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TNCs & Congestion

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SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY

TNCs & Congestion

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Executive Summary

Congestion in San Francisco worsened between 2010 and 2016. The Transportation Authority's Congestion Management Program monitoring indicates that average AM peak arterial travel speeds decreased since 2009 by -26%, while PM peak arterial speeds have decreased by -27% during this same time period. Vehicle hours of delay on the major roadways increased by 40,000 hours on a typical weekday, while vehicle miles travelled on major roadways increased by over 630,000 miles on a typical weekday.

During this period significant changes occurred in San Francisco. Roadway and transit networks changed, including the implementation of transit red carpet lanes, the expansion of the bicycle network, and the opening of the Presidio Parkway (rebuilt Doyle Drive). San Francisco added 70,000 new residents and over 150,000 new jobs, and these new residents and workers added more trips to the City's transportation network. Finally, new mobility alternatives emerged, most visibly TNCs.

In recent years, the vehicles of transportation network companies (TNCs) such as Uber and Lyft have become ubiquitous in San Francisco and many other major cities. Worldwide, the total number of rides on Uber and Lyft grew from an estimated 190 million in 2014 to over 2 billion by mid-2016 (1). In San Francisco, this agency (the San Francisco County Transportation Authority or SFCTA) estimated approximately 62 million TNC trips in late 2016, comprising about 15% of all intra-San Francisco vehicle trips and 9% of all intra-San Francisco person trips that fall (2).

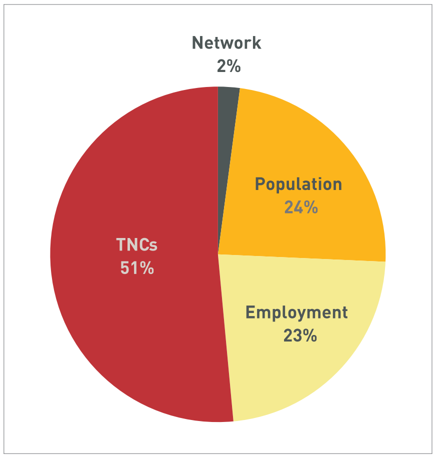
The rapid growth of TNCs is attributable to the numerous advantages and conveniences that TNCs provide over other modes of transportation, including point-to-point service, ease of reserving rides, shorter wait times, lower fares (relative to taxis), ease of payment, and real-time communication with drivers. The availability of this new travel alternative provides improved mobility for some San Francisco residents, workers and visitors, who make over one million TNC trips in San Francisco every week, though these TNC trips may conflict with other City goals and policies.

The purpose of this report is to identify the extent to which TNCs contributed to increased roadway congestion in San Francisco between 2010 and 2016, relative to other potential contributing factors including employment growth, population growth, and changes to the transportation system. This information is needed to help the Transportation Authority fulfill our role as the county Congestion Management Agency and inform our policy and planning work. As the Congestion Management Agency for San Francisco, the Transportation Authority is required by state law to monitor congestion and adopt plans for mitigating traffic congestion that falls below certain thresholds. The report is also intended to inform the Transportation Authority board which is comprised of the members of the San Francisco Board of Supervisors, as well as other state and local policy-makers, and the general public, on the relationship between TNCs and congestion in San Francisco.

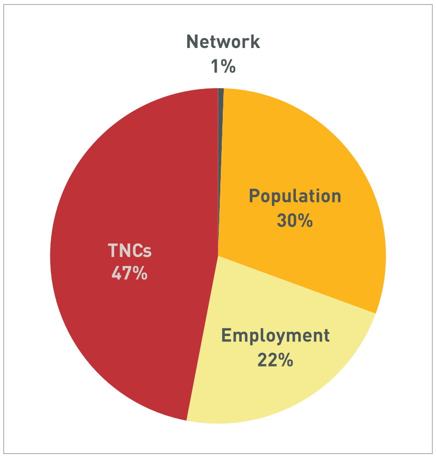
This document:

- Identifies common measures of roadway congestion;
- Discusses factors that contribute to roadway to congestion; and
- Quantifies the relative contributions of different factors, including population, employment, road network changes and TNCs, to observed changes in congestion in San Francisco between 2010 and 2016, by location and time of day.

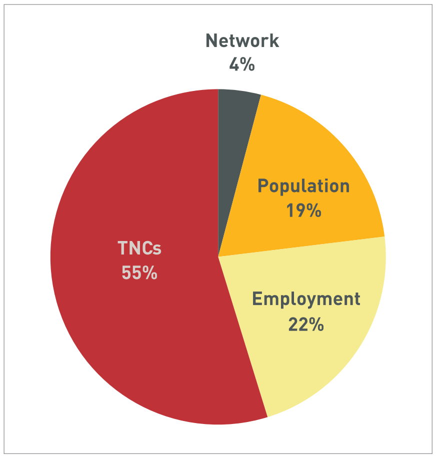
The report utilizes a unique TNC trip dataset provided to the Transportation Authority by researchers from Northeastern University in late 2016, as well as INRIX data, a commercial dataset which combines several real-time GPS monitoring sources with data from highway performance monitoring systems. These data are augmented with information on network changes, population changes, and employment changes provided by local and regional planning agencies, which are used as input to the Transportation Authority's activity-based regional travel demand model SF-CHAMP.



SHARE OF CHANGE IN DELAY BY FACTOR



SHARE OF CHANGE IN VMT BY FACTOR



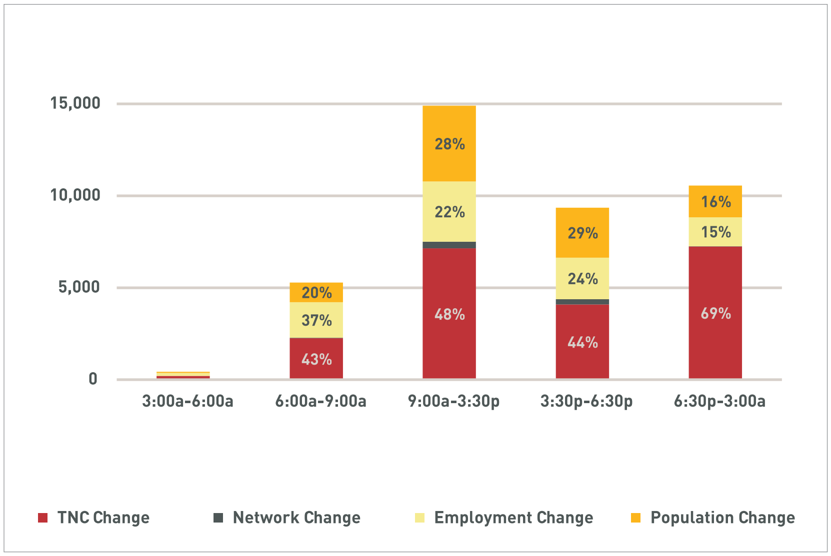
SHARE OF CHANGE IN SPEED BY FACTOR

DO TNCs AFFECT CONGESTION?

Yes. When compared to employment and population growth and network capacity shifts (such as for a bus or bicycle lane), TNCs accounted for approximately 50% of the change in congestion in San Francisco between 2010 and 2016, as indicated by three congestion measures: vehicle hours of delay, vehicle miles travelled, and average speeds. Employment and population growth—encompassing citywide non-TNC driving activity by residents, local and regional workers, and visitors—are primarily responsible for the remainder of the change in congestion.

- Daily vehicle hours of delay (VHD) on the roadways studied increased by about 40,000 hours during the study period. We estimate TNCs account for 51% of this increase in delay, and for about 25% of the total delay on San Francisco roadways and about 36% of total delay in the downtown core in 2016, with employment and population growth accounting for most of the balance of the increased in delay.
- Daily vehicle miles travelled (VMT) on study roadways increased by over 630,000 miles. We estimate TNCs account for 47% of this increase in VMT, and for about 5% of total VMT on study roadways in 2016.
- Average speeds on study roadways declined by about 3.1 miles per hour. We estimate TNCs account for 55% of this decline.

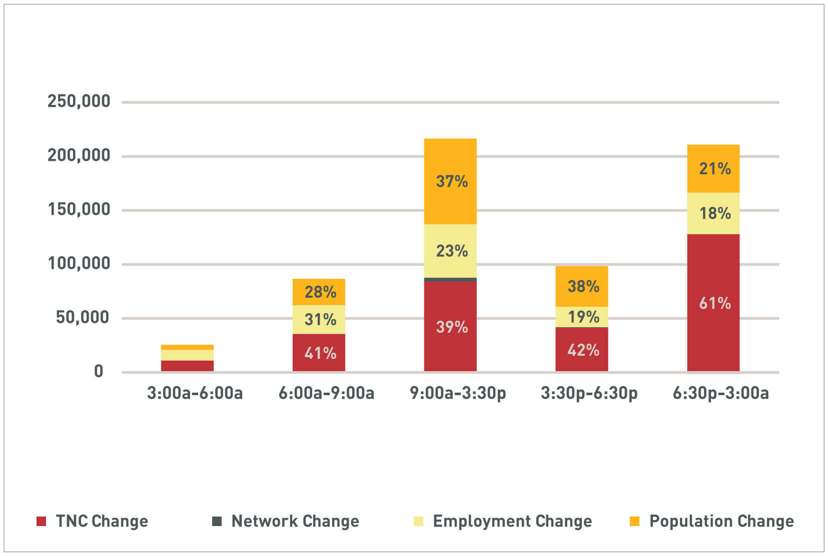
FIGURE 1. CHANGE IN VEHICLE HOURS OF DELAY BY TIME PERIOD BY FACTOR



WHEN DO TNCS AFFECT CONGESTION?

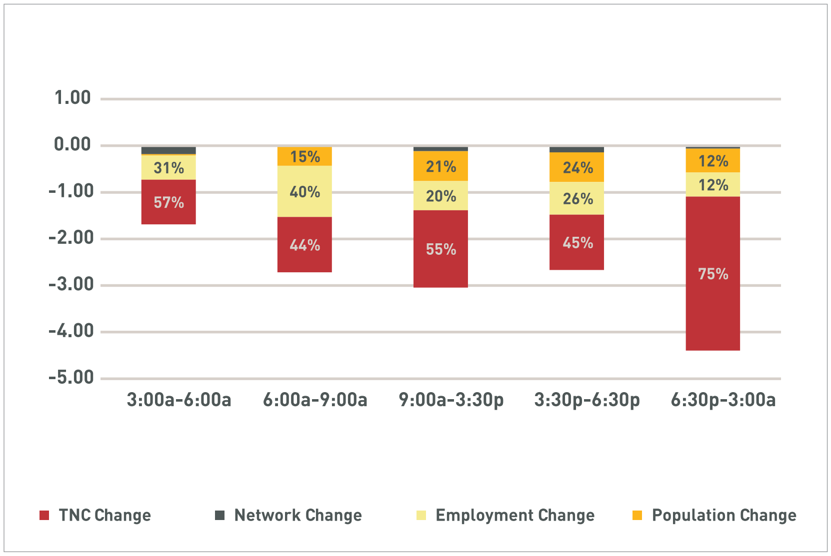
During the AM peak, midday, and PM peak periods, TNCs cause between 43% and 48% of the increased delay and account for about 20% of total delay during these time periods. Employment growth and population growth combined account for just over half of the increased delay. In the evening time period, TNCs are responsible for 69% of the increased delay, and for about 40% of the total delay.

FIGURE 2. CHANGE IN VEHICLE MILES TRAVELED BY TIME PERIOD BY FACTOR



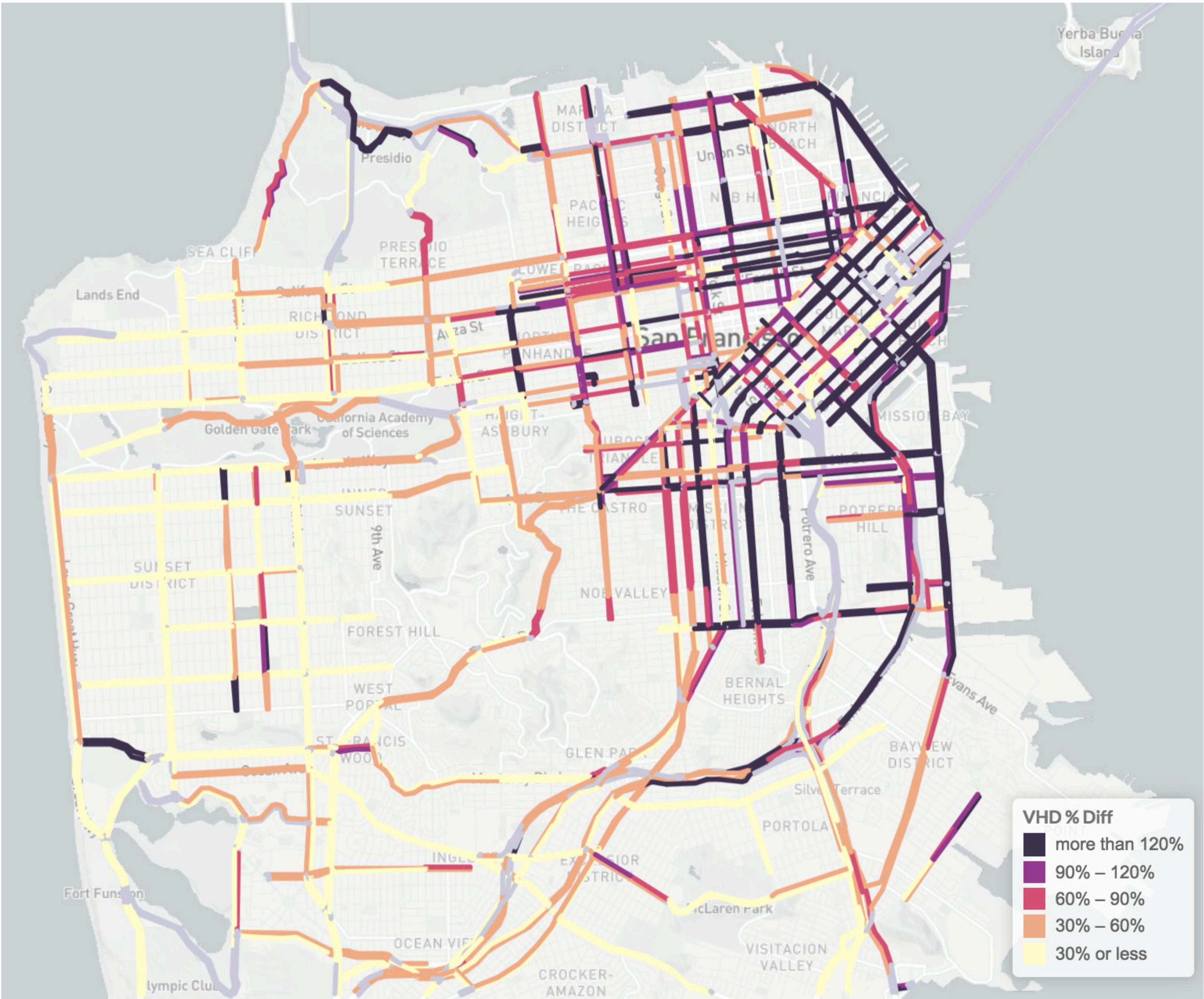
Similarly, during the AM peak, midday, and PM peak periods, TNCs cause about 40% of the increased vehicle miles travelled, while employment and population growth combined are responsible for about 60% of the increased VMT. However, in the evening time period, TNCs are responsible for over 61% of the increased VMT and for about 9% of total VMT.

