Approaches to Presenting External Factors with Operations Performance Measures

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16. Abstract

External factors (e.g., fuel prices, economic conditions, employment levels) are those influences that affect transportation system performance but are typically outside the control of transportation agencies. Transportation agencies that wish to effectively manage system performance should understand the nature and extent of this influence of external factors on system performance. Understanding the nature and extent of external factors helps in several elements of performance management, particularly in communication and target setting.

This project identified key external factors that can impact performance, and developed recommendations for including external factors in performance reporting. Based on a statistical analysis of available data, the following external factors were identified as being highly correlated with system performance: 1) traffic volume levels; 2) number of employed persons; 3) number of building permits; 4) rental vacancy rate; 5) fuel price index; and 6) economic conditions index. The report also includes recommendations for including external factors in performance reporting. The recommendations include communication and chart design techniques that highlight and reinforce the connection between system performance and external factors. For example, one should illustrate the system performance and external factors on the same time scale on a single chart, preferably with seasonal adjustments applied to better visualize overall trends. The intended message from the chart should be clearly spelled so that readers are not forced to interpret complex graphics. Colors should be chosen that are complementary and easily viewable, even by those with visual impairments.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
ºF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	ºC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
ºC	Celsius	1.8C+32	Fahrenheit	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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LIST OF ABBREVIATIONS AND SYMBOLS

AR	Autoregressive Process
ARIMA	Autoregressive integrated moving average
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
BP	Building Permits
CEDS	Comprehensive Economic Development Strategy
CHR	Congested Hours
CMAP	Chicago Metropolitan Agency for Planning
CMSA	Consolidated Metropolitan Statistical Area
CPI	Consumer Price Index
DOT	Department of Transportation
DPD	Dynamic Panel Data
DVRPC	Delaware Valley Regional Planning Commission
ECI	Economic Conditions Indices
EF	External Factors
ESS	European Statistical System
FHFA	Federal Housing Finance Agency
FHWA	Federal Highway Agency
FRED	Federal Reserve Bank
GDP	Gross Domestic Product
GMP	Gross Metropolitan Product
HPI	Home Price Index
MADT	Monthly Average Daily Traffic
MPO	Metropolitan Planning Organization
MSA	Metropolitan Statistical Area
MTC	Metropolitan Transportation Commission
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal Component Analysis
PI	Personal Income
PM	Performance Measures
PTI	Planning Time Index
SCAG	Southern California Association of Governments
SEATS	Signal Extraction in ARIMA Time Series
SF	Single Family
TMAS	Travel Monitoring Analysis System
TRAMO	Time Series Regression with ARIMA Noise, Missing Observations, and Outliers
TTI	Travel Time Index
UCR	Urban Congestion Report

CHAPTER 1. INTRODUCTION

Transportation agencies that wish to effectively manage system performance should understand the nature and extent of this influence of external factors on system performance. Understanding the nature and extent of external factors helps in several elements of performance management, particularly in communication and target setting. This project identified key external factors that can impact performance, and developed recommendations for including external factors in performance reporting.

This report discusses general research associated with performance measures and elements of a performance management framework. This report was not intended to address the specific requirements associated with the FHWA rule that established national measures for system performance and other associated requirements, including specific target setting, data collection/reporting, and other general reporting requirements. That final rule ["National Performance Management Measures; Assessing Performance of the National Highway System, Freight Movement on the Interstate System, and Congestion Mitigation and Air Quality Improvement Program": Docket No. FHWA–2013–0054, RIN 2125–AF54, Federal Register - Vol. 82, No. 11, Pg. 5970 - January 18, 2017] can be found at: https://www.gpo.gov/fdsys/pkg/FR-2017-01-18/pdf/2017-00681.pdf.

FACTORS IMPACTING SYSTEM PERFORMANCE

Transportation system performance (e.g., poor mobility and travel time reliability) can be impacted by one or more key contributing factors:

- Travel demand exceeds physical capacity (e.g., bottlenecks).
- Traffic crashes and unplanned incidents (e.g., vehicle breakdown).
- Construction and work zones.
- Bad weather.
- Poor traffic signal timing.
- Special events (e.g., athletic events, festivals, etc.).

Most efforts to improve transportation system performance focus on addressing, improving, or better managing one or more of these key contributing factors.

WHAT ARE EXTERNAL FACTORS?

External factors (also called exogenous factors) are those influences that affect transportation system performance but are typically outside the control (at least operationally) of transportation agencies. Common examples of external factors include fuel prices, economic conditions, and employment levels.

WHY SHOULD YOU CARE?

By definition, external factors are typically outside the control of transportation agencies, but still influence transportation system performance. Therefore, transportation agencies that wish to effectively manage system performance should understand the nature and extent of this influence of external factors on system performance. Understanding the influence of external factors helps in several elements of performance management, particularly in communication and target setting.

PROJECT OBJECTIVES AND APPROACH

The project objectives were to:

1. Use statistical analysis to identify key external factors that can influence system performance.
2. Based on the statistical analysis and best practices in visual display, provide recommendations for including external factors in performance reporting.

This approach—using statistical analysis to identify key external factors, then providing recommendations for presenting external factors in performance reporting—is described in more detail in the following chapters and the appendix.

OVERVIEW OF REPORT

This report documents the research conducted in the following sections:

- **Chapter 1. Introduction:** Introduces the concept of external factors and why they are important.

- **Chapter 2. Analysis of External Factors:** Summarizes the conduct and results of a statistical analysis used to identify key external factors that were most strongly correlated with operations performance measures.

- **Chapter 3. Recommendations for Presenting External Factors:** Provides recommendations for presenting relevant external factors with operations performance measures.

- **Appendix:** Documents a state-of-the-practice review and statistical analysis conducted to identify key external factors that influenced performance measures in FHWA's Urban Congestion Report. The Appendix also summarizes best practices for visual displays of external factors and performance reporting.

CHAPTER 2. ANALYSIS OF EXTERNAL FACTORS

This chapter summarizes a statistical analysis that was conducted to identify external factors that are closely correlated with actual system performance measures. The objective was to identify these key external factors, such that State and local agencies can include their corresponding external factor data in their own performance monitoring and reporting efforts.

POSSIBLY INFLUENTIAL EXTERNAL FACTORS FOR ANALYSIS

The project team identified a list of possibly influential external factors for which data was available on a recurring basis. This list of possibly influential external factors included the following general categories:

- Travel demand.
- Economic, employment, and price indicators.
- Population and housing indicators.
- Weather conditions.

Table 1 lists 32 possibly influential external factors (grouped in the above four categories) that were included in the statistical analysis. Table 1 also lists the agency source for external factors data, as well as the reporting frequency. The following sections contain more detailed information on each of the 32 possibly influential external factors, including hyperlinks for obtaining the original source data.

OVERALL ANALYSIS APPROACH

In the statistical analysis, these 32 possibly influential external factors were compared to three system performance measures as calculated in FHWA's Urban Congestion Report (UCR) program: 1) travel time index; 2) planning time index; and 3) congested hours. More details on these performance measures (including data sources and calculation procedures) can be found at https://ops.fhwa.dot.gov/perf_measurement/ucr/.

The objective of the analysis was to identify those external factors from among the list of 32 (Table 1) that were most highly correlated with these system performance measures. The project team recognized that highly correlated external factors does not mean that these external factors are influencing system performance. In fact, the opposite could be happening—system performance could be influencing external factors (such as economic or employment indicators). Regardless of a proven causation, the project team determined that high correlation was a sufficient reason to recommend including key external factors in an agency's self-directed performance reporting (i.e., not the reporting required in 23 USC 150(e)).

Table 1. List of Possibly Influential External Factors.

External Factor Category	External Factor	Data Source	Reporting Frequency
Travel Demand	Average Daily Traffic Volumes	Federal Highway Administration Travel Monitoring Analysis System (TMAS)	Monthly
Economic, Employment, and Price Indicators	Gross Domestic Product (GDP) - All Industries	Bureau of Economic Analysis, U.S. Department of Commerce	Quarterly for States, annual for metropolitan statistical areas (MSAs)
	GDP - Construction		
	GDP - Manufacturing		
	GDP - Real Estate		
	GDP - Retail Trade		
	GDP - Transportation		
	Per Capita Income		
	Personal Income (PI)		
	Economic Conditions Index	Federal Reserve Bank	Monthly
	House Price Index	Federal Housing Finance Agency	Monthly
	Consumer Price Index (CPI)	Bureau of Labor Statistics, U.S. Department of Labor	Monthly, Semi-annual, Annual
	CPI - Rent Price Index		
	CPI - Fuel Price Index		
	Number of Employed	Bureau of Labor Statistics, U.S. Department of Labor	Monthly
	Number of Unemployed		
	Percentage of Unemployed		
Population and Housing Indicators	Population Estimate	U.S. Census Bureau	Annual
	Population Change		
	Natural Increase - Births		
	International Migration		
	Domestic Migration		
	Net Migration		
	Rental Vacancy Rate	U.S. Census Bureau	Quarterly
	Homeowner Vacancy Rate		
	Homeownership Rate		
	Total Building Permits	U.S. Census Bureau	Monthly
	Single Family (SF) Permits		
	Number of Structures		
Weather Conditions	Total Monthly Precipitation	National Oceanic and Atmospheric Administration	Monthly
	Total Monthly Snowfall		
	Average Monthly Temperature		

The statistical analysis used principal components analysis (PCA) to reduce the dimensions of the multivariate data. The Granger causality method was then used to identify the most influential and highly correlated external factors. Details on both of these analysis methods are included in the Appendix.

Travel Demand

Average daily traffic volumes were obtained from the Traffic Monitoring Analysis System (TMAS) at https://www.fhwa.dot.gov/policyinformation/tables/tmasdata/. TMAS data are collected by FHWA from the State Departments of Transportation (DOT)s. Researchers obtained the MSA traffic volume data from the TMAS stations using ArcGIS tools (Figure 1).

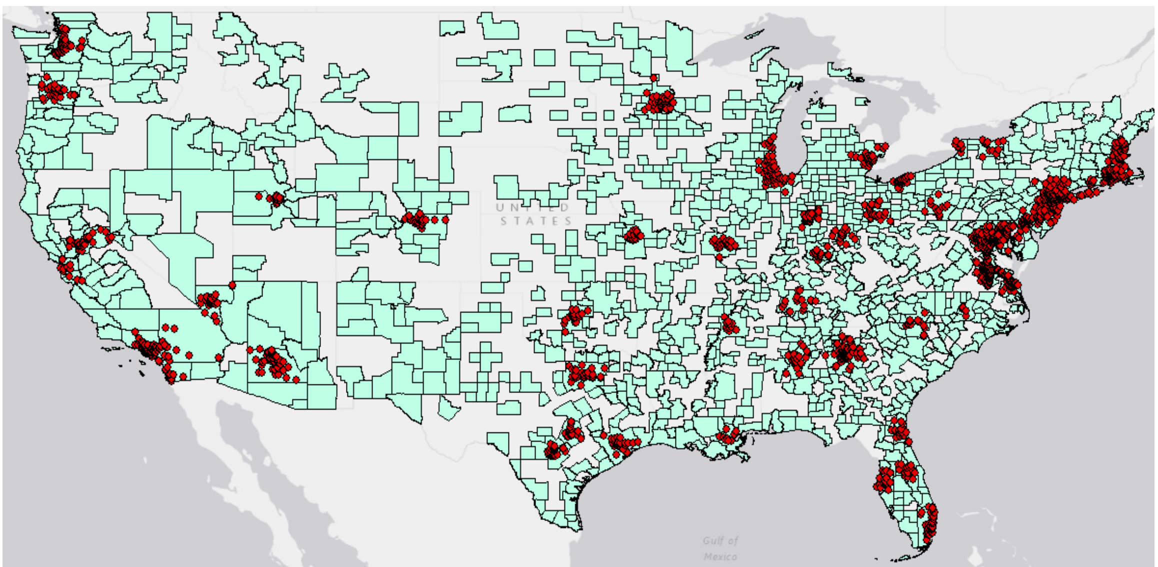


Figure 1. Graphic. TMAS Stations located at the selected 51 MSAs.

After obtaining the station volume data, monthly average daily traffic (MADT) was calculated using the following equation (2016 Traffic Monitoring Guide, page 3-30):

$$MADT_m = \frac{\sum_{j=1}^{7} w_{jm}\left(\sum_{h=1}^{24}\left[\frac{1}{n_{hjm}}\sum_{i=1}^{n_{hjm}} VOL_{ihjm}\right]\right)}{\sum_{j=1}^{7} w_{jm}}$$

Where:

- m is the month index.
- j is the day of week index.
- h is the hour index.
- i is the index for occurrence of particular hour h within a particular j day of the week in a particular month m for which there is a volume data

- $MADT_m$ is monthly average daily traffic for month m.
- VOL_{ihjm} is the recorded volume at the given hour, day and month at the given station.
- n_{hjm} is the number of times the hth hour of jth day on mth month occurs for which there is volume data ($n_{hjm} \leq 5$, e.g. the volume data for Monday 13:00 will be recorded at most five times in a given month)
- w_{jm} the weighting factor for the number of the times the jth day of the week occur during the month m ($w_{jm} = \{4, 5\}$ since every weekday will be repeated either four or five times in a given month).

The volume data were available from TMAS for January 2013 to December 2015. Partial volume data was available until June 2016; however, this data did not include the volume data from all stations. Therefore, to obtain the 2016 volume data the MADT were predicted using autoregressive integrated moving average (ARIMA) models. To obtain the missing data values for 2016, TRAMO (Time Series Regression with ARIMA Noise, Missing Observations, and Outliers) and SEATS (Signal Extraction in ARIMA Time Series) was used.(1) TRAMO/SEATS is an ARIMA model based on a seasonal adjustment method. TRAMO/SEATS, together with the X-12-ARIMA, are recommended by Federal Reserve Bank, European Statistical System (ESS) Guidelines on Seasonal Adjustment and officially used by Eurostat and the European Central Bank.

