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LBNL Transactional Network Applications

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Lighting Diagnostic Agent detects faults in operation of lighting control systems

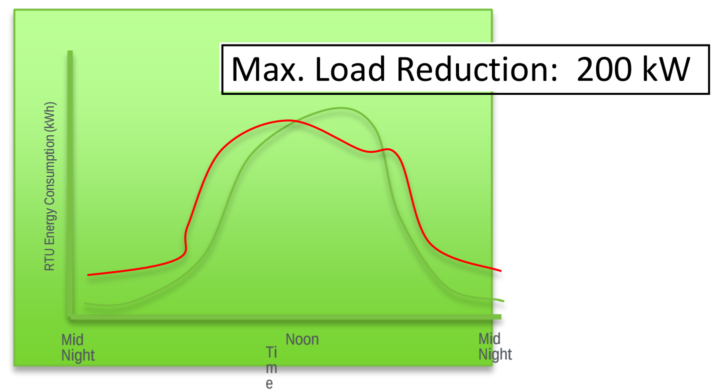
Baseline Load Shape provides basis for measuring change in peak demand and energy use

Demand Response Measurement quantifies change in load for each event

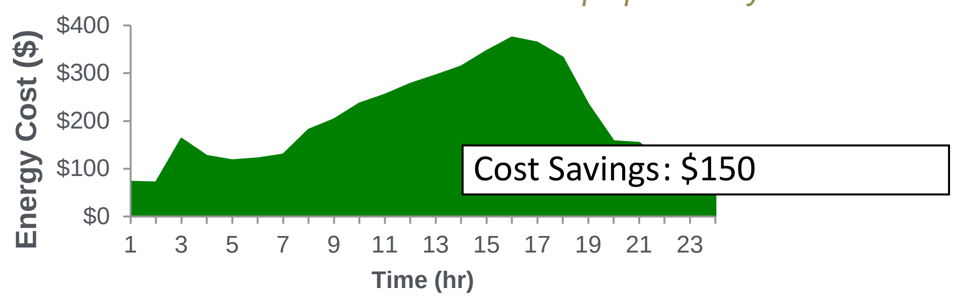
Energy Savings Measurement determines total energy savings benefit over time

Economic Savings Measurement translates results from measurement applications to financial savings ($)

Demand Response Event Scheduler coordinates DR signals from outside server with available network resources