FIGURE 3. CHANGE IN SPEED (MILES PER HOUR) BY TIME PERIOD BY FACTOR



TNCs are responsible for about 45%-55% of the decline in average speed during most times of day, and are responsible for 75% of the declines in speed during the evening time period.

FIGURE 4. % CHANGE IN VEHICLE HOURS OF DELAY



WHERE DO TNCS AFFECT CONGESTION?

TNCs increase congestion throughout the city, but their effects are concentrated in the densest parts of the city, and along many of the city's busiest corridors, as shown in **Figure 4**. In Supervisorial District 6, TNCs add almost 6,000 daily hours of delay, accounting for about 45% of the increased delay, and 30% of total weekday delay. In District 3, TNCs add almost 5,000 daily hours of delay, accounting for almost 75% of the increased delay and about 50% of total delay. TNCs are responsible for approximately 40%-60% of increases in VMT in many areas of the city. District 6 and District 10 have experienced the greatest increases in VMT between 2010 and 2016, and TNCs account for 41% and 32% of the increases in these districts, respectively.

FIGURE 5. CHANGE IN VEHICLE HOURS OF DELAY BY SUPERVISOR DISTRICT BY FACTOR

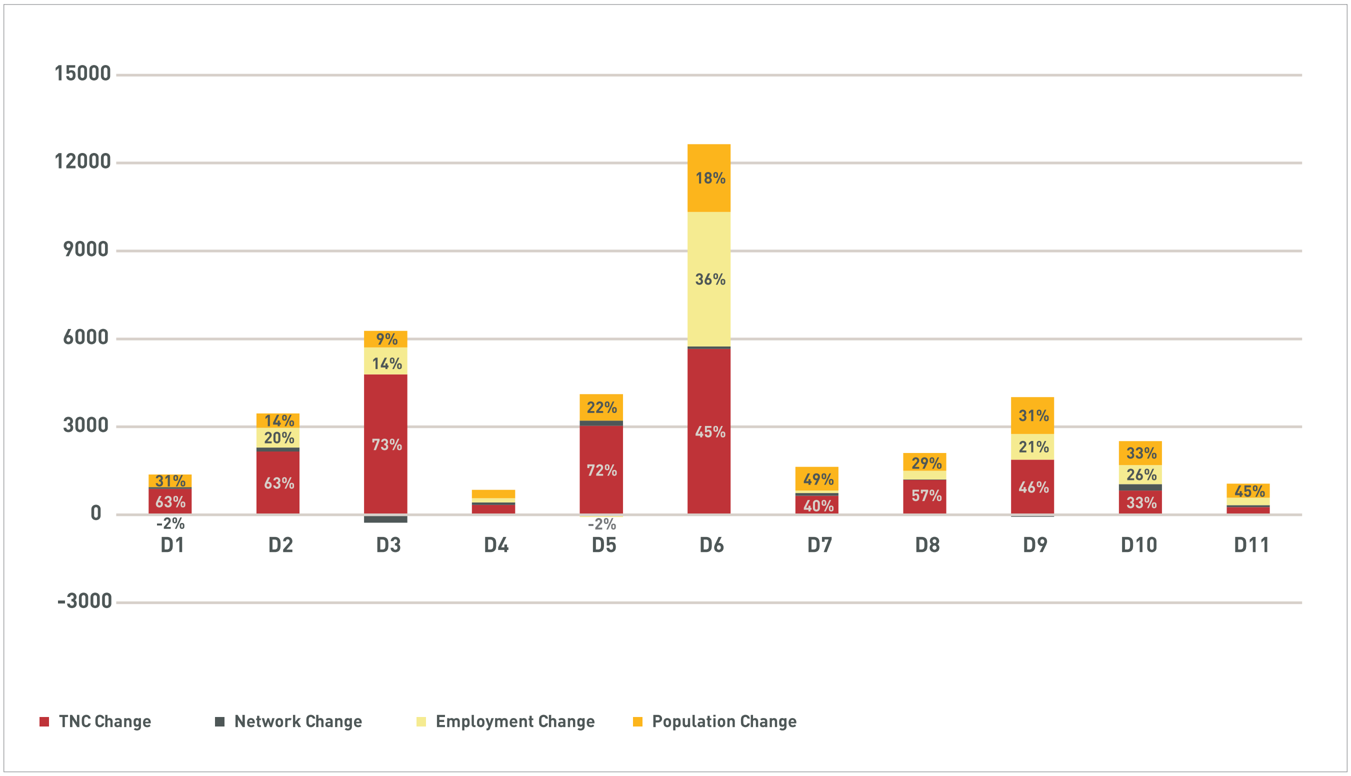
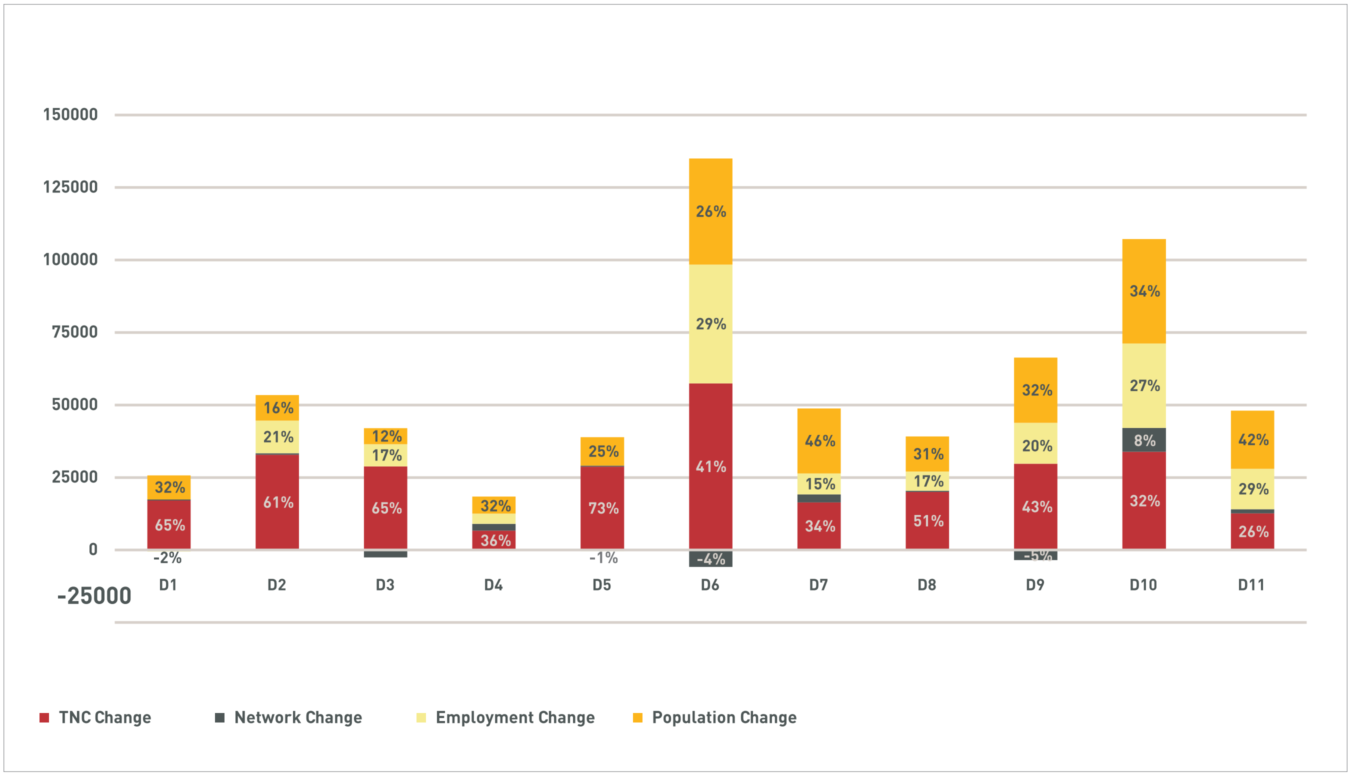


FIGURE 6. CHANGE IN VEHICLE MILES TRAVELED BY SUPERVISOR DISTRICT BY FACTOR



Introduction

In recent years, the vehicles of transportation network companies (TNCs) such as Uber and Lyft have become ubiquitous in San Francisco and many other cities. TNCs are charter party carriers as defined by the California Public Utilities Commission that provide transportation services, facilitated by smartphone apps that allow people to request and pay for rides sourced from a pool of available drivers. It is estimated that the worldwide total number of rides on Uber and Lyft grew from 190 million in 2014 to over 2 billion by mid-2016 (1). In San Francisco, TNC trips were estimated to comprise about 15% of all intra-San Francisco vehicle trips and 9% of all intra-San Francisco person trips in 2016, as documented in the San Francisco County Transportation Authority's 2017 report "TNCs Today."(2)

The rapid growth of TNCs is attributable to the numerous advantages and conveniences that TNCs provide over other modes of transportation, including point-to-point services, ease of reserving rides, shorter wait times, lower fares, ease of payment, and real-time communication with drivers. Some of these advantages are the product of the technical innovations such as directly connecting travelers and drivers, and using the location-enabled features of smartphones. Other advantages derive from the relatively light regulatory requirements under which TNCs operate compared to taxis and other for-hire vehicles. Unlike the taxi fleet, which is capped by the number of taxi medallions, there is no limit to the number of TNCs that can operate in the city, and TNCs are not subject to price controls, geographic service area requirements, disabled access obligations, vehicle emissions requirements, or other taxi requirements. The availability of this new travel alternative provides improved mobility for some San Francisco residents, workers and visitors, who make over one million TNC trips in San Francisco every week. These TNC trips may also contribute to increased congestion.

In last year's "TNCs Today" report, the Transportation Authority provided information about the number, timing, and location of intra-San Francisco TNC trips. The report also included estimates of the number of TNC drivers and vehicles on the road and reported important measures such as the number of vehicle miles travelled (VMT) generated by TNCs. However, the TNCs Today report did not address the implications of these trips on transportation network performance, such as roadway congestion. If all TNC trips simply replace private vehicle trips, then TNC trips may have a limited impact on roadway congestion. But if TNC trips replace walk, bike, and transit trips, or if they induce entirely new vehicle trips, TNC trips may have a more significant effect on congestion. In addition, the timing and location of TNC trips is important. TNC trips that occur during peak periods in the densest parts of the city likely have a greater effect on congestion than TNC trips that occur during off peak periods in less dense areas.

Purpose

The purpose of this report is to identify how TNCs have affected roadway congestion in San Francisco between 2010 and 2016. This information is needed to help the San Francisco County Transportation Authority fulfill its role as the Congestion Management Agency for San Francisco County. As the Congestion Management Agency, the Transportation Authority is required by state law to monitor congestion and adopt plans for mitigating traffic congestion that falls below certain thresholds. The report is also intended to inform the Transportation Authority board which is comprised of the members of the San Francisco Board of Supervisors, as well as other state and local policy-makers, the general public, and TNCs themselves on the relationship between TNCs and congestion in San Francisco.

This document:

- **Identifies common measures of roadway congestion;**
- **Discusses factors that contribute roadway congestion; and**
- **Quantifies the relative contributions of different factors, including population, employment, road network changes, and TNCs, to observed changes in congestion in San Francisco between 2010 and 2016, by location and time of day.**

This report shows how congestion has changed in San Francisco between 2010 and 2016 using well-established metrics such as vehicle hours of delay (VHD), vehicle miles travelled (VMT), and average speeds. It also estimates how much different factors, including TNCs, employment growth, population growth, and changes to the transportation system such as the addition of bike lanes and transit red carpet lanes, contribute to these changes in congestion.

The data used to develop this report comes from several sources. Changes in measures of congestion are based on INRIX data, a commercial dataset which combines several real-time GPS monitoring sources with data from highway performance monitoring systems. TNC information is based on the profile of local TNC usage in San Francisco documented in the TNCs Today report. The original TNC data was gathered by researchers at Northeastern University from the Application Programming Interfaces (APIs) of Uber and Lyft, and subsequently processed into imputed in-service and out-of-service trips by Transportation Authority staff. Changes in population, employment and network configurations are based on detailed information developed by the San Francisco Planning Department, Metropolitan Transportation Commission, and the San Francisco Municipal Transportation Agency (SFMTA).

Panel regression models, which are statistical models used to evaluate changes over time, were used to estimate the relationship between TNCs and congestion. Travel demand models, which simulate travel based on observed behavior, provide the ability to control for changes in population, employment, network capacities and other factors independently, and network supply models which estimate changes in speeds based on network capacities and demand, were used to control for changes in population, employment, network capacities and other factors independently. Panel regression models, travel demand models, and network supply models are well established in practice.

The report builds upon the TNCs Today report by answering the question of whether TNCs contribute to congestion in San Francisco, and by how much relative to other factors. However, it does not address other key questions, such as the effects of TNCs on safety, transit ridership, or other potential longer-term effects such as changes in vehicle ownership or residential and employment location. Subsequent reports by the Transportation Authority and the SFMTA will seek to address these important analytic and policy questions in depth and will be complemented through the larger Emerging Mobility Services and Technology (EMST) policy framework. The development of the countywide plan (the San Francisco Transportation Plan) within the ConnectSF long-range planning program, being undertaken by the Transportation Authority in coordination with other City agencies, will also make use of this report's findings. This report is research-oriented and does not include policy recommendations, but rather seeks to provide knowledge needed by the Transportation Authority board, other policy-makers, and the general public to make informed decisions.

How Do We Measure Congestion?

Congestion means different things to different people. Some people may perceive congestion based on travel speeds, while others may consider travel time delays or vehicle miles traveled as a more meaningful indicators of congestion. This report uses three common measures of roadway congestion:

VEHICLE HOURS OF DELAY

Vehicle Hours of Delay (VHD) is a measure of the overall amount of excess time vehicles spend in congestion. It is the difference between congested travel time and freeflow travel time on a given link, weighted by the number of vehicle trips on that link. For example, if during a given time period the congested travel time on a link is 1 minute greater than the freeflow time on that link, and 60 vehicles traverse that link during this time period, it will result in one hour of VHD (1 minute of delay per vehicle * 60 vehicles = 60 minutes of delay).

VEHICLE MILES TRAVELLED

Vehicle Miles Traveled (VMT) is a measure of the overall amount of motor vehicle travel, as measured in distance, that occurs on the network. It is the length of network links, weighted by the number of vehicle trips on these links. VMT is a key metric used in San Francisco, the Bay Area region (via Plan Bay Area) and the state, to evaluate transportation system performance. San Francisco additionally utilizes VMT to evaluate environmental impacts of land development projects.

SPEED

Speed is simply the average speed of vehicles on a given link during a given time period.

What Factors Affect Congestion San Francisco?

POPULATION AND EMPLOYMENT

Population and employment changes can directly affect roadway congestion. Increases in population will lead to increases in trip-making as people seek to participate in activities such as working, shopping, and going to school. Depending on travelers' choices of travel modes (such as walking, biking, taking transit, or driving), roadway motor vehicle congestion may be affected. Between 2010 and 2016, the population of San Francisco increased 8.8% from approximately 805,000 people to 876,000 (3). While about half of San Francisco trips are by walking, transit, and biking, a significant share of trips involve private vehicles, likely leading to increased congestion. Similarly, increases in employment lead to total travel as more people go to work. Between 2010 and 2016, employment in San Francisco increased significantly (28.4%) from approximately 545,000 jobs to over 700,000 jobs (4). According to the Census, approximately 48% of commute trips to, from or within San Francisco were by automobile.

