Performance Measurement & Evaluation:
Overview and Example Case Study

6 April 2017

AGENDA

1. Performance Measurement and Evaluation Overview

2. Best Practice for Performance Measurement and Evaluation using a Hypothetical Example

3. Tampa THEA CV Pilot Site Performance Measurement (Additional material)

4. Questions

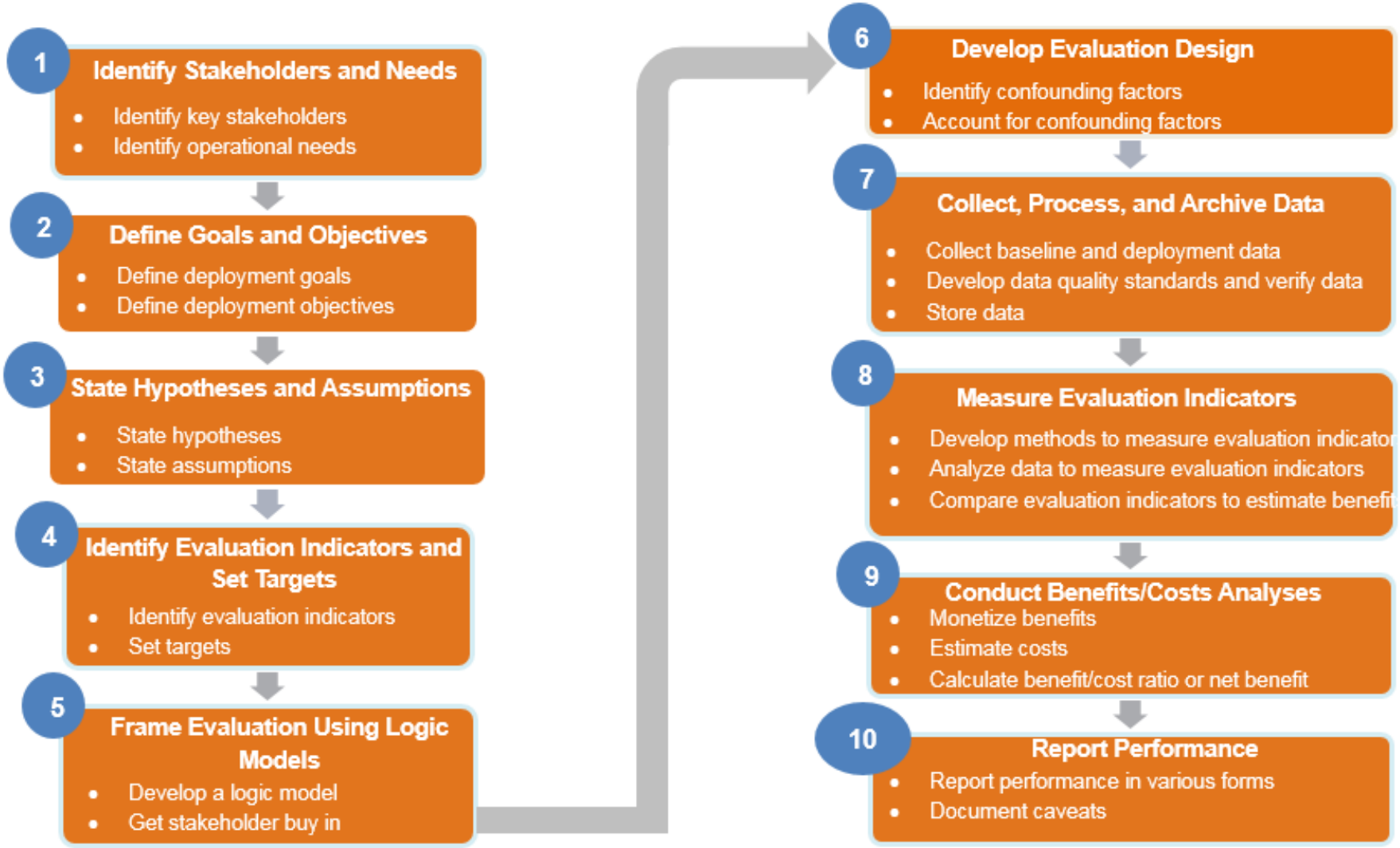
Performance Measurement & Evaluation

- **Performance Measurement**
  - Means of assessing the progress made towards attaining established goals
  - Not just about data collection, verification, and cleaning but also about using the data to understand the system

- **Performance Monitoring**
  - Ongoing tracking of performance to assess if targets have been or are likely to be met
  - Enables system managers to take corrective and proactive actions to control and manage the system
  - Allows system managers to understand the impacts of investments and policies

- **Performance Evaluation**
  - Systematic and ***objective*** examination of measures and outcomes to understand the impacts of investments and policies on performance, thus improving current and future planning and investment decisions
  - Conducted by an ***independent party*** who has no vested interest or stake in the project