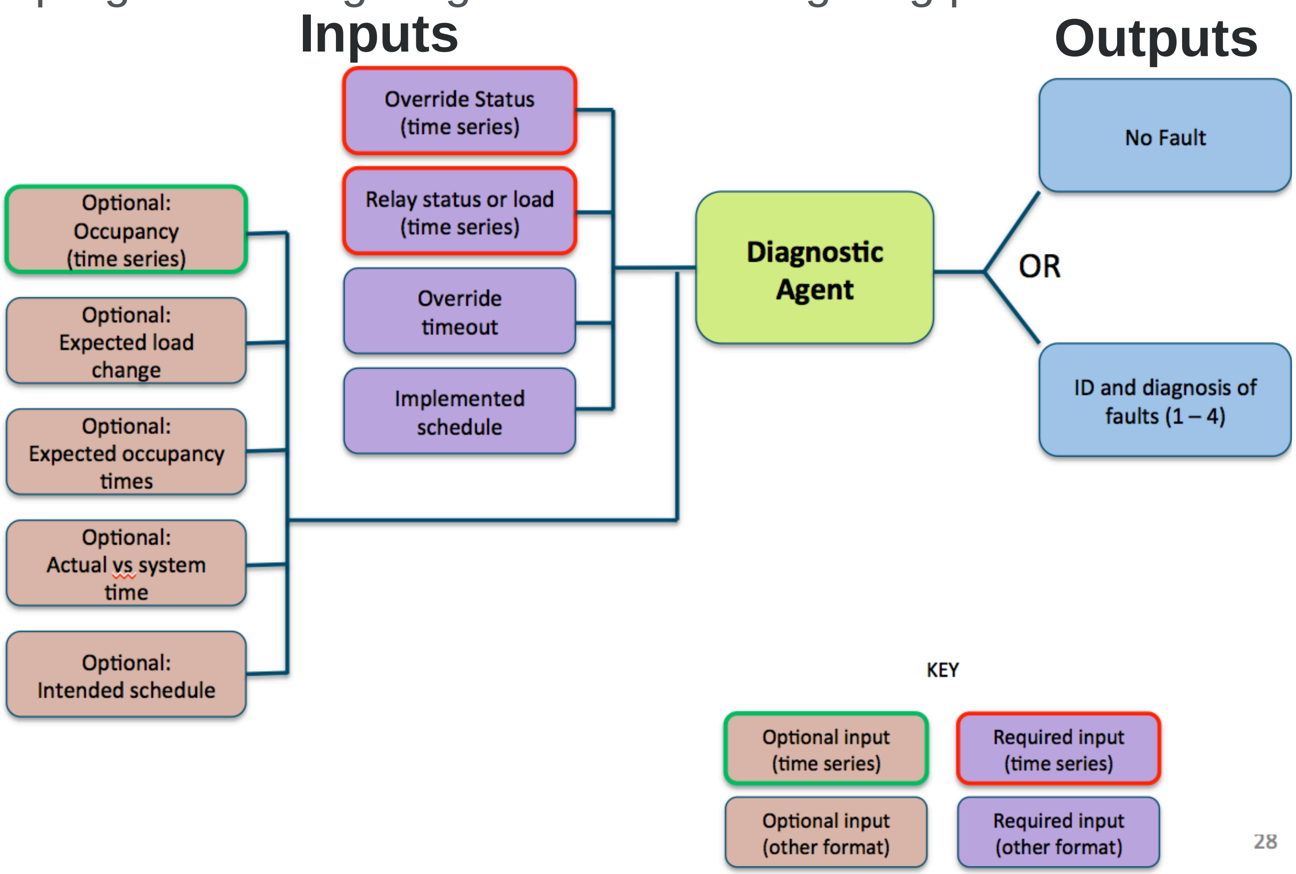


Values shown for illustration purposes only



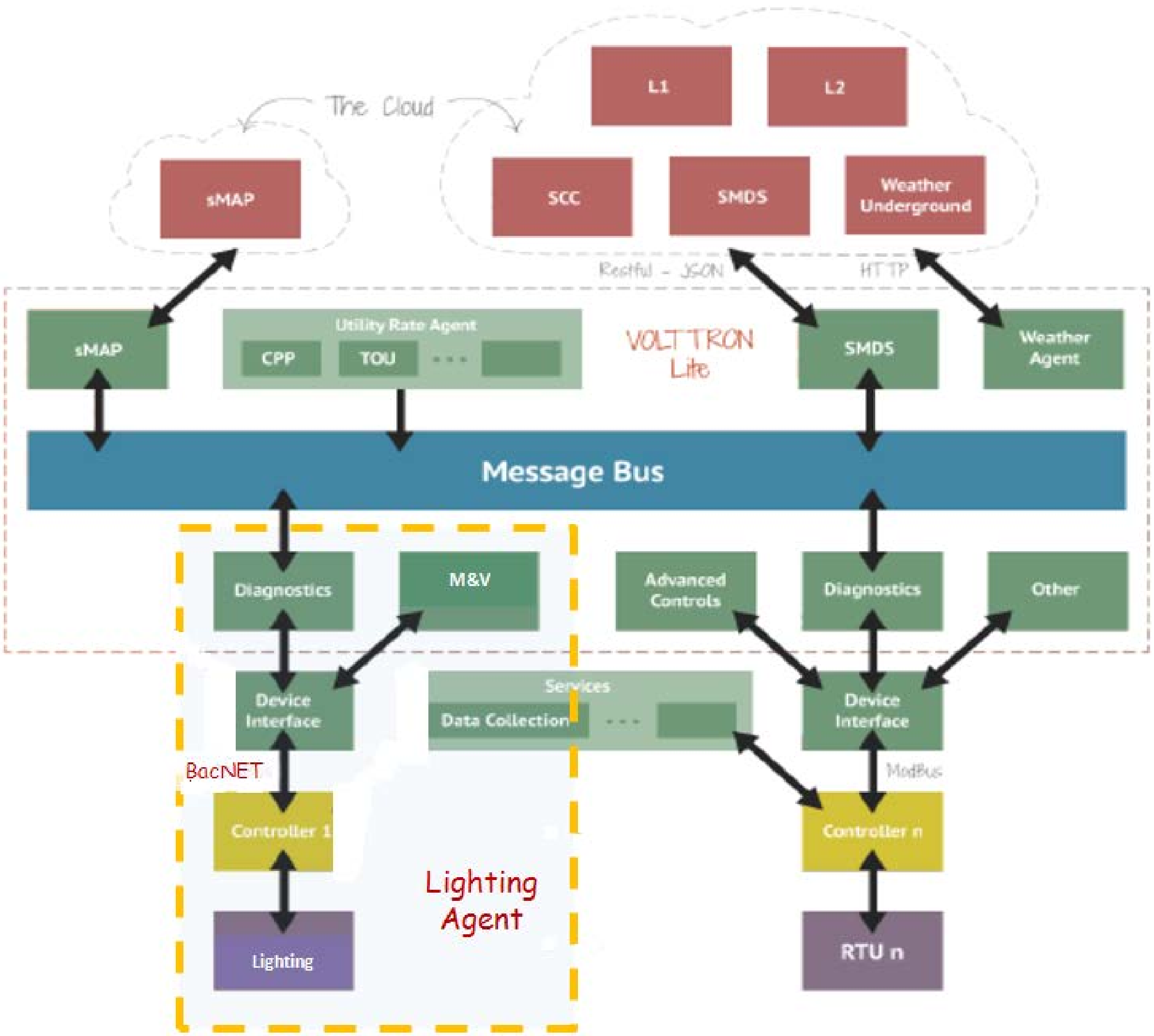
Lighting Diagnostic Agent

- Detect faults in lighting control systems where manual or scheduled control is wasting energy (e.g., lights left on at night).
- Suggest improvements to schedules to better match lighting to occupant needs.
- The FDD models operate on usage data like relay state, override times, programmed lighting schedule and lighting power load.



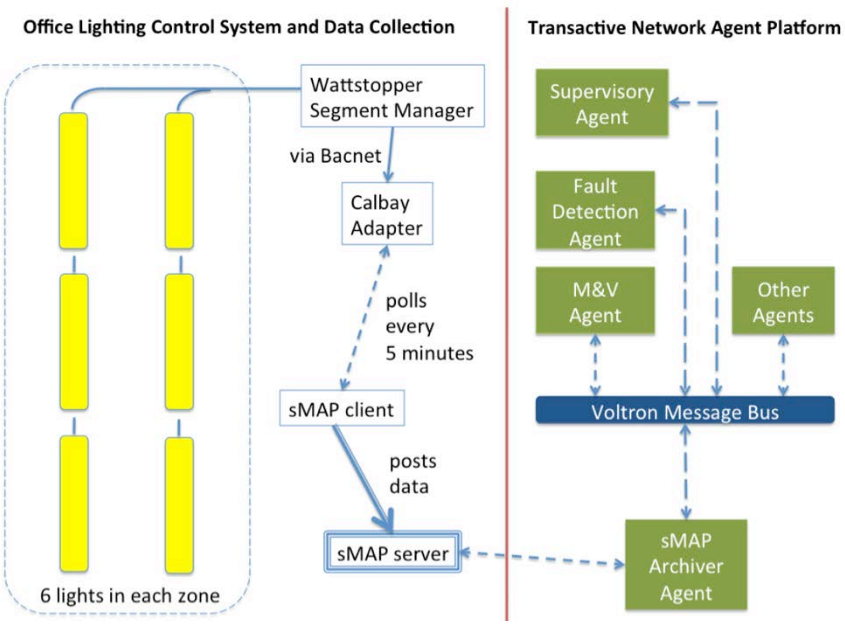
Faults:
(1) Lights not actuated according to schedule,
(2) programmed schedule is not intended schedule,
(3) schedules and
(4) override timeouts not optimally configured