NETWORK CAPACITY

Changes to network capacities affect roadway congestion. Increases in roadway capacity may alleviate motor vehicle congestion, at least in the short term, while decreases in roadway capacity may increase congestion. The analyses in this paper capture capacity changes between 2010 and 2016 and therefore encompass network capacity changes such as the rebuilding of Doyle Drive and medium-term changes such as the reallocation of right-of-way to transit red carpet lanes and bicycle lanes. To a more limited extent, the analyses could reflect short-term changes in capacity, for example the effect on congestion of construction-related, permitted lane closures that may temporarily reduce capacity for a number of days or hours. However, there is no data on unpermitted short-term capacity reductions associated with construction, delivery or other activities, and thus they are not considered in this analysis. In addition to roadway network changes, changes to transit network capacities may influence roadway congestion by inducing people to shift modes or take new trips, and are included in this analysis.

TNCS

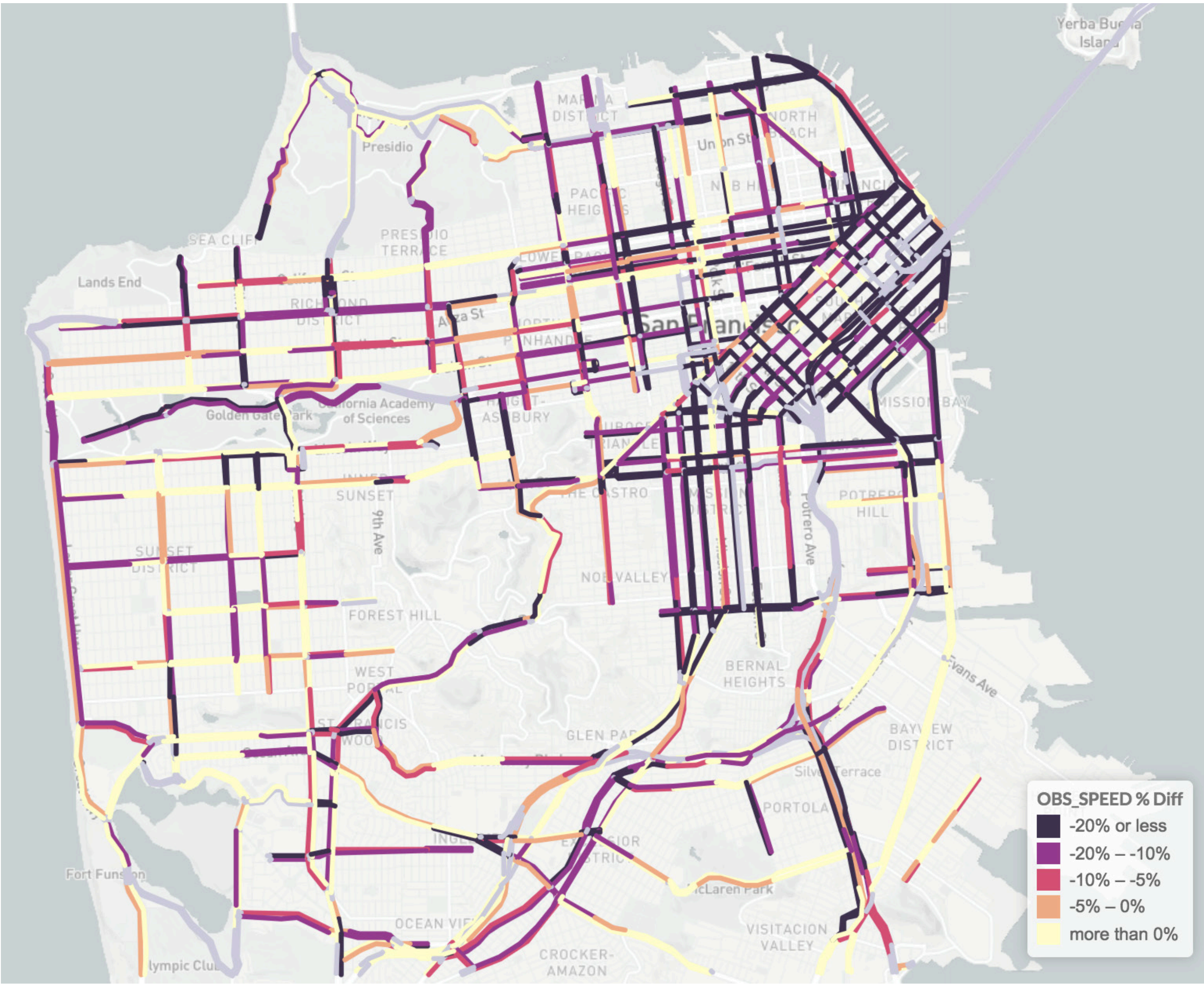
As the TNCs Today report documents, TNCs comprise a significant share of intra-San Francisco travel. TNCs may decrease congestion by inducing mode shifts to more sustainable modes by providing first- and last-mile connections to transit services, or by reducing auto ownership levels and thus incentivizing people to make more transit, bike and walk trips. In addition, higher TNC

vehicle passenger occupancies resulting from "ridesplitting" where TNCs are shared concurrently could, in theory, reduce the number of vehicles trips if they are replacing a trip that would otherwise be in a vehicle with fewer occupants. Conversely, TNCs may increase congestion if their convenience causes a walk, transit, or bike trip to shift to a TNC vehicle trip. According to recent studies, between 43% and 61% of TNC trips substitute for transit, walk, or bike travel or would not have been made at all (5,6,7,8). TNC passenger pick up and drop off activity may also result in increased congestion by disturbing the flow in curb lanes or traffic lanes. Finally, out-of-service miles (or "deadhead" miles) resulting from TNCs repositioning themselves to more optimal locations for getting new passengers, or from driving to pick up passengers who have reserved rides (whether single passenger or shared), also increases the amount of vehicular traffic and congestion.

OTHER FACTORS

Given the rapid pace of technological change in the transportation sector, other factors may also be contributing to changes in congestion. For example, increased use of online shopping and delivery services might exacerbate roadway congestion due to an increase in delivery vehicle trips and loading durations. Conversely, if these deliveries are in place of multiple vehicle trips that would have been made by individuals, they may reduce roadway congestion. New emerging mobility alternatives such as dockless shared bikes and scooters may reduce congestion if they induce mode shifts away from vehicle trips, though if these trips are shifted from transit, walk, or bike their effect on congestion would likely be minimal.

FIGURE 7. PERCENT CHANGE IN OBSERVED PM PEAK SPEEDS (2010-2016)

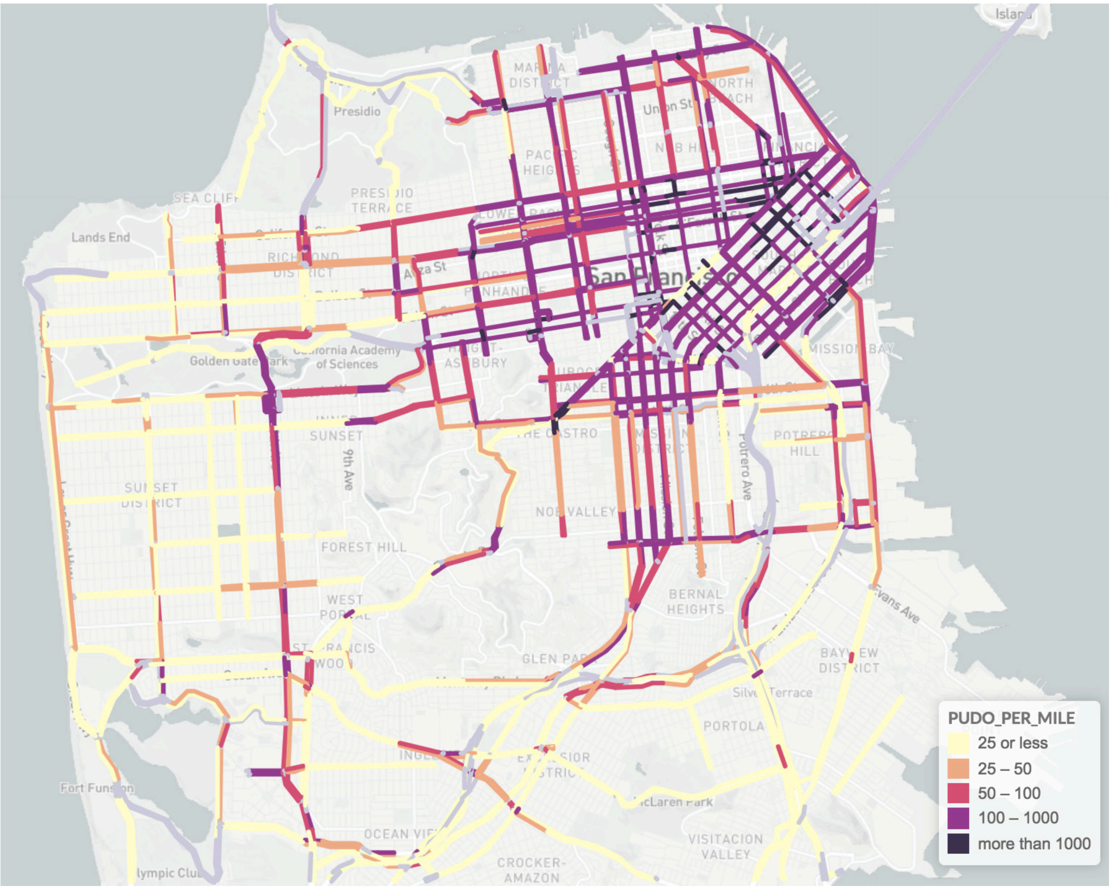


What Data is Available to Understand Congestion?

CONGESTION

Measures of roadway congestion (VHD, VMT, Speed) were calculated from observed roadway conditions in both November-December 2010 (before) and November-December 2016 (after), consistent with the TNC data, which was collected in November-December 2016. The observed roadway conditions are derived using the GPS- and fleet-based speed data licensed from INRIX. The analysis was conducted using directional segments known as Traffic Messaging Channels (TMCs), which average about 0.3 miles long. For each analysis year, data was aggregated to these TMCs and averaged across days to represent average weekday conditions for five times-of-day (TODs). **Figure 7** illustrates the percent change in observed PM peak speeds for all TMCs.

FIGURE 8. PICKUPS AND DROPOFFS PER MILE



BACKGROUND GROWTH

Background growth data was derived from San Francisco's travel demand model, SF-CHAMP. SF-CHAMP produces estimates of traffic volumes on all roads in San Francisco and requires inputs describing factors such as population, employment, and multi-modal transportation network capacity and performance. For this analysis, each one of these factors was individually controlled for in SF-CHAMP, which provides the ability to understand the relative contributions of these factors to overall changes in congestion. The version of SF-CHAMP used in this study was calibrated to 2010 conditions and does not account for TNCs. This means that when the model is run for 2016 inputs, it provides a "counterfactual" estimate of congestion if TNCs did not exist.

TNCS

TNC information was based on data originally gathered by researchers at Northeastern University from the Application Programming Interfaces (APIs) of Uber and Lyft that show the locations of available vehicles to mobile apps, and then was shared with the Transportation Authority. The data was collected from mid-November to mid-December of 2016, excluding dates around the Thanksgiving 2016 holiday. Transportation Authority staff then processed the data to impute estimates of out-of-service TNC volumes, in-service volumes, and pickups and dropoffs by directional link and time-of-day. This information was the basis for the TNCs Today, which is the only detailed profile of local TNC usage in San Francisco. **Figure 8** shows the average number of pickups and dropoffs per mile on TMC segments. Detailed descriptions of the data preparation process can be found here (2) and here (20). Note that, due to the data collection methodology, estimates of TNC volumes and pickups and dropoff reflect only intra-SF TNC trips, and are thus an underestimate of total TNC activity.

OTHER FACTORS AND LIMITATIONS

It was not possible to incorporate all the potential factors contributing to changes in congestion into this analysis, primarily because there is little available data describing these factors. For example, there is no source for comprehensive citywide information on how freight and commercial delivery and loading volumes and durations have changed between 2010 and 2016. The SF-CHAMP model data does incorporate some information on background growth in freight and commercial vehicle volumes through its commercial vehicle model. While the SF-CHAMP model is insensitive to increased levels of home shopping such as Amazon, as well as use of more recent emerging delivery services, in the most congested parts of San Francisco, commercial and freight deliveries typically use commercial vehicle loading zones (both on-street and off-street) in order to minimize the interruption of traffic flow. In fact, recent data from the San Francisco Police Department indicates that TNCs account for over 75% of citations downtown for blocking lanes of traffic (22).

Visitor travel in San Francisco has also increased significantly between 2010 and 2016. However, visitor travel is estimated to represent less than 5% of travel in San Francisco, and recent survey data indicates that TNCs are used less frequently by visitors than Muni and BART, although this is likely changing as TNCs become more ubiquitous. Increases in pedestrian travel might also impede traffic flow due to turning movements or other conflicts, but there is no data available to indicate whether increases in pedestrians in San Francisco have reduced auto speeds. Changing demographics may also contribute to increased TNC usage, as the National Household Travel Survey indicates that people with higher incomes appear to make more TNC trips. Finally, while this research does address changes in network capacity resulting from major transportation and land use projects, due to a lack of data it could not incorporate temporary unpermitted disruptions in traffic resulting, for example, from short-term construction activities.

How Do We Determine the Causes of Changes in Congestion?

In order to identify how TNCs and other factors may have affected roadway congestion in San Francisco between 2010 and 2016, two stages of analysis were performed. The first stage quantifies the contribution of TNCs to changes in congestion in San Francisco between 2010 and 2016 by estimating a statistical fixed-effect panel regression model and then applying this model to identify the relationship between the change in TNC activity and the change in roadway congestion measures between 2010 and 2016, assuming zero TNCs in 2010 and observed TNC levels (from TNCs Today study) in 2016. Observed TNC levels includes in-service TNC volumes, out-of-service TNC volumes, and TNC pick up and drop off activity. Estimates of the combined effect of the growth of non-TNC factors such as population, employment, and network changes are derived from the SF-CHAMP activity-based model system. Because the estimated model relies on the transformation of the observed speed data as the dependent variable in the regression analysis, we refer to this stage as the empirical analysis.

In the second stage, a scenario analysis, the SF-CHAMP activity-based demand model was again used, this time to systematically estimate the individual contributions to changes in roadway congestion of the factors of transportation network supply change, population change, employment change, and TNCs.

A distinguishing feature of both stages of the analysis was that it they were performed at a disaggregate level, using the previously described 1400 INRIX “Traffic Messaging Channels” (TMCs) or directional roadway segments, and across five times of day. The TMCs are approximately 0.3 miles long in San Francisco, on average. The spatial and temporal detail is important because adding vehicles does not always have the same effect on travel speeds: an additional vehicle on an uncongested segment in the early AM has a very different effect on delay than an additional vehicle on a downtown segment during the PM peak.

EMPIRICAL ANALYSIS

This study is structured as a before-and-after assessment between 2010 conditions when TNC activity was negligible and 2016 conditions when it was significant. We derived measures of roadway conditions in both years from GPS-based speed data licensed from INRIX as previously described. We estimated the relationship between the change in TNC activity and the change in roadway travel time, assuming zero TNCs in 2010, and incorporating a 2016 "counterfactual" scenario in which TNCs do not exist.