Best Practice for Performance Measurement and Evaluation

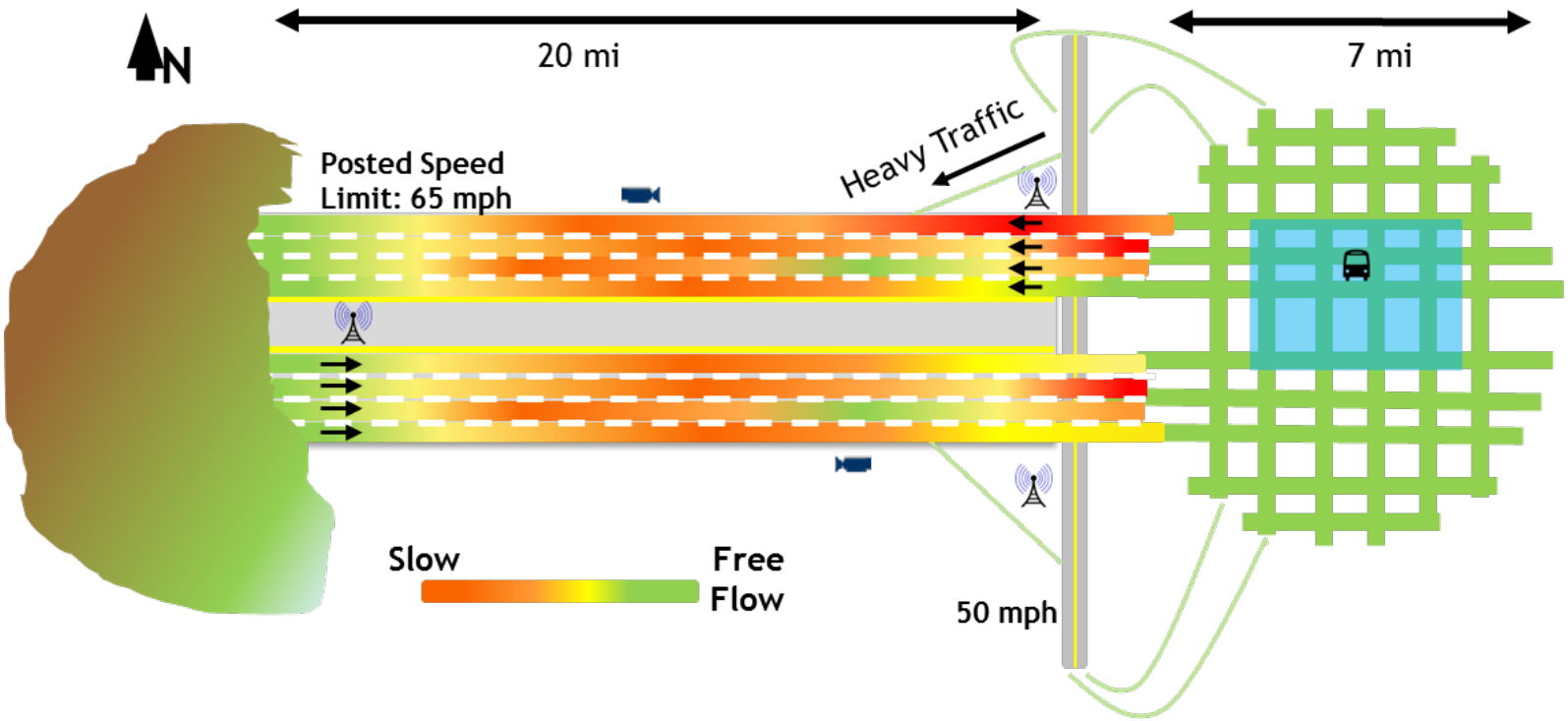


Source: Methodology to Evaluate the Benefits of Cooperative System Applications Report

Hypothetical Corridor Facing Significant Issues During AM Travel

Stakeholder Concerns

- High number of crashes
- Reduced safety during inclement weather
- Low throughput
- High emissions



Step 1: Identify Stakeholders and Needs

Purpose

- Identify stakeholders and operational needs for the transportation network

Approach

- Identify people or groups with direct interest in or will be impacted by any improvements in a transportation network
- Diagnose transportation issues and operational needs
- Identify evaluation needs and incorporate them into the ConOps

Example (for the Hypothetical Corridor)

- Stakeholders include:
  - State DOT, Metropolitan Planning Organization (MPO), State Highway Patrol, the Driving Public
- Operational needs include:
  - Reduce the high number of crashes on the corridor
  - Improve safety conditions on the corridor, including during inclement weather
  - Increase vehicle throughput on the corridor
  - Reduce vehicle emissions on the corridor
- During the concept development process, stakeholders decide to implement a Speed Harmonization Application to mitigate the problems

STEP 2: DEFINE GOALS AND OBJECTIVES

Purpose

- Define goals and objectives of the deployment

Approach

- Formulate research questions to be solved by deployment
- Align project objectives with agency's long term goals

Example (for the Hypothetical Corridor)

- Project goals are to improve safety, enhance mobility, and minimize negative environmental impacts
- Evaluation objectives are:
  - To assess the safety, mobility, sustainability, and public agency efficiency impacts of deploying the speed harmonization cooperative system application on the hypothetical corridor
  - To measure the driver perception / acceptance of the speed harmonization cooperative system application

Step 3: State Hypotheses and Assumptions

Purpose

- State hypotheses and assumptions about the application deployment

Approach

- State initial propositions of the potential impacts of cooperative system application
- State assumptions to be considered in the evaluation process

Example (for the Hypothetical Corridor)

- Hypotheses:
  - Deployment of speed harmonization application will significantly improve safety, mobility, sustainability, and public agency efficiency in the corridor
  - Drivers will find the speed harmonization application useful and valuable as they drive through the corridor
- Assumptions:
  - All communications in the CV environment will be exclusively DSRC
  - Compliance rates will be the same from year to year

STEP 4: IDENTIFY EVALUATION INDICATORS

Purpose

- To identify the right, appropriate, and consistent evaluation indicators to be used in assessing the effectiveness of cooperative system applications

Approach

- Need both quantitative and qualitative evaluation indicators
- Key attributes of good evaluation indicators should be considered*
  - **Purpose:** Chosen evaluation indicators must reflect goals of application deployment
  - **Credibility:** Chosen evaluation indicators should be supported by stakeholders
  - **Availability:** Data necessary to estimate chosen evaluation indicators must be available
  - **Clarity:** Chosen evaluation indicators should be easy to interpret
  - **Validity:** Chosen evaluation indicators should be a valid representation of what it claims to measure
  - **Reliability:** Chosen evaluation indicators should have a high likelihood of yielding the same results in repeated trials, so there are low levels of random error in measurement
  - **Responsiveness:** Chosen evaluation indicators should be able to detect change
  - **Abuse-Proof:** Guarding against unintended consequences

* Source: Revised Freeway Management and Operations Handbook

STEP 4: IDENTIFY EVALUATION INDICATORS *(CONT.)*

Example (for the Hypothetical Corridor)

- **Safety Evaluation Indicators**
  - Number of lane changes, number of hard braking events
  - Speed variance
  - Number of crashes
- **Mobility Evaluation Indicators**
  - Average delay/Travel time savings
  - Travel time reliability
  - Vehicle throughput
- **Sustainability Evaluation Indicators**
  - Fuel consumption
  - Emissions
- **Public Agency Efficiency Evaluation Indicators**
  - Agency staff time in managing incidents
  - Accuracy of targeted speed advisories
- **User Acceptance / Satisfaction Indicators**
  - Percent compliance with recommended speed advisories
  - Perceived usefulness of deployed cooperative system application