Architecture of the Transactional RTU and Lighting Networks



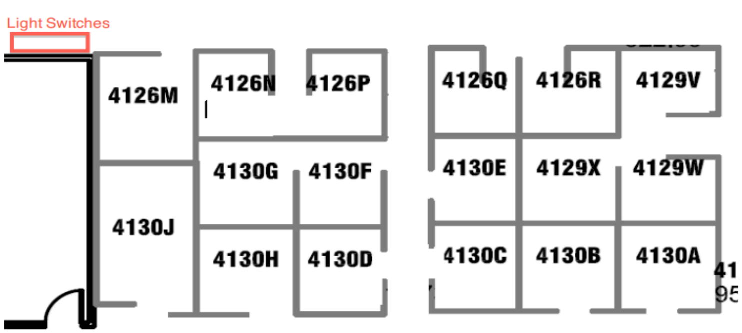
Left: Combined schematic showing the architecture of the Transactional RTU Network, and the analogous architecture of the Transactional Lighting Network

Integration of Volttron with Real Building Lighting Control System



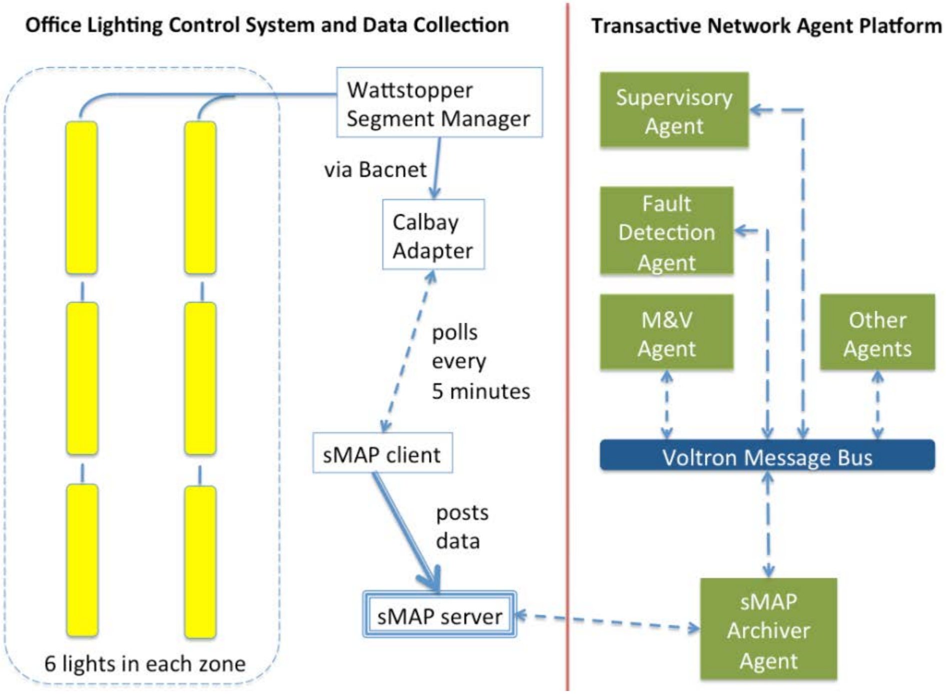
Left: Diagram of the integration of the lighting control system and Transactional Network platform and agents

Bottom left and right: floor plan and photograph of occupied office demonstration space



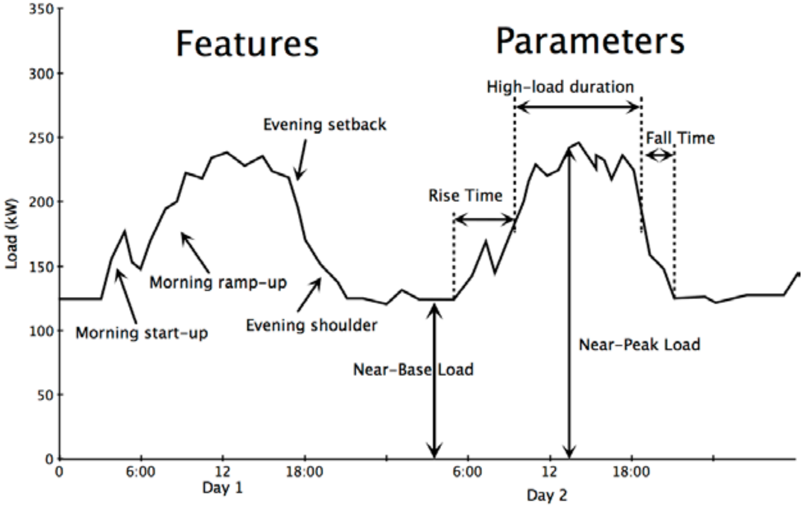
Workflow of Agent-based Transactional Lighting System

- "Supervisory Agent" is run - one of its tasks is to schedule itself (via the PNNL Scheduler Agent) to run again one minute later
- Supervisory Agent requests data from sMAP data archive
- Upon provision of data, the Supervisory Agent calls the M&V Agent and the Fault Detection Agent
- Data for the agents is delivered via the Volttron Message Bus
- Agents send the results back to the Supervisory Agent via the Volttron Message Bus
- The Supervisory Agent reads the results from the Message Bus and writes them to local files



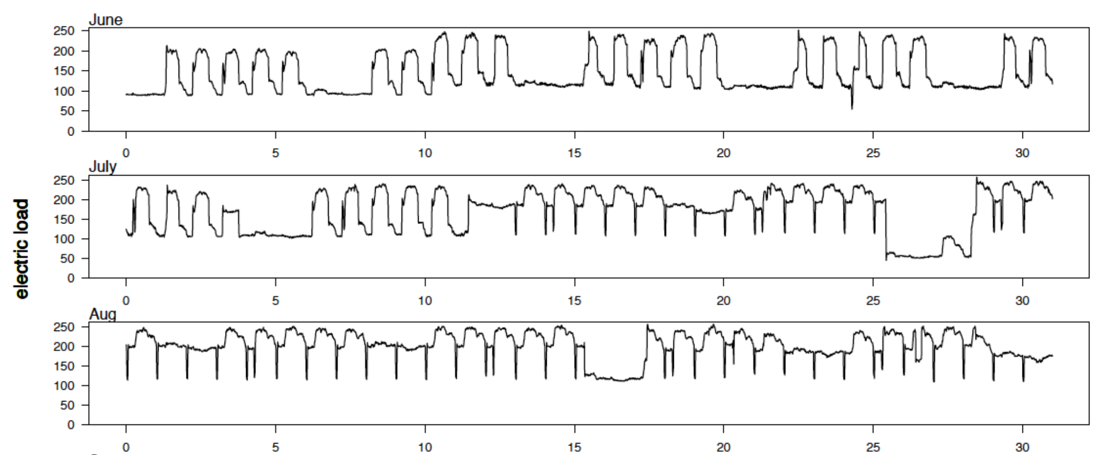
Baseline Load Shape

- **Challenge**: Measuring the *response*, in the form of energy use (kWh) or peak demand (kW), *to a change in building energy operations* requires a reference case based on historical energy use.
- **Objective**: Provide a baseline model that accounts for the influence of outside air temperature and previous loads by time of day and day of week to model loads for each day.
- **Implementation:** The Baseline Load Shape Tool *produces two baselines, one based on long term trends for energy efficiency measures, and one based on the last two weeks of data for demand response events*. The short term model accounts for recent changes in load shapes or schedules.
- The regression models used here consider the time of day, and day of the week, in addition to the measured outdoor air temperature, to develop a baseline that more closely approximates what the load would have been in the absence of an energy savings application.



