. It is the first visualization presented, so respondents' curiosity may have been greatest. It was the section where average assessment question scores were the lowest, so the challenging questions may have elicited more careful examination of the materials. Respondents may not be familiar with reading cross-sections in general, so may have needed more time to interpret the materials. Finally, interactive materials for this section were particularly thorough, effectively including two complementary visualizations of the same information.

Second, in terms of time spent per assessment question, respondents moved more quickly through the bike infrastructure and auto restrictions sections. (The transit section, as noted above, had only two assessment questions.) This may be due to the relative ease of answering these sections' assessment questions, which is corroborated by the generally higher scores on these sections of the survey. It is also possible that respondents made a conscious or unconscious decision to move more rapidly through the survey, in order to minimize their total time cost. However, time spent per assessment question ticks up again in the transit section, the final visualization presented in the survey instrument (all respondents were shown the set of visualizations in the same order). Respondents noted that these materials and associated questions were particularly difficult, so it is likely that the variation in time spent per section is largely driven by the level of complexity and difficulty of the data and questions.

On its face, it is reasonable to hypothesize that more time spent with the materials, within reason, is associated with improved performance on the assessment questions. However, our data generally suggest otherwise. While it is the case that respondents who saw the interactive cross sections materials spent longer, and scored better than, respondents who reviewed the static cross sections materials, survey respondents spent significantly longer with the interactive bike infrastructure visualization but did not perform significantly better.[3] Furthermore, overall scores were highest in the auto restrictions section, where overall time spent was lowest.

5.4 Sociodemographic analysis

We examined the sociodemographic characteristics of our "core sample," the 154 survey respondents who saw all four visualization sections and correctly answered both attention checks. Our goals here were twofold: to better understand the extent to which our sample was representative of the demographic distribution of San Francisco itself, and, when applicable, to explore whether our interactive visualizations had a different impact on members of different social and economic groups. In this section, we analyze respondents' geographic location, age, gender, commute mode/vehicle availability, race/ethnicity, educational attainment, and income.

5.4.1 Location

We used survey participants' self-reported ZIP codes to identify whether they were located within San Francisco. We found that 15.7%, or 21 of the 134 respondents who provided ZIP codes, were located in San Francisco. Additionally, we were able to use these ZIP codes to corroborate the specification of our sampling frame within Amazon Mechanical Turk: all provided ZIP codes were within the range associated with California state. This finding increased our confidence in the relevance of participants' responses to

[3] It appears possible that the interactive bike infrastructure map was simply more engrossing and "fun" to engage with, but did not provide additional clarity or insight.

the Better Market Street project, as Californians generally and San Franciscans in particular are likely to be familiar with Market Street.

5.4.2 Age

The age distribution of our survey sample is perhaps the sociodemographic characteristic that differs most from that of San Francisco's population. As shown in Figure 15, while San Francisco's citizens are spread out relatively evenly across a wide range of ages, our survey respondents were all between the ages of 20 and 66, and were heavily concentrated toward the low end of that range. The sample respondents' mean (33.2) and median (30.5) age were both well below San Francisco's median age of 38 years.

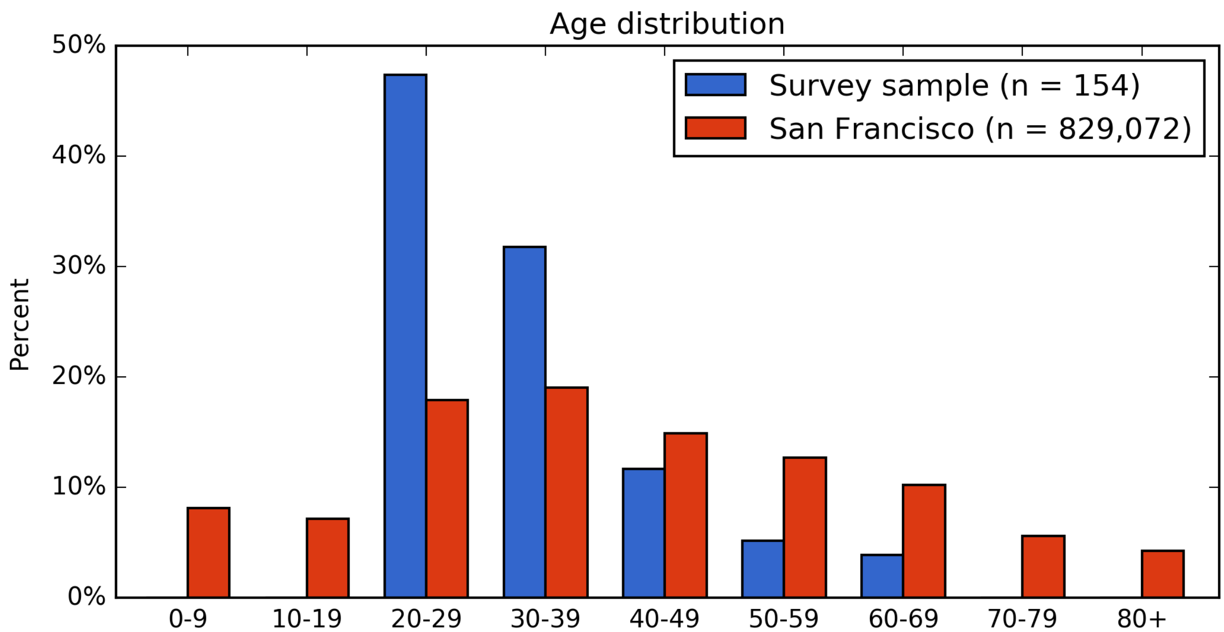

Figure 15: Age distribution of survey respondents, compared with San Francisco. Source: 2014 ACS 5-year estimates, Table B01001. Universe: total population.

The absence of respondents below the age of 18 is both unsurprising (because we limited our Mechanical Turk sampling frame to legal adults) and unproblematic from a representativeness perspective, because minors are less civically engaged than people of voting age.[4] By contrast, the overrepresentation of respondents in their 20s and 30s is potentially more problematic, because of different dynamics of digital literacy and civic engagement across age groups. Younger people tend to be more technologically adept, and thus potentially better served by our new interactive data visualizations. (Evans-Cowley and Hollander 2010) Meanwhile, older groups tend to be more engaged in conventional urban planning processes, whether due to greater motivation due to their higher likelihood of owning a home, greater

[4] Minors are unable to vote and to sign petitions; residents below age 18 can, of course, get involved in civic discourse in other ways. It is necessarily outside the scope of this study to explore the impact of interactive data visualizations on minors; however, it is to be hoped that interactive visualization may prove to be an effective technique for increasing civic engagement among youths.

ability to attend meetings due to flexible schedules and disposable income, or other economic or cultural factors. (Theiss-Morse and Hibbing 2005)

We analyzed differences in respondents' performance and attitudes, comparing participants below the sample median age of 30.5 with those above that age. Our analysis uncovered only one meaningful difference across age groups, in the bike infrastructure section of the survey. When viewing the interactive materials, participants above the age of 30 scored statistically significantly higher on the bike infrastructure assessment questions than respondents age 30 and below (2.29 vs. 1.86 questions correct, p-value = 0.027). We do not see an apparent reason for this difference. This difference was not found between older and younger respondents who viewed the static bike infrastructure materials. Notably, there was no statistically significant difference in respondents' overall level of support for the Better Market Street project across the younger and older groups.

5.4.3 Gender

The 154 respondents who saw all visualizations and correctly answered both attention checks were evenly split by gender, with 75 males, 77 females, and two respondents of other gender identity (Table 10). This near-50/50 split is very similar to the gender breakdown of San Francisco, which is 50.8% male and 49.2% female.

Table 10: Gender of survey respondents, compared with San Francisco.
Source: 2014 ACS 5-year estimates, Table B01001. Universe: total population.

	Male	**Female**	**Other**
Survey sample (n = 154)	48.7%	50.0%	1.3%
San Francisco (n = 829,072)	50.8%	49.2%	

Our analysis of the impact of interactive visualizations on respondents of different genders revealed that males' average number of correct assessment questions were higher than females' scores (2.74 vs. 2.25 questions correct, p-value = 0.005) for the interactive auto restrictions materials. By contrast, there was no significant difference in performance by gender among respondents shown the static auto restrictions materials. A similar dynamic appeared to emerge on the bike infrastructure visualization, although gender differences here were narrowly not statistically significant (interactive: males 2.23 vs. females 1.88 questions correct, p-value = 0.069; static: males 1.97 vs. females 2.03 questions correct, p-value = 0.781). Because the bike infrastructure and auto restrictions visualizations both employed Leaflet web maps, these results suggest that male respondents may benefit more from interactive map applications than female participants. This may relate to findings of gender differences in spatial cognition more broadly. (Feng, Spence, and Pratt 2007)

5.4.4 Transportation characteristics: commute mode and vehicles available

San Francisco's transportation dynamics are very different from most of the rest of the United States. Fewer than half of commuting San Franciscans drive to work or school, and the majority of workers in San Francisco households have access to zero or one vehicles. By contrast, more than 85 percent of all

Americans drive to work. (McKenzie 2015) As shown in Figure 16 and Table 11 below, the transportation characteristics of our sample are not highly reflective of San Francisco's exceptional commute mode and vehicle ownership patterns. With a driving commute mode share of 66 percent, our sample splits the difference between the local and national proportions. Survey respondents also tended to have substantially greater access to vehicles: while more than one in five San Franciscan workers does not have access to a vehicle, only 7 percent of our sample was car-free.