Step 5: Frame Evaluation Using Logic Models

Purpose

- To establish interdependencies and secure stakeholder buy-in

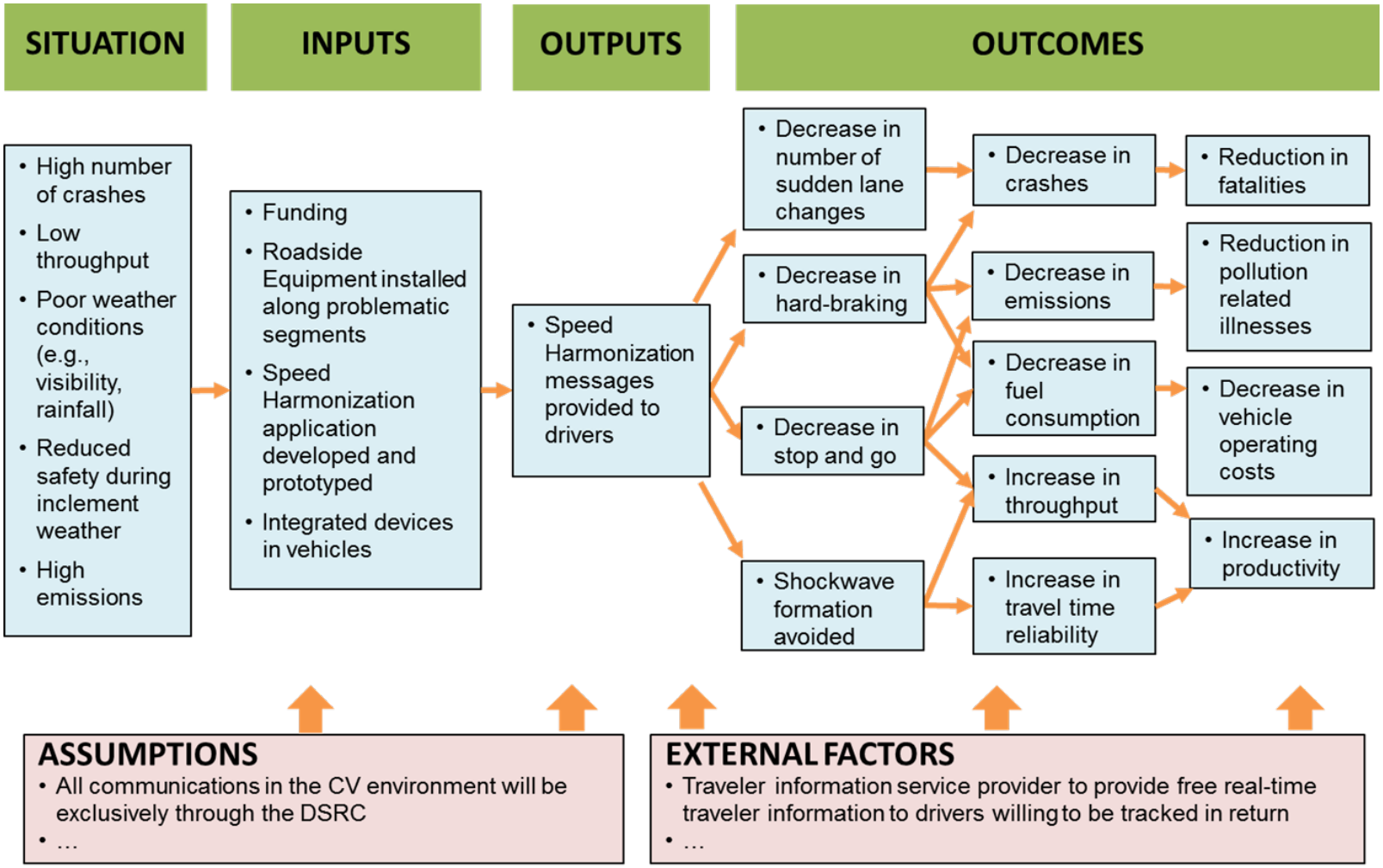
Approach

- Use Pictorial representation to relate your input, output and outcomes.
- Identify all assumptions and external factors.

Source: Comparison of Evaluation Tools and Methods Used in the United States (U.S.) and Japan Report

STEP 5: FRAME EVALUATION USING LOGIC MODELS *(CONT.)*

Logic Model for Hypothetical Corridor



Source: Methodology to Evaluate the Benefits of Cooperative System Applications

STEP 6: DEVELOP EVALUATION DESIGN

Purpose

- Develop evaluation design to account for confounding factors and isolate impacts of the deployment

Approach

- Three main types of evaluation designs
  - Non-experimental design (Simple before and after)
  - Randomized Experimental Design with control and treatment groups
  - Quasi Experimental Design with non-randomized control and treatment groups

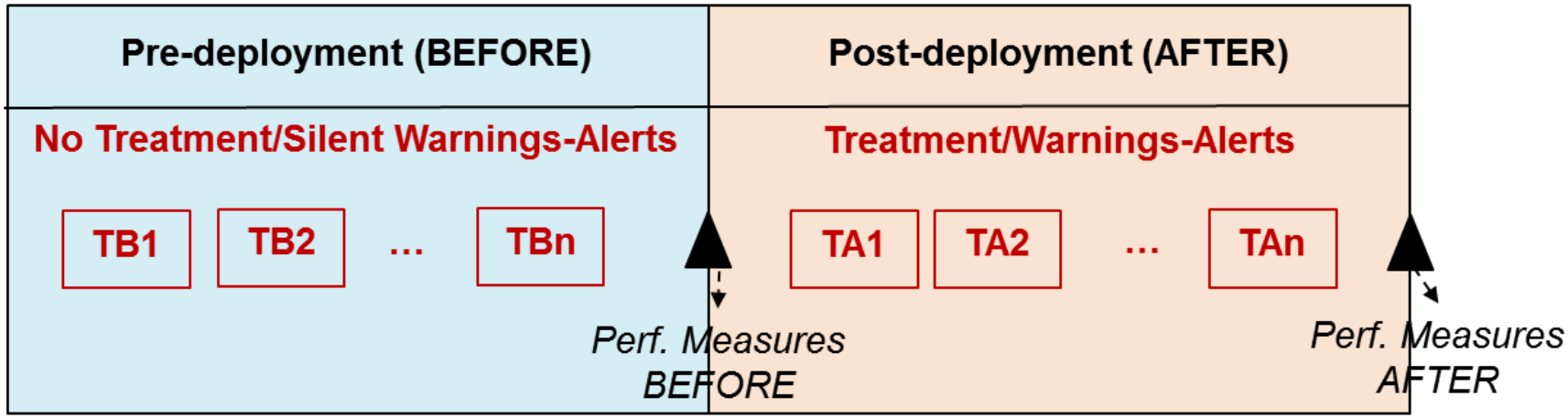
Example (for the Hypothetical Corridor)