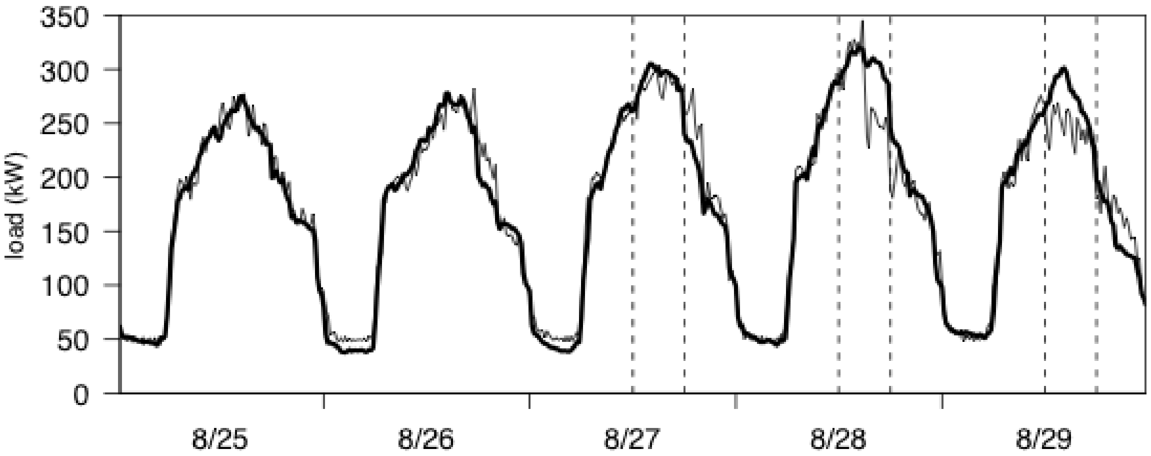
Baseline Load Shape

- **Input:**
  - Historical whole building power (for at least 2 weeks), sampled in intervals of 1 hour or less
  - Outside air temperature, sampled at least hourly
  - Event period information
- **Output:**
  - Long term predicted whole-building baseline load as a function of time.
  - Short term predicted whole building baseline load as a function of time.
  - Goodness of fit statistics: (a) standard error of the residuals during the “training” period, and (b) correlation coefficient.



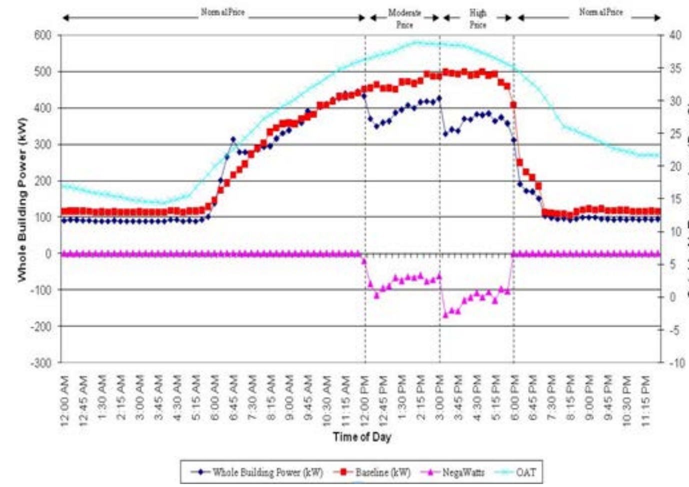
Demand Response Measurement

- **Challenge:** Actions taken for demand response (DR) events need to be measured to provide information on how well they have reduced peak electric loads.
- **Objective**: Provide a DR measurement tool that automates a standard DR baseline methodology.
- **Implementation: The DR Measurement** compares the electric load shape during a DR event to the short-term model available from the Baseline Load Shape Tool against baseline predictions to determine moment by moment savings.



Demand Response Measurement

- **Inputs:**
  - Demand response event time
  - 15-minute power data during DR event
  - Electricity use for the entire day
  - Outside air temperature
  - Baseline Load Shape



- **Outputs:**
  - DR savings as a percentage of whole building load (%)
  - Difference between actual and baseline power for each 15-minute interval during each DR event (kW and W/sq ft).
  - Difference between actual and baseline load shape (kw) for whole day.
  - Average power reduction during each DR event, in absolute terms (kW) and as a percentage of baseline average power during the event.
  - Change in energy use (increase or decrease) over each entire DR day (kWh)

Energy Savings Measurement

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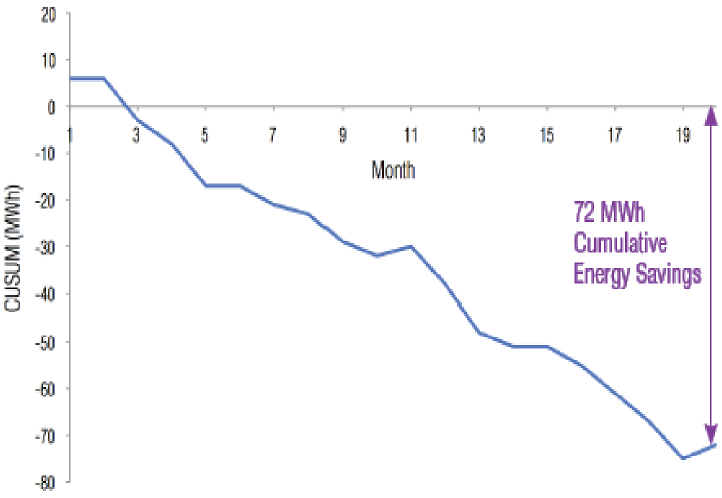
- **Challenge:** Measuring the savings in energy use (kWh) from a change in the control system operation provides whole-building performance data to help evaluate energy efficiency strategies.
- **Objective**: Provide a measurement tool that automates the development of standard baseline model to measure changes in whole building energy use over a given period before and after an intervention.