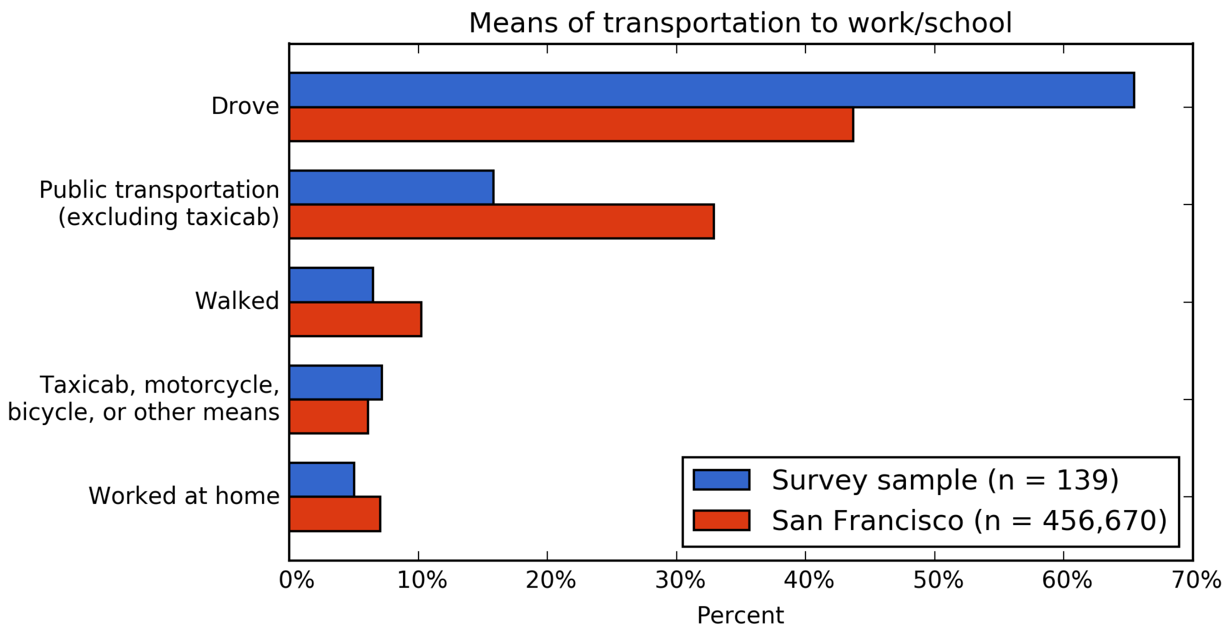

Figure 16: Commute mode of survey respondents, compared with San Francisco. Source: 2014 ACS 5-year estimates, Table B08101. Universe: workers 16 years and over.

Table 11: Number of vehicles available for survey respondents, compared with San Francisco. Source: 2014 ACS 5-year estimates, Table B08014. Universe: workers 16 years and over in households.

	Survey sample (n = 154)	**San Francisco (n = 453,362)**
No vehicle available	7.1%	20.4%
1 vehicle available	33.8%	37.4%
2 vehicles available	35.7%	28.2%
3 or more vehicles available	23.4%	13.9%

We did not conduct t-tests to examine the differential impact of interactive visualizations on subgroups divided by transportation characteristics, because we found no a-priori rationale to suppose that commute mode or vehicle ownership status would affect an individual's benefit from interactive data visualizations. If there were any relationship, it would almost certainly be a mediated one, in which one variable, such as educational attainment or income, simultaneously influenced an individual's commute mode and vehicle availability as well as that individual's response to new data visualization techniques. We did, however, check for differences in overall support for the Better Market Street project between respondents who drove to work/school and other respondents, and between respondents who had access to zero or one vehicles and respondents with access to two or more vehicles; there were no statistically significant differences in support for the BMS project as a whole across these subgroups.

5.4.5 Race and ethnicity

Figure 17 compares the racial and ethnic composition of our sample with that of the population of San Francisco. While our sample had a substantially larger proportion of White (non-Hispanic) respondents, as well as a lower percentage of Asian (non-Hispanic) respondents, its overall racial and ethnic distribution is reasonably similar to that of San Francisco. The size order of the five categories we produced for analysis is the same for the sample and the city, and the proportions of Hispanic and Black (non-Hispanic) participants closely mirror San Francisco's Hispanic and Black population percentages.

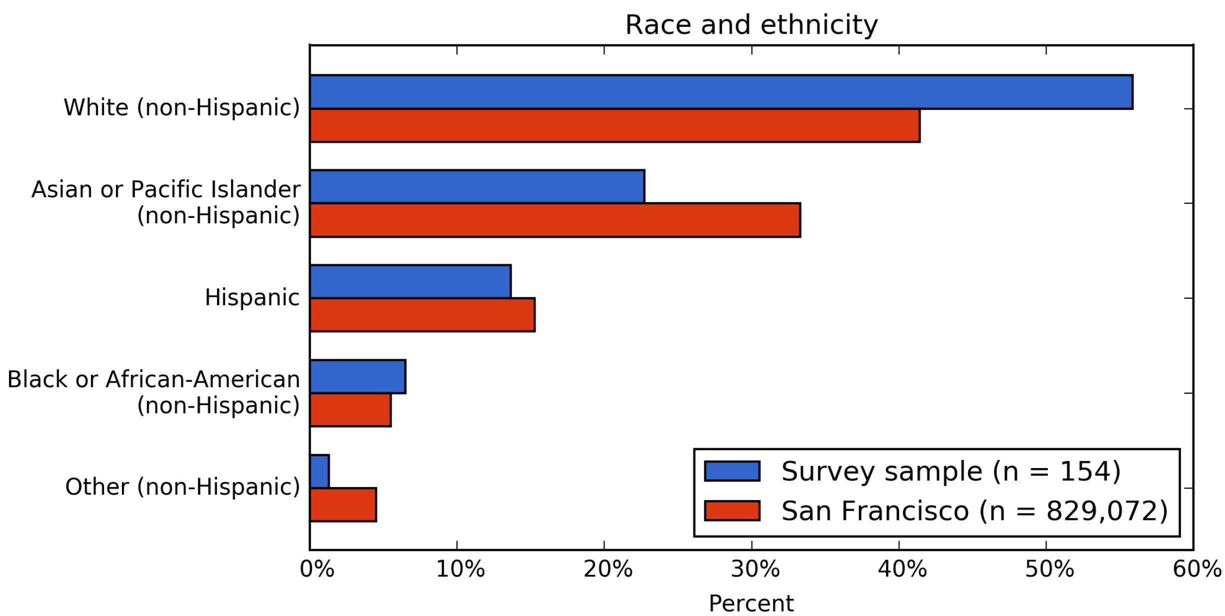

Figure 17: Race and ethnicity of survey respondents, compared with San Francisco. Source: 2014 ACS 5-year estimates, Table B03002. Universe: total population. Note: "Other (non-Hispanic)" includes American Indian and Alaska Native, Native Hawaiian and Other Pacific Islander, Some other race, and Two or more races. "Hispanic" includes respondents of all races who indicated Hispanic ethnicity.

We conducted an analysis of the difference in impact of interactive visualizations on White (non-Hispanic) respondents and respondents of other races and ethnicities. This analysis indicated that there were no statistically significant differences in the impact of our interactive visualizations across these two racial and ethnic groups. We found that White non-Hispanic respondents had statistically significantly higher scores than respondents of other races and ethnicities on the bike infrastructure assessment questions (average 2.25 vs. 1.76 questions correct, p-value = 0.000). However, this difference in performance was present for both the interactive and static visualizations, so is not attributable to the interactive visualization specifically. We identified no other statistically significant differences in the average number of assessment questions correct between White non-Hispanic respondents and respondents of other races and ethnicities.

5.4.6 Educational attainment

As shown in Figure 18 below, the educational attainment reported by our survey respondents differs substantially from that of San Franciscans 25 years and over. Notably, all of our respondents had attained at least a high school diploma or equivalent. The "some college or associate's degree" and "bachelor's degree" levels are overrepresented in our sample, while the proportion of respondents with advanced degrees was slightly lower than the proportion of San Franciscans with this high level of educational attainment.

