A DEMONSTRATION OF ROBUST DECISION MAKING (RDM) At SACOG

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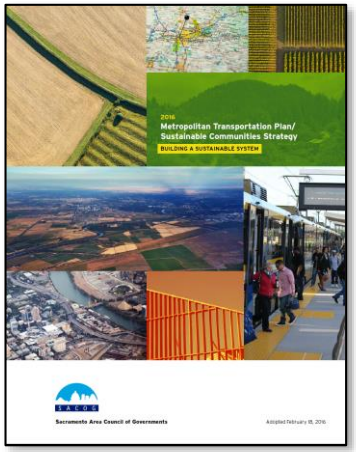
Metropolitan Planning Organizations (MPOs) Use Predictions to Craft Long-Range Plans

Multidecadal forecasts of future conditions:

- Demographic
- Economic
- Technological
- Regulatory
- Behavorial

Regional Transportation Plan



Traditional Prediction-Based Planning Methods May No Longer Be Adequate to the Task

- Problems with prediction-based approaches include:
  - Use of projected transportation demand, which depends on variables and processes not be directly measured or simulated
  - Neglect of exogenous factors, such as fuel prices, economic shocks, or deviations from past trends in technology or behavior
  - Have often proven inaccurate!

Traditional Prediction-Based Planning Methods May No Longer Be Adequate to the Task

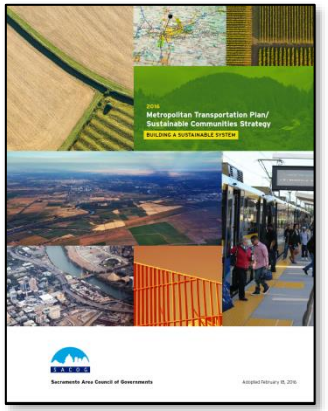
Why Do MPOs Use Predictions?

- Prediction-based approaches
  - Required by law
  - Follow established practice
- Some audiences demand predictions
- Perceived lack of alternatives

This Study Explores an Alternative Called Robust Decision Making (RDM)

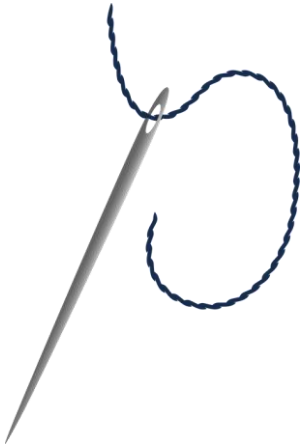
- Stress test SACOG's 2016 RTP/SCS over many futures
  - Use results to identify key vulnerabilities and potential responses
- Particularly interesting example
  - SACOG faces significant challenge of preserving mobility while
  - Meeting emission reduction goals, including those in Senate Bill 375

SACOG's 2016 Regional Transportation Plan/Sustainable Community Strategy



Lempert, R., J. Syme, G. Mazur, D. Knopman, G. Ballard-Rosa, K. Lizon and I. Edochie (2020) *Meeting Climate, Mobility, and Equity Goals in Transportation Planning Under Wide-Ranging Scenarios: A Demonstration of Robust Decision Making.* Journal of the American Planning Association

We Find That….

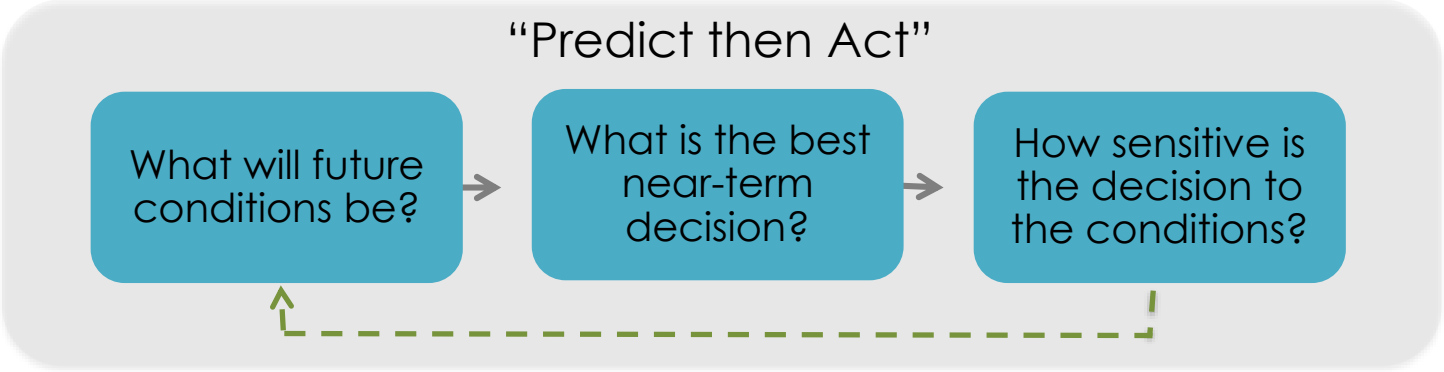


- Meeting emissions & mobility goals depends strongly on assumptions about economic growth, fuel prices, and fuel efficiency (factors often held constant)
- Simultaneously achieving mobility and emission goals is difficult
- RDM's promise in long-range planning, but model improvements needed

Outline

- **Robust Decision Making**
- SACOGs 2016 RTP/SCS
- RDM Framing and Stress Test
- RDM Policy responses
- Conclusions and next steps