Economic, Employment, and Price Indicators

Gross Domestic Product and Personal Income

The Gross Domestic Product (GDP) and Personal Income (PI) of MSAs and States are released by the Bureau of Economic Analysis (BEA), U.S. Department of Commerce at https://www.bea.gov/regional/downloadzip.cfm. The State data are released on a quarterly basis while the MSA data are released on an annual basis. Annual GDP/PI of the State is calculated as the average of quarterly GDP/PI. The quarterly MSA data were extrapolated from the State data. The following BEA datasets were used to calculate the quarterly GDP/PI:

- Quarterly State GDP and PI until 2016.
- Annual State GDP and PI until 2016.
- Annual MSA GDP and PI until 2016.

A linear regression model is applied to estimate the relationship between the annual GDP of the MSAs (GMP, or Gross Metropolitan Product) with the annual GDP of the States they belong to. Then using the estimated coefficient, the quarterly GMP was calculated by multiplying the coefficient with the quarterly GDP's.

$$GDP_{State,a} = \hat{\beta} \times GMP_{MSA,a} + \varepsilon_a$$
$$\widehat{GMP}_{MSA,q} = \frac{1}{\hat{\beta}} \times GDP_{State\,,q}$$

Where

- $GDP_{State,a}$ is the annual state GDP.
- $GMP_{MSA,a}$ is the annual GMP.
- $GDP_{State\ ,q}$ is the quarterly state GDP.
- $\widehat{GDP}_{MSA,q}$ is the estimated quarterly GMP.
- $\hat{\beta}$ is the estimated coefficient.
- ε_a is the unobserved errors.

To calculate the coefficient, 10 years of annual GDP data were used (2005-2015). For this analysis, the researchers included the following GDP components:

- GDP – All Industries.
- GDP – Construction.
- GDP – Manufacturing.
- GDP – Real Estate and Rental.
- GDP – Retail Trade.
- GDP – Transportation and Warehousing.

The analysis was conducted for each MSA separately. The same methodology was used to obtain the quarterly PI data for the MSAs.

Economic Conditions Index

The Federal Reserve Bank (FRED) reports the business cycle or Economic Conditions Indices (ECI) for the MSAs on a monthly basis at https://fred.stlouisfed.org/categories/27281. This is one of the important economic indicators used to describe the economic health of MSAs. ECI is calculated using the 12 most influential economic indicators that are assumed to determine the economic condition of the MSA. For more information, one may refer to the following document: https://research.stlouisfed.org/wp/2014/2014-046.pdf.

House Price Index

House Price Index (HPI) is the broad measure of the movement of Single-Family (SF) house prices. HPI is reported on a monthly and quarterly basis by the Federal Housing Finance Agency (FHFA) at https://www.fhfa.gov/DataTools/Downloads/Pages/House-Price-Index-Datasets.aspx. The HPI includes house price figures for the nine divisions, 50 States and the District of Columbia, and the MSAs.

Consumer Price Index

Consumer Price Index (CPI) of All Consumers, Rent Price, and Fuel Price are obtained from Bureau of Labor Statistics, U.S. Department of Labor (BLS) at https://data.bls.gov/pdq/querytool.jsp?survey=cu (note that this hyperlink is only available when using a Java browser). BLS publishes CPI information for 26 metropolitan areas (Table 2).

Some of these metropolitan areas, as defined by the U.S. Census Bureau, include suburbs or counties that extend across State boundaries. The CPI for the rest of the MSAs were calculated using the neighboring and closest MSAs as the reference point (Table 3).

Table 2. Frequency of Available CPI data (2007-2017).

Area	Frequency
Chicago-Gary-Kenosha, IL-IN-WI (CMSA)	Monthly
Los Angeles-Riverside-Orange County, CA (CMSA)	Monthly
New York-Northern New Jersey-Long Island, NY-NJ-CT-PA (CMSA)	Monthly
Atlanta, GA (MSA)	Bimonthly
Boston-Brockton-Nashua, MA-NH-ME-CT (MSA)	Bimonthly
Cleveland-Akron, OH (CMSA)	Bimonthly
Dallas-Fort Worth, TX	Bimonthly
Detroit-Ann Arbor-Flint, MI (CMSA)	Bimonthly
Houston-Galveston-Brazoria, TX (CMSA)	Bimonthly
Miami-Fort Lauderdale, FL (CMSA)	Bimonthly
Philadelphia-Wilmington-Atlantic City, PA-NJ-DE-MD	Bimonthly
San Francisco-Oakland-San Jose, CA (CMSA)	Bimonthly
Seattle-Tacoma-Bremerton, WA (CMSA)	Bimonthly
Washington-Baltimore, DC-MD-VA-WV(CMSA)	Bimonthly
Anchorage, AK (MSA)	Semi-annual
Cincinnati-Hamilton, OH-KY-IN (CMSA)	Semi-annual
Denver-Boulder-Greeley, CO (CMSA)	Semi-annual
Honolulu, HI (MSA)	Semi-annual
Kansas City, MO-KS (MSA)	Semi-annual
Milwaukee-Racine, WI (CMSA)	Semi-annual
Minneapolis-St. Paul, MN-WI (MSA)	Semi-annual
Pittsburgh, PA (MSA)	Semi-annual
Portland-Salem, OR-WA (CMSA)	Semi-annual
St. Louis, MO-IL (MSA)	Semi-annual
San Diego, CA (MSA)	Semi-annual
Tampa-St. Petersburg-Clearwater, FL (MSA)	Semi-annual

Note: CMSA = Consolidated Metropolitan Statistical Area

Table 3. Substitution of CPI Data for Missing MSAs.

MSA	State	Notes
Austin	TX	Use Houston data
Birmingham	AL	Use Atlanta data
Charlotte	NC	Use Washington DC data
Columbus	OH	Use Cincinnati data
Hartford	CT	Use Boston data
Indianapolis	IN	Use Cincinnati data
Jacksonville	FL	Use Tampa data
Las Vegas	NV	Use Los Angeles data
Louisville	KY	Use Cincinnati data
Memphis	TN	Use Atlanta data
Nashville	TN	Use Atlanta data
New Orleans	LA	Use Houston data
Oklahoma	OK	Use Dallas data
Orlando	FL	Use Tampa data
Providence	RI	Use Boston data
Raleigh	NC	Use Washington DC data
Richmond	VA	Use Washington DC-Baltimore data
Sacramento	CA	Use San Francisco data
Salt Lake City	UT	Use Portland data
San Antonio	TX	Use Houston data
Virginia Beach	VA	Use Washington DC-Baltimore data

Employment Indicators

MSA employment statistics are released by Bureau of Labor Statistics at https://www.bls.gov/bls/news-release/metro.htm. The following estimates are published on a monthly basis:

- Civilian labor force.
- Number of unemployed.
- Percentage of unemployed.

Population and Housing Indicators

Population and Migration

Population, demographics, and tourism data were obtained from the U.S. Census Bureau at https://www.census.gov/data/datasets/2016/demo/popest/total-metro-and-micro-statistical-areas.html. Population estimates indicate the population changes and the migration in the MSAs. This is annual data and includes the following population estimators:

- Population Estimate: Total population estimate.

- Population Change: numeric change with respect to the previous year.
- Natural Increase: natural increase in the given period (births).
- International Migration.
- Domestic Migration.
- Net Migration.

Homeownership and Rental Rates

Homeownership and vacancy rates provide current information on the rental and homeowner vacancy rates, and characteristics of units available for occupancy. Rental and homeowner vacancy rates, and homeownership rates are reported for the U.S., regions, States, and for the 75 largest MSAs at http://www.census.gov/housing/hvs/files/currenthvspress.pdf. Public data for the three indicators were obtained from U.S. Census Bureau at https://www.census.gov/housing/hvs/data/rates.html.

- Homeownership Rates: The proportion of households that are owners is termed the homeownership rate. It is computed by dividing the number of households that are owners by the total number of occupied households
- Homeowner Vacancy Rates: The homeowner vacancy rate is the proportion of the homeowner inventory that is vacant for sale.
- Rental Vacancy Rates: The rental vacancy rate is the proportion of the rental inventory that is vacant for rent.

Building Permits

The Building Permits Survey shows the monthly number of the new housing units in MSAs authorized by building permits. Data are obtained from the U.S. Census Bureau at https://www.census.gov/construction/bps/. The indicators are available for the following:

- Total Building Permits.
- Single Family (SF) Building Permits.
- Number of Structures.

Weather Conditions

Monthly weather and precipitation data are obtained from National Oceanic Atmospheric Administration (NOAA) at https://www.ncdc.noaa.gov/cdo-web/datatools/findstation. The data are collected from weather stations located at the airports and other locations. The following weather condition variables are used to analyze the performance measures:

- Monthly Precipitation (Rainfall).
- Monthly Snowfall.
- Average Monthly Temperature.

ANALYSIS RESULTS WITH HIGHLY CORRELATED EXTERNAL FACTORS

The statistical analysis (detailed in the Appendix) found the most important external factors correlated with system performance were as follows:

1. Traffic volume levels.
2. Number of employed persons.
3. Number of building permits.
4. Rental vacancy rate.
5. Fuel price index.
6. Economic conditions index (1 month of leading effect).

The extent to which these external factors affect or are affected by transportation system performance is still unknown, but tracking these and other external factors may provide insight into the relationship between transportation, the economy, and other sectors of interest. Table 4 contains hyperlinks where data for these six important external factors can be obtained online for state and local performance reporting.

Table 4. Source of Data for Highly Correlated External Factors

Correlated External Factor	Agency Source and Data Hyperlink
Traffic volumes	FHWA TMAS (https://www.fhwa.dot.gov/policyinformation/tables/tmasdata/) or state DOT traffic databases
Number of employed persons	Bureau of Labor Statistics, U.S. Dept. of Labor (https://www.bls.gov/bls/news-release/metro.htm)
Number of building permits	U.S. Census Bureau (https://www.census.gov/construction/bps/)
Rental vacancy rate	U.S. Census Bureau (https://www.census.gov/housing/hvs/data/rates.html)
Fuel price index	Bureau of Labor Statistics, U.S. Dept. of Labor (https://data.bls.gov/pdq/querytool.jsp?survey=cu) (note that this hyperlink is only available when using a Java browser)
Economic conditions index	Federal Reserve Bank (https://fred.stlouisfed.org/search?st=economic+conditions+index)

While these external factors are important at an aggregate national level, there may be others that are statistically significant and important to individual states or region. States and regions may also choose to track other external factors that may be of particular importance to them. Regardless, when tracking, visualizing, and publishing these external factors, states and regions should carefully consider not only the analysis in preparing the data, but also in how they present the data. The next chapter provides recommendations for presenting external factor information with performance measures.

CHAPTER 3. RECOMMENDATIONS FOR PRESENTING EXTERNAL FACTORS

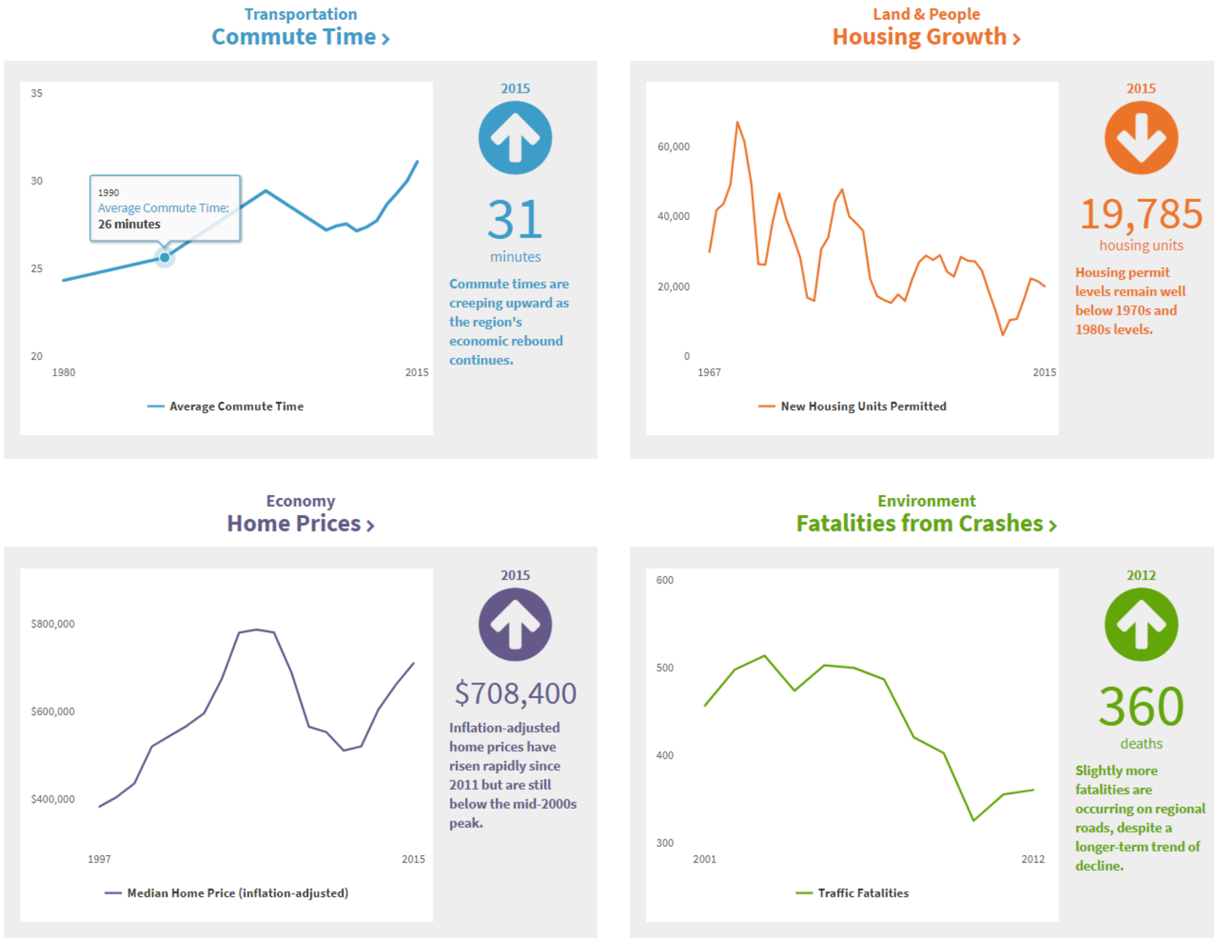
This chapter provides recommendations for presenting external factors with operations performance measures. The statistical analysis described in Chapter 2 found six relevant external factors that are were most correlated with system performance measures in FHWA's Urban Congestion Report. While these external factors are important at an aggregate national level, there may be others that are statistically significant and important to individual States or regions. States and regions may choose to track other factors that may be of particular importance to them.