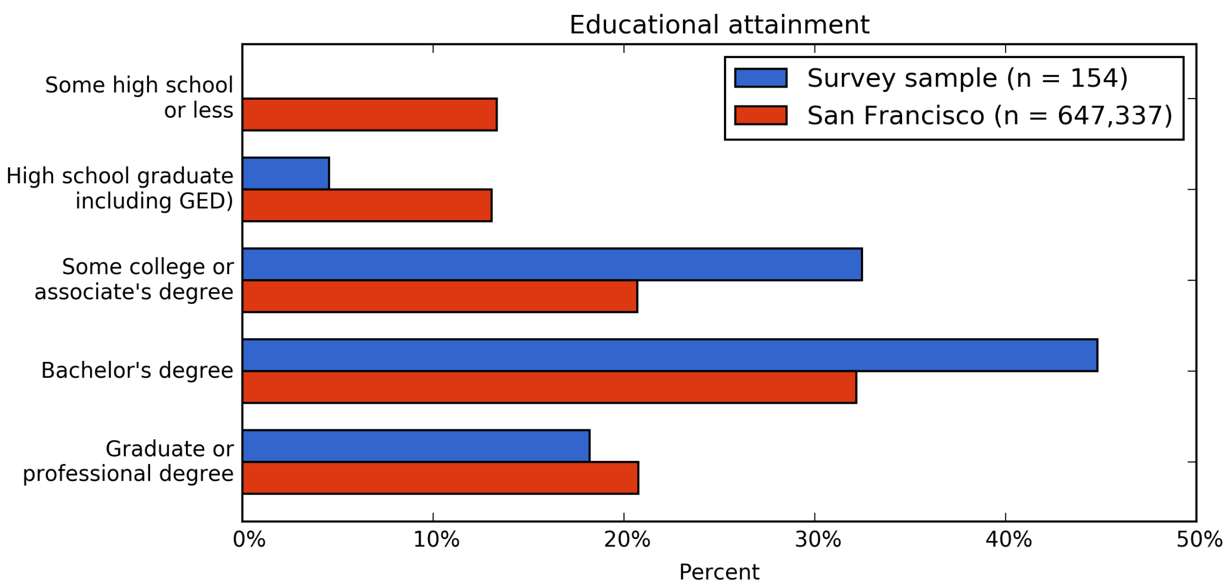

Figure 18: Educational attainment of survey respondents, compared with San Francisco. Source: 2014 ACS 5-year estimates, Table B15003. Universe: population 25 years and over.

Although the educational attainment reported by our sample does not closely resemble that of San Francisco, our overrepresentation of individuals with some college education or a bachelor's degree may actually better reflect the demographic composition of San Francisco citizens engaged with transportation planning processes. An emerging literature devoted to the relationship between education and civic and social engagement has found evidence that higher-educated individuals are more civically engaged (Campbell 2006), though this may be better attributed to flaws in the civic engagement process, or to associations between educational attainment, economic resources, and free time to participate, than to individual characteristics.

Using two-sample t-tests of means, we conducted an analysis of the relationship between respondents' educational attainment, which visualizations they viewed, and the number of assessment questions they answered correctly. This analysis indicated that our interactive visualizations of cross sections, bike infrastructure, and auto restrictions were not statistically significantly more effective for more highly educated individuals (those with at least a bachelor's degree) than for less highly educated individuals (those with an associate's degree or less education). However, our analysis revealed that our interactive transit visualization provided more benefit for highly educated respondents than for respondents with lower educational attainment. This result is documented in Table 12 below. It is not clear at this point what aspects of the interactive transit visualization were more beneficial for more educated individuals. It is possible that higher educational attainment is associated with increased numeracy, which in turn enabled respondents to interact more fluently with the complex and multidimensional data presented in the transit visualization.

Table 12: Analysis of the effectiveness of the interactive transit visualization for respondents with higher and lower levels of educational attainment.

	Average number of questions correct (max = 2)			
	Bachelor's degree or above	***Associate's degree or below***	**t-statistic**	**p-value**
Interactive visualization	1.673	1.263	2.935	0.004
Static visualization	1.294	1.033	1.931	0.058

	Average number of questions correct (max = 2)			
	Interactive visualization	***Static visualization***	**t-statistic**	**p-value**
Bachelor's degree or above	1.673	1.294	3.363	0.001
Associate's degree or below	1.263	1.033	1.404	0.167

5.4.7 Income

The income reported by our survey respondents is displayed in Figure 19, compared with the household income distribution of San Francisco. Overall, our survey sample was composed of predominantly lower income individuals than most San Franciscans: while nearly half of San Francisco households had annual incomes greater than $100,000, our respondents were likelier to earn less than $50,000 per year. (Some of this difference is likely due to the higher cost of living and wages in the Bay Area than in most of the rest of California, where many of our survey respondents were located.) This discrepancy between the sample and the city's income characteristics is not necessarily problematic, however. Tests of the interaction between income and the impact of interactive visualization did not identify any statistically significant differences in interactive visualizations' performance among lower- and higher-income groups. Also, as discussed below, income characteristics proved to be a statistically insignificant predictor of individuals' support for the entire Better Market Street project.

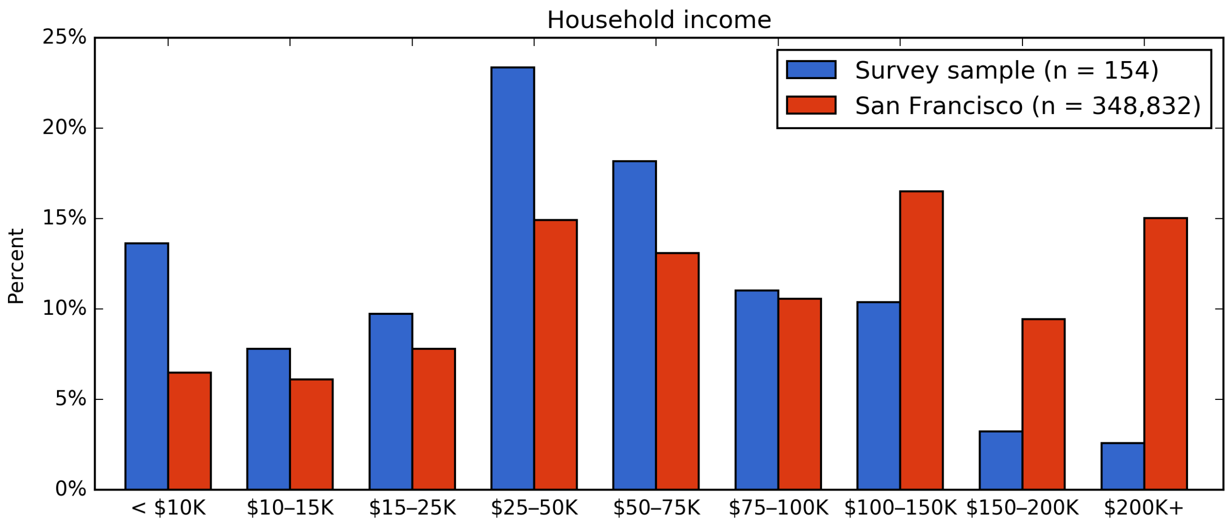

Figure 19: Household income of survey respondents, compared with San Francisco. Source: 2014 ACS 5-year estimates, Table B19001. Universe: households.

5.5 Regression analysis: support for BMS project

In addition to our preceding inquiry, which sought to understand the impact of interactive visualizations on participants' understanding of factual information, one of the study's goals was also to understand whether interactive data visualization might affect an individual's support for a project. Furthermore, we wanted to identify other key variables that help explain respondents' support for the Better Market Street project as a whole.

Table 13 demonstrates that there was significant variation in the number of interactive visualizations seen by each respondent. During our model development process, the count of interactive visualizations seen proved to outperform a collection of four dummy variables corresponding to whether respondents had seen each interactive visualization. Models that incorporated the four dummy variables tended to have a slightly higher r-squared value, but a lower adjusted r-squared due to the greater number of independent variables. Furthermore, the coefficients on the four dummy variables tended to mostly be not statistically significant at a 95% confidence level (though often significant at a 90% confidence level).

Table 13: Number of interactive visualizations seen by respondents.

Number of interactive visualizations seen	Number of respondents	Proportion of sample
0	4	2.6%
1	50	32.5%
2	57	37.0%
3	31	20.1%
4	12	7.8%

Table 14 below presents the results for our final regression analysis. This model explains respondents' reported support for the Better Market Street project as a function of the number of interactive visualizations they saw and of six self-reported attitudes. The attitudes are:

- perceptual_4 "I like cities"
- perceptual_5 "I enjoy walking on city streets"
- perceptual_6 "I enjoy driving on city streets"
- perceptual_7 "I think city streets should focus on allowing cars to travel quickly"
- perceptual_8 "I think city streets should focus on allowing pedestrians to feel safe"
- perceptual_9 "I think city streets should be safe for bicyclists"

We asked survey respondents to indicate their agreement or disagreement with each of these statements, on a scale from 1 (strongly disagree) through 3 (neutral) to 5 (strongly agree).