Traditional Planning Works Well When Uncertainty is Limited



Predict

Act

“Predict then Act” Can Break Down When Uncertainties are Deep

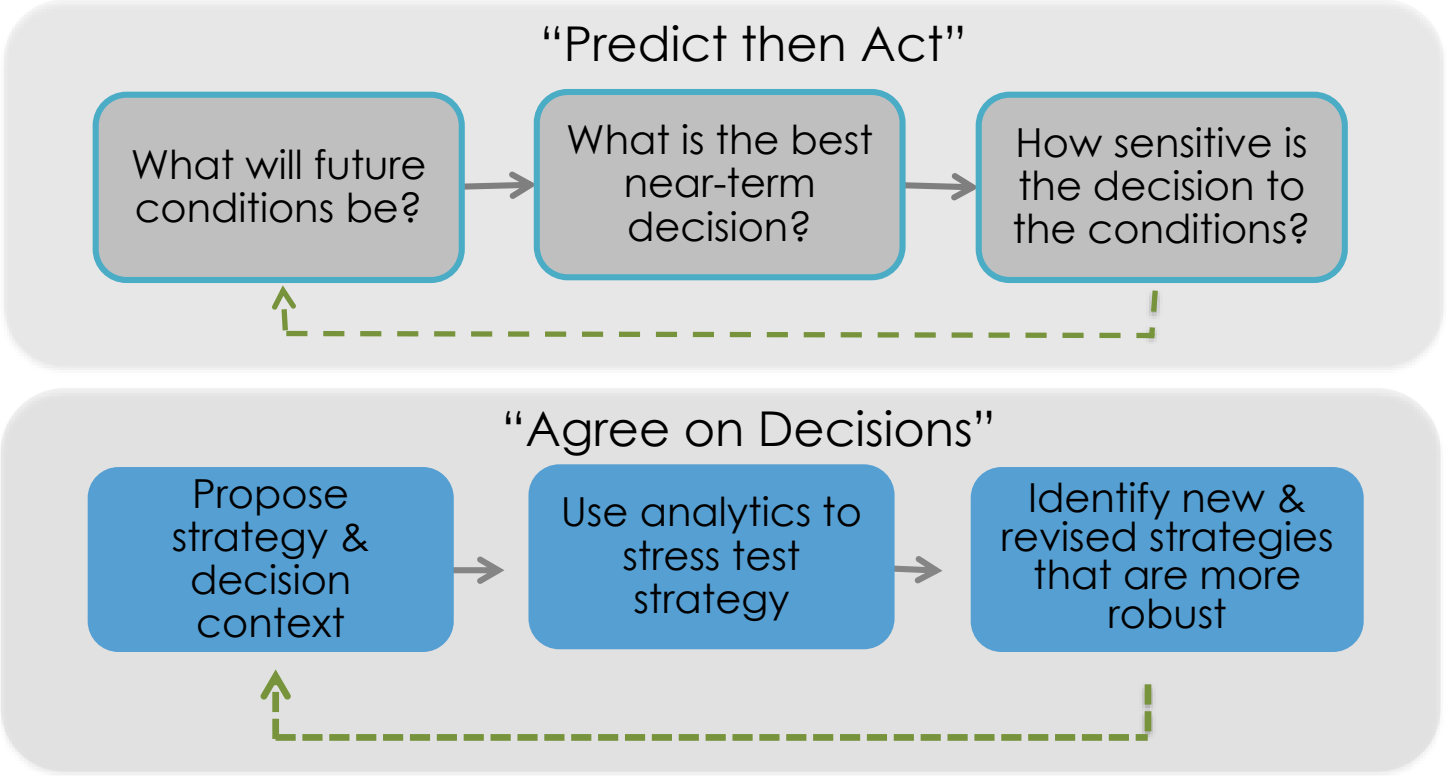
Under conditions of deep uncertainty:

- Uncertainties are often underestimated
- Competing analyses can contribute to gridlock
- Misplaced concreteness can blind decision makers to surprise

Deep uncertainty occurs
when the parties to a decision
do not know or do not agree on
the likelihood of alternative futures
or how actions are related to consequences

Robust Decision Making (RDM) enables risk management
when we can't quantify the risks with confidence

RDM Follows An Alternative Approach for Using Quantitative Information to Inform Decisions



Kalra, N., S. Hallegatte, R. Lempert, C. Brown, A. Fozzard, S. Gill and A. Shah (2014). *Agreeing on Robust Decisions: A New Process for Decision Making Under Deep Uncertainty*. WPS-6906, World Bank.

RDM Rests on a Simple Concept

- **Robust decision-making** (RDM) is an iterative, multi-scenario, multi-objective **decision** analytic framework that aims to:
  - Help identify potential **robust** strategies,
  - Characterize the **vulnerabilities** of such strategies, and
  - Display the **tradeoffs** among them.
- RDM rests on a simple concept.
  - Rather than use computer models and data as predictive tools,
  - RDM runs model thousands to millions of times to:
    - Stress test proposed policies against a wide range of futures, and
    - Uses the results to help decision identify policy-relevant scenarios and strategies robust across those scenarios.

Scenarios Often Used for Planning Under Deep Uncertainty

Scenarios come in three types

Explorative

What might happen?

Predictive

What will happen?

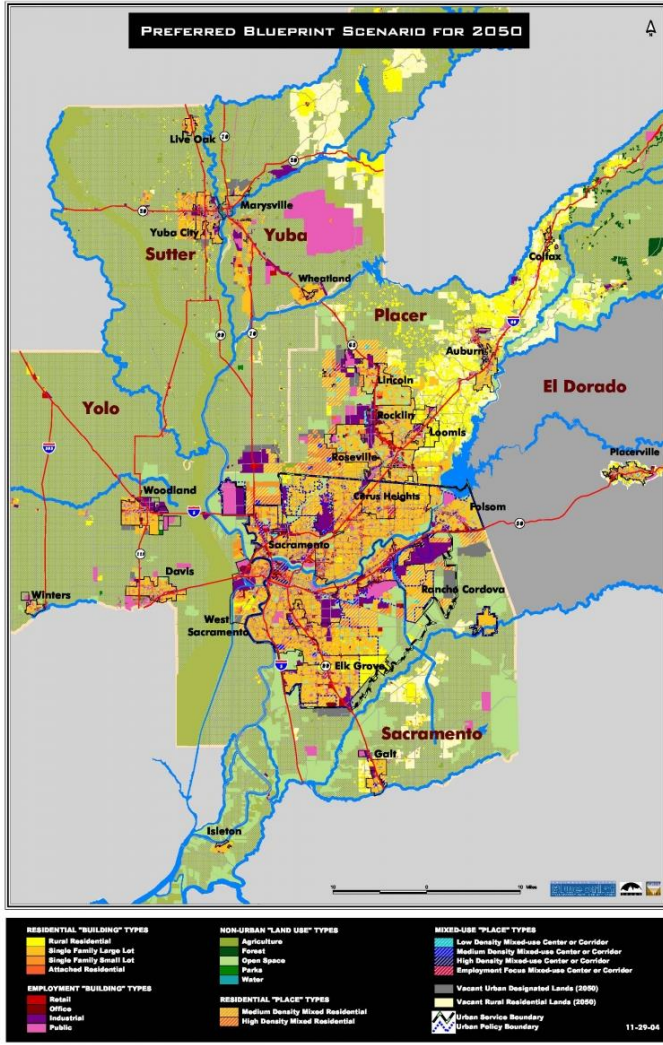
Normative

How might we reach our goals?

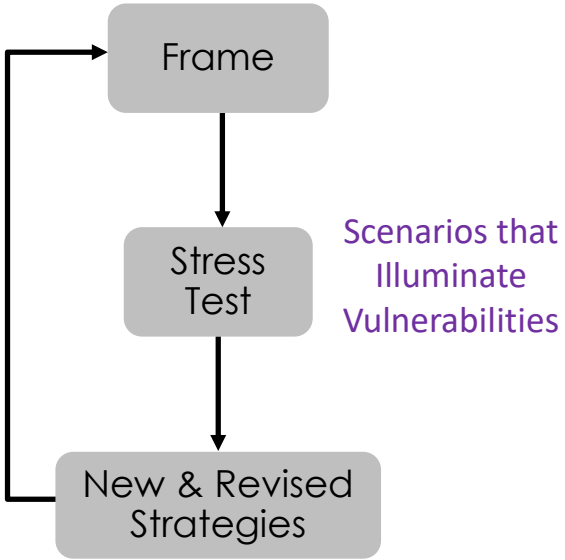
MPOs Generally Employ Normative Scenarios

- Scenario testing with limited # of changes
  - e.g, land use/transportation network
- Less use of exploratory
- ‘Goldilocks’ results