We do this using a fixed-effects panel data regression model (9). The fixed-effects models estimate coefficients based on the change between 2010 and 2016 conditions. There is precedent for using both before-and-after analysis and panel data models in transportation analysis, including to study changes in congestion (10), TNC growth (11), and the effects of new technology (12).

We converted the observed travel times to implied volumes using volume-delay functions (VDFs). This time-implied volume is the model's dependent variable, and the conversion ensures that it is linearly related to the background volumes and TNC volumes. There is one observation for each directional roadway segment, for each time-of-day, with data in 2010 and in 2016 for each observation. To control for road and transit network changes, as well as changes in socioeconomic conditions, the model includes the background traffic volume as a variable, as estimated by SF-CHAMP version 5.2. Because SF-CHAMP version 5.2 does not account for TNCs, this background traffic reflects the expected traffic volume change with no TNCs. The model also includes measures of TNC activity for each observation, with those measures set to zero in 2010. **Table 1** shows the model estimation results.

The estimated parameter on the SF-CHAMP background volume is approximately 0.92, not significantly different than 1. This is logical, because we expect that each vehicle added in background traffic should have an effect on congestion of adding about 1 vehicle to the implied volume. The Presidio Parkway scaling factor accounts for major construction that was underway on those links in 2010 but not 2016.

We include two measures of time and location-specific TNC activity. The TNC volume parameter measures net effect of TNCs. If TNCs purely substitute for other car trips, the estimated TNC parameter should be 0 as they substitute for other vehicles already counted in the background volumes. Negative values would be consistent with TNCs reducing traffic, while a value of positive 1 would be consistent with TNCs purely adding itself to background traffic. The estimated coefficient of 0.69 can be interpreted as meaning that TNCs do not purely add to traffic through induced travel or shifts from non-vehicular modes.

TABLE 1 FIXED-EFFECTS PANEL ESTIMATION RESULTS

PARAMETER ESTIMATES			
Variable	Parameter	Standard Error	T-statistic
SF-CHAMP background volume	0.9172	0.0541	16.952
Presidio Parkway scaling factor	-0.3648	0.0189	-19.327
TNC Volume	0.6864	0.0720	9.5387
Average impact duration of TNC PUDO on major arterials (s)	144.75	7.7195	18.751
Average impact duration of TNC PUDO on minor arterials (s)	79.486	12.114	6.5617

MODEL STATISTICS	
Number of Entities	7081
Number of Time Periods	2
R-squared between groups	0.5819
R-squared within groups	0.2985

The pick-up and drop-off (PUDO) parameters represent the average number of seconds that a pick-up or drop-off disrupts traffic in the curb lane. Details of the PUDO specification are documented elsewhere (13). Locally collected data show that the average time needed for a passenger to board or alight from passenger vehicles such as TNCs and taxis is about 1 minute. The higher average impact durations estimated in these models suggest that the traffic disruption persists after the stopped vehicle departs because additional time is needed for traffic flow to recover to its pre-PUDO condition.

We applied the estimated model to assess network-wide performance metrics for three scenarios:

- **2010:** reflecting observed 2010 conditions, when no TNCs were present;
- **2016 Counterfactual:** represents a counterfactual scenario of what 2016 conditions would be if there were no TNCs;
- **2016 TNC:** the full application of the model to 2016 conditions

The first and last scenarios are directly comparable to the observed speed data. The 2016 counterfactual scenario is derived by including the 2016 SF-CHAMP background traffic growth and Presidio Parkway scaling factor, but setting the TNC variables to zero.

SCENARIO ANALYSIS

While the empirical analysis allows us to quantify the contribution of TNCs to changes in congestion in San Francisco between 2010 and 2016, it does not provide insights into the relative contributions of other potential causes of change in roadway performance. To decompose these other factors, the SF-CHAMP model was used to perform a series of systematic scenario analyses.

We test each scenario using San Francisco's SF-CHAMP travel demand model. SF-CHAMP is an activity-based travel demand model that simulates the daily movements of individual travelers for a synthetic population in the 9-county San Francisco Bay Area (14,15,16). It has a long history of being successfully used to evaluate a range of policy and planning scenarios (17,18). We use version 5.2.0, which was calibrated to 2010 conditions and does not, on its own, include TNCs as a mode. Observed TNC travel flows and volumes based on the TNCs Today data set are used to account for TNCs. The remaining inputs, including transportation networks, population and employment data are not forecasts, but have been updated to reflect actual 2010 and 2016 conditions.

- **2010:** Conditions in year 2010, assuming the effect of TNCs is negligible. This is just the 2010 base SF-CHAMP model run, which was calibrated to observed 2010 conditions.
- **2016 Network Changes:** A hypothetical scenario that shows what 2016 system performance would look like if changes to the transportation networks (both roadway and transit) were the only things that changed between 2010 and 2016.
- **2016 Network and Population Changes:** A hypothetical scenario that shows what 2016 system conditions would look like if both the transportation network and population changed between 2010 and 2016.
- **2016 Network, Population and Employment Changes:** Also referred to as the "2016 Counterfactual" this is a hypothetical scenario that shows what 2016 would look like if all the observed network, population and employment changes occurred, but if TNCs had not been introduced in San Francisco.
- **2016 TNC:** This scenario incorporates all the assumed growth in population and employment between 2010 and 2016, changes to the roadway and transit networks, and also includes the effect of TNC in-service volumes, TNC out-of-service volumes, and TNC pick up and drop off activity. This scenario also accounts for mode shifts to TNCs from other travel modes.

With these scenarios, it was possible to estimate the incremental effects on congestion of network change, population change, employment change, and the introduction of TNCs in San Francisco. Additional technical details related to these scenarios are documented in other reports (19).

COMBINED ANALYSIS

These two stages of analysis result in network performance metrics for a total of five scenarios, three of which are available in both stages of analysis: 2010 Base, 2016 Counterfactual, and 2016 with TNCs. For the three overlapping scenarios, the relative contribution of TNCs to the change in congestion is similar in direction and magnitude, with the empirical analysis (which directly reflects observed speed changes) showing a somewhat greater share of the increase in congestion attributable to TNCs. **Table 2** shows the relative contribution of TNCs to each of the congestion metrics for the two stages of the analysis.

TABLE 2. CONTRIBUTION OF TNCS TO CHANGE IN CONGESTION BY ANALYSIS STAGE

METRIC	Empirical Analysis	Scenario Analysis
Vehicle Hours of Delay	64%	51%
Vehicle Miles of Travel	44%	47%
Speed	65%	55%

For the results presented here, the shares from the scenario analysis are applied to the total change in congestion from the empirical analysis to obtain a best estimate of the specific contribution of each factor to changes in network performance. This represents a lower-bound estimate of the effects of TNCs on congestion, relative to the estimated effect of TNCs on congestion as estimated in the empirical analysis.

How has Congestion Changed in San Francisco?

Traffic congestion has been getting worse since 2009. The Transportation Authority's Congestion Management Program (CMP) monitoring indicates that average AM peak arterial travel speeds have decreased since 2009 by -26%, while PM peak arterial speeds have decreased by -27% during this same time period. On freeways, average AM peak speeds have decreased by -30%, while average PM peak freeway speeds have decreased by almost -16% (21).

FIGURE 9. SAN FRANCISCO ARTERIAL AND FREEWAY SPEEDS (2009-2017)

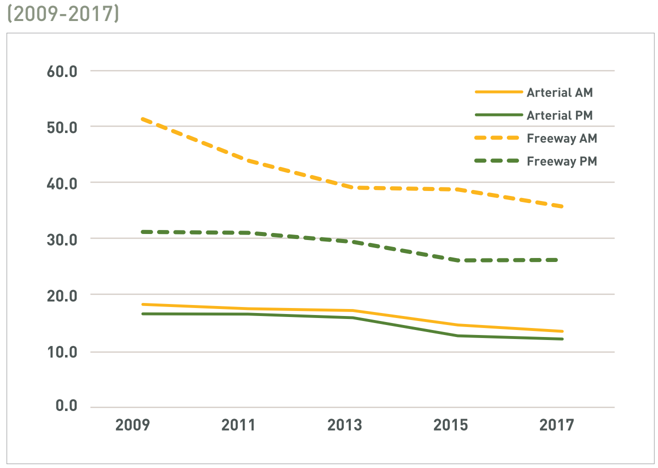


FIGURE 10. 2009 PM PEAK LEVEL OF SERVICE

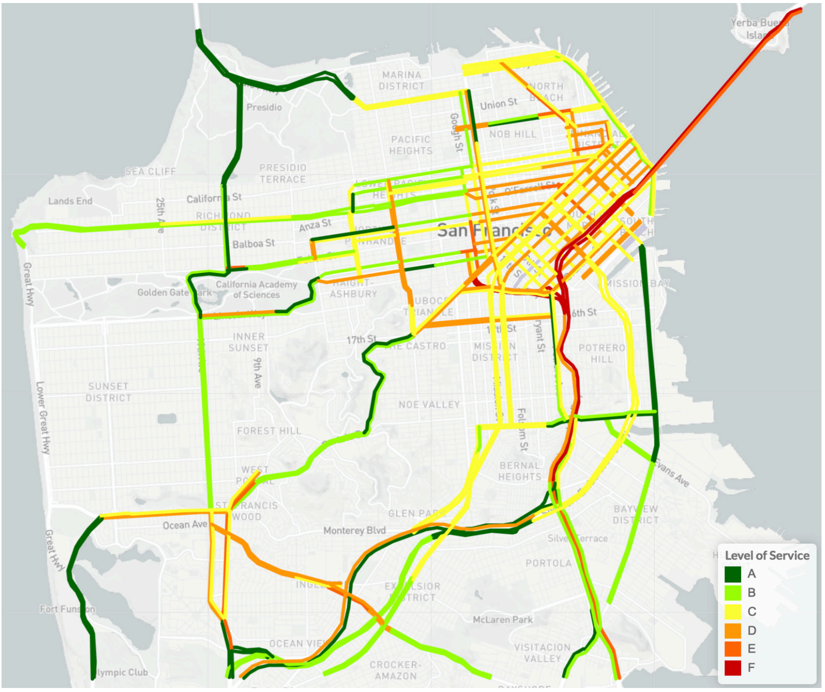
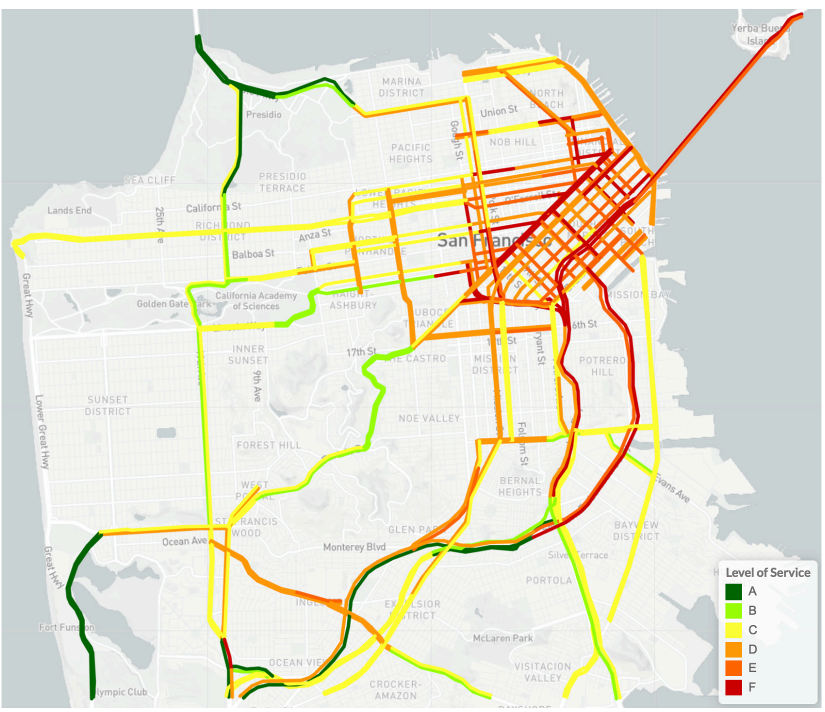


Figure 10 and **11** shows this change visually by mapping the PM peak roadway level-of-service (LOS) in 2009 and 2017, with the data showing lower level-of-service in 2017. LOS is a traffic engineering concept, based on volume to capacity (v/c) relationships of a given roadway facility, used to evaluate the operating conditions on a roadway. LOS describes operating conditions on a scale of A to F, with "A" describing free flow, and "F" describing bumper-to-bumper conditions. This corresponds to the period in which TNCs emerged.

FIGURE 11. 2017 PM PEAK LEVEL OF SERVICE



Do TNCs Affect Congestion?

Given the significant worsening of congestion in San Francisco in recent years, a critical question is whether, and to what degree, TNCs have affected congestion. Using the congestion measures, data, and methods previously described, it appears that TNCs contributed approximately 50% of the overall increases in congestion in San Francisco between 2010 and 2016, although this varies widely by neighborhood and time-of-day. Employment and population growth—an expression of greater economic activity in the city that encompasses the driving activity of all non-TNC travelers/motorists—account for the other half of the increase in congestion.

FIGURE 12. TOTAL DELAY AND CHANGE IN DELAY

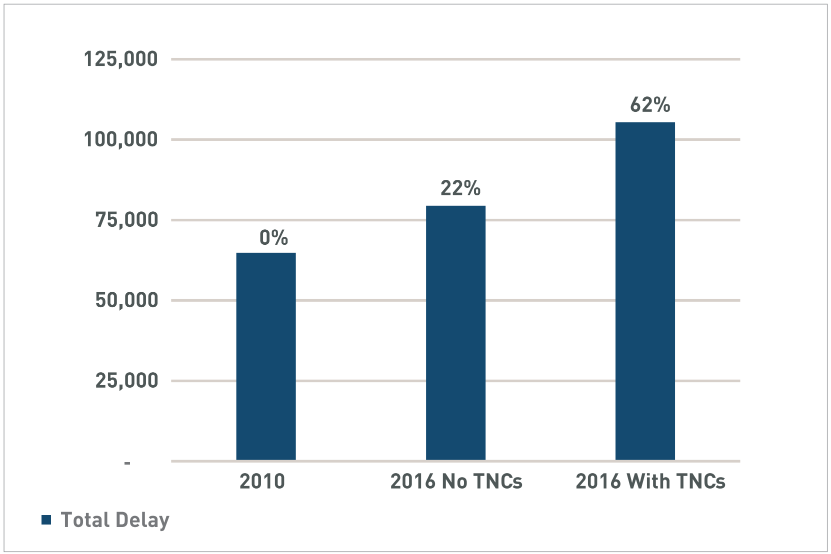
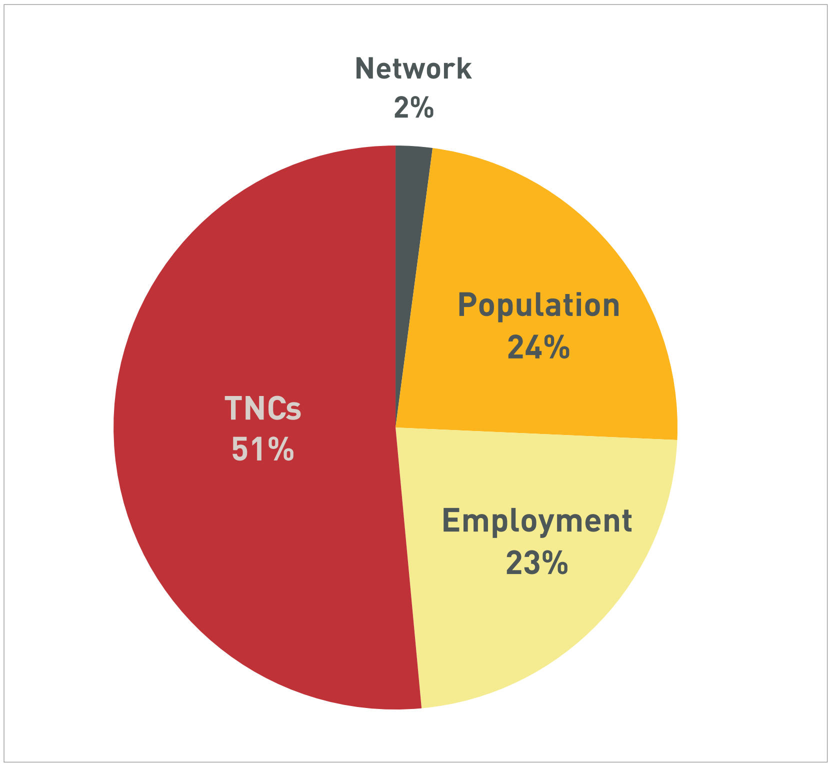


FIGURE 13. SHARE OF CHANGE IN DELAY BY FACTOR



VEHICLE HOURS OF DELAY

Vehicle Hours of Delay (VHD) is the number of extra hours that vehicles are in traffic beyond what they would have experienced under uncongested "free flow" conditions. **Figure 12** indicates that daily vehicle hours of delay increased on study roadways from approximately 65,000 hours in 2010 to over 105,000 hours in 2016 with TNCs, an increase of 62%. In the counterfactual 2016 scenario, where TNCs are unavailable and travelers use other modes, the daily vehicle hours of delay are approximately 79,000, an increase of 22% over 2010. This suggests that TNCs are responsible for about 25% of the total delay on monitored streets (the difference between 105,000 hours and 79,000 hours of delay in 2016).