- Limited use of randomized design supplemented with before/after depending on the evaluation indicators

STEP 6A: NON-EXPERIMENTAL DESIGN

Not Recommended

- Impact of deployment is assessed by examining changes in the post-deployment period given the trend in the pre-deployment period
- Weakest design type since it has no control group, does not account for confounding factors, and doesn't control for other threats to internal validity, possibly leading to false conclusions
- ***Example***: Before/After Studies, Longitudinal Studies

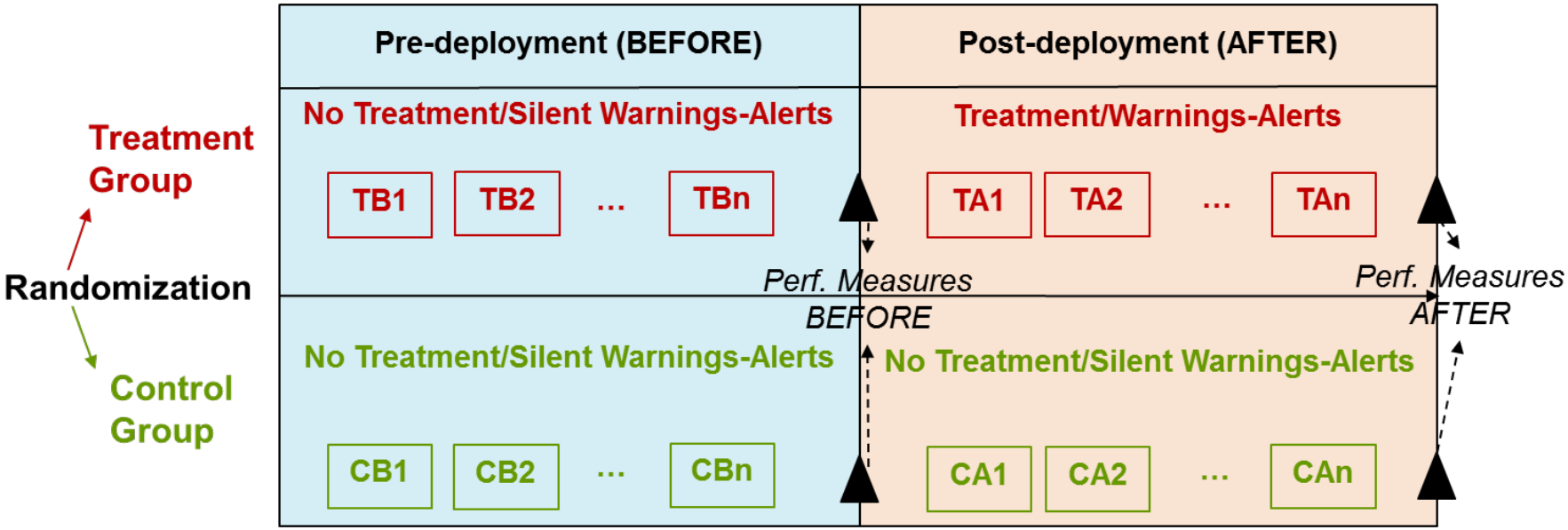


LEGEND

TB1, TB2,...,TBn: BEFORE data collection/measurement pts
TA1, TA2,...,TAn: AFTER data collection/measurement pts

STEP 6B: RANDOMIZED EXPERIMENTAL DESIGN

- Study subjects are randomly assigned to the control and treatment groups
- Most effective in controlling for confounding factors and other threats to internal validity; provides the most assurance that outcomes are the result of the deployment
- If the chosen evaluation indicators (e.g., ***number of hard braking events***) require disaggregate vehicle data from equipped vehicles then this is the only option