Most, but not all, of these attitudes proved to be statistically significant predictors of respondents' support for the project. Although some are not significant ("I think city streets should focus on allowing pedestrians to feel safe" in particular), omitting the statistically insignificant attitudes substantially reduced the model's explanatory power, as measured by adjusted r-squared. Furthermore, it is reasonable to include the entire battery of attitudes. A correlation analysis confirmed that these perceptual variables are not highly collinear.

Table 14: Regression results for Ordinary Least Squares model explaining respondents' support for Better Market Street project as a function of the number of interactive visualizations seen and a suite of self-reported attitudes.

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                support   R-squared:                       0.358
Model:                            OLS   Adj. R-squared:                  0.327
Method:                 Least Squares   F-statistic:                     11.41
No. Observations:                 151   Prob (F-statistic):           1.87e-11
Df Residuals:                     143   Log-Likelihood:                -160.47
Df Model:                           7   AIC:                             336.9
Covariance Type:            nonrobust   BIC:                             361.1
================================================================================
                   coef    std err          t      P>|t|      [95.0% Conf. Int.]
--------------------------------------------------------------------------------
Intercept        1.0965      0.486      2.257      0.026         0.136     2.057
n_vis            0.2476      0.062      4.016      0.000         0.126     0.369
perceptual_4    -0.1876      0.096     -1.958      0.052        -0.377     0.002
perceptual_5     0.2258      0.084      2.697      0.008         0.060     0.391
perceptual_6     0.1974      0.058      3.423      0.001         0.083     0.311
perceptual_7    -0.0908      0.062     -1.476      0.142        -0.212     0.031
perceptual_8     0.0486      0.094      0.516      0.607        -0.138     0.235
perceptual_9     0.3978      0.073      5.455      0.000         0.254     0.542
==============================================================================
Omnibus:                        0.211   Durbin-Watson:                   1.905
Prob(Omnibus):                  0.900   Jarque-Bera (JB):                0.354
Skew:                          -0.067   Prob(JB):                        0.838
Kurtosis:                       2.804   Cond. No.                         80.0
==============================================================================
```

Sociodemographic variables are notably absent from our final model presented above. We explored model specifications that included a wide range of sociodemographic elements, including:

- Age (continuous)
- Educational attainment (dummy: bachelor and above)
- Gender (dummy: female)
- Income (dummy: $50,000+)
- Access to vehicles (dummy: no vehicles)
- Employment status (dummy: employed)
- Commute mode (dummies for transit, biking/walking, and other, all relative to driving)
- Race/ethnicity (dummy: White non-Hispanic)
- Location (dummy: San Francisco)

None of these sociodemographic variables was a statistically significant predictor of respondents' support for the Better Market Street project – a remarkable finding in its own right.

5.6 Respondents' support for each option

After they interacted with a mix of dynamic and static data visualizations, survey respondents were asked which project option they would prefer if San Francisco decided to proceed with the Better Market Street project. We used a series of chi-squared tests to assess whether exposure to each of the four dynamic visualizations had a significant impact on respondents' preferred alternative. Our analysis indicated that there was no statistically significant relationship between exposure to any of the four interactive visualizations and the likelihood of favoring a given option. This is probably a desirable result, as it would otherwise mean that our dynamic visualizations were systematically biasing respondents toward one or another option.

Table 15: Proportion of survey respondents who preferred each BMS project option.

Option	Percent preferring this option
1	9.8%
2	30.7%
3	43.1%
I'm not sure	16.3%

5.7 Qualitative feedback

We solicited open-ended comments from each respondent in two places on the survey:

1. After asking survey participants to indicate which project option they would prefer if San Francisco chose to move forward with BMS (see section 5.6), we then asked: "Why do you prefer this option? (Or if you answered "I'm not sure," please explain why.)"

2. At the very end of the survey, we asked respondents: "Please provide any final comments or suggestions below."

These two questions formed the basis for a qualitative analysis of respondents' feedback.

5.7.1 Open-ended comments on option preference

We solicited open-ended comments on each respondent's reasons for preferring their favored project option. In keeping with the evident Mechanical Turk ethos of full completion,[5] 216 of 225 participants provided some qualitative rationale. We coded these comments for whether they:

- Involved consideration of impacts to one or more modes of transportation
- Involved consideration of balancing impacts to competing modes (particularly auto vs. other modes)
- Expressed a preference for one or two specific modes
- Involved consideration of multiple project options
- Mentioned the static or interactive visualizations
- Expressed difficulty in choosing an option to support

The number of comments in each category is presented in Table 16. Given that our visualizations presented elements of Better Market Street in sequence according to transportation mode, it is not surprising that the majority of respondents to this question gave a reason that involved impacts to one or more transportation modes. About half of the respondents to this question focused on one or two particular modes, and often expressed an opinion about which option they support based on what would benefit them. Comments about bicyclist and pedestrian improvements were common, as were comments from the perspective of motorists. A much smaller proportion of respondents (19%) wrote a comment that gave thought to balancing the needs of competing modes (typically, private automobiles vs. other modes). From this disparity, we can infer that most members of the public would view similar visualizations dealing with real projects primarily in light of their own needs and preferences and only secondarily in terms of balancing competing interests. This suggests that in designing visualizations to help inform the public about planning projects, it is important to present information that individuals need to assess how a project would affect their own personal circumstances.

For every comment code, there were no significant differences between respondents whose comments fit into the code and those whose comments did not in terms of the number of interactive visualizations seen. In other words, interactivity did not seem to have a relationship to the type of comment respondents gave for this question. However, those that left a comment that gave consideration to balancing competing modes, or who mentioned using the visual materials in some way, answered more questions correctly on average. This may suggest that individuals that gain a better understanding of a planning project, whether through excellent materials, their own aptitude, or some other factor, have more capacity for thinking about the impacts of a project beyond their own interests. This leads us to believe that better visualization

[5] Although none of the questions in our survey instrument were marked as required fields in Qualtrics, missingness was very low, generally well below 10% for each question.

could be related to more potential for cooperation among competing interests in the public, though more work would need to be done to assess the causality of this relationship.

Table 16: Codes for open-ended comments on option preference.

Code	N (% of respondents)	Examples
Impacts to one or more modes of transportation	142 (66%)	"Pedestrians are always in danger on Market Street especially. We need something that benefits the pedestrians." "I do not know if the traffic restriction is good for the city."
Preference for one or two specific modes	198 (45%)	"Best option for cars." "I like the buffered cycle track in each direction." "As a cyclist, I think this would be the safest for people on bicycles."
Balancing impacts to competing modes	42 (19%)	"Because it provides the most benefit for both pedestrians and cyclists, as well as the smoothest traffic options." "It seems like the most fair option for pedestrians and drivers."
Expressed difficulty in choosing an option	36 (17%)	"I don't like any of these." "I don't feel I'm qualified to understand the full consequences of the project." "They all have different benefits and drawbacks."