WHAT OTHERS HAVE DONE ALREADY

Many States, cities, and regional entities have already chosen to begin some sort of external factors tracking, posting various types and styles of dashboards and display types both in print and on the internet. Seeing how other regions choose to display external factors in relation to transportation performance measures can spur ideas and provide good (and bad) examples and principles by which to follow in the development of new visualizations.

Using tools other than Excel, such as Tableau or HighCharts, may help regions assess and determine which external factors are most meaningful and spur creativity and thought about how best to display external factors in relation to transportation performance measures. Ideally, these visualizations will provide a clear, concise, and meaningful message to an intended audience.

San Francisco's Metropolitan Transportation Commission's Vital Signs project (http://www.vitalsigns.mtc.ca.gov/) offers one good example of displaying external factors as an interactive, though if viewed statically, would not be ideal. Figures 2 through 5 offer examples of chart designs that follow many good analysis and design principles. Each of these figures presents charts that use a simple and effective visual design aesthetic that allows the viewer to focus on the information. Note that these examples may not be ideal to fit your data or message and could still be improved to increase usability and clarity.

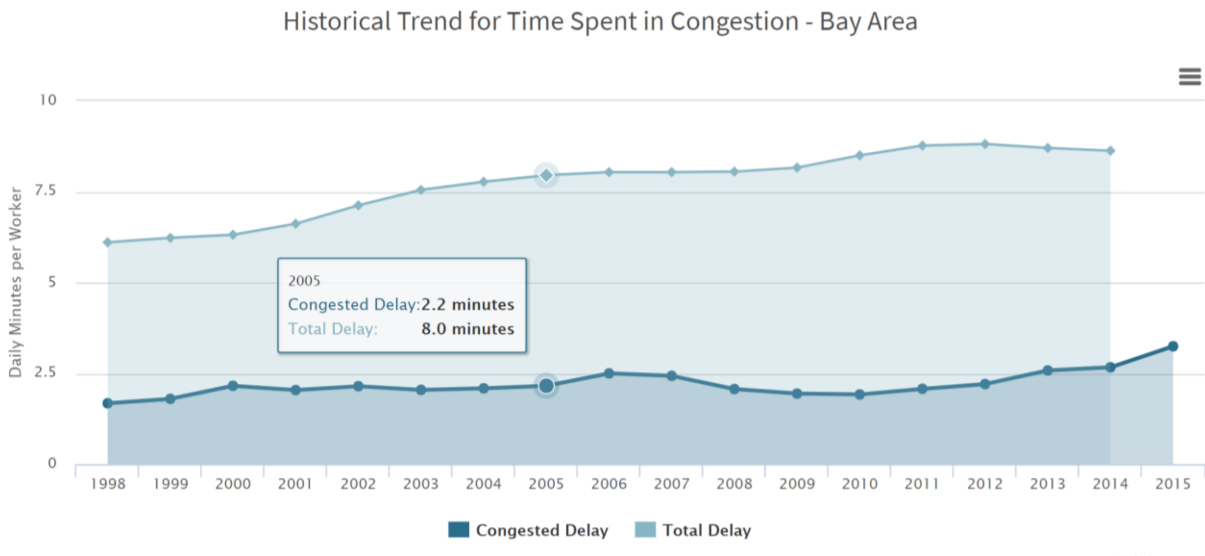


Source: Vital Signs – Metropolitan Transportation Commission/Association of Bay Area Governments, http://www.vitalsigns.mtc.ca.gov/

Figure 2. Chart. San Francisco MTA's Vital Signs Dashboard Segment.

Figure 2 is an effective illustration of external factors because:

- Each chart has an indicator with supporting messaging of the current trend and explaining what the creator wishes the reader to learn.
- Multiple external factors are shown on the same screen view as the transportation factor. Although time ranges differ across the charts, the 12-year period spanning 2001-2012 is present in each.
- Users can interact with the data and click to dive deeper into that particular topic.



Source: Vital Signs – Metropolitan Transportation Commission/Association of Bay Area Governments, http://www.vitalsigns.mtc.ca.gov/

Figure 3. Chart. San Francisco MTA's Vital Signs Deep Dive Page.

Figure 3 is an effective illustration of external factors because:

- The chart effectively overlays two performance measures on the same chart, allowing viewers to quantify visually what component of total delay is due to congestion.
- Both trend lines are set on the same time scale allowing for simple comparisons.
- Both trend lines are annualized, eliminating seasonal variation, allowing the viewer to see trend movement.
- Users can interact with the data, easily comparing the two measures. Additional descriptive text on the webpage (not shown) conveys information relevant to understand what the data means.

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Statewide Transportation Policy Goals 64

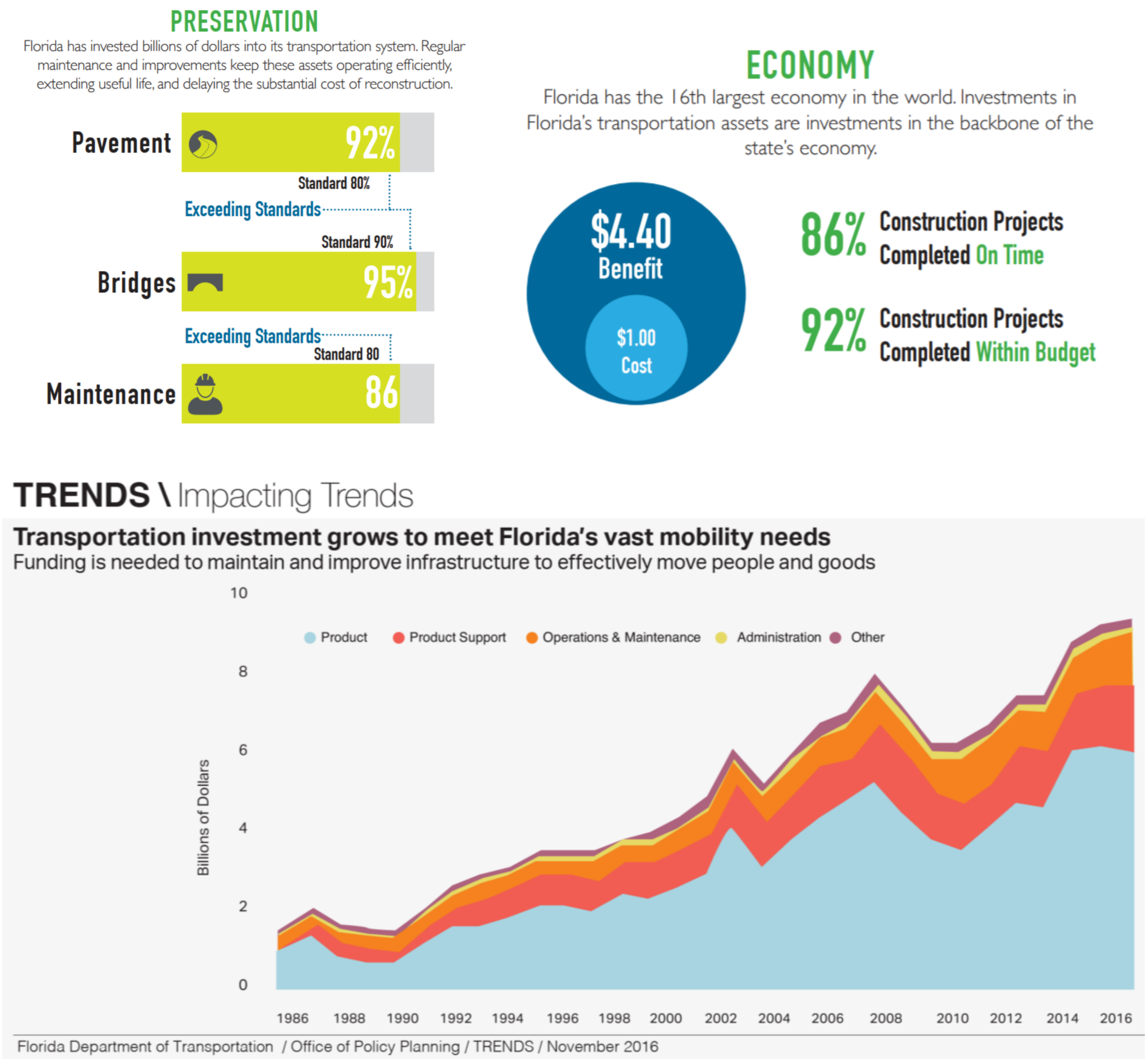
Statewide policy goal/ WSDOT performance measure	Previous period	Current period	Goal	Goal met	Five-year trend *(unless noted)*	Desired trend
Safety						
Rate of **traffic fatalities** per 100 million vehicle miles traveled statewide (Annual measure: calendar years 2014 & 2015)	0.80	0.95[1]	<1.00	✓		↓
Rate of **recordable incidents** for every 100 full-time WSDOT workers (Annual measure: calendar years 2015 & 2016)	4.3	4.6	<5.0	✓		↓
Preservation						
Percentage of state **highway pavement** in fair or better condition by vehicle miles traveled (Annual measure: calendar years 2014 & 2015)	93.3%	93.0%	≥ 90.0%			↑
Percentage of **state bridges** in fair or better condition by bridge deck area (Annual measure: fiscal years 2015 & 2016)	92.1%	91.2%	≥ 90.0%	✓		↑
Mobility (Congestion Relief)						
Highways: Annual (weekday) vehicle **hours of delay** statewide relative to **maximum throughput speeds**[2] (Annual measure: calendar years 2014 & 2015)	32.3 million	N/A	N/A	N/A	(Four-year trend)	↓
Highways: Average **incident clearance times** for all Incident Response program responses (Calendar quarterly measure: Q3 2016 & Q4 2016)	12.0 minutes	12.6 minutes	N/A	N/A	(Five-quarter trend)	↓
Ferries: Percentage of trips departing on time[3] (Fiscal quarterly measure: year to year Q2 FY2016 & Q2 FY2017)	95.4%	95.9%	≥ 95%	✓		↑
Rail: Amtrak Cascades on-time performance[4] (Annual measure: fiscal years 2015 & 2016)	72.1%	74.8%	≥ 80%	–		↑

Source: https://www.wsdot.wa.gov/Accountability/GrayNotebook/SubjectIndex.htm

Figure 4. Graphic. Washington DOT's Grey Notebook.

Figure 4 is an effective illustration of external factors because:

- Each metric is clearly defined with current and previous period values, goals, and historical trend information.
- Goals are clearly shown as met (or not) with a clear illustration of what the desired trend should be.
- Multiple external factors are shown on the same view, allowing the reader to quickly ascertain overall performance.
- The visual design is particularly effective for print.



Source: http://www.fdot.gov/planning/FastFact2016.pdf

Figure 5. Graphic. Florida DOT's Fast Facts Examples.

Figure 5 is an effective illustration of external factors because:

- When applicable, metrics are segmented to clarify the information conveyed.
- Where applicable, standards and goals are clearly shown in terms relevant to the reader.
- Each chart contains either a descriptive title or supporting explanatory messaging conveying what the creator wishes the reader to learn.
- The visual design is particularly effective for print.

The primary goals of displaying external factors is to convey a particular message about those factors and their relationship to transportation. These examples do a good job visually with conveying information and visually retain the reader's interest. However, they do not necessarily to a good job making a connection between transportation and the external factor (or other element as some are unrelated to external factors). Success will be largely based on how you present your data and how well your message is understood by your audience.

CONSIDERATIONS FOR DISPLAYING EXTERNAL FACTORS

Regardless of which external factors states or regions may select to follow with transportation performance measures, they should consider several broad factors early in the process before any measures are displayed on a website. These considerations represent a cohesive, big-picture view that will maximize the effectiveness and reach of the effort.

Think About Your Audience

Likely the most important factor to consider when making any graphic or data visualization is to consider who the audience or consumer of the information will be. Understanding who will be consuming the information will provide insight into what information is relevant, how timely that information should be, and how they might best consume the information. For example, if the primary consumer of your audience is working professionals in the same field, what the visualization looks like and what it contains could be considerably different than if the primary consumer is the general public with little knowledge on the topic. Understanding your audience—their knowledge level on the topic, what interests them and why, and other behavioral elements—will increase the effectiveness of your message. In general, all visualizations should be simple, but with a knowledgeable audience, information that is more technical can be conveyed. This naturally leads to the second, and likely equally important guideline.

What Message Do You Want to Convey?

Understanding who your audience is will greatly inform not only what your message is, but how it will be conveyed. With external factors affecting transportation, is the message to simply show how different factors correlate with transportation performance measures, or are there facts and revelations that need to be conveyed to specific groups? When your target audience views the visualization, the focus should be the one to three messages that, if they gleaned nothing else, would be most crucial to their deeper understand of the topic.