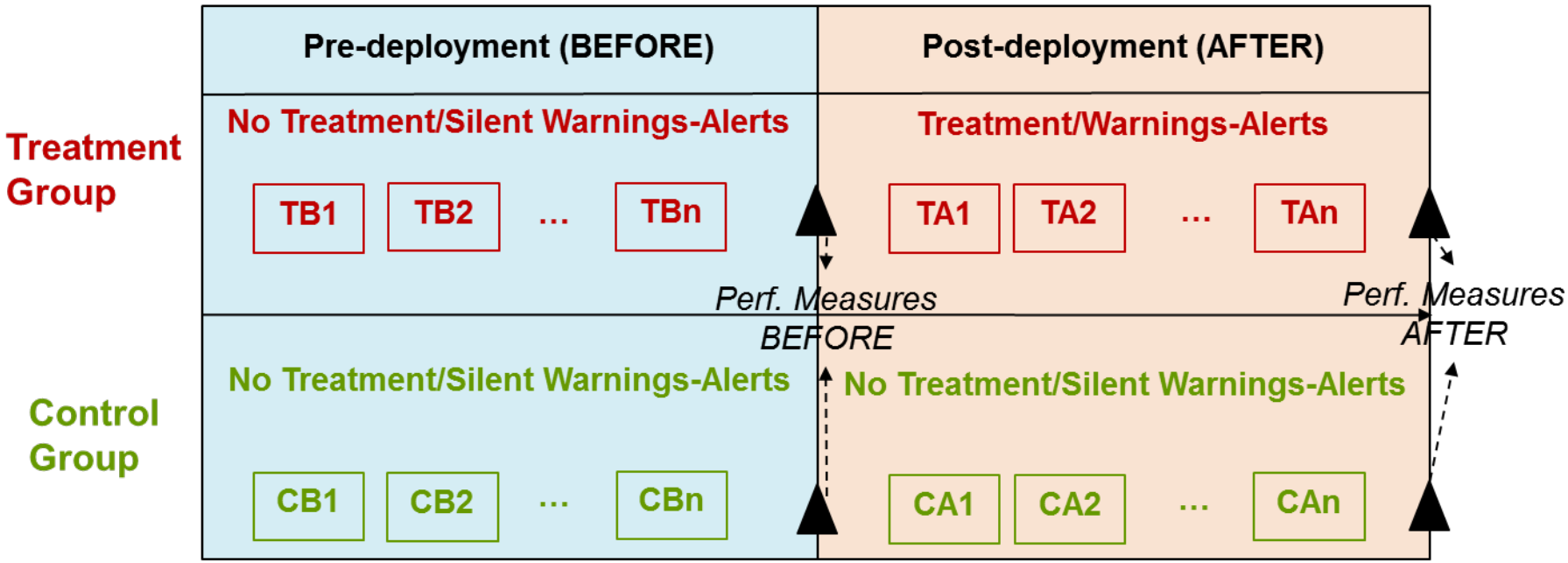


LEGEND

TB1, TB2,...,TBn:	BEFORE data collection/measurement pts for treatment grp
CB1, CB2,...,CBn:	BEFORE data collection/measurement pts for control group
TA1, TA2,...,TAn:	AFTER data collection/measurement pts for treatment group
CA1, CA2,...,CAn:	AFTER data collection/measurement pts for control group

STEP 6C: QUASI-EXPERIMENTAL DESIGN

- Approximation of randomized experimental design; ***no*** random assignment
- Results may not be conclusive, since control and treatment groups cannot be assumed to be similar (possible selection bias)



LEGEND

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TA1, TA2,...,TAn:	AFTER data collection/measurement pts for treatment group
CA1, CA2,...,CAn:	AFTER data collection/measurement pts for control group

Step 7: Collect, Process, and Archive Data

Purpose

- To collect, process, and archive data that will be used for measuring performance and assessing impacts of the deployment

Approach

- Collect data from multiple sources according to the evaluation design
- Process and verify data
- Archive data

Example (for the Hypothetical Corridor)

- Time-stamped Roadside Unit (RSU) logs, time stamped speed harmonization messages, time-stamped Onboard Unit (OBU) messages, traffic data, etc.
- Collected data are cleaned and validity checks conducted
- Raw and cleaned data are stored in the state DOT's database

STEP 8: MEASURE EVALUATION INDICATORS

Purpose

- Analyze collected and verified data to calculate evaluation indicators using appropriate measurement methodologies

Approach

- Use appropriate methods to measure evaluation indicators
  - Field and user survey data
  - Analytical tools
    - Sketch planning tools, deterministic tools, and traffic simulation tools
- Compare evaluation indicators to determine impacts (benefits) of the deployment

Example (for the Hypothetical Corridor)

- Using field data
  - Average delay & travel time savings will be calculated using speed data from ITS devices and CVs
- Using analytical tool
  - Number of lane changes will be measured using microscopic traffic simulation (e.g., VISSIM)

STEP 9: CONDUCT BENEFITS-COSTS ANALYSES

Purpose

- Conduct benefits-cost analyses to determine the cost-effectiveness of the deployment

Approach

- Monetize benefits
- Estimate costs
- Calculate benefit-cost ratio and net benefit

STEP 9A: MONETIZE BENEFITS

Purpose

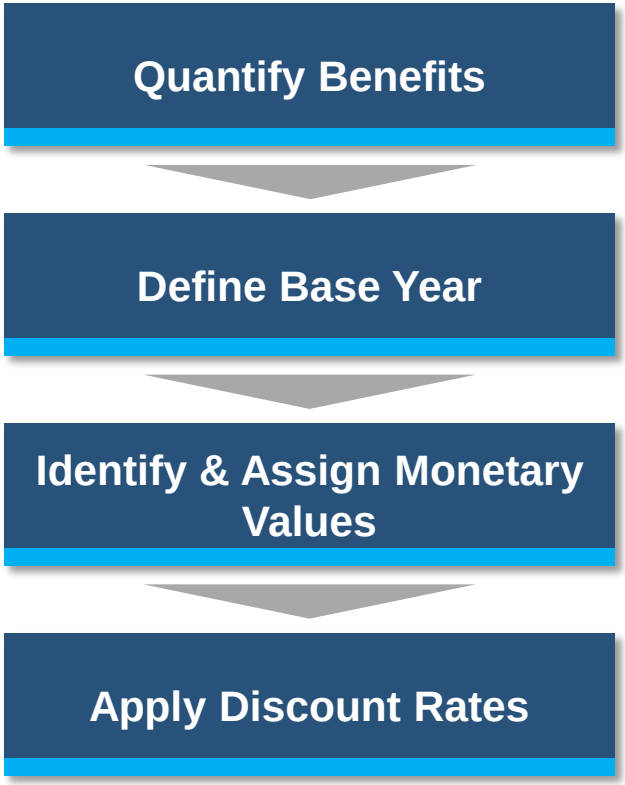
- Monetize benefits obtained from the deployment

Approach

- Assign monetary values to measured benefits
- Use the most recent published sources

Example (for the Hypothetical Corridor)

- Monetary equivalents obtained from appropriate sources
- Benefits to be monetized include:
  - **Safety benefits:** monetize reduction in crashes
  - **Mobility benefits:** monetize travel time savings
  - **Sustainability benefits:** monetize reduction in emissions, and fuel use



STEP 9A: MONETIZE BENEFITS *(CONT.)*

Calculated Yearly Benefits for Speed Harmonization Application

(Example for the Hypothetical Corridor)

Benefit Category	Evaluation Indicator	Expected Yearly Benefits
Mobility	Travel time savings	10,000 Hours
Safety	Number of crashes	1. Reduce critical injuries by 1 2. Reduce property damaged only crashes by 3
Sustainability	1. Emissions 2. Fuel use	1. Reduce each emission type by 10 tons 2. Reduce fuel use by 20,000 gallons