Consideration of multiple project options	15 (7%)	"I believe this to be the best option for future growth…I question the cyclists' safety…with option 1&3." "Although I was leaning toward Option 3, I was not impressed by the performance charts in the previous section."
Mentioned the static or interactive visualizations	15 (7%)	"Although I was leaning toward Option 3, I was not impressed by the performance charts in the previous section." "Because based on the interactive models, I found that option 2 is the fastest."

5.7.2 End-of-survey question

Of the 225 survey participants who saw all four visualizations, 75 provided qualitative feedback in the open-ended comments section at the end of the survey. Our goal was to use these codes to better assess the extent of participants' earnest engagement with the survey's topic and tasks. We coded these comments according to:

- Whether they expressed a sentiment about the subject matter of the survey (negative or positive)
- Whether they expressed a sentiment about the structure of the survey instrument (negative or positive)

Out of 75 responses, about one-third of comments had no substantive content; these were comments such as "good luck," or "none." Thirty-one responses included comments about the survey instrument, with 14 of those including a critical or constructive comment. One respondent said, for example, "the graphs are hard to read for comparison, the maps need to be bigger." Others left general positive feedback: "Very interesting study. Thank you for allowing me to participate." Twenty-one responses included a substantive comment about the topic of the survey. Some respondents added opinions that often built upon their previous open-ended response. One individual wrote, "I largely believe city atmosphere should accommodate cars and buses before looking to accommodate pedestrians or bicyclists," while another added, "Every major street should have a bike lane."

Overall, responses to this question provided some helpful feedback on the survey but were not a helpful indicator of overall engagement. It is clear that some respondents had a positive experience, that others faced some confusion, and that some were quite engaged with the subject matter. However, there were too few responses to this question to learn more about the survey sample's overall level of engagement in the process.

6 Discussion

6.1 Goals of interactive data visualization

Two key findings of our study are:

1. In at least some cases, interactive data visualizations can improve individuals' absorption and understanding of quantitative data about transportation planning decisions.
2. Interactive visualizations appear to have a positive impact on survey participants' overall level of support for the Better Market Street project.

These two findings are both very promising in terms of their implications for the value and future of rich online data visualization within transportation planning public engagement processes. However, it is important to recognize that they are approximately orthogonal to one another in terms of the goals of data visualization. Are transportation agencies seeking to maximize factual information transfer, or maximize public support for a proposed project?

Within professional practice, each public agency must determine for itself which goal to pursue, especially if it emerges that the goals are in conflict (as when, for example, more detailed understanding of a project leads to deeper opposition to that project). In our controlled survey environment, our results pointed more unambiguously to the potential for interactive visualizations to increase public support than to improve public understanding. However, in an actual planning context in which engaged citizens approach a project with deeper motivation and buy-in, it is possible that the net impact of visualizations on project support could be smaller. It is also possible that if visualizations can enable the public to better understand projects, they may make flaws in the project more apparent, leading to decreased support. Finally, there may be a middle ground; visualizations may foster more creative solutions to public concerns about a project. Indeed, if high-quality data design uncovers flaws in a project, it creates the potential for members of the public to work with planners to address those shortcomings and develop a better project.

6.2 Hypotheses: Why did some visualizations work?

Our research design enabled us to make rigorous claims about the degree of effectiveness of some forms of digital data visualization, relative to traditional static public engagement materials. However, our survey methodology did not provide us with a strong basis to explain why some visualizations "worked" better than others. We may nevertheless speculate about potential explanations, and consider how those potential causal links could be further tested.

The clearest distinction in terms of the value added by interactive visualizations over static materials was that the two map-based visualizations (bike infrastructure and auto restrictions) did not register statistically significant increases in respondents' performance on assessment questions or heuristic evaluations. The map-based visualizations represented a fundamental reconfiguration of the presentation of information, from a set of often stylized and decontextualized quasi-spatial data displays to a familiar webmap format that situated spatial data in a fuller context. By contrast, the cross sections and transit visualizations more closely resembled the shape of their corresponding static materials. The interactive cross sections materials, in particular, essentially contained the entirety of the static materials, plus additional highlights and an interactive bar chart.

One potential implication of the poorer performance of the map-based visualizations is that additional context can quickly inhibit, rather than enhance, respondents' comprehension of spatial information. When we designed the map visualizations, we imagined that situating proposed bike infrastructure and auto restrictions within a familiar cartographic context would help respondents quickly and accurately visualize the extent of the project's impacts. However, our intuition may have been incorrect: additional information may in fact be overwhelming and inhibit understanding. In the future, this hypothesis could be further tested by creating a stripped-down web base map, such as the monochromatic base layers built by Stamen Design,[6] and keeping to an absolute minimum the number and complexity of point, line, and polygon features displayed atop the base map. The performance of this minimalist interactive webmap could then be compared with a more complex webmap, and with static map materials.

6.3 Hypotheses: Why did the number of visualizations seen affect project support?

One promising finding from our research is that the number of interactive visualizations seen by each respondent was a statistically significant predictor of the respondent's level of support for the Better Market Street project as a whole. As above, however, we cannot confidently explain why this is the case. One potential explanation is that rich digital data visualizations project the appearance of competence: interactive data displays are impressive, and that impression translates into increased enthusiasm about the project itself. Another possibility is that interactivity itself, by enabling participants to more deeply explore project alternatives, breeds greater familiarity with the project, and this deeper exposure engenders a stronger sense of commitment or involvement on the part of respondents.

A third, and most optimal, explanatory mechanism is that interactive materials led to better understanding of this project, and better understanding led directly to more support. This would obviously be a win-win:

[6] http://maps.stamen.com/toner/#12/37.7706/-122.3782

planners who developed compelling data visualizations could expect both improved understanding of and support for their projects. However, this hypothesis overlooks the real conflicts that often emerge between participants' subjective preferences and the goals of a project. For example, some of our respondents expressed skepticism or outright hostility toward some of the objectives of Better Market Street. For these respondents, a fuller understanding of the implications of the BMS project options is very unlikely to translate into increased support for the project.

6.4 Real-world considerations

Two considerations present themselves as we examine how to map the implications of our research onto professional practice in the real world. First, we approached this study from an intentionally narrow and focused vantage point, and we used narrow evaluation questions to address our hypotheses. But it is important to examine what differences exist between our laboratory setting and the greater laboratory of democracy. How does the real way in which interested parties peruse, absorb, and compare information resemble, or not resemble, our more carefully controlled experiment here?