Implementation: The Energy Savings Measurement Tool provides a cumulative savings against a standard baseline energy use model to measure energy savings accumulated over a given time period

Energy Savings Measurement

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- **Inputs:**
  - Interval load data (1-hour frequency or faster).
  - Long term baseline load shape predicted before an efficiency action
  - Date at which the efficiency action was undertaken.
- **Outputs:**
  - Difference between actual load and baseline load for each time interval after the efficiency action.
  - Cumulative savings from the efficiency action to the present.
  - Energy savings expressed in kWh/sqft.
  - Energy savings expressed as a percent of whole building baseline load.

Economic Savings Measurement

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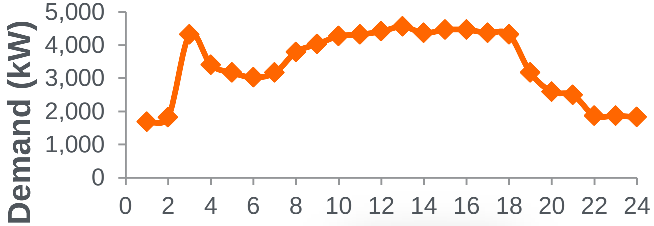
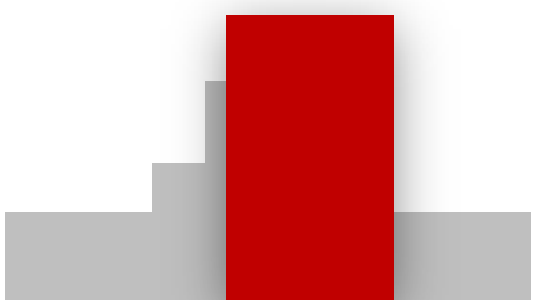
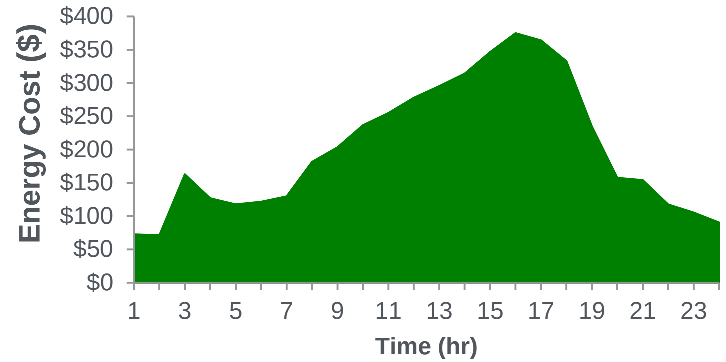
- **Challenge**: Total energy saved or the reduction in peak demand need to be translated into financial savings to help evaluate the importance of the efficiency or DR effort.
- **Objective:** Automatically convert accumulated energy (kWh) savings or DR event data (kW) into projected cost savings ($).
- **Implementation**: The Economic Savings Measurement Tool estimates how much money is saved from implementing an efficiency measure or participating in a DR event. This tool combines results from the DR and Energy Savings Tools with electricity cost data.





Critical Peak Pricing Tariff



Economic Savings Measurement

Inputs:

- Cumulative energy savings based on the Energy Savings Measurement tool (kWh) for a given period
- Peak Demand Reduction based on DR Measurement Tool (kW)
- Tariff data – time of use costs. $/kWh by time of use period
- DR event - critical peak pricing costs ($/kWh for DR hours).

Output:

- Total electricity cost for each 15-minute time interval
- Total electricity cost for baseline operation, for each 15-minute time interval
- Extra cost or reduced cost ($) for each 15-minute time interval
- Cumulative savings ($) over a specified set of time intervals.
- Cumulative savings for an entire efficiency action
- DR savings are for the last DR event.

Demand Response Event Scheduler

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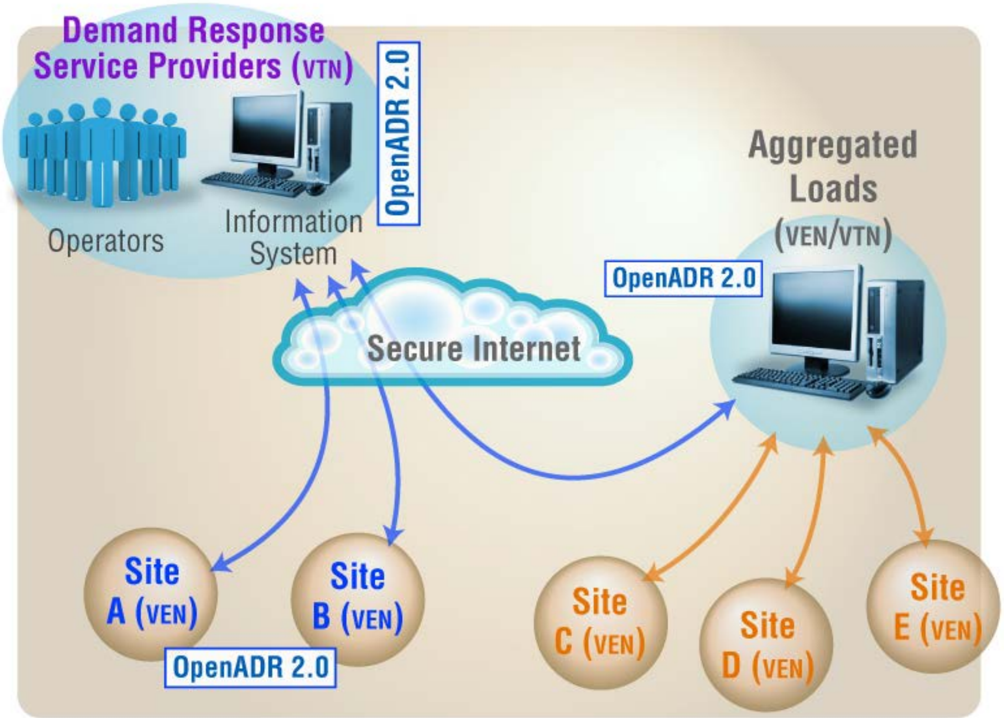
The **DR Event Scheduler** receives an external DR signal from an Open Automated Demand Response (OpenADR 2.0a) DR Event Server and publishes it to the Volttron bus. The agent enables other DR applications to act on this information to modify electric loads. The first phase of development supports an automated response to critical peak prices.