STEP 9A: MONETIZE BENEFITS *(CONT.)*

Mobility Benefits Monetization

Number of Years After Initiation (t)	Expected Yearly Benefit (Hours)	Hourly Value of Travel Time (2013 $)	Expected Yearly Benefits ($)	Discount Factor for 7%*	Present Value of Benefits (2013 $)
1	10,000	$12.5	$125,000	0.9346	$116,825
2	10,000	$12.5	$125,000	0.8734	$1,091,750
3	10,000	$12.5	$125,000	0.8163	$1,020,375
4	10,000	$12.5	$125,000	0.7629	$953,625
5	10,000	$12.5	$125,000	0.7130	$891,250
6	10,000	$12.5	$125,000	0.6663	$832,875
7	10,000	$12.5	$125,000	0.6227	$778,375
8	10,000	$12.5	$125,000	0.5820	$727,500
9	10,000	$12.5	$125,000	0.5439	$679,875
10	10,000	$12.5	$125,000	0.5083	$635,375
Total Present Value (2013 $)					$877,925

$$* \text{Discount Factor} = \frac{1}{(\text{Interest Rate} + 1)^t}$$

STEP 9A: MONETIZE BENEFITS *(CONT.)*

Total Monetized Benefits for Speed Harmonization Application

Year	Mobility	Safety	Sustainability	Annual Discounted Benefits
1	$116,825.00	$5,221,028.63	$3,596,300.04	$74,622,438.00
2	$109,175.00	$4,879,142.31	$3,363,230.59	$69,738,395.00
3	$102,037.50	$4,560,160.14	$3,145,620.63	$65,181,397.00
4	$95,362.50	$4,261,847.57	$2,940,495.05	$60,918,069.00
5	$89,125.00	$3,983,087.32	$2,749,228.42	$56,934,587.00
6	$83,287.50	$3,722,203.48	$2,569,586.74	$53,205,918.00
7	$77,837.50	$3,478,637.41	$2,401,975.38	$49,724,869.00
8	$72,750.00	$3,251,271.84	$2,245,602.64	$46,475,447.00
9	$67,987.50	$3,038,430.85	$2,098,945.25	$43,433,330.00
10	$63,537.50	$2,839,555.80	$1,961,453.97	$40,590,371.00
Total (2013 $)				$48,952,139.86

STEP 9B: ESTIMATE COSTS

Purpose

- Estimate costs associated with the deployment

Approach

- Identify and categorize all sources of cost
  - Capital Cost
  - Operation and Maintenance Cost
  - Replacement Cost

Example (for the Hypothetical Corridor)

- **Capital Costs**
  - Systems engineering cost (e.g., planning and design cost)
  - Software development cost
  - Roadside equipment cost
  - Vehicle on-board unit cost
  - Backhaul comm. upgrade cost
  - Driver and staff training cost
- **Operation and Maintenance Cost**
  - Periodic maintenance cost
  - Re-training of agency staff cost
- **Replacement Cost**
  - Malfunctioning equipment replacement cost
  - Obsolete inductive loop detectors replacement cost

STEP 9B: ESTIMATE COSTS *(CONT.)*

Cost Component	Quantity	Average Input Unit Cost (2013 $)	Average Simulated Unit Cost (2013 $)	Average Simulated Total Cost (2013 $)
Capital Costs				
Driver Training Hours: Light Vehicles	1,000	$20.84	$20.87	$20,865.44
Backhaul Communications Upgrade	20	$27,666.67	$27,494.80	$549,896.04
Inductive Loop Detectors	80	$3,000.00	$2,998.54	$239,883.38
RSE Planning & Design	20	$6,650.00	$6,651.30	$133,026.09
Roadside Equipment (RSEs)	20	$10,683.33	$10,668.26	$213,365.19
Light Vehicle OBU	500	$4,150.00	$4,130.03	$2,065,016.46
Light Vehicle Software Package	500	$2,000.00	$2,001.63	$1,000,813.70
Software Development & Testing	1	$250,000.00	$249,933.54	$249,933.54
Systems Engineering Costs	N/A	N/A	N/A	$632,317.08
Outreach Costs	N/A	N/A	N/A	$270,993.04
Total Capital Cost				**$5,376,109.96**
Operation and Maintenance (O&M) Costs				
Operation and Maintenance Costs (Annually)	N/A	N/A	N/A	$360,420.74
Total Operation & Maintenance Cost				**See next slide**
Replacement Costs				
Replacement Cost-RSEs	2	$10,683.33	$10,682.73	$21,365.45
Replacement Cost-Inductive Loops	4	$3,000.00	$2,996.78	$11,987.12
Total Replacement Costs				**$33,352.57**

STEP 9B: ESTIMATE COSTS *(CONT.)*

Number of Years After Deployment	Expected Yearly O&M Costs ($)	Discount Factor for 7%	Present Value of O&M Costs (2013 $)
1	$0.00	0.9346	$0.00
2	$360,420.74	0.8734	$314,791.00
3	$360,420.74	0.8163	$294,211.00
4	$360,420.74	0.7629	$274,965.00
5	$360,420.74	0.713	$256,980.00
6	$360,420.74	0.6663	$240,148.00
7	$360,420.74	0.6227	$224,434.00
8	$360,420.74	0.582	$209,765.00
9	$360,420.74	0.5439	$196,033.00
10	$360,420.74	0.5083	$183,202.00
Total Present Value (2013 $)			$2,194,530.00

Cost Category	Cost (2013 $)
Capital Cost	$5,376,109.96
Operation and Maintenance Cost	$2,194,529.80
Replacement Cost	$33,352.57
Total Present Value (2013 $)	$7,603,992.33

Step 9c: Calculate Benefit-Cost Ratio and Net Benefit

Purpose

- Calculate benefit-cost ratio and net benefit to determine return on investments

Approach

- Benefit-Cost Ratio = $\frac{\sum(Bi, Bi+1, \ldots, Bn)}{\sum(Ci, Ci+1, \ldots, Cn)}$, i = 1 to n years (1)

  Where:

  B_i : Monetized benefits of the application for year *i*

  C_i : Cost of deploying the application for year *i*

  n : Number of years the application will be deployed

- Net Benefit = $\sum(Bi, Bi+1, \ldots, Bn) - \sum(Ci, Ci+1, \ldots, Cn)$, i= 1 to n years (2)

  Where:

  Bi, Ci, and *n* have the same definitions as used in equation (1)

STEP 9C: CALCULATE BENEFIT-COST RATIO & NET BENEFIT *(CONT.)*

- Benefit/Cost Ratio = $\frac{\$48,952,139.86}{\$7,603,992.33}$ → **6.4:1**

- Net Benefit = $48,952,139.86− $7,603,992.33 → **$41,348,147.53**

- Based on the Benefit/Cost ratio and Net Benefit values obtained, it can be concluded that the potential benefits that will be realized from deploying the speed harmonization application far outweighs the potential cost/resources to be incurred/expended.