This generally means that in any visualization, descriptive text, or narrative, instructions that guide the consumer should be included to leave nothing to chance when viewing the visualization. Good graphics should allow your primary message to be conveyed easily and quickly, but also allow those who are curious to dive deeper into the data and make discoveries and connections on their own. Doing this will actively engage your audience, keep their attention and interest longer, and allow them to think creatively about the message you are conveying.

Be careful to consider alternate messages that might come from your visualization. These unintended messages can shift the conversation away from the desired dialogue to one that is either unimportant or irrelevant to the intended message.

How Will Your Audience Use Your Visualization?

How your audience will use your visualization and the information it provides is the summation of the two guidelines previously discussed. In this case, now that your audience is more informed about which external factors affect transportation, what action should they take next? Should they share your visualization on social media or other similar outlets? Should they use this information in discussion, planning, or policymaking (and if so, how would this best be accomplished in each case)?

Placing specific thought in how your audience may use your visualization and ultimately your message—why you are displaying these particular external factors in the first place—will broaden the reach of your message and visualization.

Ultimately, your goal should be that your identified audience should be able to grasp the primary message from your visualization in about five seconds or less and then remain interested enough to dig deeper into the information to glean at least one additional piece before moving their attention span elsewhere.

OTHER CONSIDERATIONS IN VISUALIZING EXTERNAL FACTORS

From a macro-perspective, understanding who will be using the visualizations of external factors and how they will be used in addition to understanding and clearly conveying your own message is a critical first step. However, once your audience, message, and intended use are set, actually creating the visualization takes careful thought and consideration.

Several difficulties lie in the path to creating an engaging and meaningful comparison between external factors and transportation performance measures. These include:

- Showing a meaningful relationship between the external factor and the transportation measure.
- Providing context of the two measures clearly and succinctly.
- Explaining the factor's relationship meaning and conveying the intended message to your audience.

Additionally, there are other, more practical, hurdles to overcome in the analysis and assessment of external factors that make addressing the previous three hurdles difficult. The following tips will help in addressing these and other hurdles to ensure that any visualization of external factors maximizes the ability to convey the intended message to your audience.

Carefully Choose How External Factors Are Assessed

Selecting which external factors to use may seem obvious and inherent in this process, but choosing how those external factors are displayed can make a considerable difference in conveying a message about that factor and making it easier to understand. For example, unemployment is a reasonable factor to consider in terms of transportation performance measures and may show a high degree of correlation with congestion. However, it may make more sense to display employment gains in real numbers with transportation performance measures.

This is beneficial for a couple reasons. First, unemployment and transportation measures may be inversely (or negatively) correlated—an increase in unemployment means a decrease in congestion—creating an X-looking line on a chart. These types of relationships can be difficult for readers to fully grasp quickly compared to positive correlations (parallel lines on a chart). Transforming data and placing trend lines in a positive correlation/relationship will greatly increase the readability and interpretability of your visualization.

Second, putting an external factor in different terms may help make interpreting the results of your analysis and creating a meaningful message from your visualization simpler. In the same example, it is much easier and makes more sense to say, "As employment increases by X, [traffic congestion] increases by Y," than the alternative of "As unemployment decreases by X, [traffic congestion] improves by Y." This is partially due to the use of negatives in voice, but also relates back to the negative correlation.

Determine If External Factors Require Seasonal Adjustment

Similar to the previous discussion, careful thought should be given to if the external factors (or transportation performance measures other than the performance measures required under 23 USC 150(c)) should be seasonally adjusted. Many times, plotted data may look erratic with several peaks and valleys over time that make determining the direction and scale of a trend nearly impossible. In this case, one should consider seasonally adjusting the data before performing the correlation analysis.

There are other benefits to seasonal adjustment that might not be as obvious. Most importantly, seasonally adjusting data will allow the user and audience to make month-to-month comparisons (e.g., compare July data with June data). Without seasonal adjustment, these comparisons are not appropriate because an up or down tick in the trend line may be heavily influenced due to seasonality. Instead, users would have to compare the same month year over year in order to accurately compare data. Using the unemployment example, this data set is highly seasonal, often seeing drops in unemployment around the holiday season as companies hire temporary workers. Seasonal adjustment removes that influence, allowing a comparison of December to January.

Another benefit to seasonal adjustment is that changes in trend direction (or severity) can be more quickly determined through month-to-month comparison. Without the adjustment, it would take over a year or more to discover the same trend. When comparing against transportation performance measures, this rapidity of response would allow the audience to make more accurate and timely decisions when using any visualization created with the data.

Be Thoughtful about How Data Is Displayed

Once the external factors have been thoroughly transformed and analyzed, displaying the factors in such a way as to make your message clear to your audience is crucial. There are several basic techniques that should be used to ensure that any visualization made will be readable and understandable to your audience.

Make sure that you plot both the external factor and the transportation performance measure on the same graph. This may seem obvious, but often times (and as seen earlier in other examples), this does not happen. Placing two lines on the same chart introduces some challenges, but can also be powerful in conveying your message. It will be much easier for your audience to assess the trend if the lines lie together. However, this requires additional effort on the part of the creators of the visualization to think about what the relationship they are charting actually means. Does it make intrinsic sense?

When creating charts with two lines, there are a few key design techniques worth noting.

- **Align the Time Axis**: Ensure that both datasets are displayed on the same time scale (months, quarters, years) and align them as appropriate. In some cases, one series may lead or lag the other. In these cases, use discretion to determine if the line should be shifted, but if so, clearly mark the shift on the visualization.
- **Clearly Identify the Dual Axis**: In most cases, each dataset will have different units and will require the use of a dual axis. Be sure to clearly mark which axis/units refer to each line, by either color or some overt statement. Additionally, ***note the units being used*** and if there are any special notes about the units.
- **Align the Lines to the Proper Scale**: When creating visualizations, especially bar or line charts, the general rule of thumb is to set the axis origin at zero to avoid misrepresenting the data. However, when using dual axes to show a correlative relationship, it is permissible to reset the base point. This will ensure that both lines can be seen clearly and the trend is apparent. Be mindful of how the trend is being represented and avoid clear misrepresentations.
- **Use Complementary Colors**: Avoid using the red-green combination, as this is troublesome to color blind people. Also be mindful that your visualization may be printed in black and white; use colors that also contrast when printed in black and white to avoid axes confusion. Alternately, consider using texture, such as dashes or dots, for one dataset.

In summary, when tracking, visualizing, and publishing external factors in comparison with transportation performance measures, State and local agencies should carefully consider not only the analysis in preparing the data, but also in how they present the data.

TYING IT ALL TOGETHER

Understanding and applying these principles will allow visuals of external factors to be much more effective and meaningful. Figure 6 illustrates an external factor (employment) found to be statistically related to the travel time index (TTI) in Austin, Texas, in a format typical of Microsoft Excel chart defaults. Note how, even with trend lines drawn, it is difficult to glean any meaningful information from the chart. There are many issues with this visualization:

- **There is no clear meaning or message to the chart**. If the reader *can* understand what the relationship between the external factor and the transportation performance measure is (which is incorrectly shown by the trend lines), he or she is left with a "So what?" feeling.
- **Unadjusted and transformed data confuse the chart**. The employment data (which is not easily understood to be so) appears to have some sort of seasonal pattern that makes interpreting the relationship difficult. Additionally, poor formatting make the chart extremely difficult (if not impossible) to read.
- **The graphic cannot be reasonably reused by others**. In addition to the confusion and vagueness of the message, any user of the information cannot reuse this visualization either to tell their own story or to disseminate the agency's message.

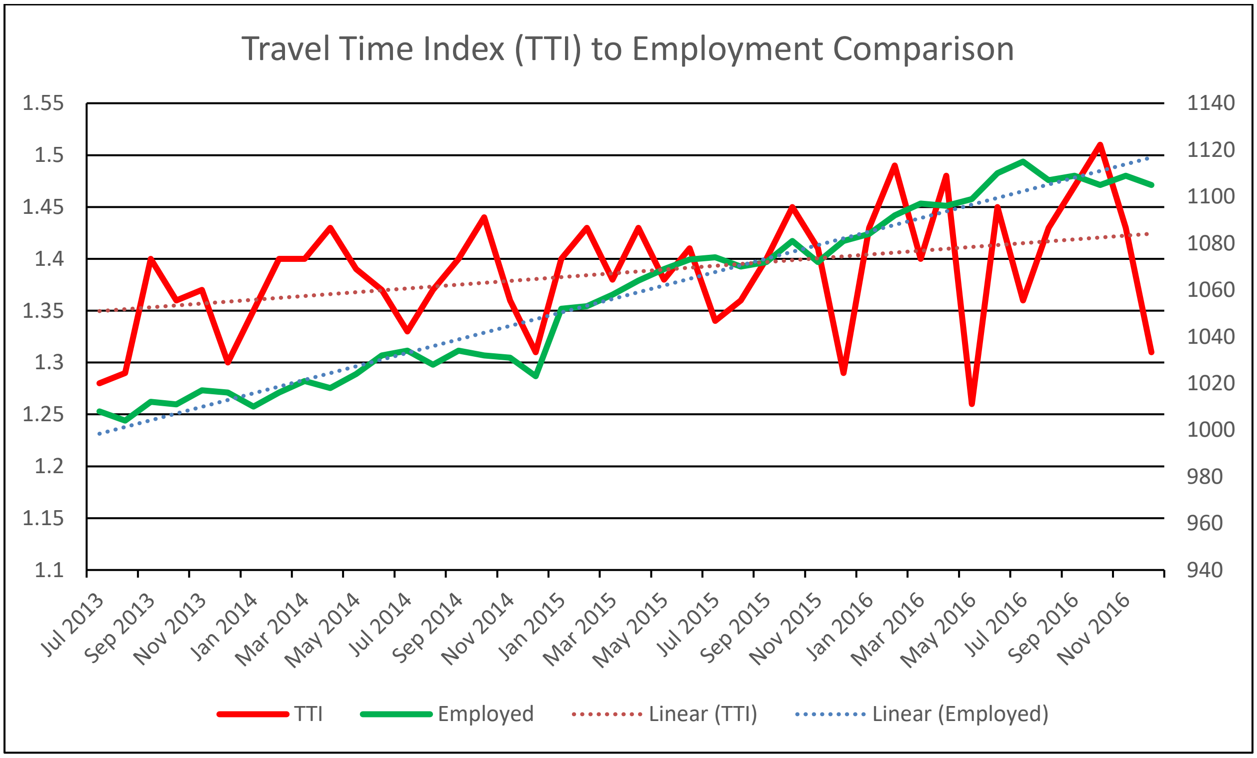


Figure 6. Chart. Default Excel Chart Formatting.

Without proper analysis and thought into what the analysis means, simply displaying the results will likely degrade the credibility of the analyzer. While it is easily the most difficult task, ascribing some sort of meaning to the results of the analysis is crucial to progressing any discussion on the topic.

Figure 7, however, illustrates the same data thoughtfully developed into a visualization that is easily digestible and clearly conveys the message the authors intended. Note that in this graphic, the data has been seasonally adjusted to more clearly and accurately show trend information. Additionally, both the title and supporting text clearly interpret the chart's meaning for the reader, yet still allowing the reader to examine the data more carefully. Superfluous information has been removed or greyed, colors coordinate with one another, and each element on the chart has some meaning for the reader.

By clearly defining what the creator of the chart found in the deeper analysis, confusion and potential misinterpretation has been nearly eliminated from the external factor comparison with the performance measure. Additionally, the added text message interpreting what the data represent provides accurate and controlled messaging for the reader to take and reuse in other places, like media outlets, reports, or briefings. The entire graphic could also be used, if desired by the reader, to add further depth to their use.

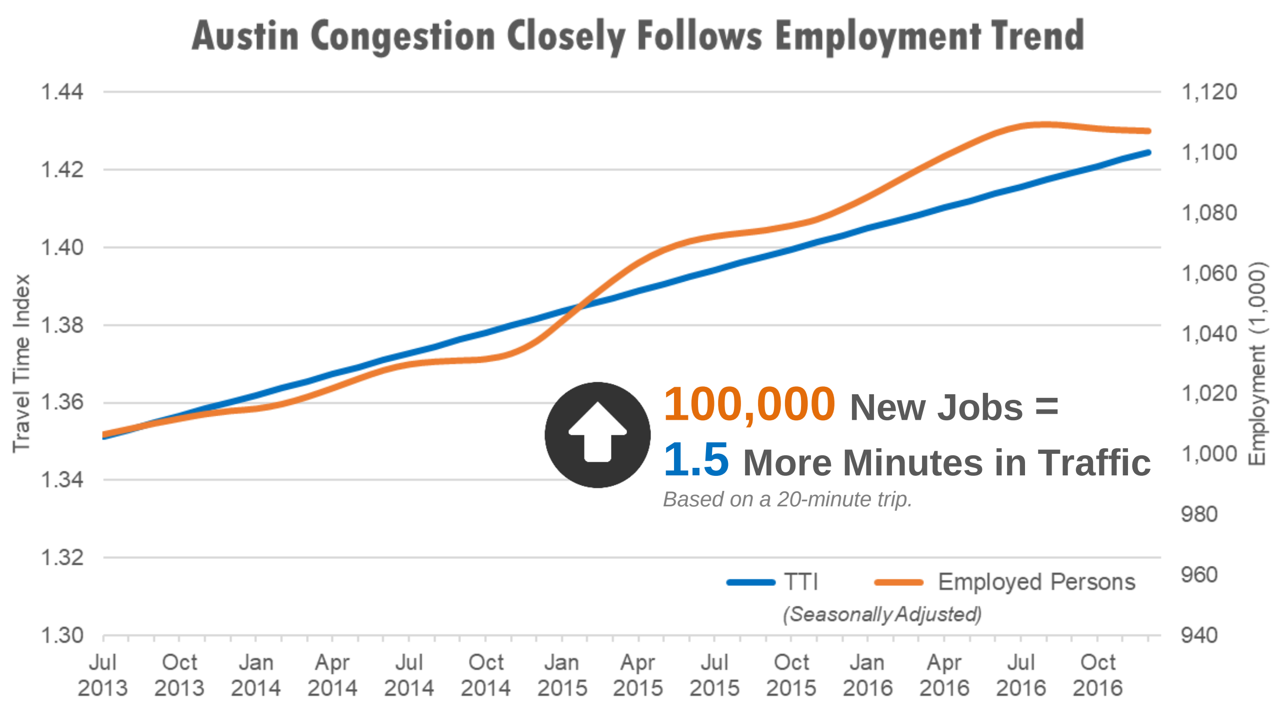


Figure 7. Chart. Same Data as Figure 6, but Improved Visual.