Current MPO scenarios used for predict then act



RDM Employs Exploratory and Normative Scenarios in an Iterative Analytic Process

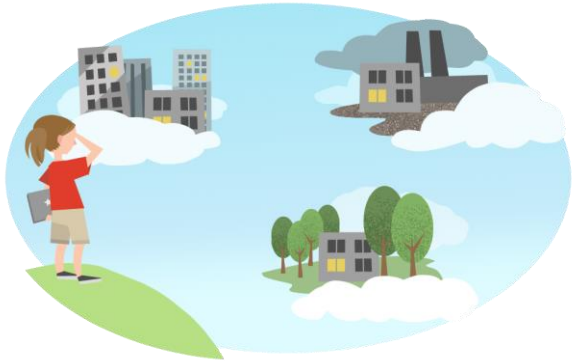


RDM Steps

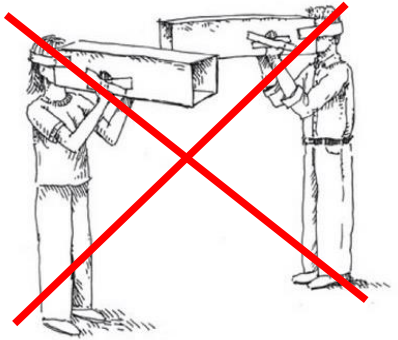
- Frame the decision challenge, including:
  - What are we trying to achieve?
  - What actions might we take to achieve our goals?
  - What uncertainties affect our achieving our goals?
- Stress test proposed strategies over a wide range of futures
  - Identify most important factors affecting whether we meet or miss our goals
- Identify new or revised strategies that meet our goals over a wider range of relevant futures

RDM Helps People Make Better Decisions, Not Better Predictions

Plan over multiple futures

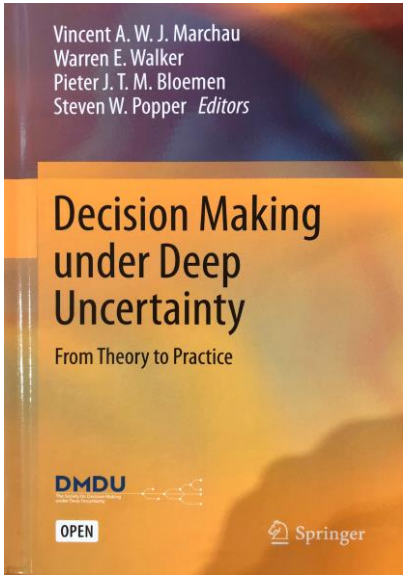


Prediction is perilous



RDM:

- Helps create better plans
- Engages multiple points of view
- Facilitates engagement and consensus among diverse stakeholders



RDM is one approach for Decision Making Under Deep Uncertainty (DMDU)

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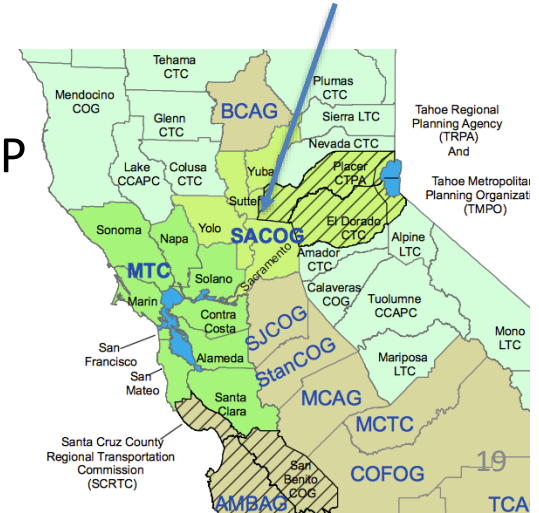
SACOG Long-Range Plan Exemplifies Current Planning Approach

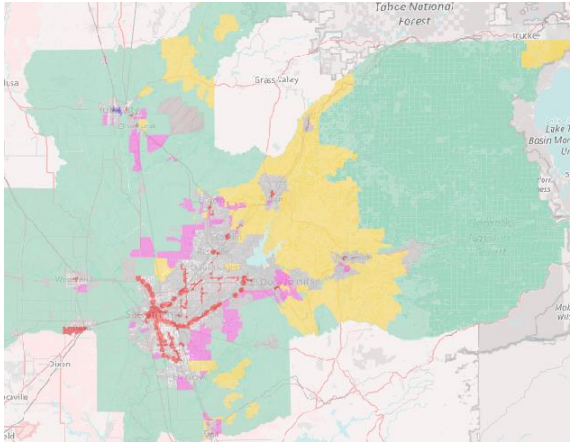
- SACOG is the regional planning agency for the six-county Sacramento area
- SACOG's long range RTP/SCS proactively links land use, air quality, and transportation needs in the Sacramento region, and is updated every 4 years
- Projects/programs that want to use federal transportation funding must be included in the RTP
- Increasingly, streamlining and grant benefits from consistency with the SCS

SACOG



Growth Projections

- How much region will grow?
- Jobs, population, housing
- Demographic and economic trends
- Expert review and sensitivity analysis
- Becomes ‘control total’ in plan



Legend

Community Type and Change from MTP/SCS

- Ag/Other
- Developing or Rural Residential to Ag/Other
- Rural Residential
- Ag/Other to Rural Residential
- Developing
- Ag/Other to Developing
- Downzoned Established
- Established
- Upzoned Established
- Downzoned Center/Corridor
- Center/Corridor
- Upzoned Center/Corridor

Land Use Projections

- How and where region will grow?
- Parcel level analysis
- Market analysis
- Specific plan feasibility
- Local jurisdiction consultation

Transportation Inputs

How will people get around?

Travel demand model

- Parcel level LU and demographic inputs
- Travel behavior
- New modes
- Exogenous factors

Summary of Long-Range Planning

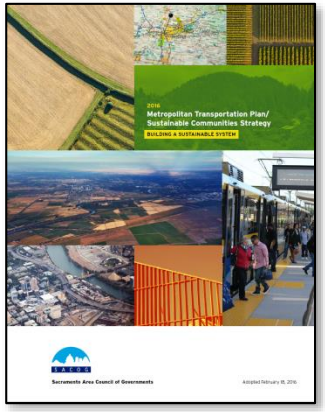
Rigorous assessment of existing conditions, trends, emerging factors

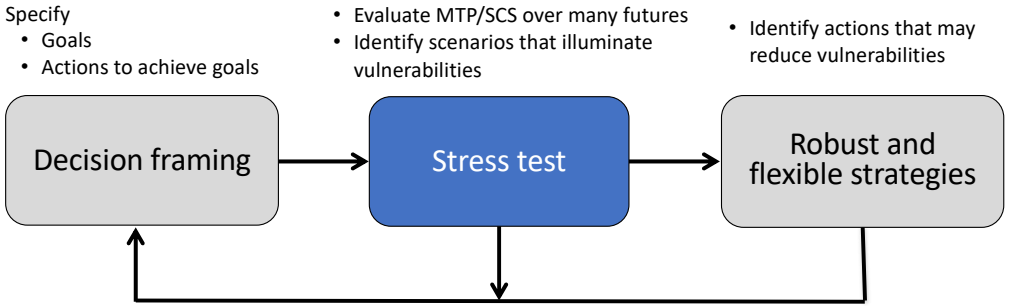
To make predictions

On highly complex urban systems

We Use RDM to Stress Test SACOG's Plan

SACOG's 2016 Regional Transportation Plan/Sustainable Community Strategy





Some key limitations of this demonstration:

- Focus on a few goals of SACOG's RTP/SCS
  - GHG reductions
  - GHG reductions as calculated according to Senate Bill 375
  - Mobility
  - Equity
- Very simple simulation model
- Consider only a few potential responses to vulnerabilities
  - Replacing gas tax with mileage-based fees
  - ZEV penetration

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Structuring RDM Analysis
Key Factors Focus Analysis on Policy Question

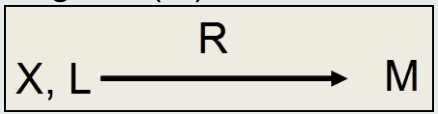
Question: Under what conditions will SACOG's 2016 RTP/SCS meet its goals?

Uncertain Factors (X)	Policy Levers (L)
Relationships (R)	**Performance Metrics (M)**

Frame → Stress Test → New Strategies

Key Factors Focus Analysis on Policy Question

Question: Under what conditions will SACOG's 2016 RTP/SCS me

Uncertain Factors (X)	**Policy Levers (L)**
What uncertain factors outside decision makers' control affect their ability to pursue their goals?	What actions might they take to their goals?
Relationships (R)	**Performance Metrics (M)**
How might policy levers (L) and uncertainties (X) be related to decision makers' goals (M)? 	What are decision makers trying to achieve?

X	L
R	M

Frame → Stress Test → New Strategies

Identify Key Factors In the Analysis

Uncertain factors (X)	Policy Levers (L)
• Gas prices • ZEV market share • Fleet fuel economy • Economic growth • Millennial behavior • VMT elasticity to cost of driving • VMT elasticity to economic growth	• Base case policy - *2016 MTP/SCS* • Response options - Mileage based fee - ZEV penetration
Relationships (R)	**Performance Metrics (M)**
• Cohort model	• Total GHG emissions • SB375 GHG emissions • Mobility • Equity

We Focus on Four Goals

Target values represent projections from current MTP/SCS for year 2036

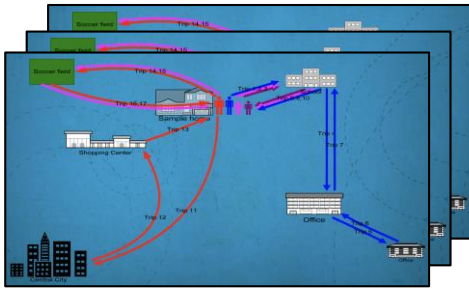
Goal	Metric	Target value (per day)
GHG Reduction	Total GHG emissions[1]	<16,400 Metric Tons CO_2e
SB 375 Emissions	SB 375 GHG emissions	<13,100 Metric Tons CO_2e
Mobility	Total Person Trips	>11.8 million person trips
Equity	Person Trips by Low and Middle-Income Cohorts	>3.75 million person trips

[1] GHG emissions from all passenger vehicle travel in the SACOG region.

X	L
R	M

We Built Simulation Model Using Data From SACOG's Travel Demand Model

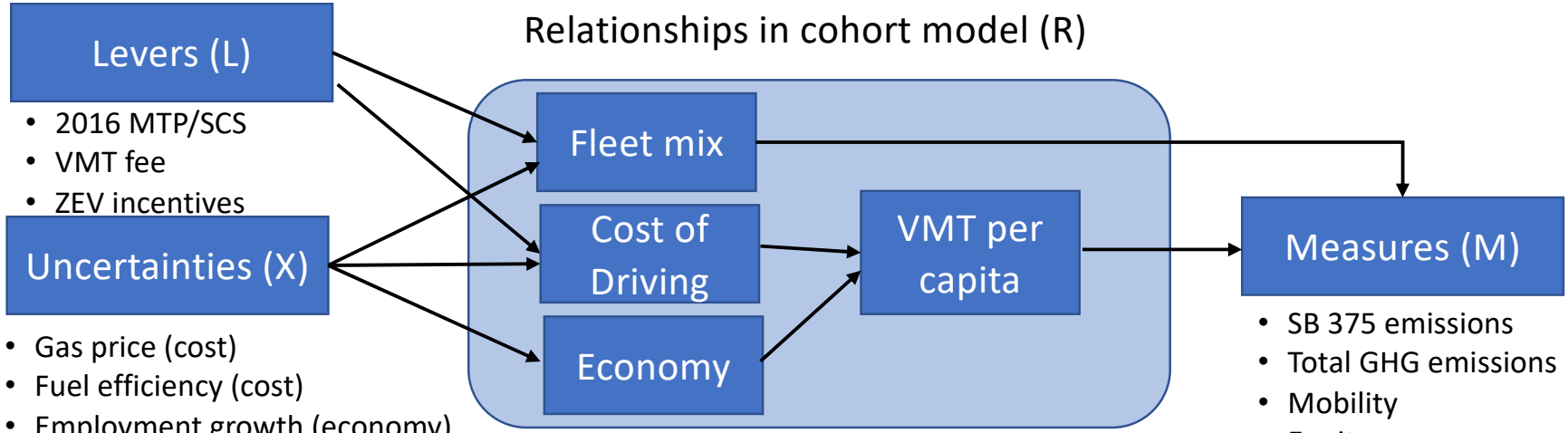
- SACOG developed a cohort-based model to support recent stress-test for CARB of SB 375 targets
  - Model calibrated using runs of SACOG's large-scale SACSIM travel demand simulation
- Building on this analysis, our model projects 2036 VMT, GHG emissions, and Trips by:
  - Beginning with age-income cohort data provided by SACOG
  - Assuming variance in age-income distributions largely due to variance in density-distance to transit
  - Shifting and transforming age-income distributions contingent on various policy levers and uncertain future trends
  - Using these new distributions to estimate desired model outputs



	VMT/Capita Distribution (across density and transit access variables)					
	Low Income, Under 16	Low-Middle Income, Under 16	Middle Income, Under 16	High-Middle Income, Under 16	High Income, Under 16	Low Income, 17 to 25
	3.04	3.87	4.77	5.31	5.72	10.62
	4.88	6.06	7.04	7.55	7.94	15.24
	1.55	1.93	3.04	3.77	2.95	3.27
	1.67	1.57	3.27	4.00	5.37	8.88
	3.77	4.07		2.20	3.96	24.08
	1.40	2.05	4.73	3.38	4.42	11.51
Maximum VMT/Capita	23.32	8.04	7.04	7.65	10.50	43.86
Minimum VMT/Capita	1.40	1.57	3.04	2.20	2.95	3.27
Mean VMT/Capita	3.38	3.44	4.18	4.72	5.21	11.05

X	L
R	M

Simulation Connects Levers and Uncertainties to Measures



X	L
R	M

We Analyzed a Wide Range of Uncertainties

Uncertain parameter	Lower Bound	MTP/SCS value for 2036	Upper Bound
External			
Price of Gasoline (2010$)	$1.00/gal	$4.70/gal	$8/gal
Average ICE Fuel Efficiency	15 mpg	28.2mpg	50 mpg
Employment Growth	21%	49%	61%
Technology adoption			
ZEV/Plug-in Hybrids	0%	13%	40%
Behavioral			
Millennial Behavior	0	0	1
Sensitivity to cost of driving	-0.762%	-0.24%	-0.026%
Sensitivity to economic growth	0.6%	0.65%	0.7%

Notes: [1] For this analysis, ZEVs include BEVs, fuel cells, and plug-in hybrids.
[2] Employment growth is used as proxy for economic growth.