From our review of the literature and from anecdotal observations, one major difference we have identified is that interested members of the public will take as much or as little time as they desire to learn about a project. This is a major contrast with our paid survey methodology, where respondents were incentivized to absorb a large amount of information as quickly as possible. Interviews or focus groups with members of the public – both casually engaged and rigorously engaged individuals – would help increase our understanding of how they engage with official information, what answers they are seeking, and how they measure successful understanding.

Another issue that arose in our research was the potential for interactive data visualizations to inequitably impact citizens' comprehension of a project. We found evidence that some interactive visualizations worked "better" for members of one group than another; in each of these few cases, the interactive visualization worked to the benefit of an already privileged group, such as individuals above age 30 or with a bachelor's degree or higher educational attainment. These differential impacts, though few in number, raise the question of whether planning agencies have a responsibility to invest resources in interactive visualizations only when they demonstrably help to level the playing field of understanding. Closely linked to this question is the need for transportation planners to design hybrid online/in-person public engagement strategies that proactively seek to reduce disparities in information access between more and less privileged social and economic groups, not to mention language options and accessibility for persons with disabilities that are required by law.

6.5 Upstream information flow

Our work in this professional report has focused on the flow of information from planners to members of the public: a "downstream" flow. While this directional information transfer is a critical component of a high-functioning public engagement ecosystem, the "upstream" flow of knowledge and opinions from members of the public to planning practitioners is equally crucial. Technological tools have much to offer in this arena, such as interactive games that help constituents express their preferences across different long range transportation plan alternatives.

In this study, we have used a randomized, quantitative survey methodology to examine the impact of different types of interactive data visualization on information transfer from planning practitioners to members of the public. By contrast, a research project seeking to identify best practices in digital design aimed at gathering information from the public and making it richly interpretable by planners would probably need to draw heavily on expert informant interviews and case studies, because each planning agency's political context is so different. Such a study could also incorporate a survey of planning and transportation agencies to identify the penetration of technologically sophisticated information-gathering and -sharing tools throughout the sector (as well as exemplars from outside the sector). It would also be important to incorporate an examination of the afterlife of information gathered from the public: are agencies truly listening and responding to constituents' input, or are digital tools merely another facade that masks unresponsive planning actors?

6.6 Cost-benefit analysis

Finally, as transportation agencies and other planning organizations consider further investment in technologically sophisticated data visualizations, they will need to examine both the benefits and the costs of that investment. The primary cost to agencies will be one of human resources: many visualizations are time-intensive to develop, and they could supplement rather than supplant other labor-intensive project deliverables such as static maps (which are seen as a firm requirement in existing engagement efforts). Agencies might also incur higher IT costs in terms of bandwidth used by data-intensive visualizations, but this difference is likely to be trivial when compared with the labor costs. Human resources costs will include professional development for existing employees, recruitment of new and technically skilled workers, and the maintenance of a formal or informal community of data visualization knowledge and practice.

In some cases, the interactive data visualization techniques we presented in this work can easily be scaled and adapted to other contexts. For example, the workflows of creating the two Leaflet-based interactive maps (for the bike infrastructure and auto restrictions sections) were very similar to one another and would be easy to apply to most data already in a GIS. For example, the recent release of proposed Bay Area Bike Share station expansion locations was announced via a website[7] that offered static PDF maps of proposed stations. These locations are already in a GIS shapefile, and it would be trivial (less than an hour at the very most) to create an interactive map of these data.

In other instances, the appropriate interactive data visualization will be novel in design and have limited reproducibility. The development costs associated with these visualizations will be concomitantly higher. In some cases, these costs can be ameliorated via careful information design: for example, the highly multidimensional data presented in the static transit materials required a customized interactive bar chart that remained fairly confusing, though more helpful than the original materials according to our

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[7] "Introducing Bay Area Bike Share, Your New Regional Transit System." Accessed April 19, 2016. http://www.bayareabikeshare.com/expansion.

respondents. More careful design of what data will be presented can reduce complexity at the outset, in turn streamlining the process of building rich interactive visualizations.

As always, the fundamental question is: *compared to what?* It is outside the scope of this research to assess the current costs in money and staff time of existing public engagement practices and to contrast those costs with the projected costs of a more tech-savvy engagement strategy. However, our data indicate that the benefits of interactivity are real – both in terms of information transfer and generation of support – and it is likely that in many situations the benefits will outweigh the costs of rich data visualization, especially as the technological skills of members of the planning workforce continue to increase.

7 Conclusion

We conducted this study to better understand whether interactive data visualization tools might help planners communicate with the public about complex projects more effectively. Specifically, we were interested in whether such visualizations might help enhance the public's understanding of planning projects, as well as whether they might increase the public's support for projects. Our findings indicate potential on both fronts. Based on a comparison of existing images and our simple interactive visualizations that both attempt to explain core elements of the Better Market Street project in San Francisco, we found that respondents that saw interactive visualizations not only scored better on questions that tested their understanding, but also supported the project more strongly.

To the best of our knowledge, this is the first study that applies principles of evaluating information visualization to an urban planning or transportation context. There is great potential for more inquiry in this area for two reasons. First, the ability of planners to clearly communicate about their projects is crucial to their success in improving cities. Second, at the same time, the opportunities to use newly accessible visualization methods to communicate in more sophisticated ways is large and growing. Given these two factors, it is important for planners to better understand whether such visualizations actually help in the task of communication, and to generate best practices for using these tools. We believe our results speak positively to the first point; there is much work to do to understand further how planners can best use visualizations to improve public engagement in the future.

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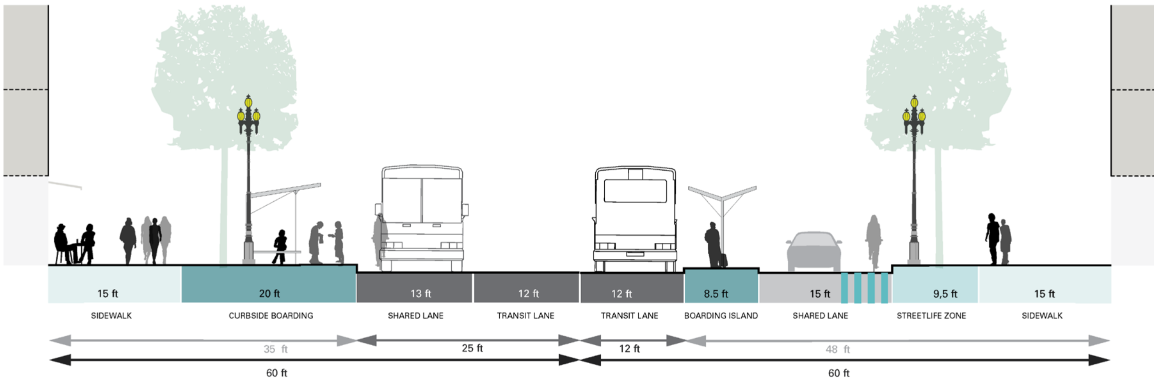
9 Appendices

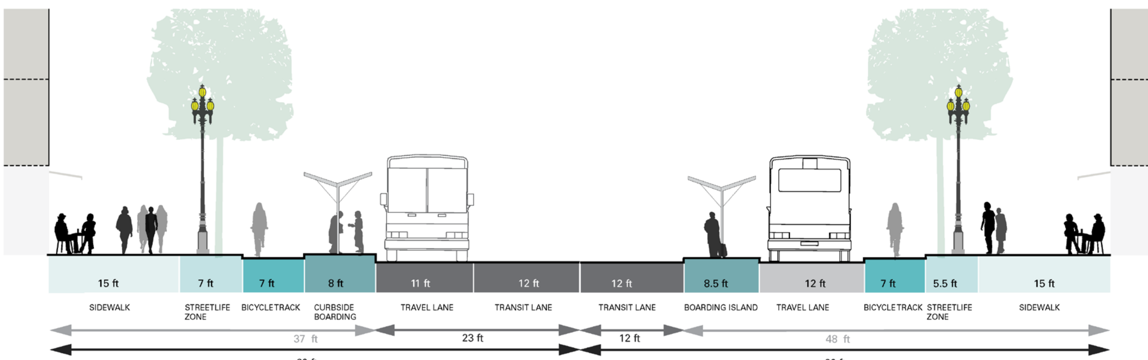
Appendix A Cross-sections of each proposed Better Market Street option

Option 1, Market Street:



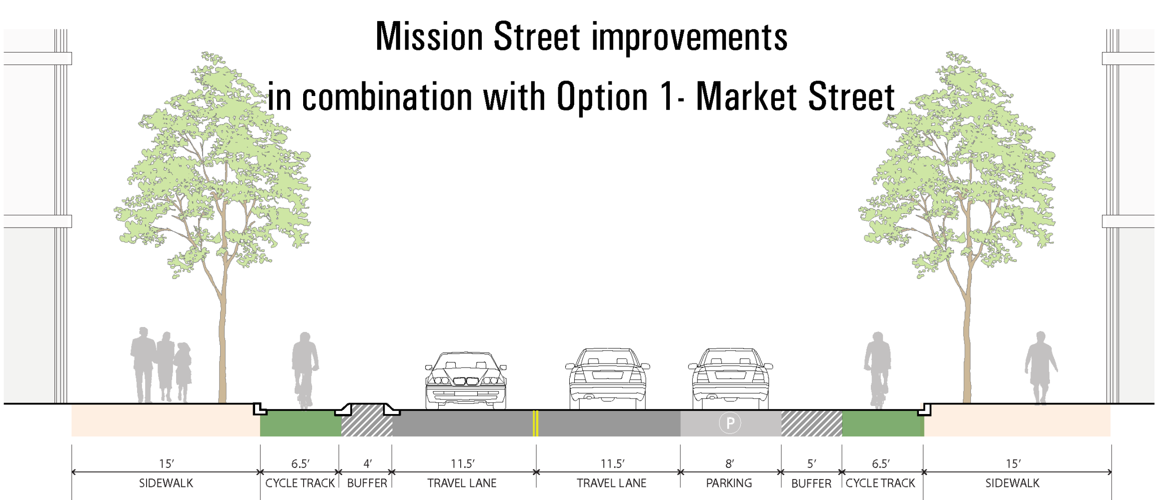
Market Street Section

Option 2, Market Street:



Market Street Section

Option 3, Mission Street: *(Option 3's Market Street cross-section is identical to Option 1's)*



Mission Street Section

Appendix B Static and dynamic visualizations