Figures 8 and 9 explain in more detail the negative and positive results, respectively, of chart design/features chosen to display. In this explanation, nuances about the visualization itself have been explained that could help improve any similar illustration of external factors compared with transportation performance measures. A more detailed discussion of the use of color, size, spacing, axes, and design can be found in the Appendix.

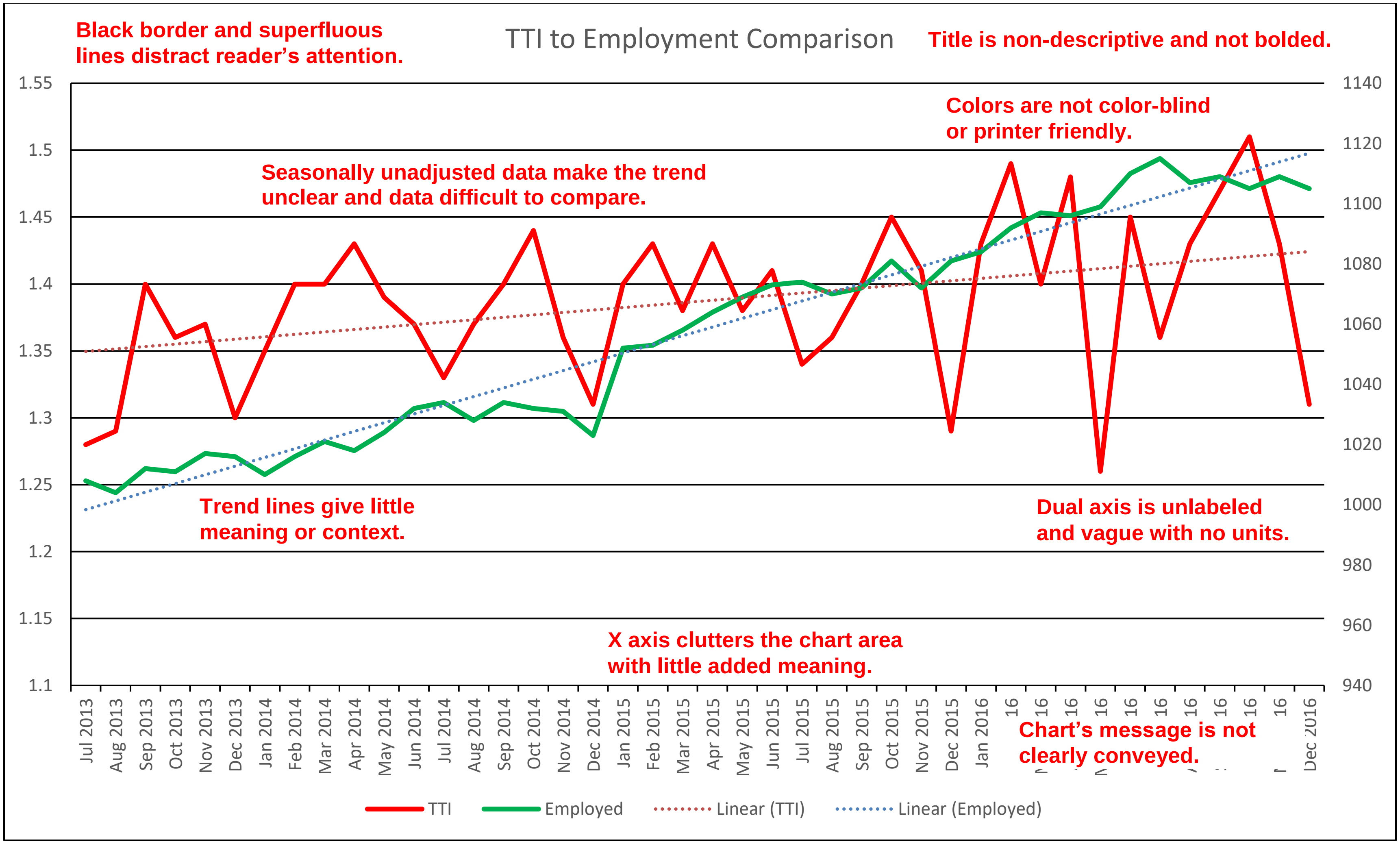


Figure 8. Chart. Detracting Elements from a Bad Example.

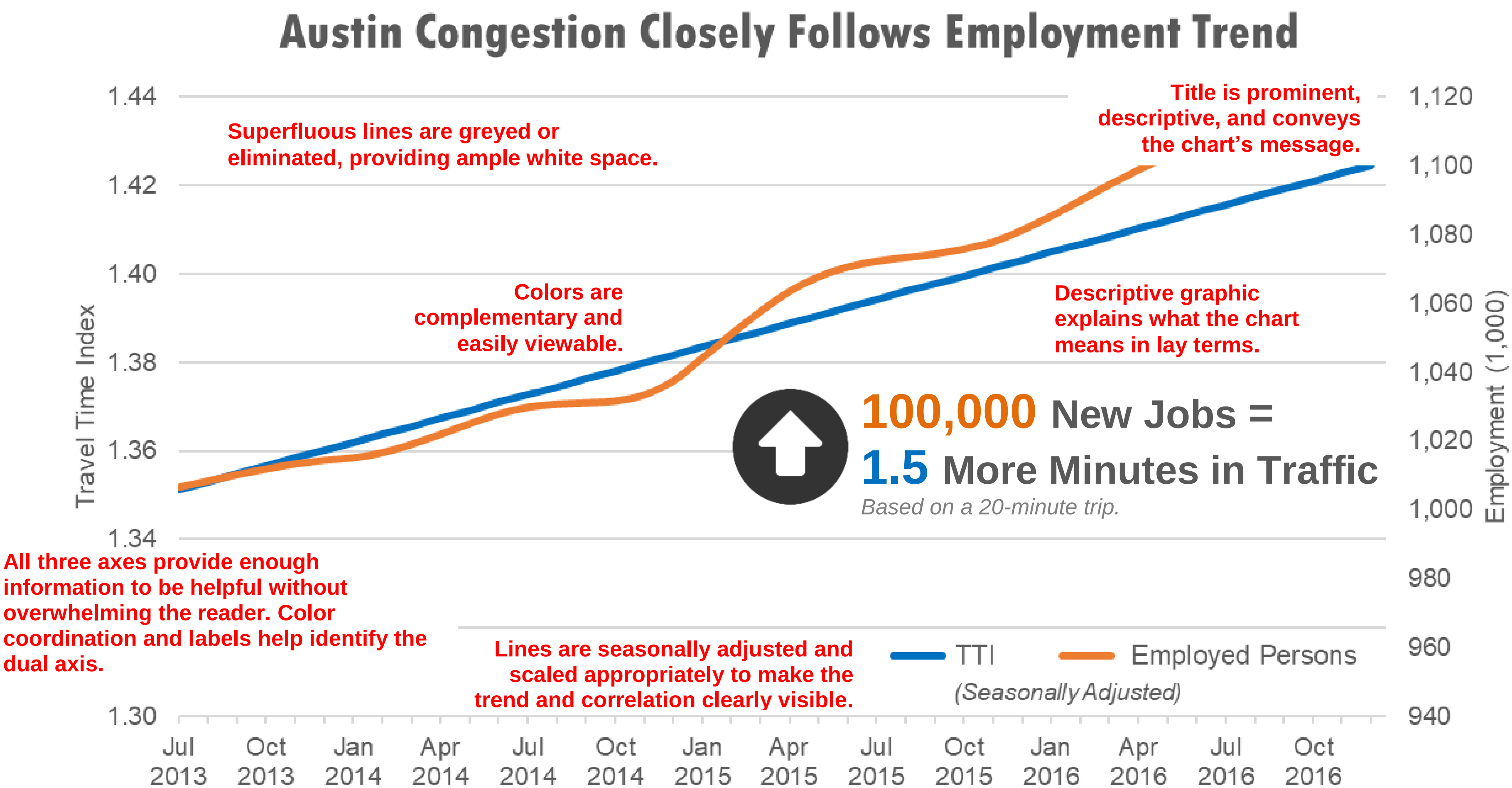


Figure 9. Chart. Elements of What Makes a Good Visualization.

Note that this example does not provide an end-all format for creating visuals, but it does convey a measure of graphic best practices that should be followed in order clearly disseminate information of any type.

One of the best ways to develop your graphic skills is to frequently examine what others have done, both with good and poor examples. Additionally, look at other non-transportation resources for graphic and chart design ideas, paying specific attention to how the message and point of the visualization is being conveyed to the reader.

REFERENCES FOR CHAPTER 3

1. Maravall, A., and V. Goméz. 1996. TRAMO/SEATS (Time series Regression with ARIMA noise, Missing values and Outliers/Signal Extraction in ARIMA Time Series). *Bank of Spain*.

APPENDIX. IDENTIFYING AND PRESENTING EXTERNAL FACTORS

This Appendix documents a state-of-the-practice review and statistical analysis conducted to identify key external factors that influence transportation system performance measures. The Appendix also presents key principles for information and visualization design.

STATE-OF-THE-PRACTICE REVIEW

Table 5 summarizes a sample of agencies that collect performance measures and have in recent performance reports or web based dashboards reported external factors broadly grouped into the categories listed above. While there are more examples available, this selection is highlighted because they represent more complete sets of measures or attributes that are readily available and produced in a single document or dashboard. Private sector freight and airline companies also plan for external factors however there is limited detailed information on the process and procedures or the measures they actually use documented in the literature.

Washington State DOT has published the Gray Notebook quarterly since 2001. This document records selected performance measures from across the State as well as local areas of interest. In 2010, six statewide transportation policy goals were reaffirmed in statute to guide the planning for operation and performance of and investment in the state’s transportation system. These six goals were in the areas of Preservation, Safety, Mobility, Environment, Stewardship, and Economic Vitality. Biennial Transportation Attainment Reports along with the quarterly Gray Notebook assess progress toward the goals and contribute to the overall performance of the transportation system.

Florida DOT’s Planning Division tracks transportation-related "Trends" described as information that could pose threats to successful implementation of the Florida Transportation Plan. This information can be used by Florida's decisionmakers, transportation professionals and the interested public to assist in understanding transportation-related issues and making wise and informed decisions. Travel demand is measured with vehicle miles travelled and freight volume. Other external factors presented include population, transportation funding, tourism, fatalities, housing, energy consumption, and mode of travel.

Table 5. Summary Table of Factors Being Recorded by Different Agencies.

Agency	Document	Travel Demand Indicators	Economic Indicators	Population and Housing	Weather	Safety	Year
Washington State DOT	Gray Notebook & Attainment Report	Yes	Yes	No	No	Yes	2016
Florida DOT	Fast Facts	Yes	Yes	Yes	No	Yes	2016
Florida DOT	Trends \ Dashboard	Yes	Yes	Yes	No	Yes	2017
Metropolitan Transportation Commission	Vital Signs	Yes	Yes	Yes	No	Yes	2017
Chicago Metropolitan Agency for Planning	Regional Economic Indicators Website	No	Yes	Yes	No	No	2017
South Carolina DOT	Performance Dashboard	Yes	Yes	No	No	Yes	2017
Southern California Association of Governments	Performance Measures Appendix to Regional Transportation Plan	Yes	Yes	Yes	No	Yes	2016
Delaware Valley Regional Planning Commission	Comprehensive Economic Development Strategy Performance Measure Website	Yes	Yes	Yes	No	No	2016

The Metropolitan Transportation Commission (MTC) is the transportation planning and coordinating agency for the nine-county San Francisco Bay area. MTC developed Vital Signs, an interactive website that tracks factors related to transportation land use, the environment, the economy, and social equity. Travel demand is measured with daily miles traveled and the site also tracks other factors such as population, mode of travel, unemployment, fatalities, home prices, income, and economic output (regional domestic product).

The Chicago Metropolitan Agency for Planning (CMAP) is the regional planning organization for the Northeastern Illinois counties of Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will. As a part of their comprehensive regional plan the agency develops coordinated strategies that help address issues related to transportation, housing, economic development, and other quality of life issues. The CMAP website has multiple pages of statistics that track or provide a recent history of factor areas such as household income, unemployment, education, workforce participation, congestion, and freight.

South Carolina DOT produces a performance dashboard that displays statistics of different measures in the areas of economy, mobility, preservation, safety, and strategic planning. Specific measures include, freight reliability and delay, interstate reliability and delay, fatalities and serious injuries, bicycle and pedestrian fatalities.

Southern California Association of Governments published a list of performance measures as an appendix to their Regional Transportation Plan/Sustainable Communities Strategy. The Plan is a long-range visioning plan that balances future mobility and housing needs with economic, environmental and public health goals. As a part of the vision, performance measures are identified as well as the measure definition and source.

The greater Philadelphia area MPO, Delaware Valley Regional Planning Commission, as a part of their Comprehensive Economic Development Strategy, tracks performance measures in the areas of unemployment, income, population, construction, mode of travel, vehicle miles travelled, air quality, tourism, housing affordability, job growth, regional domestic product, and volume and tonnage of freight.