X	L
R	M

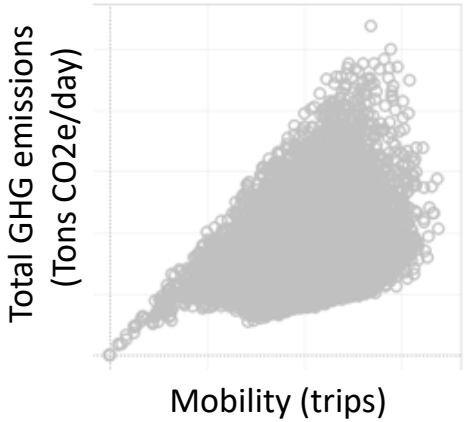
Analysis Employs Suite of Software Tools

- Simulation in R with R-shiny interfaces
- Scenario discovery toolkit extracts scenarios from database of runs
- Tableau visualization software enables interactive data exploration

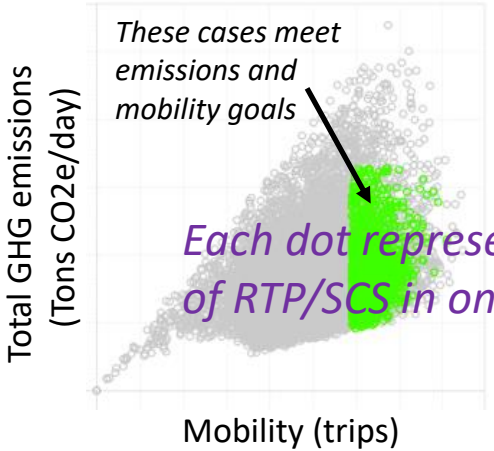
X	L
R	M

We Stress Test the MTP/SCS Over Multiple Futures

1) Test policy in 10,000 futures

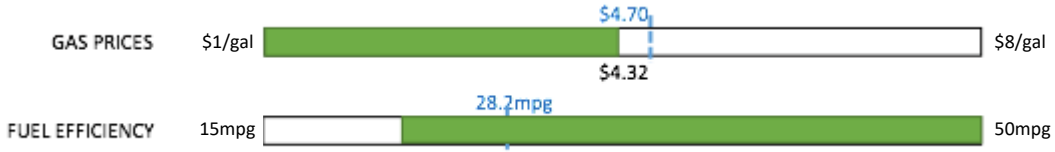


2) Note cases of interest



Each dot represents performance of RTP/SCS in one future

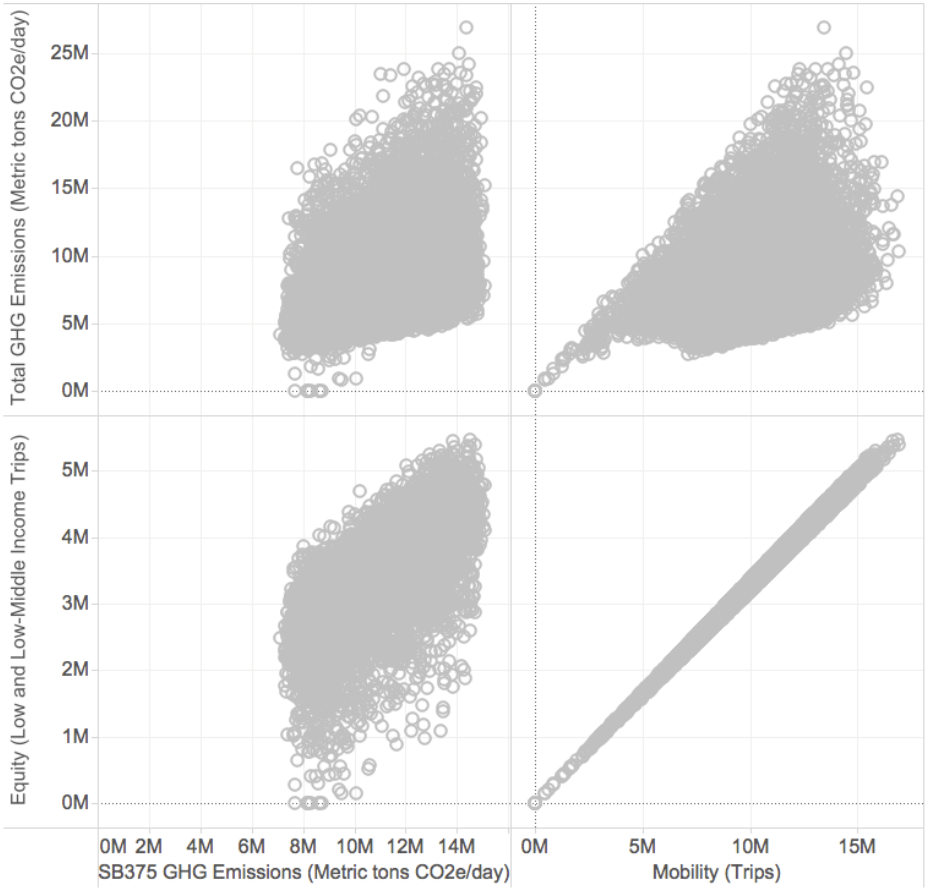
3) Identify key drivers of meeting and missing goals using Scenario discovery