The static and dynamic materials we presented in the Qualtrics survey can be viewed at the following website: https://rawgit.com/drewlevitt/bms-datavis/master/.

Appendix C Survey instrument

The following is a static presentation of our survey instrument. A live, interactive version of the survey can be accessed at http://tinyurl.com/bms-visualization-survey.

University of California at Berkeley
Consent to Participate in Research

Can Data Visualization Improve Public Understanding of Transportation Project Alternatives?

Introduction and Purpose

We are Drew Levitt and Paul Sohn, graduate students in the Department of City and Regional Planning at the University of California, Berkeley, working with our faculty advisor, Professor Paul Waddell. We would like to invite you to take part in our research study, which concerns how interactive data visualization can help increase public understanding of transportation projects. Specifically, we hope to explore whether digital materials like interactive charts and maps can more effectively convey factual information about planning projects, compared with standard non-interactive materials.

Procedures

If you agree to participate in our research, we will ask you to complete the online survey that begins on the next page. The survey will involve reviewing online graphics or PDFs about a transportation project and answering questions about the facts presented in those graphics/PDFs. We will also ask some basic questions about you (age, gender, etc.). It should take about 20 minutes to complete.

Benefits

Other than your monetary compensation, there is no direct benefit to you from taking part in this study. It is hoped that the research will inform city planning/transportation agencies about the best ways to use data visualization to communicate with individuals like you about their projects and plans.

Risks/Discomforts

As with all research, there is a chance that confidentiality could be compromised; however, we are taking precautions to minimize this risk.

Confidentiality

We will not collect any personally identifiable information in this survey. What information we do collect will be handled as confidentially as possible, and to minimize the risks to confidentiality, we will store data in a password-protected service, with access limited only to the researchers. When the research is completed, we may save the data for use in future research done by ourselves or others. We will retain these records for up to 5 years after the study is over. The same measures described above will be taken to protect confidentiality of this study data.

Compensation

You will be paid according to the rate agreed on through Amazon Mechanical Turk.

Rights

Participation in research is completely voluntary. You are free to decline to take part in the project. You can decline to answer any questions and are free to stop taking part in the project at any time. Whether or not you choose to participate, to answer any particular question, or continue participating in the project, there will be no penalty to you or loss of benefits to which you are otherwise entitled.

Questions

If you have any questions about this research, please feel free to contact us:
Paul Sohn: paulsohn@berkeley.edu
Drew Levitt: drew.levitt@berkeley.edu

If you have any questions about your rights or treatment as a research participant in this study, please contact the University of California at Berkeley's Committee for Protection of Human Subjects at 510-642-7461, or e-mail subjects@berkeley.edu.

If you agree to take part in the research, please continue to the next page below.

Market Street is San Francisco's premier cultural, civic, and commercial corridor. It is San Francisco's busiest pedestrian street, bicycle thoroughfare, and transit corridor.

The above photograph looks northeast along Market Street, with San Francisco Bay and the Ferry Building visible at center.

Better Market Street is a project being coordinated by multiple public agencies, including the San Francisco Planning Department and San Francisco Municipal Transportation Agency, to remake Market Street. The following is a description of the project's goals, taken from the Better Market Street website:

"We will create a sense of **place**, optimize **mobility**, and foster **economic development** by:

- Supporting the City of San Francisco's planned growth and economic development.
- Providing faster and more reliable transit service for all users.
- Improving safety, comfort and mobility for pedestrians and bicyclists.
- Creating thriving public spaces that attract a diversity of people and uses."

The Better Market Street website presents **three conceptual options** for the project that are being studied in the environmental review process:

OPTION 1: MARKET STREET

This option improves Market Street's curbside lane using striping, sharrows and other enhancements. Bicycles, transit and vehicles share the outside lanes, with transit only center lanes. The majority of the curb remains in the existing location.

OPTION 2: MARKET STREET

This option proposes a one-way cycletrack on Market Street in each direction from Steuart Street to Grant Street and 5th Street to Octavia Boulevard. Four lanes for transit and vehicles remain with transit only center lanes. The curb moves to accommodate the cycletrack, reducing the Streetlife Zone area.

OPTION 3: MARKET STREET + MISSION STREET

This option proposes a one-way, buffered cycletrack on Mission Street in each direction. All transit moves from Mission Street to Market Street and two lanes of vehicular traffic remain on Mission Street. Pedestrians benefit from street life improvements on both Market and Mission Streets..

In the following sections, we will ask you to:

- Answer some demographic questions about yourself
- Review detailed information about each of these alternatives
- Answer factual questions about the information you reviewed
- Answer some questions about your opinions

Please click to proceed below.

ABOUT YOU

This first section will ask you some demographic questions about yourself.

What is your age (in years)? _____

What is the highest level of education you have completed?

- Some high school or less
- High school graduate (including GED)
- Some college or associate's degree
- Bachelor's degree
- Graduate or professional degree

What is your gender?

- Male
- Female
- Other: ________

Please provide the best estimate of the income you received in the past 12 months:

- $0–$9,999
- $10,000–$14,999
- $15,000–$24,999
- $25,000–$49,999
- $50,000–$74,999
- $75,000–$99,999
- $100,000–$149,999
- $150,000–$199,999
- $200,000 or more

How many vehicles are owned, leased, or available for regular use by the people who currently live in your household? Please be sure to include motorcycles, mopeds and RVs. Do not include bicycles.

- No vehicles
- 1
- 2
- 3 or more

Last week, did you work for pay at a job or attend school?

- Yes
- No

(If answered "Yes" to the previous question) How did you usually get to work or school last week? If you usually used more than one method of transportation during the trip, select the one used for most of the distance.

- o Car, truck, or van
- o Bus or trolley bus
- o Streetcar or trolley car
- o Subway or elevated railroad
- o Ferryboat
- o Taxicab
- o Motorcycle
- o Bicycle
- o Walked
- o Worked at home
- o Other method (please specify): ______________

Are you of Hispanic, Latino, or Spanish origin?

- o Yes
- o No

What is your race? *(please select all that apply)*

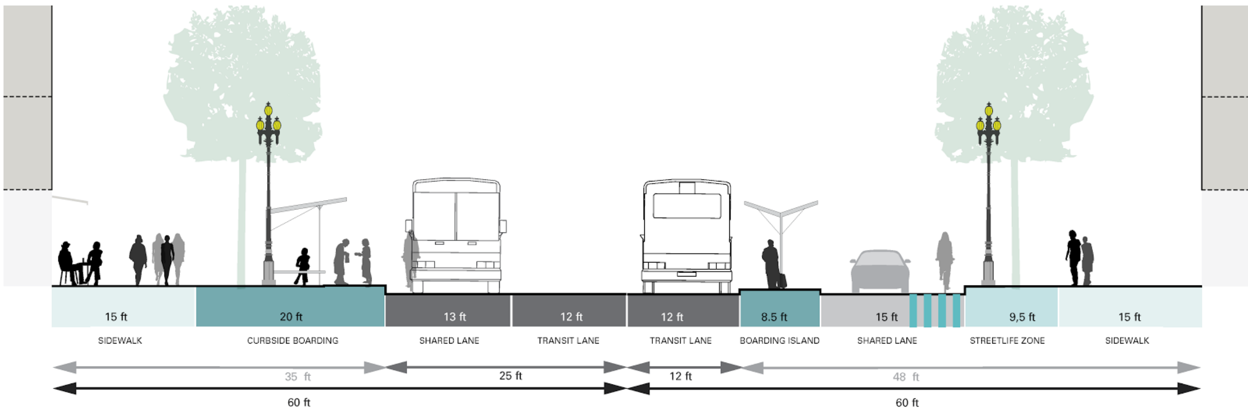
- ☐ White
- ☐ Black or African-American
- ☐ American Indian or Alaska Native
- ☐ Asian or Pacific Islander
- ☐ Some other race (please specify): ______________

What is your home ZIP code? _________

CROSS SECTIONS

Now, we will display some materials about the Better Market Street project. Please review the following graphics regarding the proposed street design for Market Street under each alternative:

[STATIC OR DYNAMIC VISUALS HERE; SAMPLE BELOW]



Market Street Section

Now, we want to see how clearly these materials communicated their information. Referring back to the above materials, please answer the following questions to the best of your ability. Don't worry if the answer is not obvious. If you are not sure about an answer, just take your best guess.

Which transportation mode (bike, auto, transit, or pedestrian) has the most space on Market Street in Option 2?

- o Bike
- o Auto
- o Transit
- o Pedestrian

Which option provides the most space for bicyclists and pedestrians, combined, on Market Street? *(If two or more options are tied, please select all that apply.)*

- ☐ Option 1
- ☐ Option 2
- ☐ Option 3

Which option provides the least space for pedestrians on Market Street? *(If two or more options are tied, please select all that apply.)*

- ☐ Option 1
- ☐ Option 2
- ☐ Option 3

How useful were the materials on this page in helping you answer these questions?

- o Not at all useful
- o Not very useful
- o Neutral
- o Somewhat useful
- o Very useful

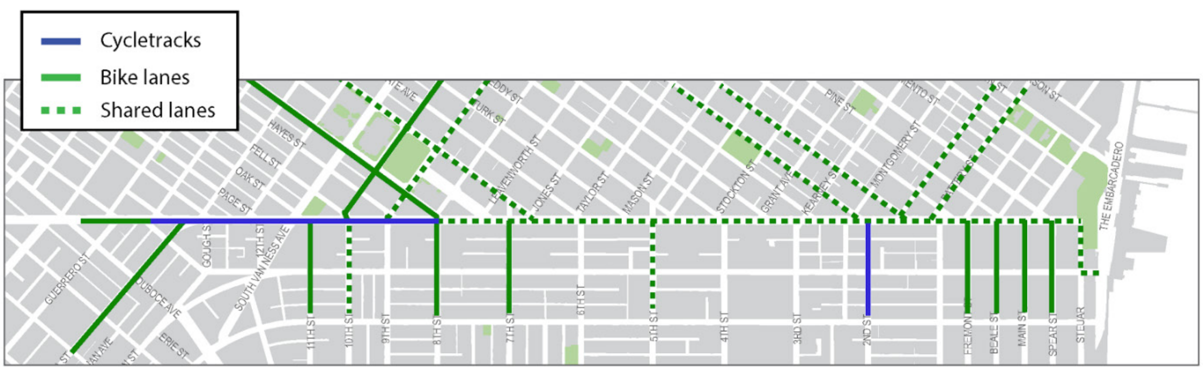
How confident are you in your answers on this page?

