CADMUS

Memorandum

To: Andres Fergadiotti and Cassie Cuaresma, Southern California Edison

From: Cadmus

Subject: EUL analysis of Residential Smart Communicating Thermostat—Vendor A and B

Date: February 1, 2019

This memorandum summarizes Cadmus findings and recommendations for estimating the effective useful life (EUL) of residential smart communicating thermostat (SCT) technology with two-way communication and automatic scheduling capabilities.

This study relied on the analysis of thermostat connectivity data from two vendors (Vendor A and Vendor B), including a total of 210,975 SCTs. On December 26, 2018, an interim memo was submitted to Southern California Edison (SCE) that included findings and recommendations limited to Vendor A.

Background

In February 2017, SCE developed a workpaper for residential SCTs. The workpaper provided estimates of potential cooling and heating savings for eligible smart thermostats across all California climate zones. The California Public Utilities Commission (CPUC) *ex ante* review (EAR) team raised some concerns with the savings modeling approach, the net-to-gross multiplier applied to the savings, program eligibility requirements and eligibility verification plan, and the EUL assigned to the measure. SCE has collaborated with the EAR team to resolve these issues.

In response to a joint California IOU smart thermostat research plan, submitted by SCE in November 2017, CPUC staff extended interim approval of the SCE workpaper through the end of 2018. CPUC staff, however, emphasized that additional efforts, undertaken by a third party, would be required to align the workpaper's projected savings values with actual smart thermostat performance data. CPUC staff also required that SCE validate the estimated 11-year EUL with supporting data or by using the default EUL for retrocommissioning and operational measures adopted in Decision (D.) 16-08-019. This memo summarizes the Evaluation Team's findings and recommendations for estimating EUL, based on in-hand data.

Objectives

The study's objectives include reviewing Vendor A's EUL analysis of SCTs, identify the assumptions used in its approach, suggest ways to improve accuracy, and carry out an independent EUL analysis, based on available data from Vendor A and Vendor B.

This memo summarizes the Evaluation Team's approach for estimating survival functions and survival rates for residential SCTs activated in California and for using these to calculate the EUL. The Team included potential factors that might affect survival rates, discussions of possible sources of bias and mitigation strategies, and an approach for estimating confidence intervals for the survival functions.

Approach

Definition of Effective Useful life

An EUL is an estimate of the median number of years that measures installed under the program remain in place, operating and providing savings. EUL values are for new equipment, allowing the EUL to be directly employed with CPUC authorized annual avoided costs and measure-specific energy savings to determine lifecycle dollar benefits associated with a measure.

The Database of Energy Efficiency Resources (DEER)[1] provides estimated EUL values for many different measures for utilization in cost-effectiveness calculations. Typically, these are based on retention studies that use measure equipment failure data to develop a measure's survival curves, and—hence—statistically determine the median life of measures.

When available and applicable, EUL values should be taken from DEER. When EUL data are unavailable in DEER, additional studies, manufacturer data, or past maintenance records may be utilized to justify a proposed EUL for a measure, subject to review.

DEER does not provide an EUL for SCT, thus additional data and analysis must be used to develop a proposed value.

Effective Useful Life Evaluation Protocol

Per California's Energy Efficiency Evaluation Protocols, there are two allowable methods for EUL analysis: basic rigor and enhanced rigor.[2] Both methods require survival analysis or other analysis methods that specifically control for right-censored data. Right-censored data are failures that might take place after data collection.

Sample size requirements should be determined using power analysis, results from prior studies on similar programs, and professional judgments. A power analysis to determine the required sample size must be calculated by setting power to at least at 0.7 for basic rigor and to 0.8 for enhanced rigor to determine the sample size required at a 90% confidence level (alpha set at 0.10).

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1 Database of Energy Efficiency Resources, available online: http://deeresources.com

2 CA Energy Efficiency Evaluation Protocols available online: http://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=5212

Connectivity Data

Vendor A provided the activated date and last-connected date (i.e., the date of the last day that each thermostat remained online) for 72,000 thermostats, installed between July 2012 and June 2018. Thermostats in the Vendor A dataset were sampled from a total of about 600,000 thermostats activated in California between July 2012 and June 2018. Vendor A selected a random sample of 1,000 thermostats from all thermostats activated each month during the study period (July 2012 and June 2018). Each month's sample was selected by sorting the population by a random number and selecting the first 1,000 thermostats. Vendor A did not report the total number of thermostats installed each month.

Vendor B also provided the activated date and the last-connected date for 138,975 thermostats, installed between January 2014 and December 2018. The Vendor B dataset includes all thermostats installed in California since January 2014.