STATISTICAL ANALYSIS OF POSSIBLE EXTERNAL FACTORS

To estimate the effect of external factors on highway performance measures both spatial and temporal dependencies need to be addressed accordingly. External factors such as social-economic changes or weather may be subject to spatial or geographical limitations. The temporal relationship between the change in an external factor and the manifestation of its effect in highway performance measures, as well as the persistence or duration of the effect, is another aspect. External factors may affect highway performance immediately, or may only have an effect after a lag time or after a period of persistent stimulus. Such a relationship is referred as *dynamic relationship*. The researchers used several statistical tools to address the multivariate dynamic process to:

- Identify the external factors that have temporal and spatial impact on the performance measures.
- Identify the factors that have lagged effects.
- Quantify the relationships.

Multivariate methods for time series analyses such as vector autoregressive and state space models are widely used in econometrics. In addition to describing the time-varying response of dependent highway performance variables, these techniques enable a researcher to quantify the time-dependent effects of exogenous (input) factors on the endogenous (output) variables. Endogenous variables are the processes that are determined inside of the system of interest while the exogenous (or independent) variables are determined outside of the system. For example, the travel time index across the 51 metropolitan statistical areas is the multivariate endogenous factors, while the monthly traffic volume and gross domestic project of these areas are exogenous factors.

The relationship between the performance measures in this study and external factors are formulated in the following way:

Vector form:

$$\begin{pmatrix} y_{PM_1,MSA_1,t} \\ y_{PM_1,MSA_2,t} \\ \cdots \\ y_{PM_1,MSA_{51},t} \end{pmatrix} = \Phi^1 \times \begin{pmatrix} y_{PM_1,MSA_1,t-1} \\ y_{PM_1,MSA_2,t-1} \\ \cdots \\ y_{PM_1,MSA_{51},t-1} \end{pmatrix} + B^0 \times \begin{bmatrix} x_{1,MSA_1,t} & \cdots & x_{K,MSA_1,t} \\ x_{1,MSA_2,t} & & x_{K,MSA_2,t} \\ \vdots & \ddots & \vdots \\ x_{1,MSA_{51},t} & \cdots & x_{K,MSA_{51},t} \end{bmatrix} + \tag{1}$$

$$+B^1 \times \begin{bmatrix} x_{1,MSA_1,t-1} & \cdots & x_{K,MSA_1,t-1} \\ x_{1,MSA_2,t-1} & & x_{K,MSA_2,t-1} \\ \vdots & \ddots & \vdots \\ x_{1,MSA_{51},t-1} & \cdots & x_{K,MSA_{51},t-1} \end{bmatrix} + \begin{pmatrix} \varepsilon_{MSA_1,t} \\ \varepsilon_{MSA_2,t} \\ \cdots \\ \varepsilon_{MSA_3,t} \end{pmatrix}$$

Matrix form:

$$Y_{PM,t} = \Phi^1 \times Y_{PM,t-1} + B^0 \times X_{K,t} + B^1 \times X_{K,t-1} + E_t \tag{2}$$

Where,

- $Y_{PM,t}$ – is the performance measures vector on date t.
- PM – is the performance measure index (3 in total).
- $X_{K,t}$ – is the matrix of K external factors on date t.
- $X_{K,t-1}$ – is the matrix of K external factors on date $t-1$.
- MSA – is the metropolitan statistical area index (51 in total).
- Φ^1 – is the matrix of autoregressive coefficients where 1 refers to the number of past values (1 for one month, 2 for two months, etc.)

- B^0 – is the matrix of coefficients of external factors whose present values influence the performance measures.
- B^1 – is the matrix of coefficients of external factors whose past values influence the performance measures. These factors are referred as *leading indicators*.
- E_t – is the vector of unobserved error term.

Modeling the multivariate dynamic models can become computationally costly. Therefore, the researchers applied several multivariate tools to make the process relatively easier to execute. The steps taken to conduct the statistical analysis are described in Figure 10. Researchers used PCA to reduce the data dimensionality.[(1)] After reducing the multivariate data researchers have conducted Granger causality test to identify the most influential external factors affecting the performance measures.[(2)] This analysis was conducted for each performance measure individually. As the result of this process the researchers obtained the preliminary list of the influential external factors. Each external factor's present and lagged effects were examined as well.

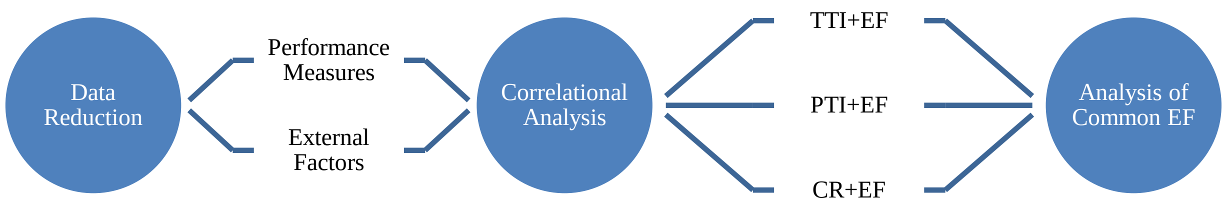


Figure 10. Chart. Statistical Analysis Methodology.

To identify the final list of the influential external factors, the researchers selected the variables that were found to be influential for at least two performance measures. After identifying the list of five influential factors, authors conducted a Dynamic Panel Data (DPD) analysis of the three performance measures.[(3)]

Figure 11 shows the performance measures in this study across the three MSAs: Austin, Baltimore and Chicago. The time series plots indicate similarities among the same performance measures across the MSAs while the correlation plots indicate that the performance measures of different MSAs are correlated.

To observe the trend and seasonality, the time series were decomposed into the unobserved components using the state space models as shown in Figure 12. Note that the example only shows Austin data.

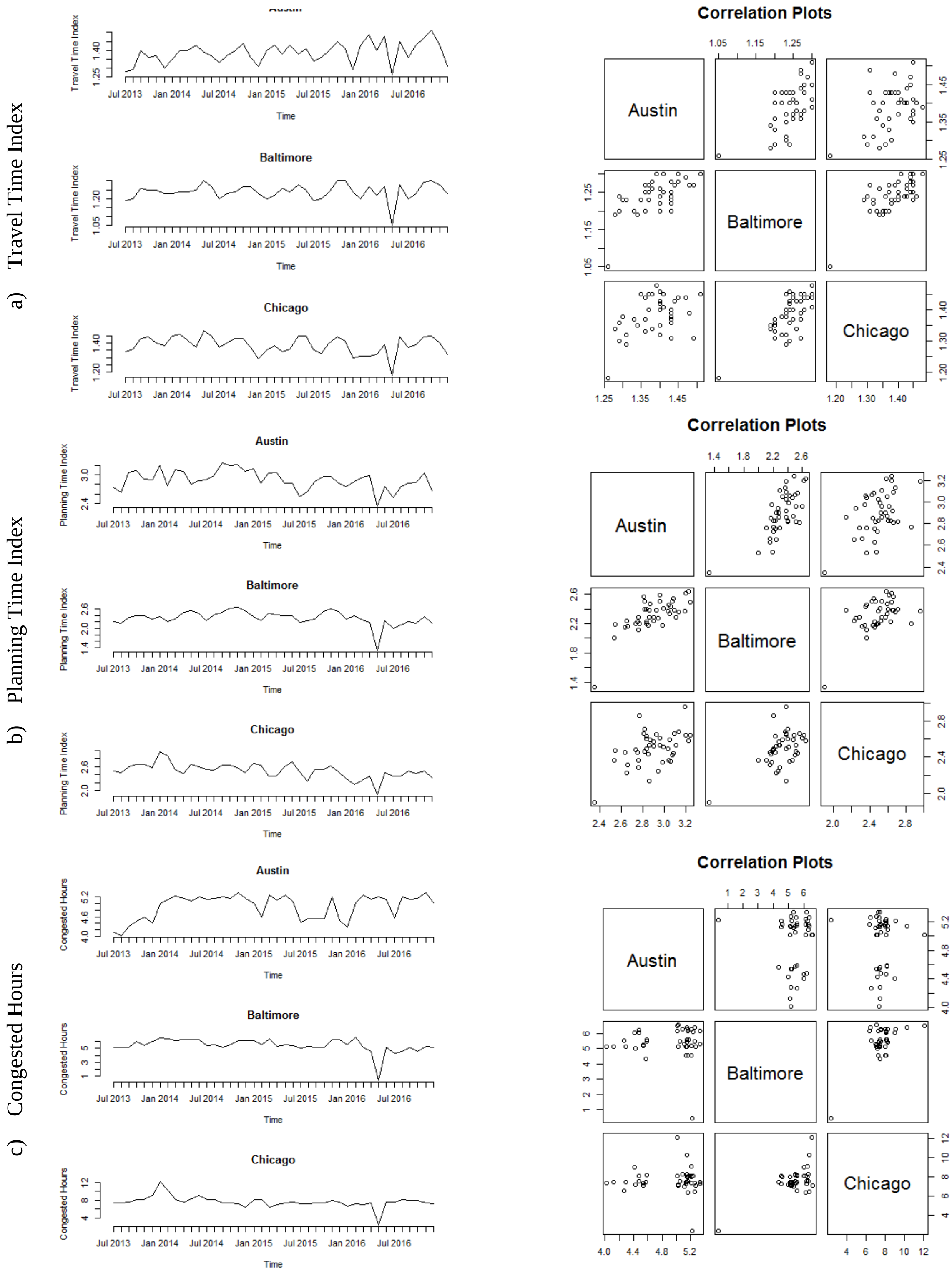
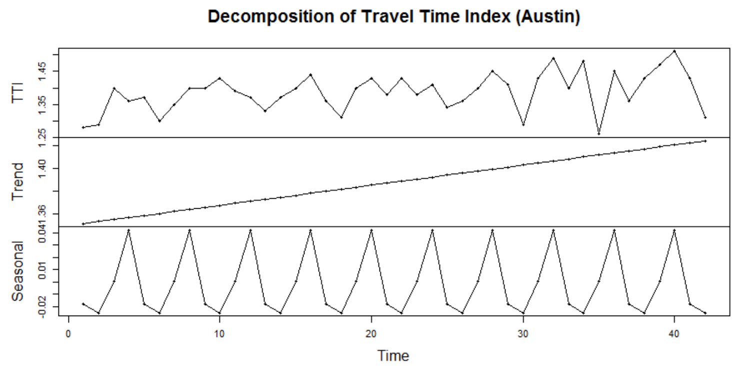
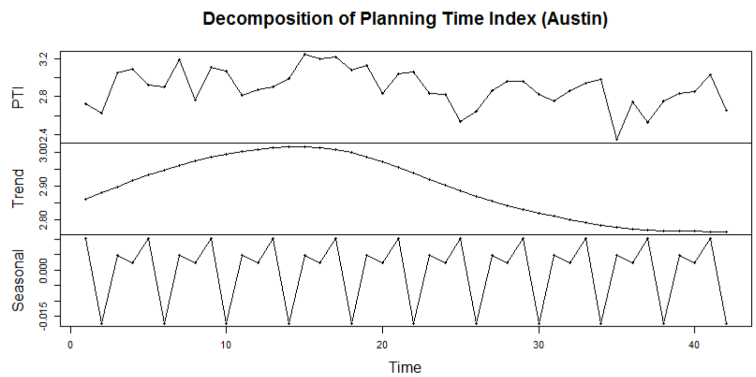


Figure 11. Chart. Time Series and Scatter Plots of Performance Measures.

a) Travel Time Index



b) Planning Time Index



c) Congested Hours

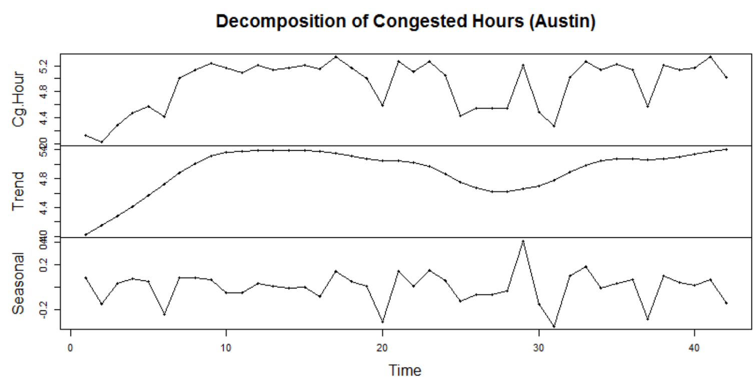


Figure 12. Chart. Trend and Seasonality Decomposition of Performance Measures (Austin).

Selection of Most Influential External Factors

To select the influential factors, the dimension of multivariate data was reduced using the principal components analysis. Granger causality method was later applied to identify the most influential factors and their lagged effects on each performance measure.

PCA was used to reduce the dimension of the performance measures and the external factors. As shown in Figure 13, most of the variability in performance measures across the 51 MSAs are explained by the first and second PCA. Looking at the time series plots of the variances we can observe that the series are marginally stationary.