Step 10: Report Performance

Purpose

- To present evaluation results to stakeholders

Approach

- Identify the various stakeholders and report evaluation results in a way they will understand
- There should be a clear link between the reporting of evaluation results and hypotheses tested
- Use different formats
  - Dashboards, graphs, charts, tables, etc.

Example (for the Hypothetical Corridor)

- Evaluation results will be presented in charts and tables

Tampa THEA CV Pilot Site Performance Measurement

TAMPA (THEA) PILOT DEPLOYMENT OVERVIEW

Objective

- The objective of this deployment is to alleviate congestion and improve safety during morning commuting hours.
  - Deploy a variety of V2V and V2I safety, mobility, and agency data applications to create reinforcing benefits for motorists, pedestrians, and transit operation

Source: THEA

Approach

- Employ DSRC to enable transmissions among approximately 1,600 cars, 10 buses, 10 streetcars, 500 pedestrians with smartphone applications, and approximately 40 roadside units along reversible lanes and major city arterials to provide the following benefits:
  - Reduce morning peak hour queues and related collisions
  - Reduce wrong-way entries into the reversible lanes
  - Increase pedestrian safety at several street-crossing locations
  - Optimize bus rapid transit (BRT) operation through signal priority
  - Reduce conflicts between streetcars and turning vehicles
  - Improve traffic progression through enhanced signal coordination

STEP 1: IDENTIFY STAKEHOLDERS AND NEEDS

- **Tampa THEA Stakeholders**
  - City of Tampa
  - Hillsborough Area Regional Transit (HART)
  - MacDill Air Force Base
  - Amalie Arena
  - Tampa Downtown Partnership (TDP)

- **Tampa THEA Site Needs**
  - Improve safety by reducing number of vehicular and pedestrian crashes/severity of crashes
  - Improve mobility by reducing travel delays during peak periods
  - Improve transit operations by reducing transit signal delay
  - Mitigate negative environmental impacts due to queuing

STEP 2: DEFINE GOALS AND OBJECTIVES

- **Tampa THEA Site Goals**
  - Develop and deploy CV Infrastructure to support CV Applications identified
  - Improve mobility in the Tampa central business district area
  - Improve safety in the pilot area
  - Reduce negative environmental impacts of transportation within the pilot area
  - Improve agency efficiency in managing the Tampa area transportation system
  - Develop business environment for sustainability

- **Tampa THEA Site Objectives**
  - Detect and warn of potential conflicts between trolleys, vehicles, and pedestrians
  - Help HART buses stay on predictable schedule through TSP applications
  - Provide CV mobility and safety applications to improve overall mobility and reduce stops and idle time within the CBD, thus reducing emissions
  - Improve data collection capability, reducing the costs of collecting data
  - Work with state and local government to encourage positive legislation and funding in support of CV technology

STEP 3: STATE HYPOTHESES AND ASSUMPTIONS

- **Tampa THEA Site Hypotheses**
  - The pilot deployment will reduce vehicle to vehicle, vehicle to trolley, and vehicle to pedestrian crashes and incidents (or other safety surrogate measures if crashes are rare) in the pilot deployment area
  - The pilot deployment will improve traffic signal progression through use of CV data
  - The pilot deployment will reduce negative environment impacts through reductions in crashes, improvement in signal progression, and resulting reductions in vehicle and bus idle times
  - The pilot deployment will result in improved public agency efficiency and decision-making by transportation managers
- **Tampa THEA Site Assumptions**
  - It is assumed that the CV devices, i.e., the RSEs, the OBEs, and other sensors to be used for data collection are certified for data standards conformance
  - For long-term benefit/cost analysis, it is assumed compliance rates (i.e., complying with recommended CV advisory) of drivers will be the same from year to year *(Note: Not part of PeM Plan)*