Figure 13 illustrates how much each of the factors contributes to changes in delay between 2010 and 2016. TNCs account for 51% of the increase in delay. Population change and employment change are responsible for just under 47% of the increase in delay, and network changes account for only about 2% of additional delay.

VEHICLE MILES TRAVELED

The amount of vehicle miles traveled, or VMT, that is generated is a fundamental measure of transportation system performance. Higher levels of VMT are associated with greater levels of emissions of greenhouse gases such as CO2 as well as other pollutants. In addition, higher levels of VMT are also associated with greater roadway congestion. The VMT estimates in this report include both in-service and out-of-service VMT generated by TNCs on San Francisco roadway segments for which INRIX speed monitoring data is available. In-service VMT refers to the vehicle miles traveled when transporting a passenger. Out-of-service VMT refers to the vehicle miles traveled while circulating to pickup a passenger.

FIGURE 14. TOTAL VMT AND CHANGE IN VMT

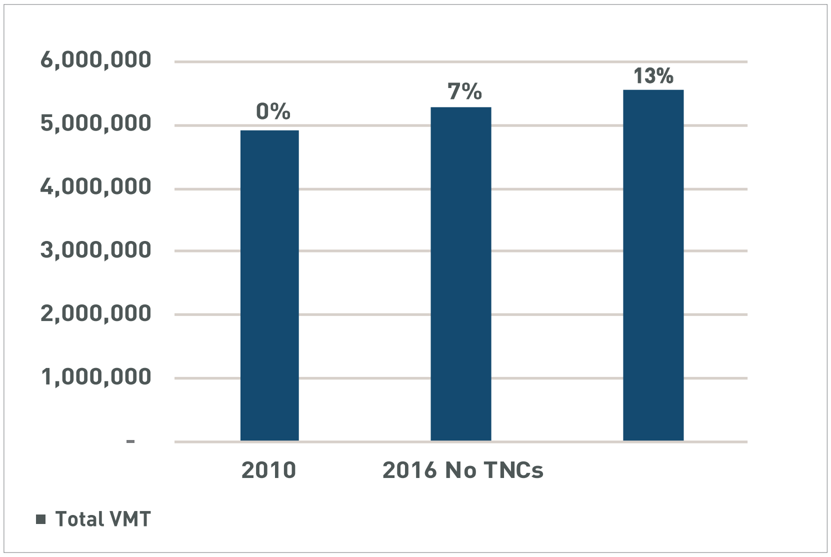


FIGURE 15. SHARE OF CHANGE IN VMT BY FACTOR

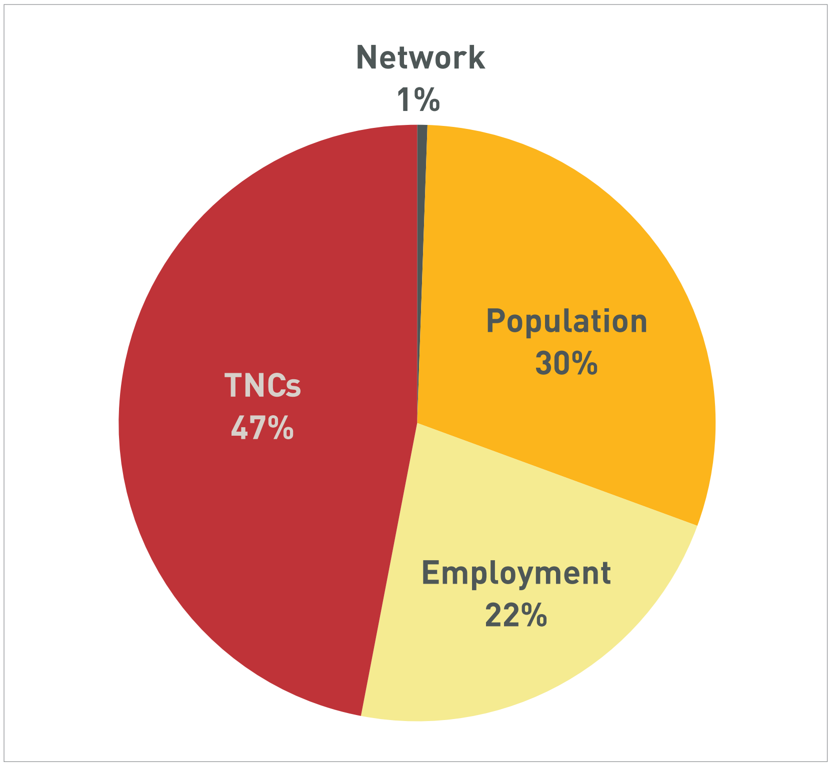
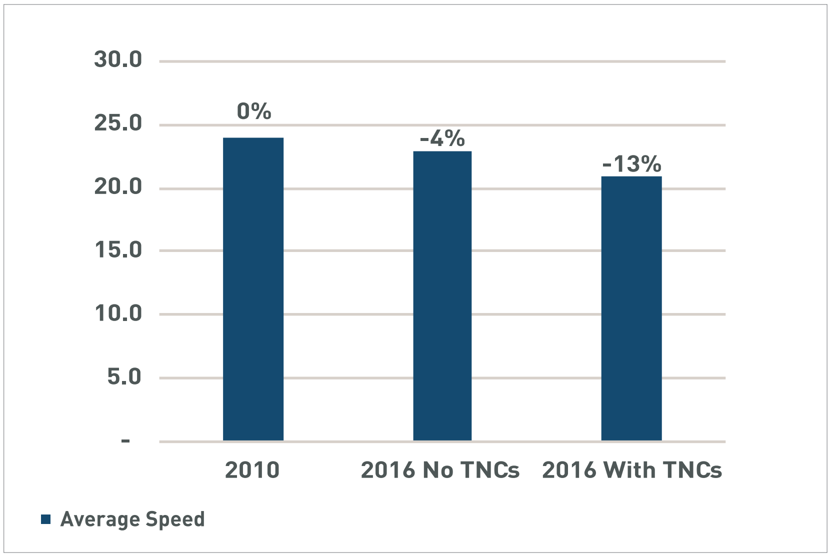


Figure 14 indicates that daily VMT on study roadways increased from approximately 4.9 million miles in 2010 to 5.6 million miles in 2016 on study roadways on a typical weekday, an increase of 13%. In the counterfactual 2016 scenario, where TNCs are unavailable and travelers used other modes, daily VMT increases to 5.3 million miles, an increase of approximately 7%. The relative increases in VMT are lower than the relative increases in hours of delay due to the non-linear relationship between traffic and delay. One additional VMT in congested conditions increases delay more than one additional VMT in uncongested conditions. TNCs also contribute relatively more to delay than to VMT because of the additional delay associated with TNC pick up and drop off activity does not result in additional VMT.

Figure 15 illustrates the sources for the changes in VMT between 2010 and 2016. TNCs are estimated to account for 47% of the increase in VMT, and about 5% of total VMT in 2016. Population change and employment change are responsible for just over 52% of the increase in VMT, and network changes account for about 1% of changes in VMT.

AVERAGE SPEED

FIGURE 16. AVERAGE SPEEDS AND CHANGE IN SPEEDS



The average speed captures a length-weighted estimate of the speeds on all study roadways. **Figure 16** indicates that average speeds decreased from just over 24.0 miles per hour (mph) in 2010 to approximately 20.9 mph in 2016, a decline of 13%. In the counterfactual 2016 scenario, where TNCs are unavailable and travelers used other modes, average speeds decline by only 4%.

FIGURE 17. SHARE OF CHANGE IN SPEED BY FACTOR

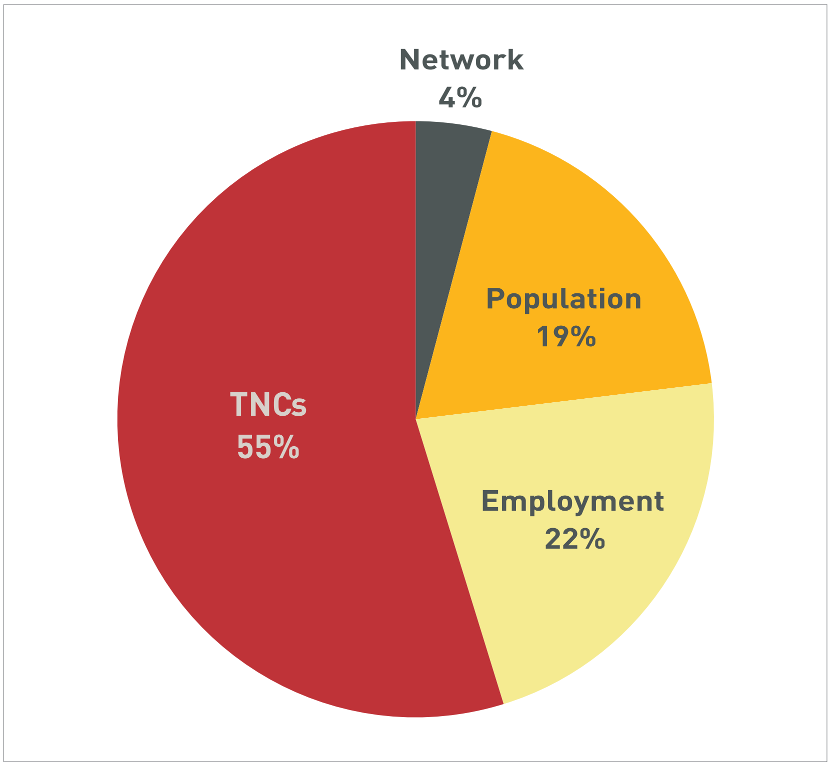


Figure 17 illustrates the sources for the changes in speed between 2010 and 2016. TNCs account for 55% of the decrease in speeds. Population change and employment change are responsible for just over 41% of the decrease in speeds, and network changes decrease speeds by approximately 4%.

When do TNCs Affect Congestion?

TNC usage varies by time-of-day, and thus affects congestion differently at different times of day. An additional vehicle on the roadway during congested time periods results in more congestion than an additional vehicle during uncongested time periods. The following summaries use five times of day derived from the SF-CHAMP model, which vary in length: the AM peak, PM peak, and early AM periods are 3 hours long, while the midday and evening periods are 6.5 and 8.5 hours long, respectively. The figures below demonstrate that TNCs significantly contribute to increased congestion across all times of day, especially in the evening, but during the AM and PM peaks and the midday as well.

VEHICLE HOURS OF DELAY

FIGURE 18. DELAY BY TIME PERIOD

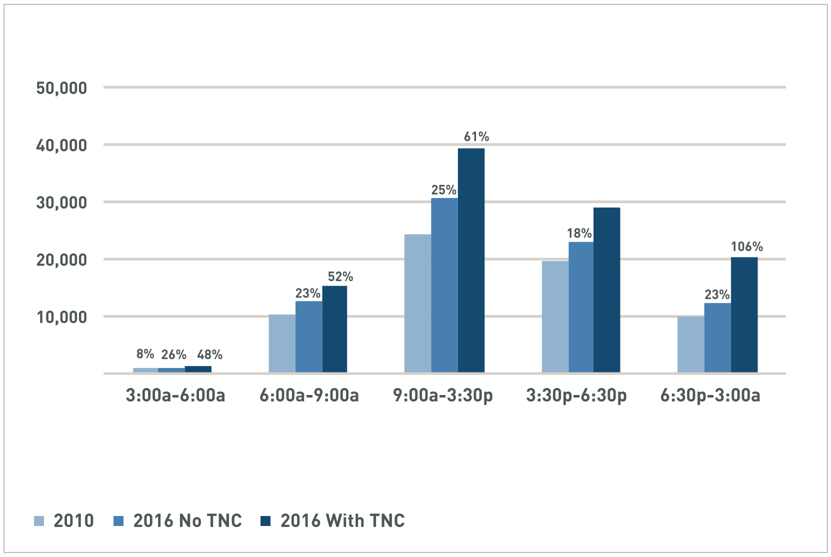


Figure 18 compares the VHD from 2010 to the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. This figure shows that TNCs increased VHD in all time periods relative to 2016 No TNC scenario. The greatest total increases in delay occurred during the midday and evening period. TNCs increase delay in the evening from 23% without TNCs to 106% in reality, and increase the delay in the midday from 25% without TNCs to over 60%, and also increase delay significantly in the PM and AM peak periods.

FIGURE 19. CHANGE IN DELAY BY TIME PERIOD BY FACTOR

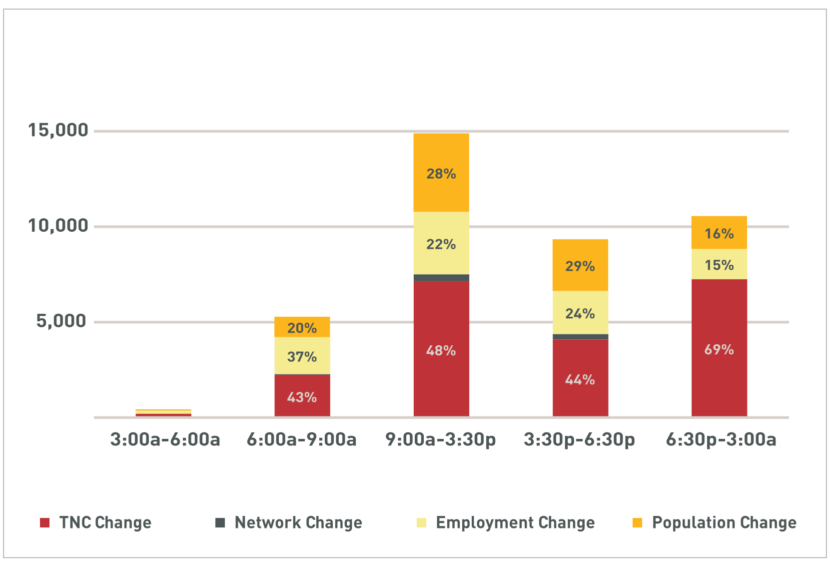


Figure 19 illustrates the total increase in delay between 2010 and 2016, as well as the share of this delay caused by TNCs, network changes, population changes and employment changes. During the AM peak, midday, and PM peak periods, TNCs cause between 43% and 48% of the increased delay and about 20% of total delay. Employment growth and population growth combined account for just over half of the increased delay. In the evening time period, TNCs are responsible for almost 70% of the increased delay, and for about 40% of the total delay.