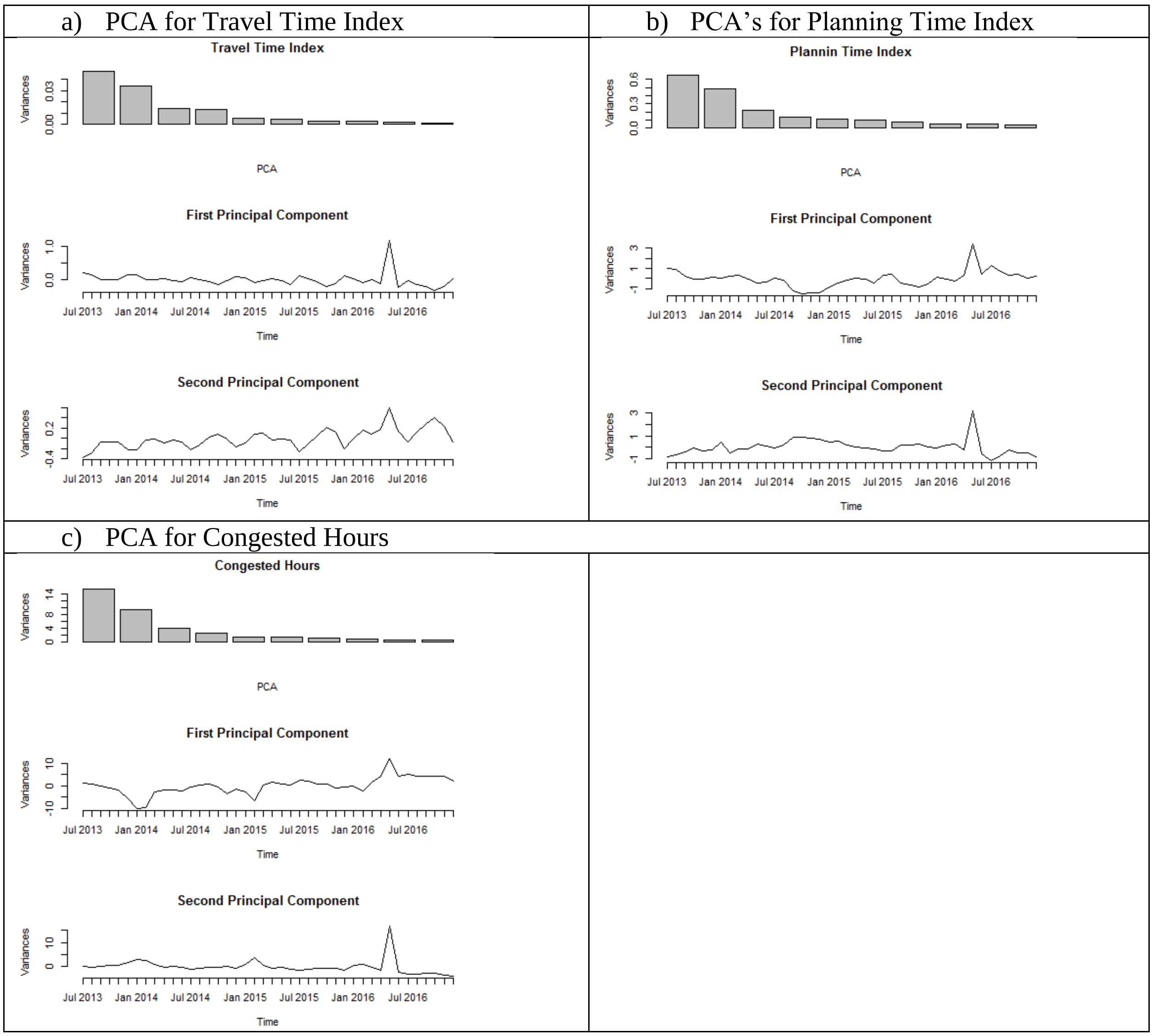


Figure 13. Chart. Principal Component Analysis of Performance Measures.

The PCA of the external factors were computed using the natural logarithms to normalize the data. For the majority of the external factors, the first PCA is able to account for most of the variability among the external factors (Figure 14).

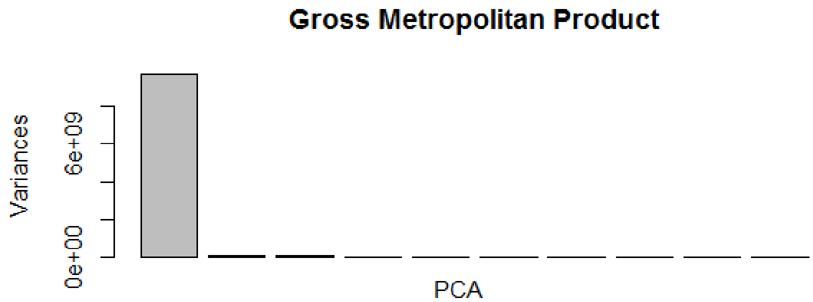


Figure 14. Graphic. PCA for GMP.

For some other variables such as MADT, more than one PCA was found to be important to explain the correlation among the multivariate series (Figure 15). However, when inspecting the first four PCA’s, it can be observed that the first PCA is a stationary series (i.e., the series oscillates around the mean). As the PCA order increases the series becomes less stationary and more stochastic thus indicating that the series can be reduced to one PCA only. As the conclusion, only the first order PCA of all variables was used for the empirical analysis.

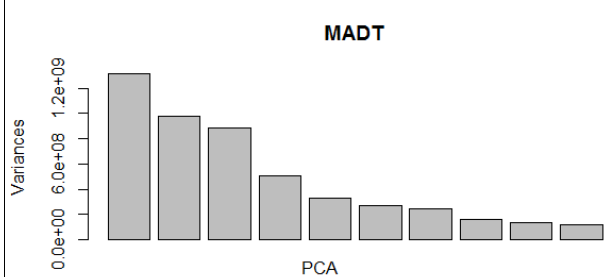
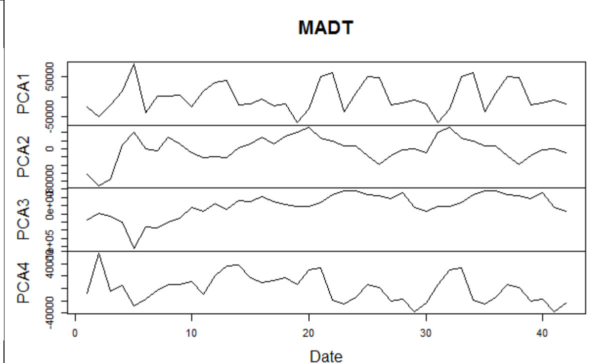
a) PCA Histograms	b) PCA Series
	

Figure 15. Chart. PCA Plots of MADT

Granger Causality was applied to identify the most significant influential factors. The effects of both current and lagged effects (up to three lags) of the external factors are examined using the Granger test. The results are shown in Table 6. In this table only the marginally significant ($p-value < 0.5$) results have been reported. As it can be observed among the most significant external factors, the variables MADT, economic conditions index, number of employed, fuel price index, rental vacancy rate and total building permits appear to influence all three performance measures significantly. Leading effects indicate that the effect takes place after the indicated number of months, e.g., any changes in the economic condition index of the MSA will affect the travel time after one to three months. The descriptive statistics of the selected variables are also shown in Table 6.

Table 6. List of Selected External Factors.

Travel Time Index				**Planning Time Index**				**Congested Hours**			
External Factor	*Leading Effects*	*Granger Coefficient*	*P-Value*	*External Factor*	*Leading Effects*	*Granger Coefficient*	*P-Value*	*External Factor*	*Leading Effects*	*Granger Coefficient*	*P-Value*
MADT*	0	2.61	0.11	MADT	0	5.28	0.03	MADT	0	7.32	0.01
Economic Conditions Index*	1 – 3 months	6.72	0.00	Economic Conditions Index	1 – 3 months	3.35	0.03	Economic Conditions Index	1 – 3 months	3.19	0.04
				Real Estate GDP	0	3.35	0.08				
				Number of Unemployed	0	3.05	0.09				
Number of Employed*	0	2.41	0.13	Number of Employed	0	1.48	0.23	Number of Employed	0	2.38	0.13
Fuel Price Index*	1 – 3 months	2.15	0.11	Fuel Price Index	1 – 3 months	2.37	0.09	Fuel Price Index	1 – 3 months	4.64	0.02
Rental Vacancy Rate*	0	2.56	0.12	Rental Vacancy Rate	0	2.36	0.09	Rental Vacancy Rate	0	6.58	0.01
Home owner Rate	0	3.03	0.09					Home owner Rate	2	13.32	0.00
								Rent Price	2	8.08	0.00
Total Building Permits*	0 – 1 month	6.66	0.01	Total Building Permits	0 – 1 month	1.07	0.30	Total Building Permits	0 – 1 month	3.53	0.06
Single-Family BP	0	5.89	0.02								
								Population Change	2	7.55	0.00
				Average Temperature	3	1.67	0.19	Average Temperature	0	5.36	0.03

*External Factors selected for the analysis. Note: only significant factors are included in the table.

The results of the causality analysis indicate that the variables MADT, economic conditions index, number of employed, fuel price index, rental vacancy rate and total building permits are the most influential external factors. The economic conditions and fuel price indices have a leading effect (1 to 3 months) on the performance measures.

PRESENTATION AND CHART BEST PRACTICES

When creating visuals, specifically charts, graphs, and dashboards, care should be given to not only what data and information is displayed to the reader, but also how the chart visually appears. Giving thought to the layout, design, coloring, and formatting of a chart will help to effectively communicate the desired message.

The following principles should be followed to create visualizations that look professional, convey your particular message, and engage your identified audience.

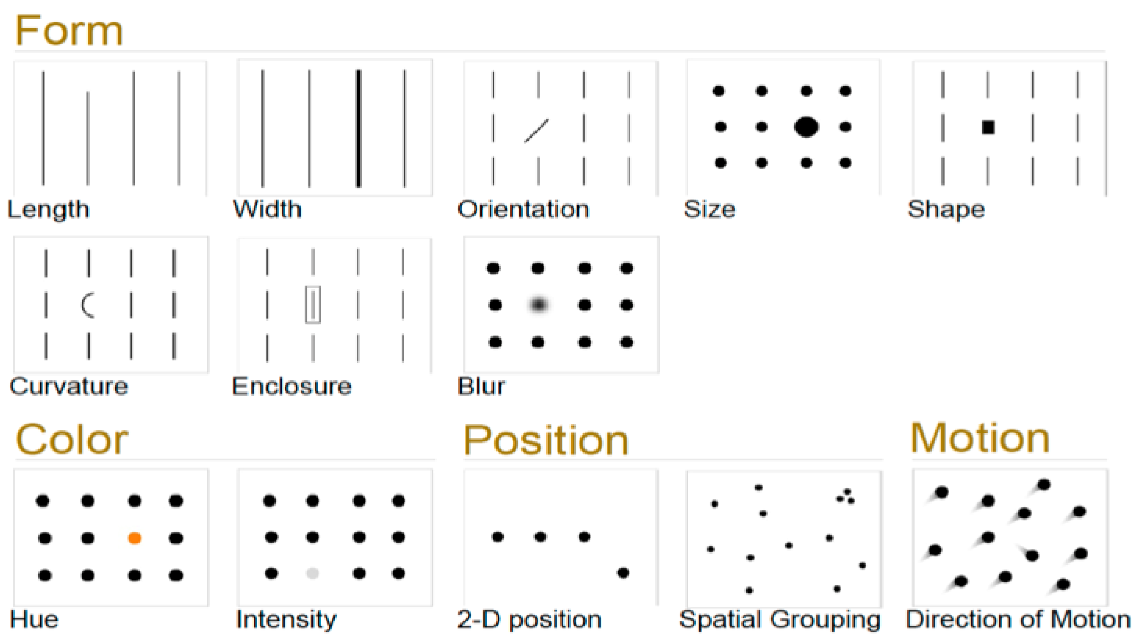
Understand How People Process Information

Creating good visualizations requires that one understands how humans generally process and interpret information, on both a conscious and subconscious level, and then leverages this knowledge into a graphic.

First, we naturally approach visualizations with one of two primary goals: to explain or answer specific questions about something or to explore and glean valuable insights thereby increasing understanding.(4) In the latter, the viewer creates his own questions to answer based on the information seen. These two approaches are directly related to the type of audience and the intended message discussed earlier.

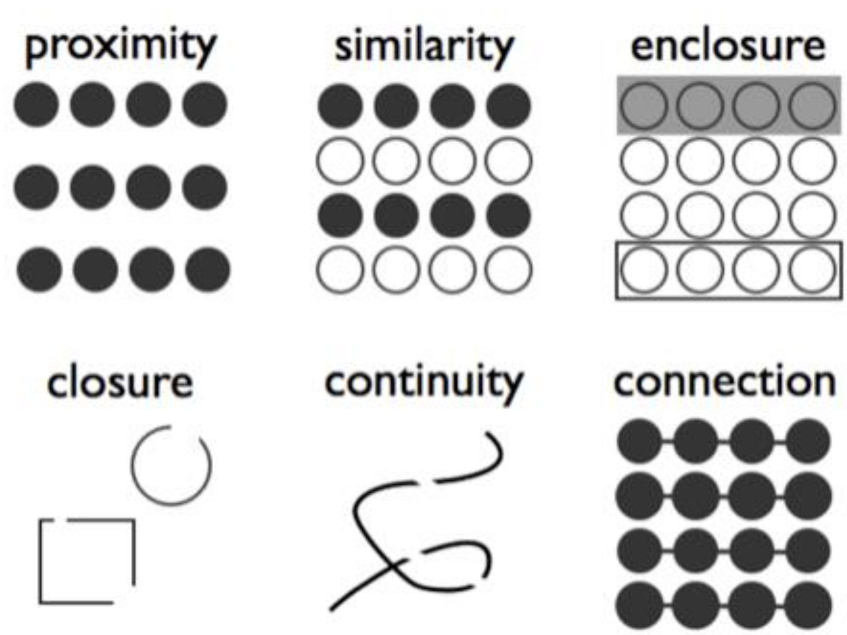
Second, how we approach visualizations (what we see) is heavily influenced by memory. Our long-term memory makes us expect a visualization to work a certain way (e.g., the lowest value to be zero and each increment equally spaced). We expect things to flow from left to right or more important elements to be bigger, darker, or otherwise distinguished. Separately, our working memory continually breaks information into small chunks (usually about three at a time) to process.(5) Any more information than this at one time can lead to information overload and a loss or confusion of the message. In short, keep it simple.