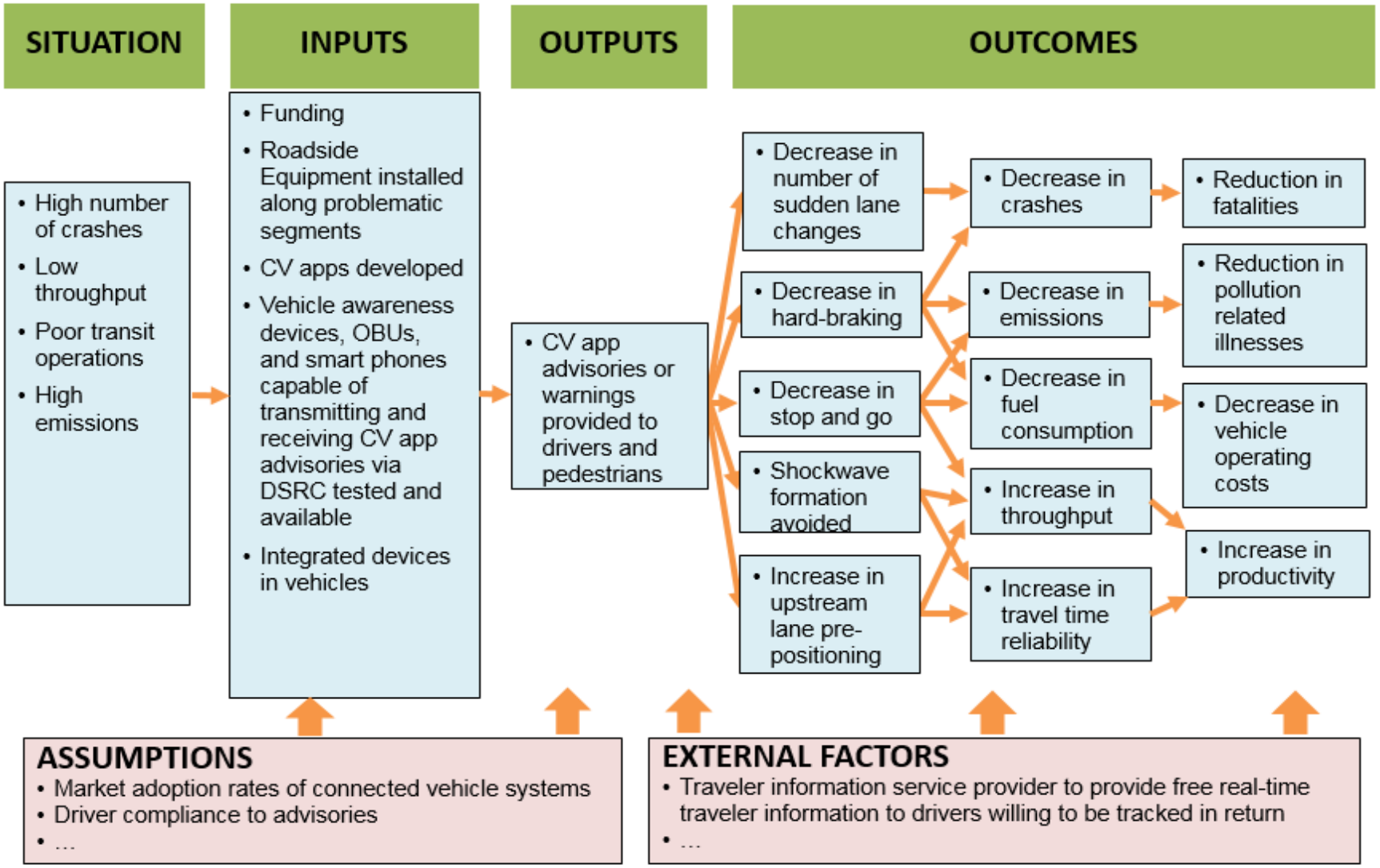
Step 4: Identify Evaluation Indicators and Set Targets

- **Tampa THEA Site Evaluation Indicators**
  - Mobility
    - Average travel time and travel time reliability
    - Vehicle throughput
  - Safety
    - Number of crashes/ crash rate
    - Number/Severity of conflicts or near misses
  - Environment
    - Changes in idle speed emissions
    - Changes in running emissions
  - Agency Efficiency
    - Customer satisfaction

- **Tampa THEA Site Evaluation Indicator Targets**
  - Generic mobility improvement of 10% expected

STEP 5: FRAME EVALUATION USING LOGIC MODELS

Logic Model for Tampa THEA CV Pilot Site (*Not part of PeM Plan*)



STEP 6: DEVELOP EVALUATION DESIGN

- **Tampa THEA Site Confounding Factors**
  - Changes in weather conditions between the pre and post deployment periods
  - Special events
  - Tampa downtown waterfront construction
  - Unusually high/low crashes or incidents
  - Economic conditions
  - Fuel prices

- **Tampa THEA Site Evaluation Designs**
  - Randomized experimental design
    - For use cases that involve applications such as forward collision warning, curve speed warning
  - Quasi-experimental design
    - For use cases where there are sample collection constraints
  - Non experimental design
    - For use cases that involve transit operations (transit drivers can't be randomly selected or grouped into treatment/control groups due to agency operating parameters)

STEP 7: COLLECT, PROCESS, AND ARCHIVE DATA

- **Tampa THEA Site Data Collection Plan**
  - Baseline and deployment data will be collected
  - Types of data to be collected include
    - CV pilot system data such as Basic Safety Messages (BSM), RSU logs
    - Non-system data collected from external databases like loop detectors
    - Survey data from pilot participants
- **Tampa THEA Site Data Processing**
  - Data quality checks will be conducted depending on data type
  - Data will be complete, standards based, consistent, accurate, and time-stamped
  - All personally identified information (PII) will be removed before archiving
- **Tampa THEA Site Data Archival**
  - CV pilot data will be archived by a master server located at THEA TMC
  - Develop comprehensive metadata document describing captured data and storage
  - Organize data using acceptable data hierarchy structure
  - Operational data environment (ODE) will act as real-time data router brokering data from different sources to variety of users
  - Data free of PII will be stored on RDE

STEP 8: MEASURE EVALUATION INDICATORS

- **Tampa THEA Site Evaluation Indicators Measurement**
  - Appropriate methods will be developed to measure evaluation indicators
    - For example travel time reliability will be calculated as 90th or 95th percentile travel time
  - Comparison of evaluation indicators to estimate benefits based on use cases and evaluation design
    - Randomized experimental design
      - Evaluation indicators will be compared between randomly selected treatment and control groups
    - Quasi-experimental design
      - Evaluation indicators will be compared between non-randomly selected treatment and control groups
    - Non experimental design
      - Evaluation indicators will be compared between before (pre) and after (post) periods

STEP 9: CONDUCT BENEFITS-COSTS ANALYSES

- **Tampa THEA Site Benefit/Cost Analysis** *(Note: Not part of PeM Plan)*
  - **Monetize benefits**
    - Quantify benefits
    - Define base year
    - Identify and assign monetary values
    - Apply discount rates
  - **Estimate costs**
    - Identify and categorize costs
    - Define base year
    - Apply discount rates and inflation factors
    - Calculate total cost
  - **Calculate benefit/cost ratio**
    - Divide benefits by cost to obtain benefit/cost ratio
    - Deduct total cost from total benefit to get net-benefit

STEP 10: REPORT PERFORMANCE

- **Tampa THEA Site Performance Reporting**
  - Reporting to the community and stakeholders
    - Dashboard
      - Uses an interactive infographic approach to track and report performance measures
      - Users will be able to assess each of the performance measures
    - Reporting to independent evaluators
      - Data downloads through restricted channels
    - Website
      - Share performance results with the outside world
  - Reporting Frequency
    - For dashboard, performance information will be provided on a daily basis
    - IE will receive performance reports based on agreed frequency

THANK YOU

Questions?