Both Vendor A and the Evaluation Team used the last-connected date to define whether a thermostat was “dead” or “alive.” In the Vendor A analysis, the cutoff date used was June 30, 2018, meaning thermostats were considered dead if the last-connected date occurred before June 30, 2018. The cutoff date used in the Vendor B analysis was December 27, 2018, and thermostats were considered dead if the last-connected dates occurred before December 27, 2018.[3]

Connectivity as A Proxy for Evaluating Effective Useful Life

Internet connectivity is not a requirement for use of energy-efficient features for either Vendor’s thermostats. Similarly, connectivity does not imply that energy-efficient features are used. Connectivity, however, is the only variable in Vendor A and Vendor B data that could serve as a proxy for energy-efficient feature usage and hence for the energy savings’ EUL. Therefore, conclusions drawn based on this analysis should be understood to represent the EUL of SCT’s connectivity, not of energy efficiency feature usage or of thermostats’ energy savings.

Effective Useful Life Analysis

The Evaluation Team implemented a survival analysis method on the thermostat connectivity data to account for right censorship in the data and to provide unbiased estimates of survival functions and rates, using non-parametric Kaplan-Meier estimation methodology in R statistical software (Vendor A used the same methodology in Stata statistical software). Table 1 shows the resulting estimated survival

[3] Due to the frequency of temporary disconnects recorded in the Vendor B data, thermostats that disconnected within seven days of the dataset compilation (January 2, 2019) were excluded from the analysis.

rate (the probability of surviving to time *t*) and cumulative hazard (the probability failing at or before time *t*) for Vendor A and Vendor B.[4]

Table 1. Survival Analysis Results for Vendor A and Vendor B

Time	Vendor A		Vendor B	
	Survival Rate	Cumulative Hazard	Survival Rate	Cumulative Hazard
1 day	98.9%	1.1%	99.7%	0.3%
1 week	97.8%	2.2%	99.1%	0.9%
1 month	97.0%	3.0%	98.1%	1.9%
1 year	93.1%	6.9%	92.2%	7.8%
2 years	89.8%	10.2%	83.5%	16.5%
3 years	86.2%	13.8%	74.2%	25.8%
4 years	82.3%	17.7%	64.2%	35.8%
5 years	77.2%	22.8%	52.4%	47.6%
6 years	71.6%	28.4%	NA	NA

Figure 1 shows the survival function for sampled Vendor A thermostats activated in California. The results indicate that 71.6% of the Vendor A thermostats remain connected six or more years after installation. Figure 2 shows the survival function for Vendor B thermostats activated in California. The results indicate that 52.4% of Vendor B thermostats remain connected five or more years after installation.

Figure 1. Survival Function for Vendor A Sampled Thermostats Activated in CA

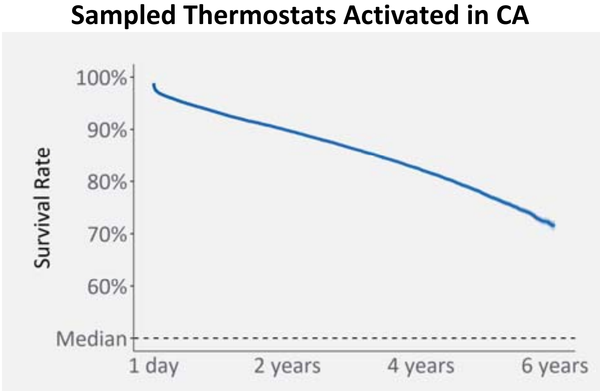
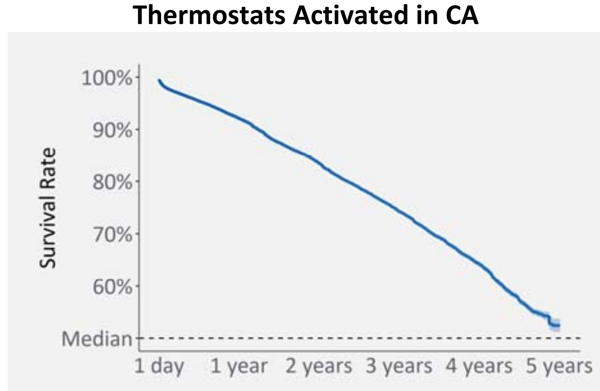


Figure 2. Survival Function for Vendor B Thermostats Activated in CA



Using median lifetime estimates, the Evaluation Team determined the EUL based on the trend in daily survival rates over time. A combination of linear and non-linear regressions were used to predict when the survival rate is expected to be 50%, representing the median lifetime of the devices (or the EUL). The

[4] Note that Vendor A results include a subsample of Vendor A thermostats activated in California. Vendor B results include all Vendor B thermostats activated in California after 2014.

resulting median lifetime estimate is an extrapolation, based on the survival rates of thermostats installed during the past six years for Vendor A and during the last five years for Vendor B.

The nonlinear decreases in survival rates over time indicated daily survival rates differed throughout the thermostat lifecycles. Due to changing trends over time, the Evaluation Team used different subsets of the survival rate series as well as linear and nonlinear regressions to determine the EUL estimate and its uncertainty.