VEHICLE MILES TRAVELED

FIGURE 20. VMT BY TIME PERIOD

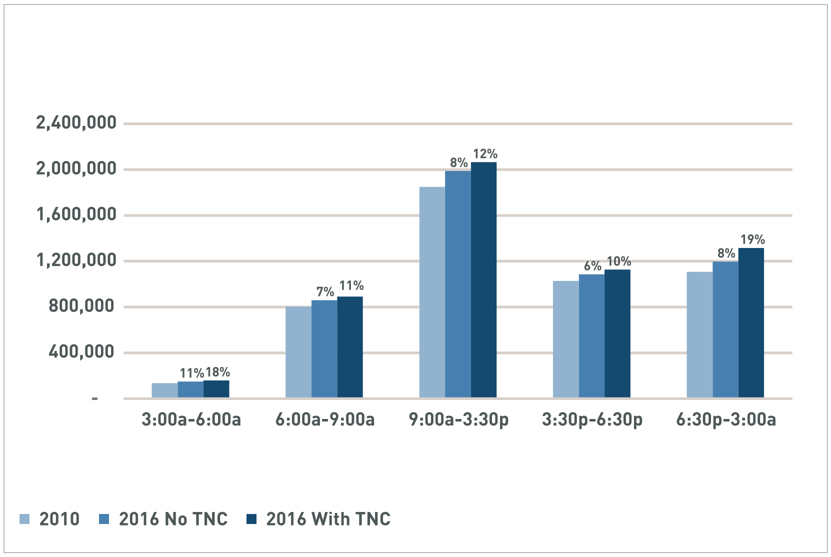


Figure 20 compares the VMT from 2010 to the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. This figure shows that TNCs increased VMT in all time periods relative to 2016 No TNC scenario, with the greatest increases occurring during the midday and evening period.

FIGURE 21. CHANGE IN VMT BY TIME PERIOD BY FACTOR

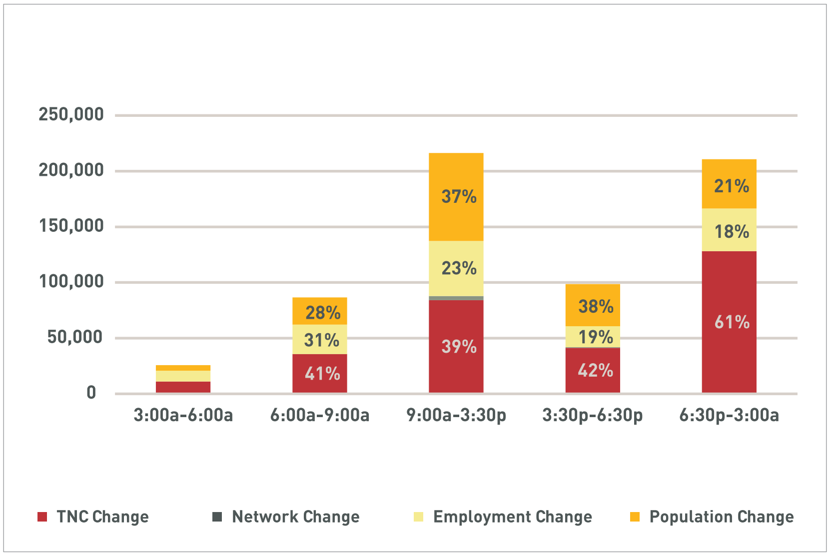


Figure 21 illustrates the total increase in VMT between 2010 and 2016, as well as the share of this delay caused by TNCs, network changes, population changes and employment changes. TNCs contribution to increased VMT varies by time period. During the AM peak, midday, and PM peak periods, TNCs cause about 40% of the increased vehicle miles travelled, while employment and population growth combined are responsible for about 60% of the increased VMT. However, in the evening time period, TNCs are responsible for over 61% of the increased VMT and for about 9% of total VMT.

AVERAGE SPEED

FIGURE 22. SPEED BY TIME PERIOD

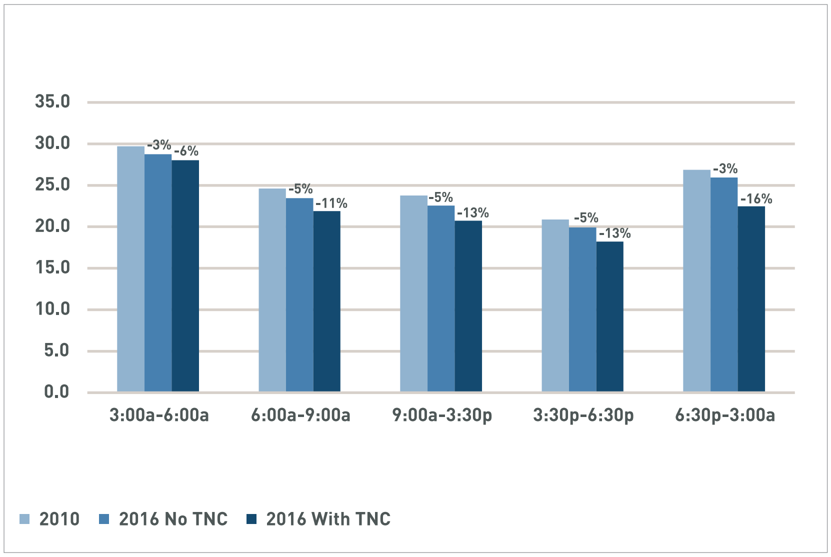


Figure 22 compares speeds from 2010 to the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. This figure shows that average speeds have declined across all time periods, but that this decline has been exacerbated by TNCs.

FIGURE 23. CHANGE IN SPEED BY TIME PERIOD BY FACTOR

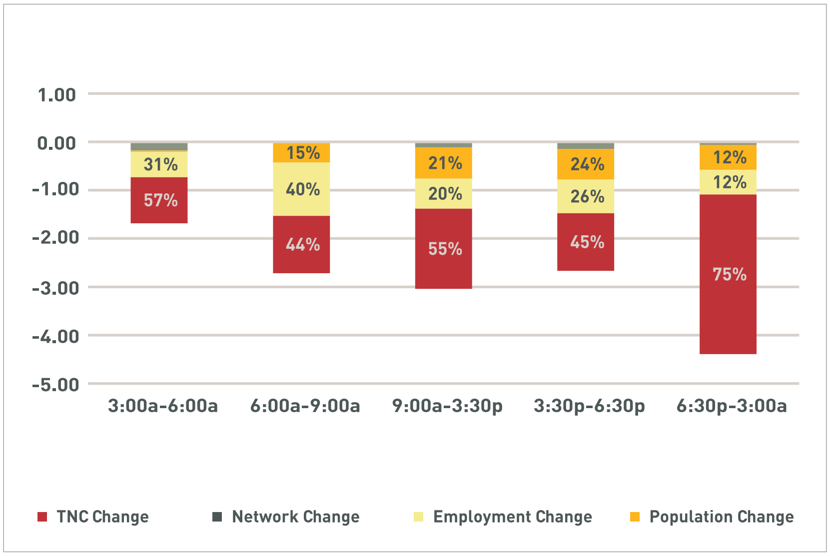
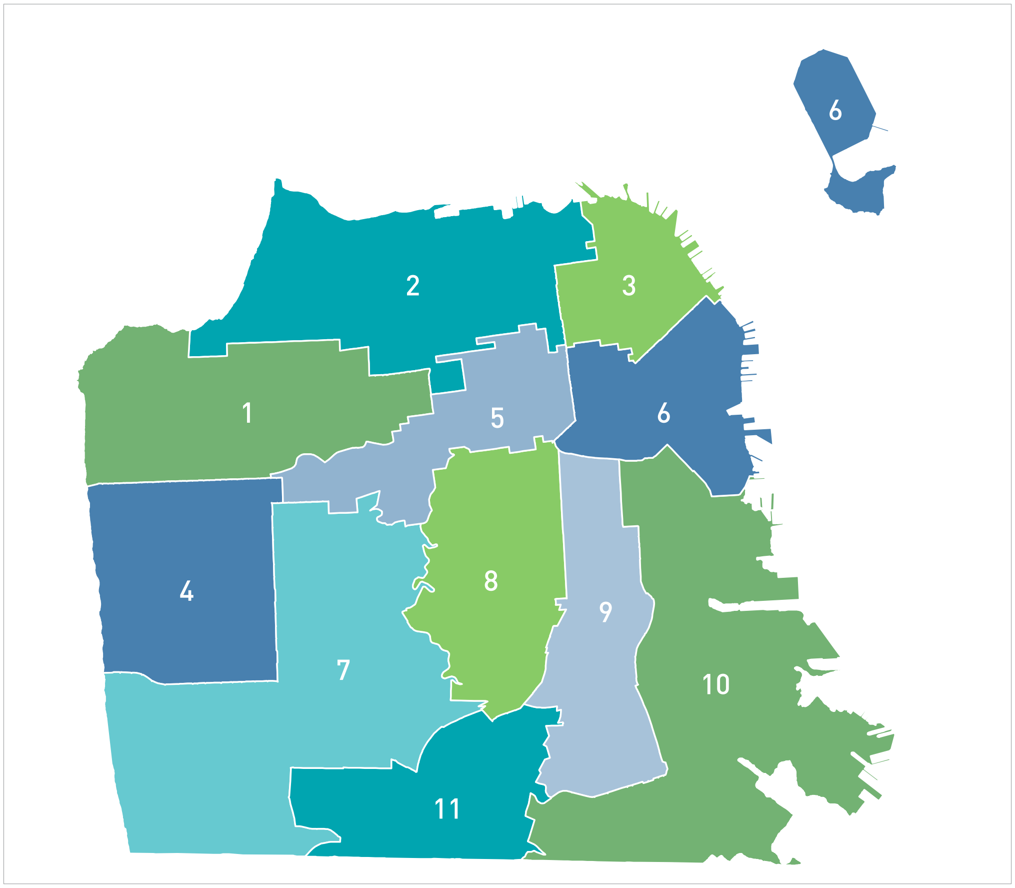


Figure 23 shows the decrease in average speeds between 2010 and 2016, as well as the share of this delay caused by different factors. The decline in average evening speeds has been most precipitous, dropping over 4 miles per hour, with almost 75% of this change attributable to TNCs. Speed decreases during the other time periods were about 3 miles per hour, with about 45%-55% of this decrease caused by TNCs.

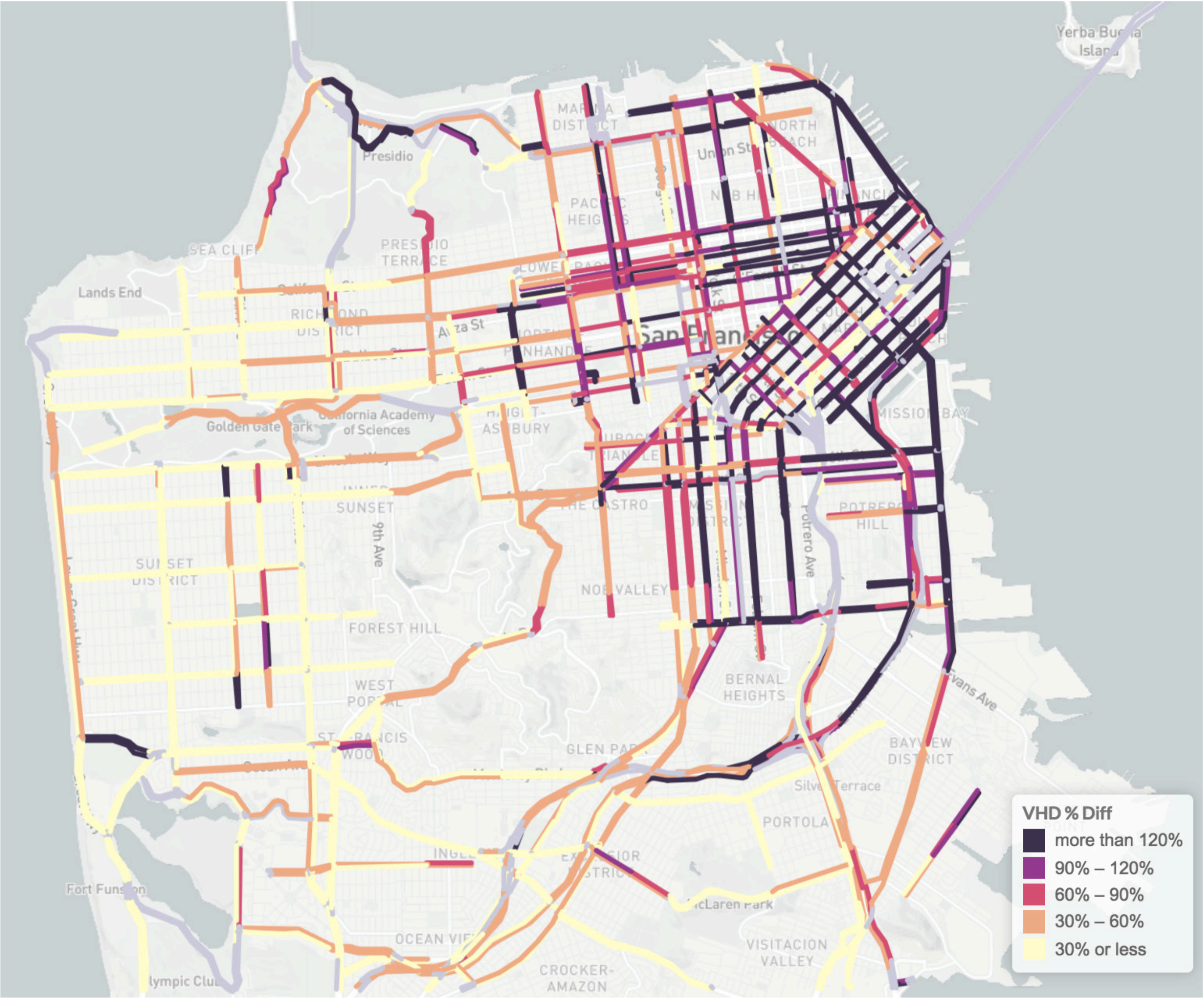
FIGURE 24. SAN FRANCISCO SUPERVISOR DISTRICTS



Where do TNCs Affect Congestion?

TNC usage varies across the city, and thus affects congestion differently in different neighborhoods. An additional vehicle on the roadway in more congested areas results in more congestion than an additional vehicle in less congested areas. The following sections first use maps to illustrate overall changes in the congestion measures on the INRIX segments, followed by supervisorial district-level charts. **Figure 24** illustrates the San Francisco Supervisor districts. The subsequent figures demonstrate that TNCs significantly contribute to increased congestion, especially in the densest parts of the city.