Frame → Stress Test → New Strategies

Uncertainties Generate a Wide Range of Outcomes

10,000 cases
Base case policy



Frame → Stress Test → New Strategies

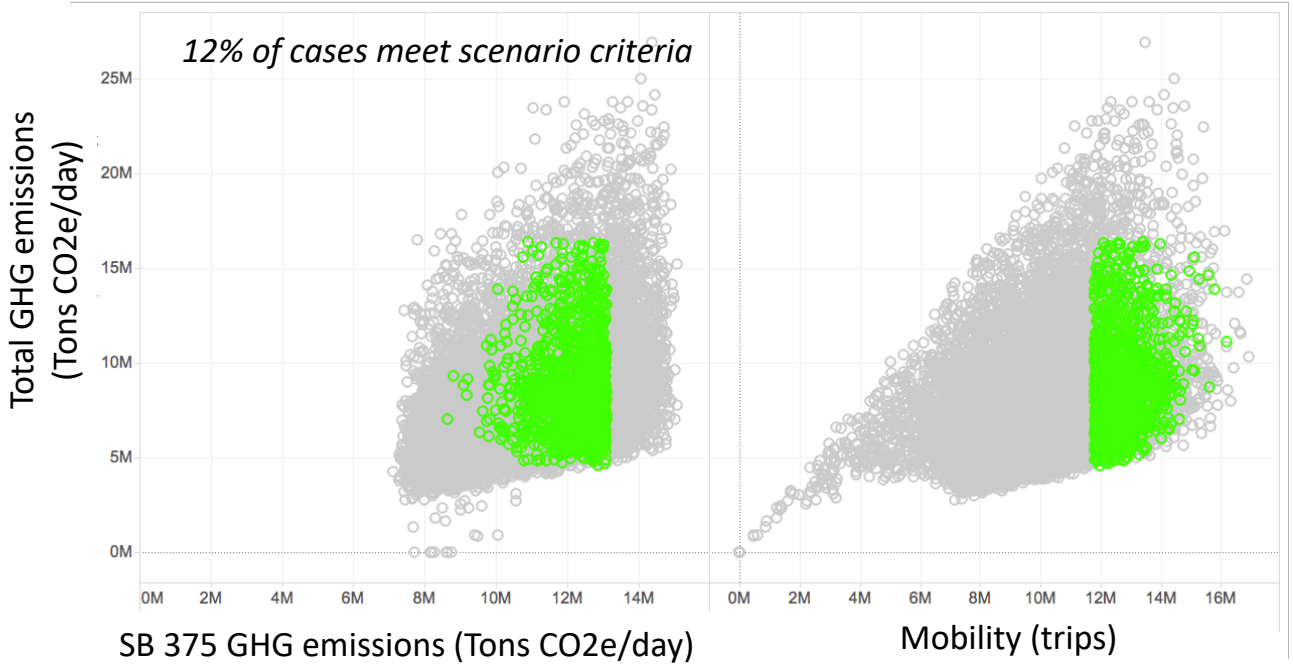
We Organized Results By Considering Relevant Scenarios

Policy-Relevant Scenario	Total GHG (metric tons CO_2e/day)	SB 375 GHG (metric tons CO_2e/day)	Daily Person-Trips per Capita	Daily Person-Trips Per Capita (low income)
Meet All Goals	≤16,400	≤13,100	≥ 3.83	≥ 3.03
Miss SB375, Meet Other Goals	≤16,400	> 13,100	≥ 3.83	≥ 3.03
Miss Total GHG, Meet Other Goals	> 16,400	≤ 13,100	≥ 3.83	≥ 3.03
Meet Both GHG Goals, Miss Mobility Goals	≤ 16,400	≤ 13,100	< 3.83	n/a
Miss Mobility Goals	n/a	n/a	< 3.83	n/a
Miss Equity Goals	n/a	n/a	n/a	< 3.03
Achieve Ultra-low TotalGHG, Meet Other Goals	≤ 8,200	≤ 13,100	≥ 3.83	≥ 3.03
Meet SB375 Only*	n/a	≤13,100	n/a	n/a

* Note, this study's SB 375 emission calculations assume fixed values for fuel prices, fuel efficiency, and ZEV penetration, so do not depend on these uncertainties