- o Not at all confident
- o Not very confident
- o Neutral
- o Somewhat confident
- o Very confident

BICYCLE FACILITIES

Please review the following graphics regarding the bicycle facilities under each alternative:

[STATIC OR DYNAMIC VISUALS HERE; SAMPLE BELOW]



Bicycle Circulation

Now, we want to see how clearly these materials communicated their information. Referring back to the above materials, please answer the following questions to the best of your ability. Don't worry if the answer is not obvious. If you are not sure about an answer, just take your best guess.

Which option has the most distance of cycletracks on Market Street? *(If two or more options are tied, please select all that apply.)*

- ☐ Option 1
- ☐ Option 2
- ☐ Option 3

Which option would result in the most bike infrastructure on Market and Mission Streets combined?

- Option 1
- Option 2
- Option 3

Imagine you are bicycling along Market Street. Beginning at South Van Ness Avenue and moving toward the Embarcadero, under Option 2, where does the cycletrack first change to a shared lane?

- 3rd Street
- 5th Street
- 8th Street
- Fremont Street

Under option 3, beginning at the Embarcadero and traveling toward South Van Ness Avenue, where does the shared lane first change to a cycletrack? Please select "8th Street."

- 6th Street
- 8th Street
- 10th Street
- There are no cycletracks on Market Street under Option 3

How useful were the materials on this page in helping you answer these questions?

- Not at all useful
- Not very useful
- Neutral
- Somewhat useful
- Very useful

How confident are you in your answers on this page?

- Not at all confident
- Not very confident
- Neutral
- Somewhat confident
- Very confident

AUTO RESTRICTIONS

Please take a few moments to review the following graphics regarding restrictions for private automobiles under each alternative:

[STATIC OR DYNAMIC VISUALS HERE; SAMPLE BELOW]

Now, we want to see how clearly these materials communicated their information. Referring back to the above materials, please answer the following questions to the best of your ability. Don't worry if the answer is not obvious. If you are not sure about an answer, just take your best guess.

Which option recommends restrictions on private cars along the greatest length of Market Street? *(If two or more options are tied, please select all that apply.)*

- ☐ Option 1
- ☐ Option 2
- ☐ Option 3

Imagine you are driving from the Embarcadero toward Van Ness Avenue at 1 pm. Under Option 1, how far could you drive along Market Street before having to pick a different route due to the recommended auto restrictions?

- o To Fremont Street
- o To 5th Street
- o To Van Ness Avenue (all the way)
- o Cars cannot travel in this direction on Market Street at this time

Imagine you are driving from South Van Ness Ave toward the Embarcadero at 3 pm. Which option's recommended auto restrictions would allow you to drive the farthest distance along Market Street before having to pick a different route due to auto restrictions?

- o Option 1
- o Option 2
- o Option 3

How useful were the materials on this page in helping you answer these questions?

- Not at all useful
- Not very useful
- Neutral
- Somewhat useful
- Very useful

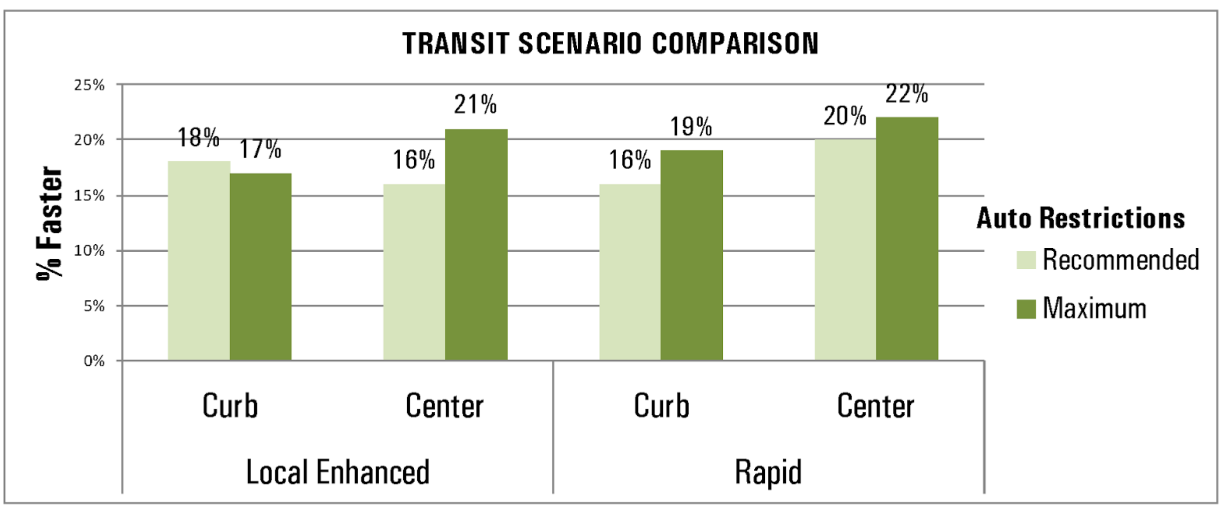
How confident are you in your answers on this page?

- Not at all confident
- Not very confident
- Neutral
- Somewhat confident
- Very confident

TRANSIT SPEED IMPROVEMENTS

First, please take a few moments to explore the information presented below. Two types of bus service – local enhanced and rapid – run along Market Street, Additionally, each bus line can pick up passengers on the right side of the street (curb boarding) or at a dedicated boarding island in the middle of the street (center boarding). The charts below show improvements to transit speed for each of these combinations under each option's recommended and maximum auto restrictions.

[STATIC OR DYNAMIC VISUALS HERE; SAMPLE BELOW]



Now, we want to see how clearly these materials communicated their information. Referring back to the above materials, please answer the following questions to the best of your ability. Don't worry if the answer is not obvious. If you are not sure about an answer, just take your best guess.

Under Option 2's recommended auto restrictions, which type of service experiences the greatest increase in speed? Please select the fourth option.

- o Local service, with curbside boarding
- o Local service, with center boarding
- o Rapid service, with curbside boarding
- o Rapid service, with center boarding

Imagine you are riding a rapid bus that stops at a center boarding island. Which option has the same transit performance for this type of service under both recommended and maximum auto restrictions? *(Please select all that apply.)*

- ☐ Option 1
- ☐ Option 2
- ☐ Option 3

Now imagine you are riding a local enhanced bus that boards at the curb. Which option's recommended auto restrictions provide the largest performance improvement for this type of service?[8]

- o Option 1
- o Option 2
- o Option 3

How useful were the materials on this page in helping you answer these questions?

- o Not at all useful
- o Not very useful
- o Neutral
- o Somewhat useful
- o Very useful

How confident are you in your answers on this page?

- o Not at all confident
- o Not very confident
- o Neutral
- o Somewhat confident
- o Very confident

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[8] When writing this question, we had intended the single correct answer to be Option 2. However, this design was based on incorrectly entered data. We subsequently corrected the data, resulting in the correct answer being "both Option 1 and Option 2"; however, we failed to modify the question to permit respondents to select multiple answers. We therefore accepted either "Option 1" or "Option 2" as correct. Several highly engaged respondents commented on this error in their open-ended feedback at the end of the survey.

YOUR PERCEPTIONS

This final section will ask you to provide your opinions.

Having reviewed some details about the Better Market Street project, how strongly do you personally support or oppose the project?

- ○ 1 - Strongly oppose
- ○ 2
- ○ 3 - Neutral
- ○ 4
- ○ 5 - Strongly support

Assume for a moment that San Francisco decides to proceed with the Better Market Street project, using one of the three options presented in these materials. Which option would you prefer? (Descriptions of the options are repeated below for reference):

OPTION 1: MARKET STREET

This option improves Market Street's curbside lane using striping, sharrows and other enhancements. Bicycles, transit and vehicles share the outside lanes, with transit-only center lanes. The majority of the curb remains in the existing location.

OPTION 2: MARKET STREET

This option proposes a one-way cycletrack on Market Street in each direction from Steuart Street to Grant Street and 5th Street to Octavia Boulevard. Four lanes for transit and vehicles remain with transit-only center lanes. The curb moves to accommodate the cycletrack, reducing the Streetlife Zone area.

OPTION 3: MARKET STREET + MISSION STREET

This option proposes a one-way, buffered cycletrack on Mission Street in each direction. All transit moves from Mission Street to Market Street and two lanes of vehicular traffic remain on Mission Street. Pedestrians benefit from street life improvements on both Market and Mission Streets.

- ○ Option 1
- ○ Option 2
- ○ Option 3
- ○ I'm not sure

Why do you prefer this option? (Or if you answered "I'm not sure," please explain why.)

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Imagine that you are a resident of San Francisco and you use Market Street regularly. How would you rate your support for the following options?

	1 (Strongly oppose)	2	3 (Neutral)	4	5 (Strongly support)
Option 1	○	○	○	○	○
Option 2	○	○	○	○	○
Option 3	○	○	○	○	○

To what extent do you agree with the following statements?

	1 (Strongly disagree)	2 (Disagree)	3 (Neutral)	4 (Support)	5 (Strongly support)
I like cities	○	○	○	○	○
I enjoy walking on city streets	○	○	○	○	○
I enjoy driving on city streets	○	○	○	○	○
I think city streets should focus on allowing cars to travel quickly	○	○	○	○	○
I think city streets should focus on allowing pedestrians to feel safe	○	○	○	○	○
I think city streets should be safer for bicyclists	○	○	○	○	○

Please provide any final comments or suggestions below.

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This concludes the survey and the HIT. Thank you for participating.

Your validation code is: [MTurk validation code]

Be sure to copy down this code now! Once you click "Finish and exit survey" below, your response will be entered and you will not be able to retrieve this code again. Check the box below to confirm you have recorded this code. To receive payment for participating, click "Accept HIT" in the Mechanical Turk window, enter this validation code, then click "Submit".

☐ I have recorded my validation code and am ready to complete the survey.