FIGURE 25. % CHANGE IN DELAY INRIX SEGMENT



VEHICLE HOURS OF DELAY

Figure 25 shows the percent increase in VHD between the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. It indicates that the greatest increases in delay occurred in the core northeastern quadrant, as well as along key corridors such the Mission corridor.

FIGURE 26. DELAY BY SUPERVISOR DISTRICT

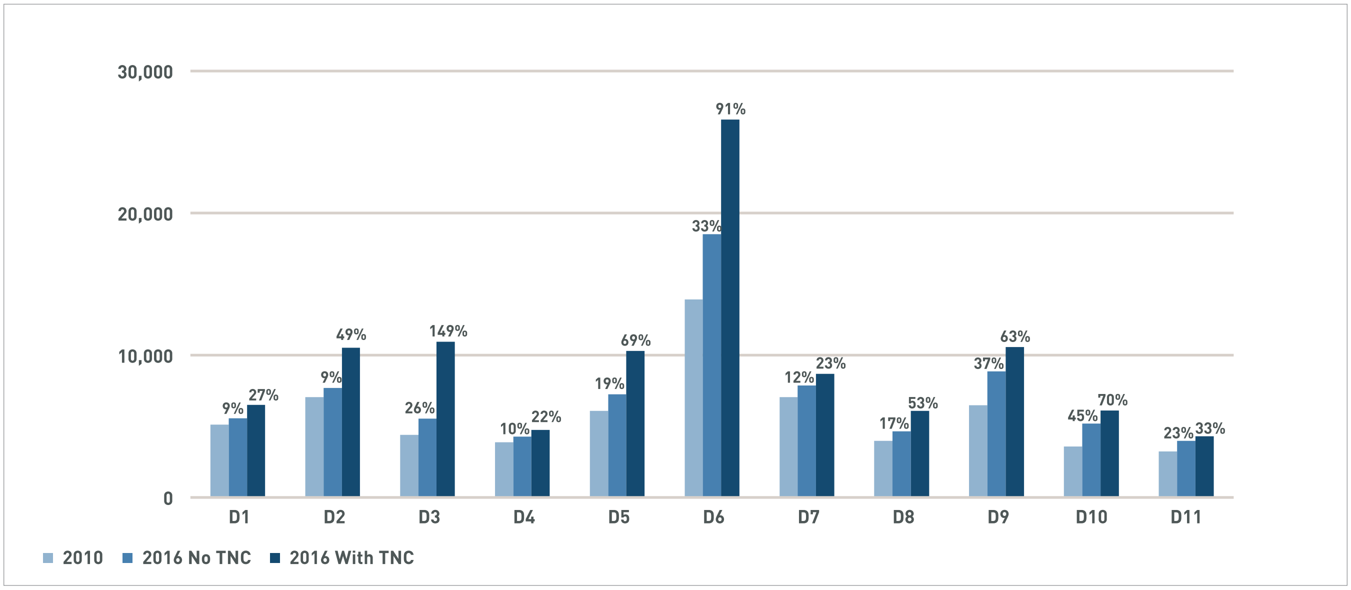


Figure 26 compares the delay from 2010 to the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. This figure shows that TNCs increased delay in all districts relative to 2016 No TNC scenario. The greatest total increases in delay occurred in District 3 and District 6. The greatest relative increase in delay occurred in District 3, while the greatest total amount of delay occurred in District 6.

FIGURE 27. HOURS OF DELAY BY SUPERVISOR DISTRICT

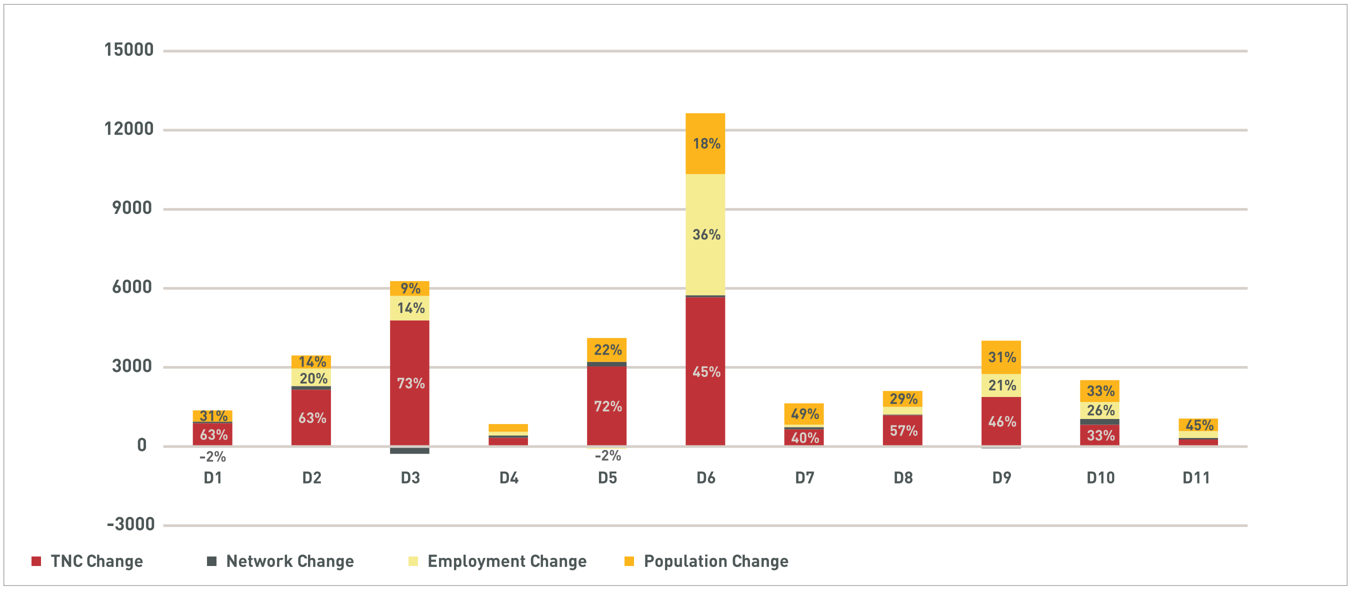
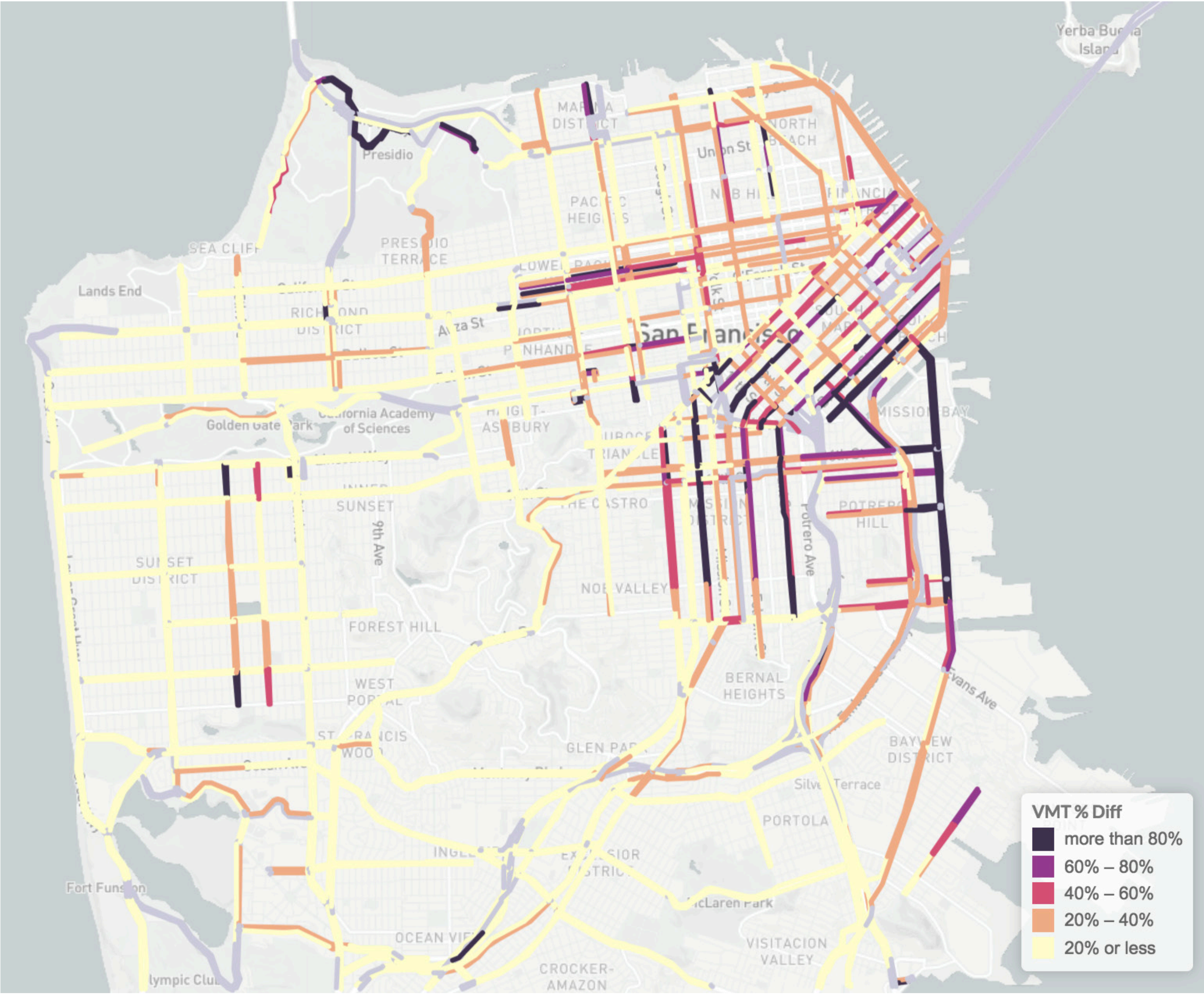


Figure 27 illustrates the total increase in delay between 2010 and 2016, as well as the share of this delay caused by TNCs, network changes, population changes and employment changes. The greatest increases in delay occurred in Districts 3 and 6, with approximately 73% of the increase in delay in District 3 due to TNCs, and about 45% of the increase in delay in District 6 due to TNCs. We estimate that approximately 36% of total delay in District 3 and District 6 combined is due to TNCs.

FIGURE 28. % CHANGE IN VMT BY INRIX SEGMENT



VEHICLE MILES TRAVELED

Figure 28 shows the percent increase in VMT between the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. It indicates that the greatest increases in vehicle miles travelled occurred along key corridors, and with general increases in the northeast quadrant.

FIGURE 29. VMT BY SUPERVISOR DISTRICT

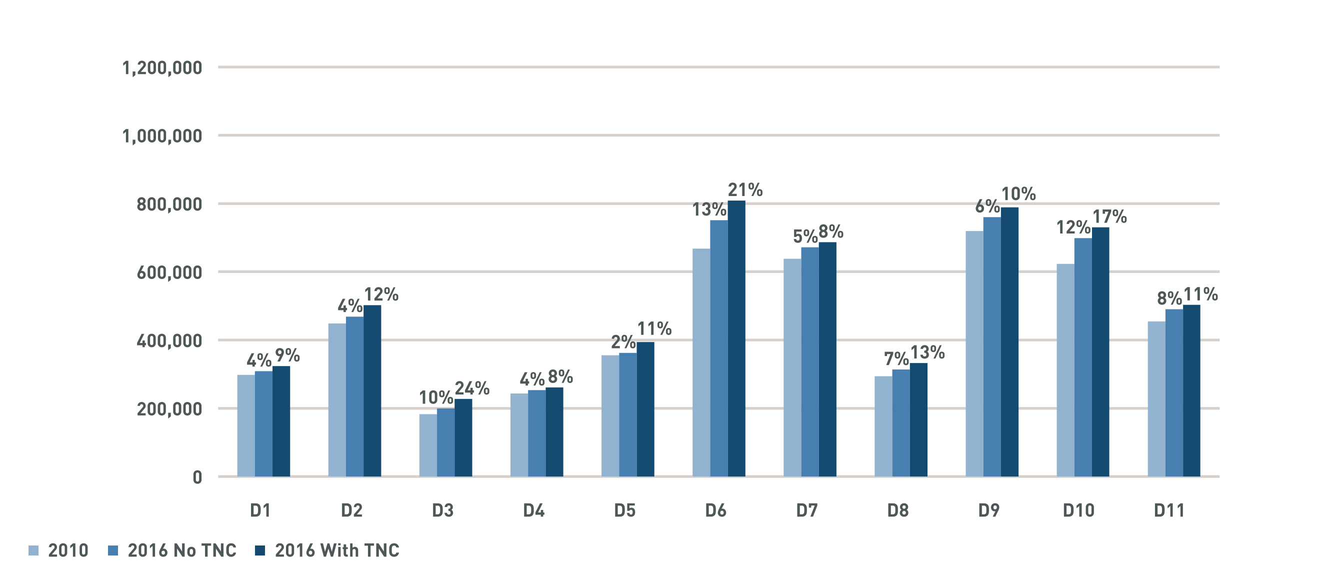


Figure 29 compares the VMT from 2010 to the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. The percentage change shown is relative to the 2010 Base scenario. This figure shows that TNCs increased VMT in all districts relative to 2016 No TNC scenario, with the greatest total increases occurring in Districts 6 and District 10, and the greatest relative increase occurring in District 3.