Meet All Goals Scenario Bounded Above by Emissions and Below By Trips

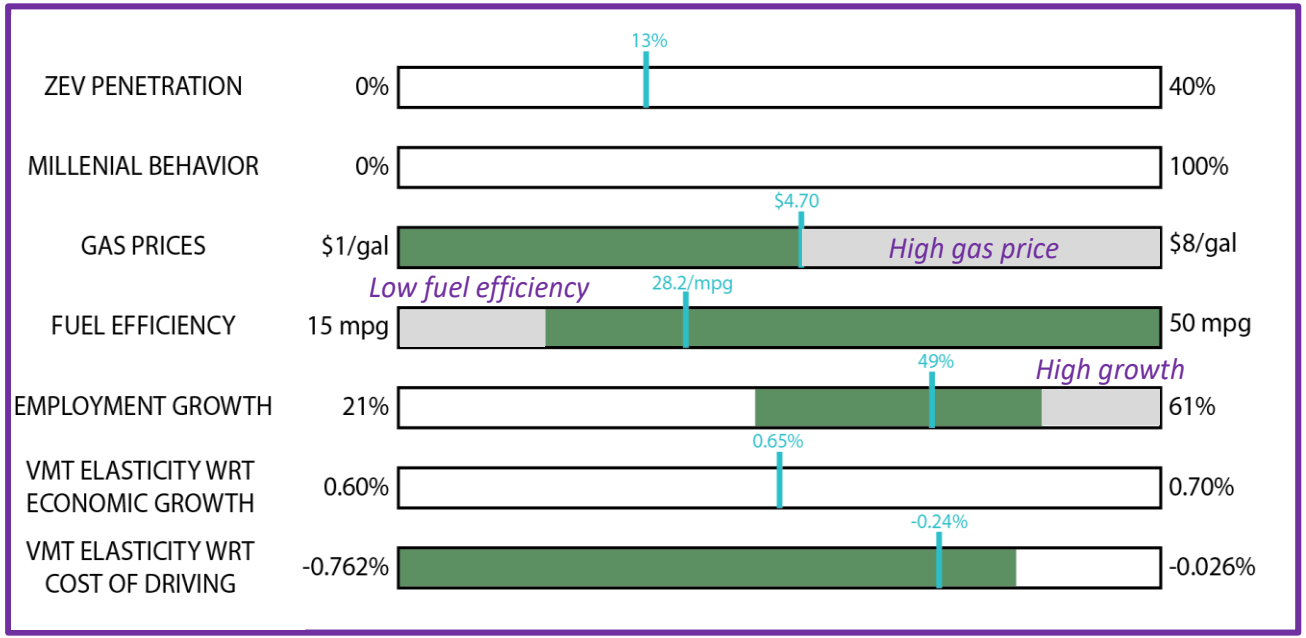
2016 RTP/SCS



Green = case meets scenario criteria
Grey = case does not meet scenario criteria

Frame → Stress Test → New Strategies

Gas Prices and Economic Growth Among Key Drivers of *Meet All Goals Scenario*



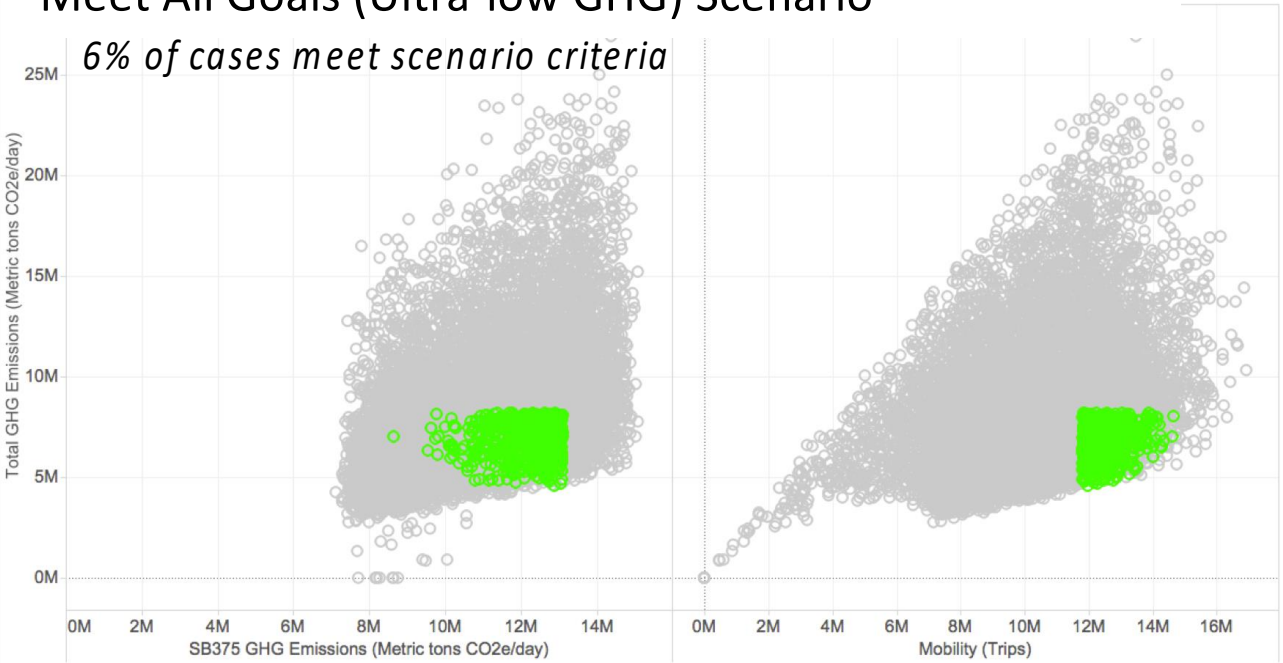
Can SACOG meet its goals over a wider range of futures?

12% of futures meet these conditions

- Green bars show parameter variation ranges that best differentiate futures within and outside of this scenario.
- Variables without green bars are not a key driver/differentiator for this scenario.

Other Policy-relevant Scenarios

Meet All Goals (Ultra-low GHG) Scenario



Key drivers:

- ZEV penetration not low
- Gas price not high
- Fuel efficiency high
- Economy neither low or high

Frame → Stress Test → New Strategies

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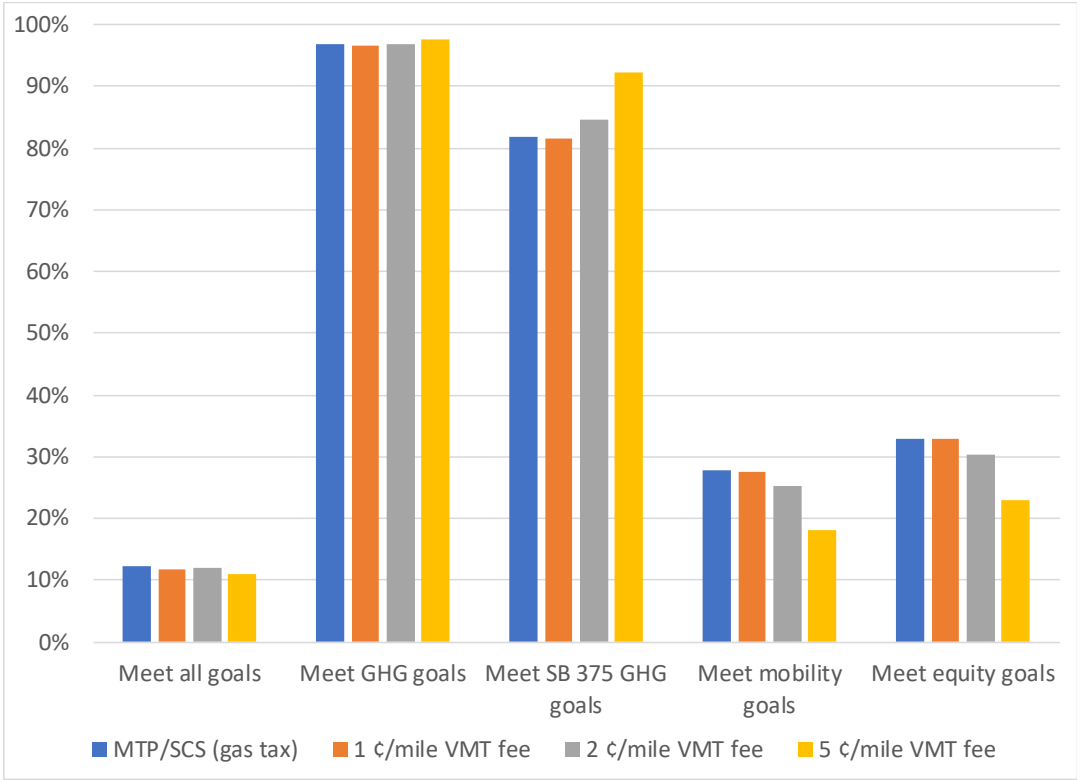
How Might SACOG Make Its RTP/SCS More Robust?

1. Replace state fuel tax with VMT fee
   - Study examined VMT fees of 1, 2, and 5 cents/mile
     - 1 cent/mile ~ corresponds to current gas tax
   - VMT fee applies to all vehicles, including ZEVs, and has larger relative effect on ZEVs than ICEs

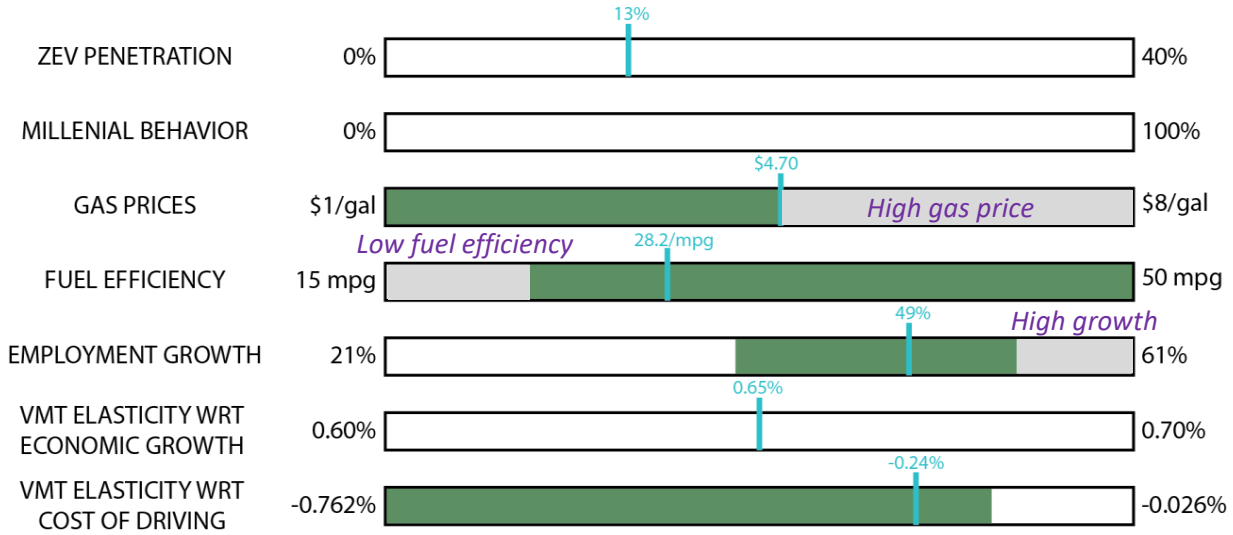
2. Unspecified policies to increase ZEV penetration
   - Where ZEV > 30%
   - With 1 cent/mile VMT fee