Demand Response Event Scheduler

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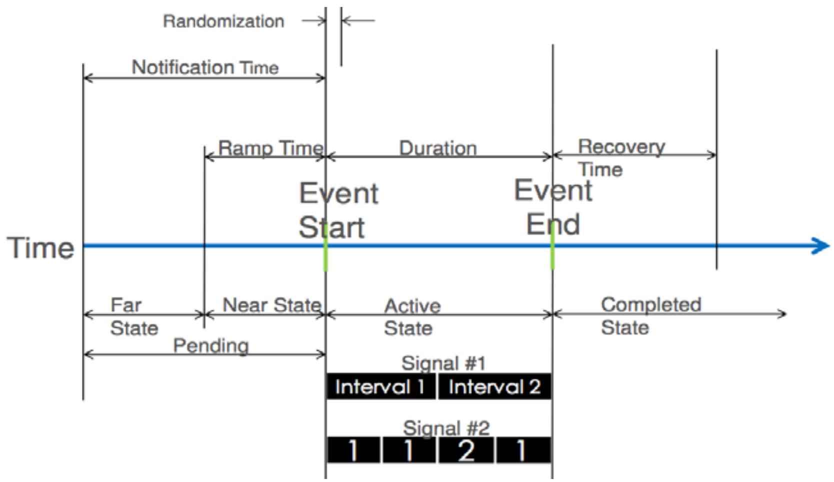
- The DR Event Scheduler provides a client for the Transactional Network to receive common demand response signals, using the EnerNoc OpenADR 2.0a open-source client. The system uses a two-way client server architecture to continuously listen to grid signals.
- **Inputs**: DR signals from an external OpenADR server contain DR event information
  - Event pending (for responses that include strategies such as precooling)
  - Event start time
  - Event end-time

- **Outputs**:
  - Notification sent back to the server that the event information is received
  - Record of event notifications with timestamp to historian



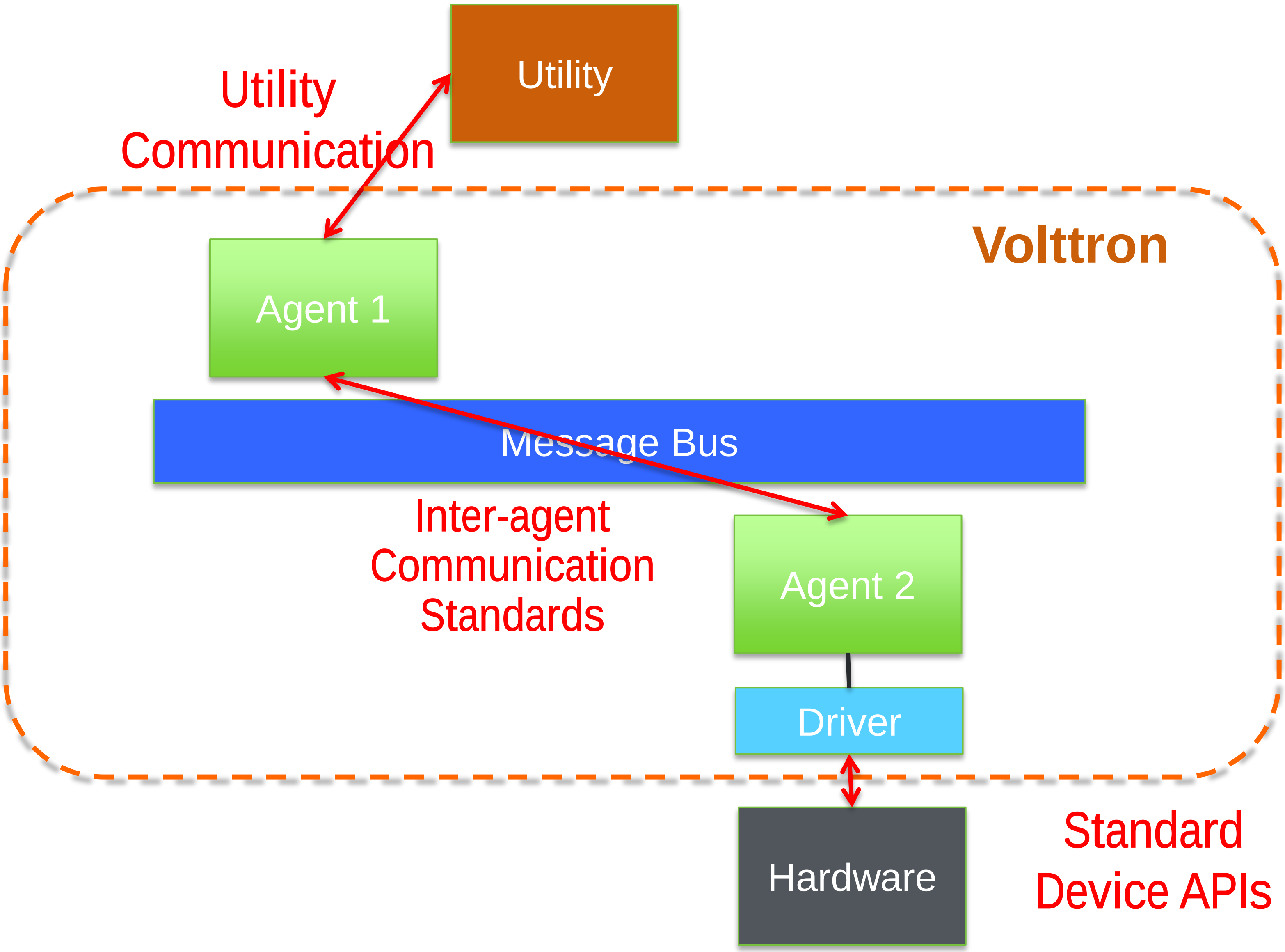
Volttron Feedback -- Pros

- Easy installation of development environment & debugging
- Open, transparent, easy to debug
- Easy to “roll your own” solution – very flexible
- Ships with some standard Pub/Sub topics defined
- Messages are strings, easy to see what’s happening and diagnose problems
- Easy to find where agents handle incoming messages, easy to debug
- Helpful community (PNNL)

Volttron Feedback -- Recommendations

- Standard interfaces, taxonomy, and automated discovery would help to interact with other agents
- Error handling and reporting should be standardized
- Need some simpler example agents, showing just one function with few dependencies
- Need style guidance about passing parameters in the topic name vs. in the message payload
- For production environment: more automation of agent launching and crash recovery, monitoring of currently running agents, would be helpful

Transactional Network Research Needs



Summary

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Lighting Diagnostic Agent Detects faults in lighting control systems

Baseline Tool provides the basis for measuring the effect of a change in energy use arising from a control action (e.g. DR event or energy efficiency measure).