FIGURE 30. CHANGE IN VMT BY SUPERVISOR DISTRICT BY FACTOR

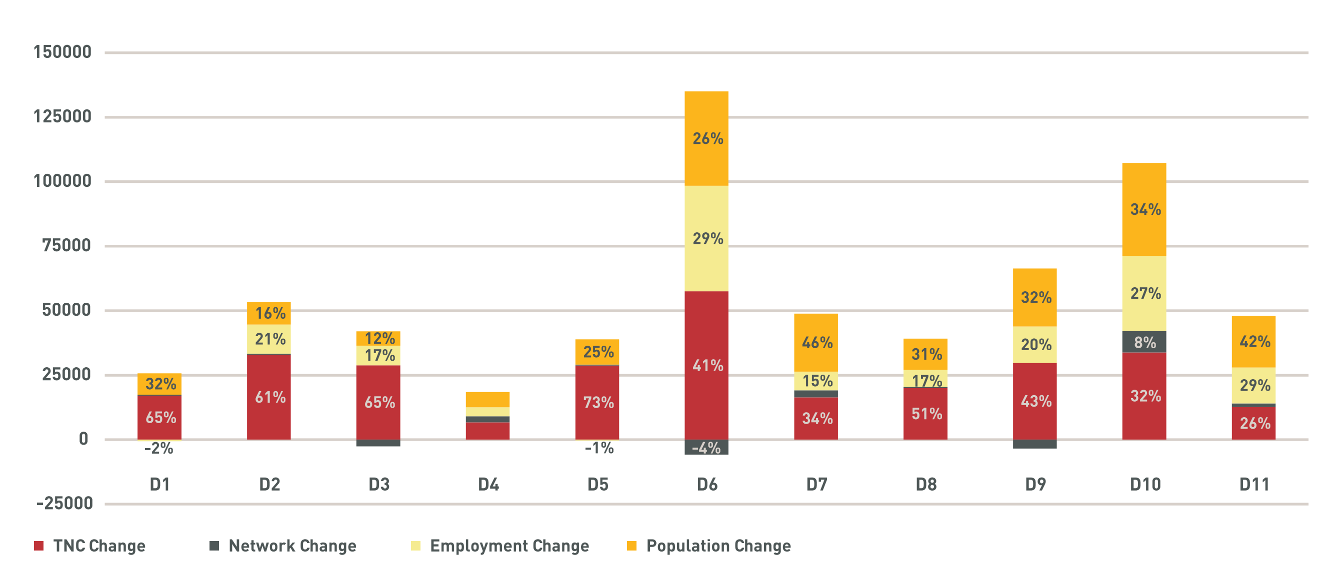
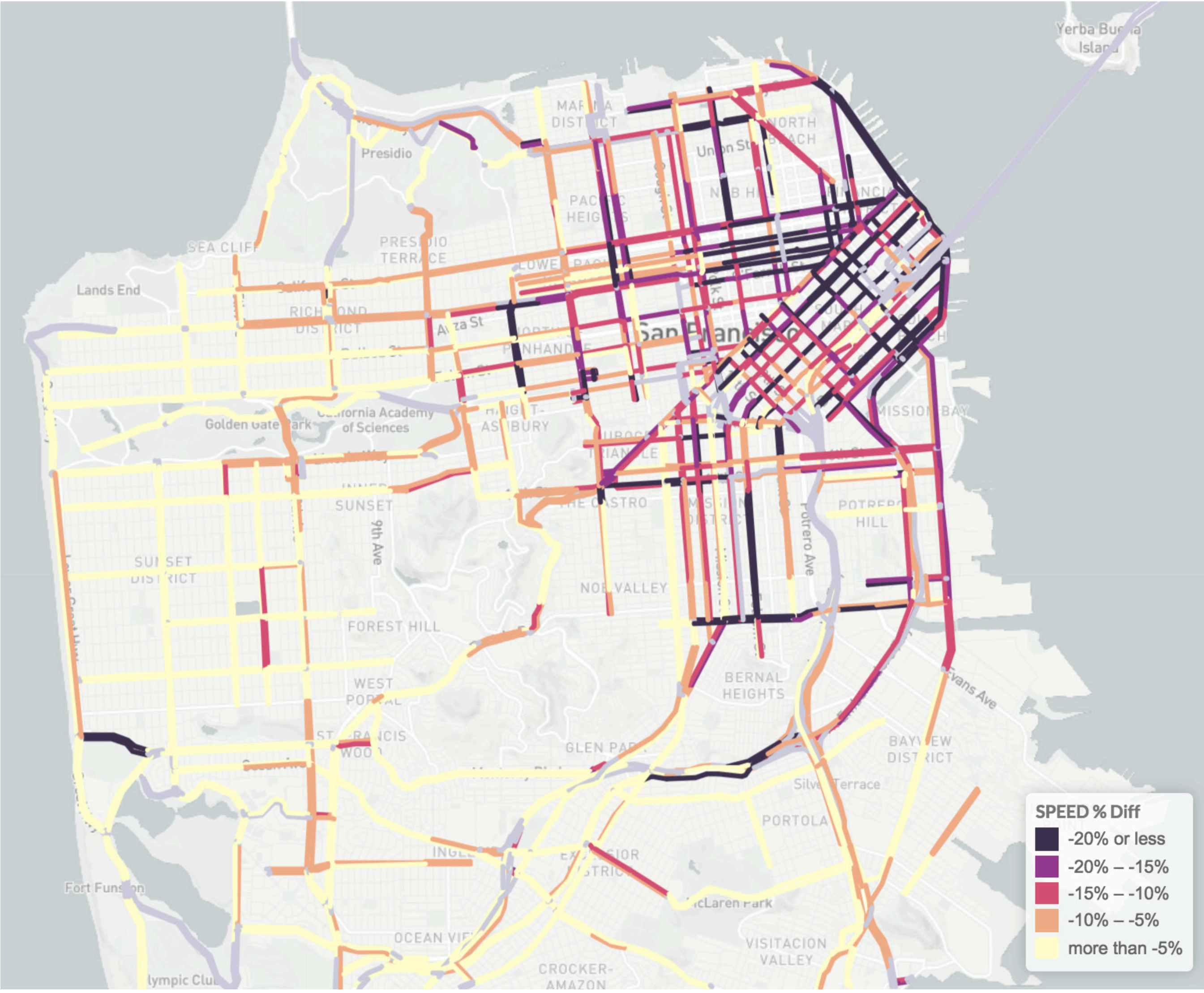


Figure 30 illustrates the total increase in VMT between 2010 and 2016, as well as the share of this delay caused by TNCs, network changes, population changes and employment changes. As noted, the greatest total increases occurred in Districts 6 and 10. TNCs accounted for 44% and 35% the increased VMT in these districts, respectively. While the total increase in VMT in Districts 3 and 5 were less than observed in other districts, the share of this increase attributable to TNCs in these districts was over 70%, the highest in the city.

FIGURE 31. % CHANGE IN SPEED BY INRIX SEGMENT



AVERAGE SPEED

Figure 31 shows the percent decrease in speed between the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. It indicates that the greatest decreases in speeds occurred South of Market, Downtown, and along the Embarcadero and with general increases in the northeast quadrant.

FIGURE 32. SPEED (MILES PER HOUR) BY SUPERVISOR DISTRICT

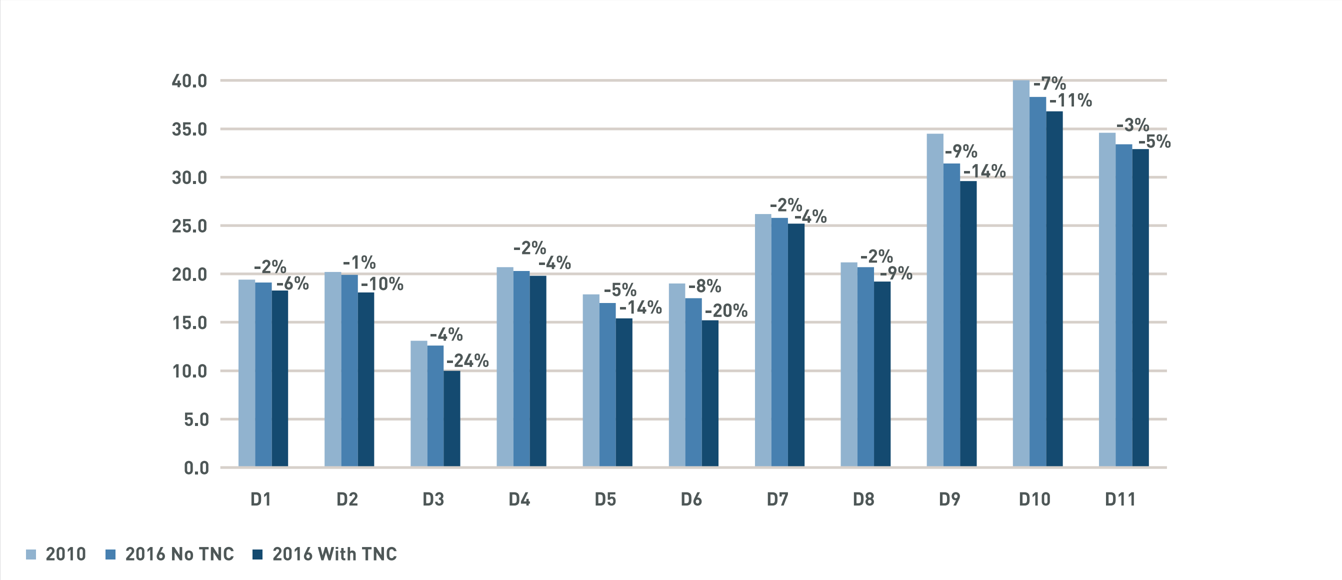


Figure 32 compares speeds from 2010 to the 2016 No TNC scenario in which TNCs don't exist, and to the 2016 with TNC scenario. The percentage change shown is relative to the 2010 Base scenario. This figure shows that average speeds have declined in all districts, with the greatest relative declines between the 2016 No TNC and 2016 With TNC scenarios occurring in Districts 3, 6, 5 and 9. Overall speeds were lowest in District 3 and highest in District 10.

FIGURE 33. CHANGE IN SPEED BY SUPERVISOR DISTRICT BY FACTOR

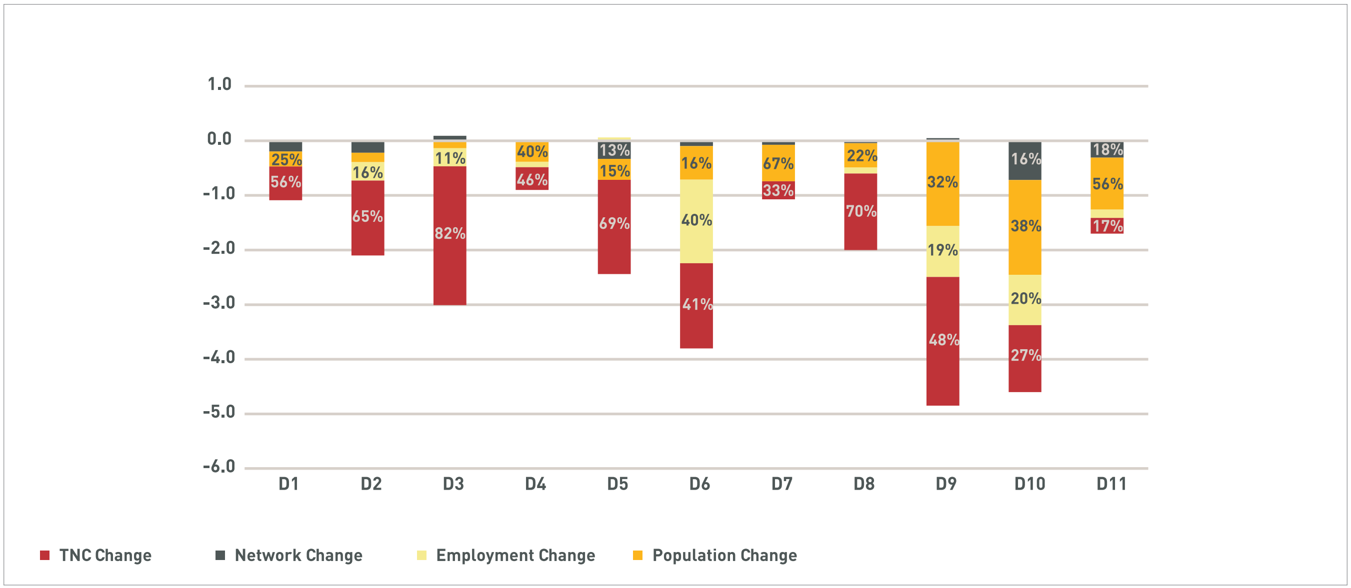


Figure 33 shows the decrease in average speeds in each District between 2010 and 2016, as well as the share of this delay caused by different factors. The greatest declines in speed occurred in Districts 9 and 10. While almost 50% of this decline was due to TNCs in District 9, only 27% of the decline in District 10 was due to TNCs. Districts 3 and 6 also experienced notable declines in speed, with 82% of the decline in speed in District 3 attributable to TNCs. Note that the more than half of the decline in speeds in District 6 is attributable to employment and population growth.

Conclusion

Congestion in San Francisco worsened between 2010 and 2016. The Transportation Authority's Congestion Management Program monitoring indicates that average AM peak arterial travel speeds decreased since 2009 by -26%, while PM peak arterial speeds have decreased by -27% during this same time period. Vehicle hours of delay on the study roadways increased by 40,000 hours on a typical weekday, while vehicle miles travelled on study roadways increased by over 600,000 miles on a typical weekday. In addition, travel times have become less reliable.

During this period significant changes occurred in San Francisco. Roadway and transit networks changed, including the rebuilding of Doyle Drive, the implementation of transit red carpet lanes, and the expansion of the bicycle network. San Francisco added 70,000 new residents and over 150,000 new jobs, and these new residents and workers add more trips to the city's transportation network. Finally, new mobility alternatives emerged, most visibly TNCs. TNCs have become an important travel option in San Francisco.

By late 2016, TNCs were estimated to generate over one million intra-San Francisco vehicle trips in a typical week, representing approximately 15% of all intra-SF vehicle trips, and the number and share of TNC trips in San Francisco has undoubtedly increased since 2016. The rapid growth of TNCs is attributable to the numerous advantages and conveniences that TNCs provide over other modes of transportation, and the availability of this new travel alternative has undeniably provided improved mobility for many San Francisco residents and workers.

TNC vehicle trips contribute significantly to increased congestion. After accounting for the effects of increased employment, increased population, and transportation network changes, TNCs are estimated to cause 51% of the increase in vehicle hours of delay, 47% of the increase in vehicle miles traveled, and 55% of the decline in speeds citywide between 2010 and 2016.

It is important to note that the effect of TNCs on congestion varies considerably by time-of-day. During most of the day, approximately 40% to 50% of the increase in vehicle hours of delay is attributable to TNCs, but in the evening, almost 70% of the increase in vehicle delay is due to TNCs. Similarly, during most of the day approximately 40% on the increase in vehicle miles traveled is due to TNCs, but in the evening TNCs account over 60% of increased VMT. Speeds declined by about 2 to 3 miles per hour during most of the day, with TNCs accounting for about 45% to 55% of this decrease. However, evening speeds declined by almost 4.5 miles per hour on study roadways, and TNCs are estimated to cause 75% of this decrease.

The effects of TNCs on congestion also varies significantly by location. The greatest increases in vehicle hours of delay occurred in Supervisorial Districts 3, 5 and 6, with over 70% of the increase in delay in Districts 3 and 5 due to TNCs, and about 45% of the increase in delay in District 6 due to TNCs. Vehicle miles traveled increased most significantly in Districts 6 and 10, with TNCs accounting for 41% and 32% of the increased VMT in these districts, respectively. While the total increase in VMT in Districts 3 and 5 were less than observed in other districts, the share of this increase attributable to TNCs in these districts was between 65% and 75%, the highest in the city. Average speeds have declined in all districts, with the greatest relative declines occurring in Districts 3, 6, 5 and 9.

Future Research

The report identifies the extent to which TNCs contributed to roadway congestion in San Francisco between 2010 and 2016, relative to other potential contributing factors including employment growth, population growth, and transportation network changes. The report does not include policy recommendations, but rather seeks to provide knowledge needed by the Transportation Authority board, other policy-makers, the general public, and TNCs themselves to make informed decisions.

Subsequent reports by the Transportation Authority and others will address additional important analytic and policy questions in depth, including:

- **TNCs and Street Safety (SFMTA).** How do TNCs affect the safety of people who use the roads, including public transit riders, bicyclists and pedestrians?
- **TNCs and Transit Ridership (SFCTA).** How do TNCs affect public transit ridership and mode share?
- **TNCs and Public Transit Operations (SFMTA)** How do TNCs affect public transit service operations?
- **TNCs and Disabled Access (SFMTA).** To what extent do TNCs serve people with disabilities?
- **TNCs and Equity (SFCTA).** Can TNCs be accessed by all San Francisco residents including communities of concern and those without smartphones or credit cards? Are all neighborhoods served equitably?
- **TNCs and Land Use.** What effects do TNCs have on trip generation? How does TNC demand vary by land use type and intensity? How do TNCs affect parking and loading demand?

Additional data collection will be necessary in order to help answer these questions. We welcome research collaborations to obtain further information, including data to validate or enhance these findings, TNC vehicle occupancy information, traveler demographics and travel purposes, travel costs, TNC fleet composition data, and a range of other data items.

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