Futures Meeting Study Goals With Varying VMT Fees

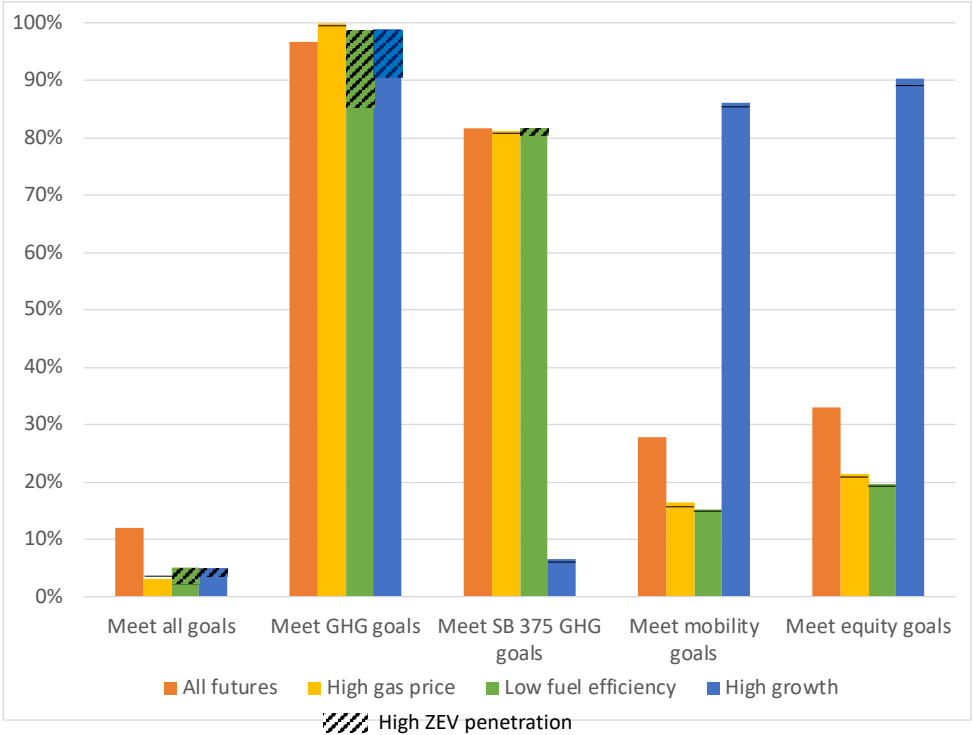


Three Scenarios Where Policy Fails to Meet Goals

- High gas
- Low fuel
- High growth



Higher ZEV Penetration Helps in Low Fuel Efficiency and High Growth Scenarios



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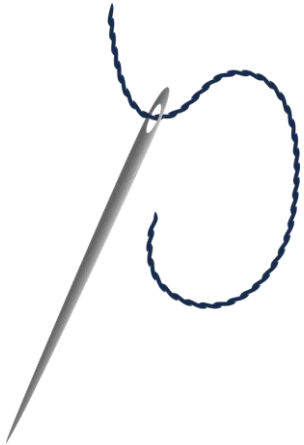


We Find That…

1. Current plans vulnerable to unmodeled assumptions
2. Promising steps to incorporate RDM into long-range planning
3. Yet work needed to improve the modeling

Unmodeled Assumptions

Current Plans Vulnerable to Unmodeled Assumptions

- Economic growth, fuel price, and fuel efficiency key factors
- Traditional planning often treats these exogenous factors as static predictions
- ZEV and millennial travel behavior seem less important in meeting MTP goals

Barriers to incorporate RDM into long-range planning

1. Unfamiliarity
2. Complexity of tools
3. Statutory requirements and guidelines

Steps to incorporate RDM into long-range planning

1. RMD on qualitative scenarios produced in traditional planning
2. Incremental
3. ‘Shadow process’

RDM Uses Models as Exploratory, Not Predictive Tools

Consider two fundamentally different ways to use computer simulation models

Consolidative models:

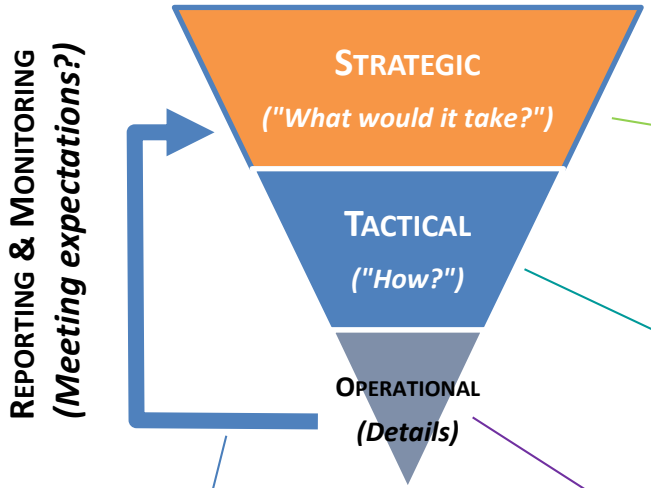
- Gather all relevant knowledge into a single package which, once validated, can be used as a surrogate for the real world
- Used for prediction

Exploratory models:

- Map assumptions onto consequences, without privileging any one set of assumptions
- Supports iterative problem-solving

Bankes (1993)

Transportation Planning Has Opportunities for RDM and Its Exploratory Models



S-T-O-RM Analysis Toolkit

Exploratory/Strategic Models can help with long-term visioning/ policy/ resilience analysis but sacrifice detail. Example is this pilot work.

Tactical Models use fixed assumptions (e.g. a single economy, fixed fuel prices) to work out how to best implement allotted funding. Example is travel model.

Operational Models help with short-term implementation details (e.g. signal timing). Example is project-level analysis.

Reporting & Monitoring should reflect observed behavior (not modeled)

Exciting work underway

- Our pilot just one example
- TMIP-EMAT
- VisionEval
- What others are you familiar with?

Next steps: modeling

- Conducting scenario analysis using conventional tools is resource intensive and limited on results
- Possible for exploratory model to cover additional relationships (congestion, adaptive pathways, etc) yet preserve run times?
- What we are working to demonstrate!

Next steps: engagement

- RDM envisions a new conversation among modelers, decision makers, and the public
- Many barriers inhibit RDM adoption in transportation/land use planning
- Working to overcome
  - Trainings
  - Community of practice
  - What are you working on that is similar?

Thank you!

http://www.rand.org/pardee/
http://www.deepuncertainty.org