Demand Response Measurement identifies the amount of load reduction achieved in response to a DR signal and characterizes it in terms relative to the building or facility.

Energy Savings Measurement measures energy savings accumulated over a given time period against a baseline

Economic Savings Measurement estimates the savings associated with the changes in energy use arising from a control action.

Demand Response Event Scheduler provides a client to receive DR signals from an outside server and convey them to the agent platform where they are converted into control signals.

Backup Slides

Lighting M&V Agent

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- Quantifies savings associated with scheduling and occupancy-based controls, relative to a base case of no automated controls

- Inputs:
  - Lighting load interval data from “pre” or base case period period
  - Lighting load interval data from “post” period
  - List of holiday dates (optional)
  - Hour of day that defines the start of the 12-hour “day” for purposes of summarizing changes by daytime and nighttime (optional; the default is 6:30 a.m.)

- Outputs:
  - Time series of difference in load between pre and post period, for an average week of each
  - Summary of average load difference by {weekend/weekday/holiday} and {daytime/nighttime}.
  - Average load reduction for an average week with no holiday

Schematic of M&V Agent Inputs and Outputs

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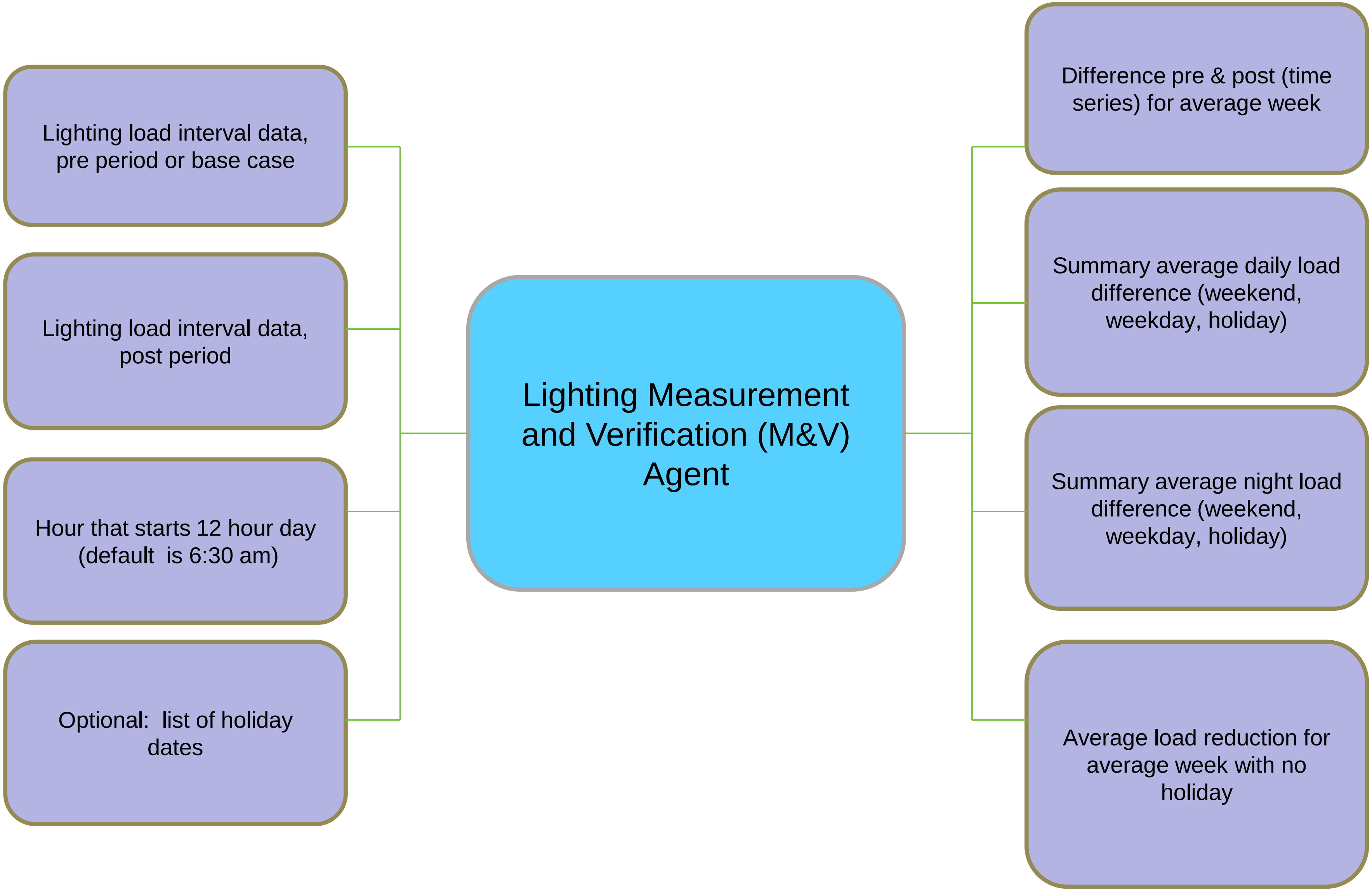