Third, our brains are trained to recognize patterns and differences. Psychologists have created two primary theories for how we do this. First are those things that catch our eye or ‘Preattentive attributes’.(6,7) These are subtle differences in patterns, colors, and position that the eye can perceive in about 10 milliseconds (see Figure 16). These attributes help our brains form patterns and organize information, leading to the second theory. The Gestalt Principle of grouping describes how our brains organize and describe information in groups similar to one another.(8) This principle also allows our brains to highlight important information and weed out noise that may distract from the primary message. Figure 17 illustrates the most common Gestalt principles.



Source: Few 2012[(9)]

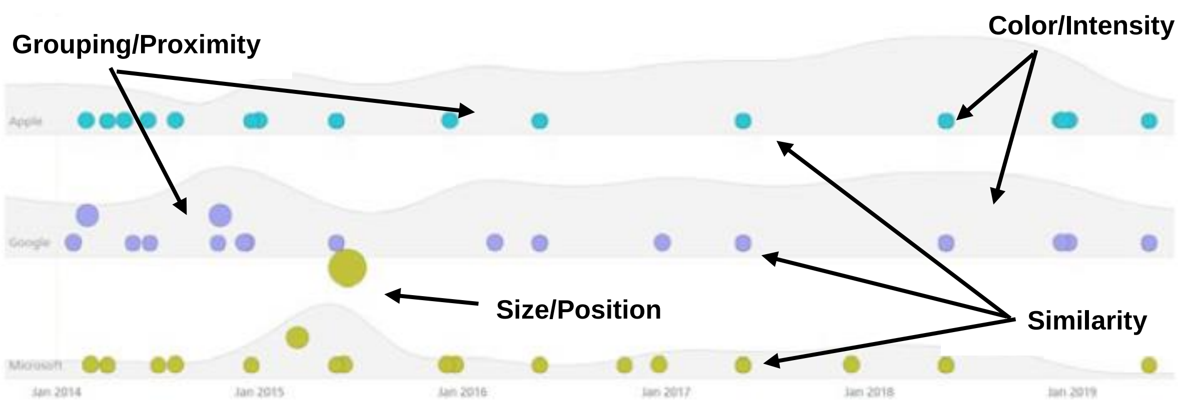
Figure 16. Graphic. Pre-attentive Attributes of Visual Perception.



Source: http://www.fusioncharts.com/whitepapers/downloads/Principles-of-Data-Visualization.pdf

Figure 17. Graphic. Gestalt Principles of Grouping.

Figure 18 illustrates how these abstract principles operate in a chart.[8] First, note how the primary points of interest are colored dots against the grey of the full data sets for three data series and each series uses a different color (color, similarity, and intensity). Second, each dot utilizes size to convey information about that point (size). The dots' positions also give information for the series, drawing the eye to variances (the large yellow dot above the grey line) to groupings or clusters (proximity and spatial grouping). This chart type effectively uses colors, spatial orientation, size, proximity, enclosure, and similarity to effectively convey a vast amount of information, even though you fundamentally don't know much about what the data represent.



Source: http://www.fusioncharts.com/whitepapers/downloads/Principles-of-Data-Visualization.pdf

Figure 18: Graphic. Example of Preattentive Attributes and Gestalt Principles in Action

Keeping these three principles in mind will not only help you design engaging visualizations, but will also ensure that your message is properly conveyed.

Choose the Right Graphic

The first and often most overlooked step in creating a visualization is to decide what type of graphic should be used. While in the case of external factors your options may be limited, there are several different types of graphics that can be used depending upon your intended use and message. Marketing professionals have understood this for years and offer recommendations based on what type of message and analysis is being made.[9] The following bullets present suggestions of chart types based on intent:

- Value Comparisons: Column, bar, circular area line, scatter plot, bullet.
- Composition: Pie, stacked bar, stacked column, area, waterfall.
- Distributions: Scatter plot, line, column, bar.
- Trend Analysis: Line, dual-axis line, column.
- Relationships: Scatter, bubble, line, heat maps, bump.

Note that this list is not exhaustive; there are several other types of charts that may also be used depending upon what information and message is desired. Avoid using pie charts, if possible, as they do not adequately allow the reader to comprehend the size differences if more than 3 or 4 categories are represented.

Depending on the audience and intended use, other media such as graphic art, video, or infographics may also be a suitable choice. Regardless of chart type, making the right selection will likely be the biggest factor in increasing understandability and decreasing the chance of an unclear or mixed message.

Do More with Less: Lines and Colors

Before discussing the details of the data itself, addressing the graphic from a visual standpoint will help guide its creation as data are included. Note that the process of building a chart is iterative; there is a constant need to adjust the focus on the data and design to create a graphic that clearly conveys the message to the target audience.

Lines

With all charts, ***use as few lines and elements as possible***. If nothing else is followed, this one guiding principle should be paramount over any other. Default excel charts add superfluous lines, shapes, and visual noise that distract from the intended message. Carefully consider what lines actually are necessary and give meaning. If a line or element does not give specific meaning to the chart, eliminate it. This can include:

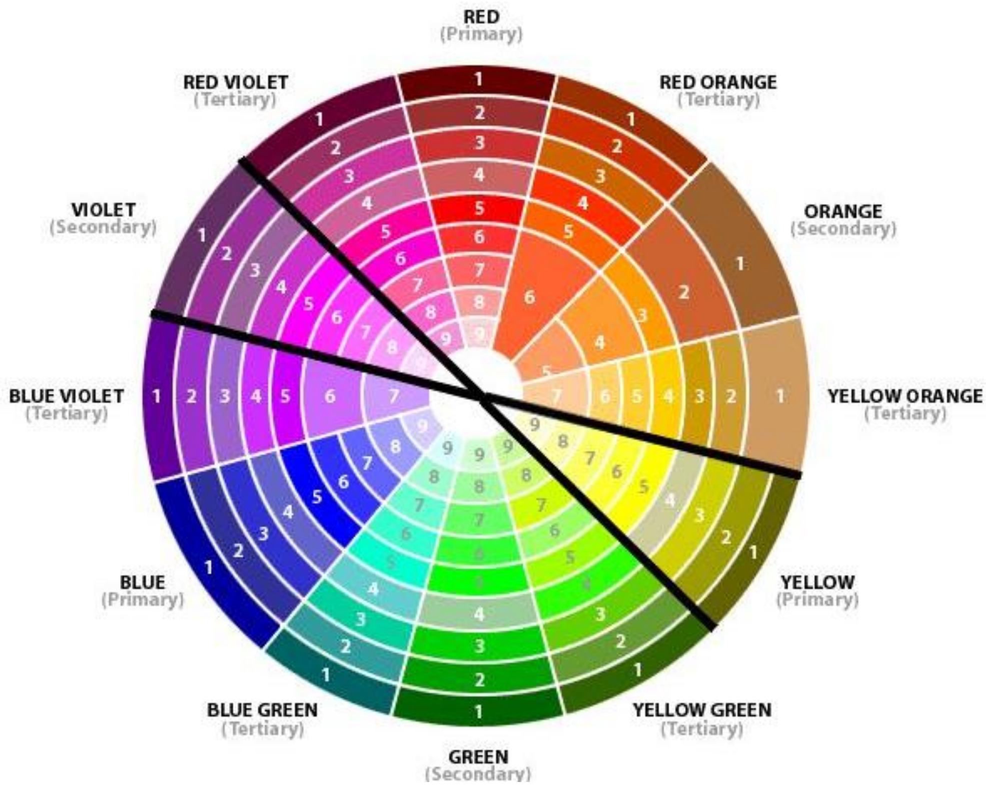
- Borders.
- 3D Char effects.
- Unnecessary tick marks.
- Gridlines.
- Trend lines (unless specifically needed).
- Unnecessary axes that lack value.
- Too many labels or legends.

Color

Using color is integral to creating engaging visualizations. Color can easily convey where data trends improved, worsened, or stayed neutral; can signify direction; or can classify groups and categories. However, there are a few simple concepts to ensure the use of color is maximized in a visualization.

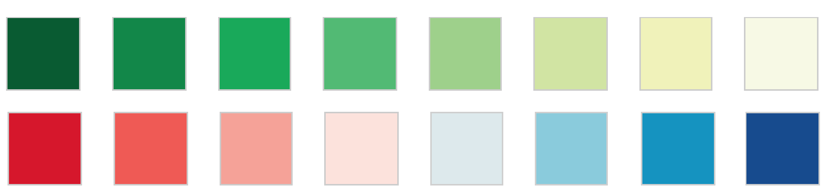
1. Use colors people can see. Be sure to use colors and color pairings that allow color-blind people to still see differences. Use specialized color-blind palates and pairing, avoiding red and green combinations for red and blue. Additionally, think about how colors may appear if printed with a black and white printer.

Use complementary colors. Avoid using color combinations that are difficult to distinguish to the eye. Instead, use colors that are opposite from each other on the color wheel (except red and green). Figure 19 displays a color wheel one can use to find complementary colors. Simply choose an initial color and match it with a color on the opposite side. Use medium intensity colors for the base color, reserving sharper and lighter hues to highlight relevant or irrelevant information.[10] Use diverging or dual-ordered palettes to visualize a range or good to bad scales (or other extremes). Figure 19 illustrates complementary colors, while Figure 20 exemplifies dual-ordered colors.



Source: https://www.doobert.com/complementary-colors/

Figure 19. Graphic. Sample Complementary Color Wheel.



Source: Few 2012[9]

Figure 20. Graphic. Ordered and Dual-Ordered Color Palettes.

2. Use colors in a theme. Display the same type of information with the same color. This uses the preattentive attribute to allow the brain to quickly associate what different data are without needing to refer to a legend. Use ordered color palettes (color from light to dark) of the same color to show intensity.

   Also, try to match colors in charts to other color shades in the document or website. If there is a particular palette used in the logo or theme, continuing that palette will keep the focus on the visualization's message.

3. When in doubt, grey it out. The use of grey can be powerful in pointing something out in the data. Broadly, grey should be used for axis lines, tick marks, and other necessary chart markers. Grey can also be used to make a statement: make an entire chart different shades of grey with one or two elements colored. This will make those elements pop and draw the eye.

Chart Elements, Legends, and Labels

Chart elements are anything other than a legend or data/axis labels that are included in a chart. Chart elements may, for example, include equations, explanatory text, arrows, or other marks. In general, a similar rule applies as for lines: less is better, unless necessary. This rule also applies for legends and labels: every chart should have these, but eliminate unnecessary text. Keeping your chart focused, well organized, and clean will keep the reader on task and your message from being lost.[10, 11]

Axes

Every chart should have both axes labeled with equally-spaced tick marks. Axis lines and major gridlines (if necessary for clarity) should appear in grey, allowing the data to pop. The vertical axis should always start at zero, with both axes maintaining appropriate aspect ratios. Distortion in width and height can make trends in the data appear more or less severe.

In dual axis charts (with a set of bars and a line both meaning different things), extra consideration should be given to add clarity as to which data refer with which axis.

Legends

Every chart, no matter how intuitive, should have a legend of some kind. Legends can be free-floating in an open area or as labels directly adjacent to the lines or bars. Either way, it should be clear what each line or bar means and to what they correspond.

Labels

Data in charts should have labels, either directly next to the points or in a data table below the chart that corresponds with the information. Be careful not to overwhelm the reader with information; sometimes, it may be better to only include labels for relevant or important data points, depending upon your message.

Titles

All charts should have a title. Titles should be descriptive, succinct, and convey some or all of the message the reader should obtain.

Data

Before creating a chart, be sure to sort the data in ascending or descending order, unless the order of the category matters. For time series data, ensure equal spacing, even if intermittent time periods are included (or consider excluding those periods).

Consider seasonally adjusting data in order to make comparisons at intervals of less than one year. Without seasonal adjustment, only annual comparisons are appropriate, hindering the reader from understanding changes in the data.

Round data labels and figures to the nearest significant figure. If in millions or billions, consider shortening or adding an “M” or “B” after a two-digit number.

If data series are being stacked on the same graph, be sure to align each series with the other. The one exception to this is if there is a noted lead or lag that is part of the intended message. If so, this should be clearly and overtly displayed.

REFERENCES FOR APPENDIX

1. Peña D. and A. Poncela. 2006. Dimension Reduction in Multivariate Time Series: Chapter in Advances in Distribution Theory, Order Statistics, and Inference. *Springer* 2006.
2. Granger C. W. J. 1991. Causality, cointegration and control. *Journal of Economic Dynamics and Control*. Vol. 12, 1991, pp. 551-559.
3. Arellano M. and S. Bond. 1991. Some tests of specification for Panel Data. *Review of Economic Studies*, Vol. 58, pp. 277-297.
4. Fusion Charts. *Principles of Data Visualization – What We See in a Visual*. http://www.fusioncharts.com/whitepapers/downloads/Principles-of-Data-Visualization.pdf. Accessed September 4, 2017.
5. Ware, C. Information Visualization, 3rd Edition. Morgan Kaufmann, 2012.
6. Preattentive Visual Properties and How to Use Them in Information Visualization. Interaction Design Foundation, 2016. https://www.interaction-design.org/literature/article/preattentive-visual-properties-and-how-to-use-them-in-information-visualization. Accessed September 4, 2017.
7. Goldstein, B. Perceiving Objects and Scenes: The Gestalt Approach to Object Perception. *Sensation and Perception*, 8th Edition. Cengage Learning, 2009.
8. Oetting, J. *Data Visualization 101: How to Choose the Right Chart or Graph for Your Data*. HubSpot Marketing, 2016. https://blog.hubspot.com/marketing/data-visualization-choosing-chart. Accessed September 7, 2017.
9. Few, Stephen. *Show Me the Numbers: Designing Tables and Graphs to Enlighten*. Analytics Press, 2012.
10. Tufte, E. *The Visual Display of Quantitative Information*, 2nd Edition. Graphic Press, 2001.
11. Peltier, J. Ten Chart Design Principles: Guest Post. Peltier Technical Services, Inc. 2008. https://peltiertech.com/ten-chart-design-principles-guest-post/. Accessed September 5, 2017.

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