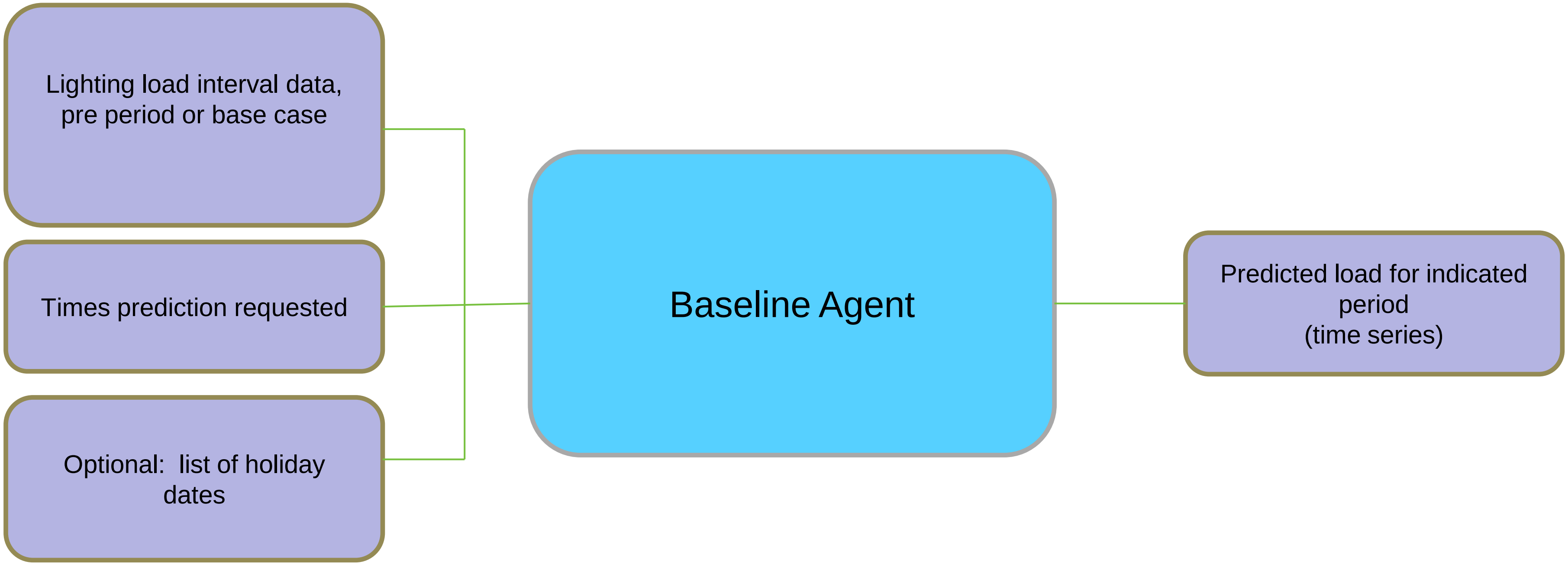
Lighting Baseline Agent

- A ‘module’ of the M&V agent that is implemented as a standalone agent, and can be called independently of the M&V agent if desired

- Inputs:
  - Time series of load data during “pre” period
  - Timestamps for which predictions are desired (typically the “post” period)
  - List of holiday dates (optional)

- Outputs:
  - Time series of predicted load during the specified period

Schematic of Lighting Baseline Agent Inputs and Outputs



Lighting Diagnostic Agent Logic

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Fault 1: Lights don't turn on/off according to programmed schedule times

- The following 'checks' underlie the logic used to detect and diagnose this fault:
  - Is the system time correct?
  - Does relay/group status match the on/off states programmed in the schedules?
  - Did a switch event (occupant override) occur?
    - Did the switch event cause the mismatch between relay status and programmed schedule?
  - If load data is available, do loads change as expected at scheduled times?

- These 'checks' are combined in the logic to determine whether the fault has occurred, and to identify potential causes, or system failures.

- System failures associated with Fault 1 include: time clock failures, command logging errors, communication failures, and actuator failures.

Lighting Diagnostic Agent Logic

Fault 2: Lights don't turn on/off according to manager's <u>intended</u> schedule

- The following 'checks' underlie the logic used to detect and diagnose this fault
  - Do programmed on/off times all for weekends, weekdays and holidays equal those specified by the building manager?
    - Schedules specified by the building manager comprise a priori data
  - If schedules are correctly programmed, and match the manager's intent, do lights turn on/off according to those programmed schedules?

- These 'checks' are combined in the logic to determine whether the fault has occurred, and to identify potential causes, or system failures

- System failures associated with Fault 2 include: programming errors, and by association with Fault 1, time clock failures, command logging errors, communication failures, and actuator failures

Lighting Diagnostic Agent Logic

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Fault 3: Schedules are not optimally defined

If any of the following are true, flag a potential to improve efficiency by reducing hours-on:

- Do programmed on/off times align with expected building occupancy?
  - Are programmed ‘on’ times much earlier than expected occupancy?
  - Are programmed ‘off’ times much later than expected vacancy?
  - Expected occupancy and vacancy times comprise a priori data
- Is duration of scheduled ‘off’ time too short on weekdays or on weekends?
- Do switch events to ‘off’ occur frequently and prior to scheduled ‘off’ times?
- If zone occupancy data is available
  - Is the time of first morning entry fairly regular (low variability), and is the average time of first morning much later than scheduled on times?
  - Is the time of last evening exit fairly regular (low variability), and is the average time of last exit much earlier than scheduled off times?

If any of the following are true, flag a potential to improve service by extending hours-on:

- If the system is auto-on (vs. manual-on)
  - Do switch events to ‘on’ occur frequently and soon after scheduled ‘off’ times?
  - Do switch events to ‘on’ occur frequently and prior to scheduled ‘on’ times?
- If zone occupancy data is available
  - Is the time of first morning entry fairly regular (low variability), and is the average time of first morning much earlier than scheduled on times?
  - Is the time of last evening exit fairly regular (low variability), and is the average time of last exit much later than scheduled off times?

Lighting Diagnostic Agent Logic

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Fault 4: Overrides are not optimally configured

If any of the following are true, flag a potential opportunity to improve efficiency by reducing the length of the override time-out:

- Do switch events to ‘off’ occur frequently and prior to elapse of the time-out?
- If zone occupancy data is available
  - Is duration of after-hours occupancy events significantly shorter than the length of the time-out?

If any of the following are true, flag a potential opportunity to improve service by increasing the length of the override time-out:

- Do switch events to ‘on’ occur frequently and soon after the time-out has elapsed?
- If zone occupancy data is available
  - Is duration of after-hours occupancy events significantly longer than the length of the time-out?