For example, when survival rates of all thermostats are used for linear extrapolation, as shown in Figure 3 and Figure 4, the median lifetime estimate is 11.8 years for Vendor A and 5.5 years for Vendor B (red dashed lines). When survival rates of thermostats that remained alive for four or more years are used, survival rates decrease faster, and median lifetime estimates are 10 years for Vendor A and 5.2 years for Vendor B (green dashed lines). The difference between these estimates demonstrates the uncertainty in extrapolating the non-parametric survival function to estimate the EUL.

Figure 3. Regression Model to Extrapolate the Survival Function for Vendor A

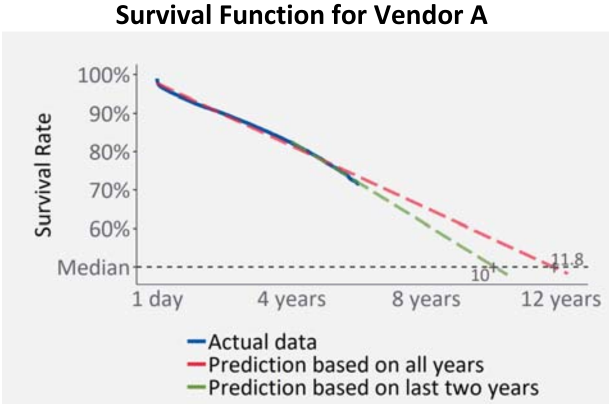
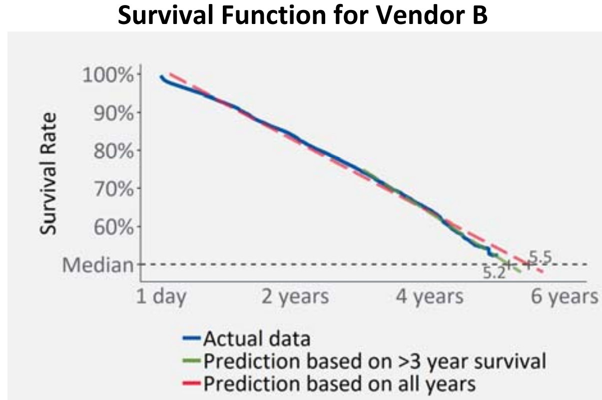


Figure 4. Regression Model to Extrapolate the Survival Function for Vendor B



To quantify the uncertainty of EUL estimates, the Evaluation Team expanded on the above example to use numerous subsets, starting with all thermostats and then progressively excluding those that died in the first month after initial connectivity, in the first two months, and so on. Figure 5 and Figure 6 show resulting EUL estimates for the range of subsets. Lines based on larger data subsets show in gray. Lines become increasingly blue when fit to smaller data subsets that only include thermostats that have lived longer. Median lifetime estimates range from 9.2 to 11.8 years for Vendor A and 5.2 to 5.5 years for Vendor B. These ranges provide a prediction interval that indicates the range of values an EUL can take when estimated based on a linear model fit to daily survival rates.

Figure 5. Range of Expected EUL for Vendor A (Linear Models)

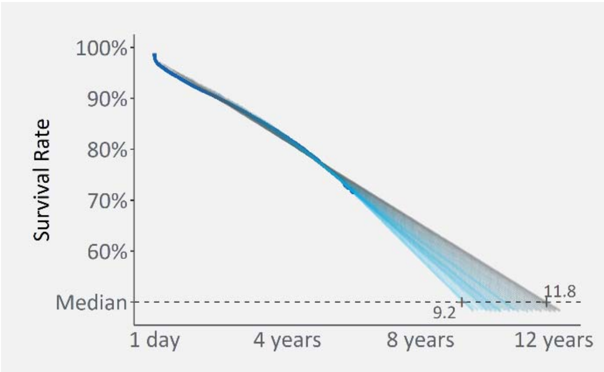
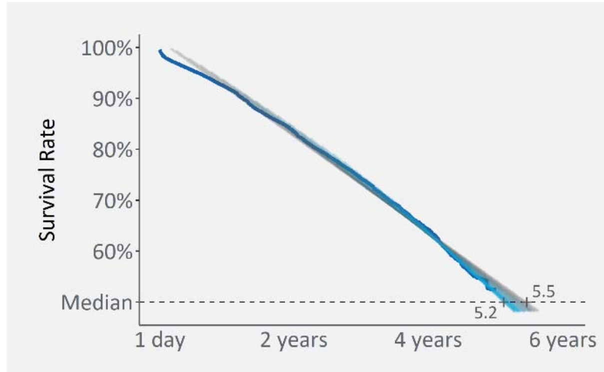


Figure 6. Range of Expected EUL for Vendor B (Linear Models)



The Evaluation Team also considered using nonlinear regressions to estimate the prediction interval due to the nonlinearity of the survival functions. Specifically, a series of extrapolations were evaluated, ranging between second- to sixth-order polynomial regressions. Extrapolations with a reasonable fit (where survival is non-increasing over the relevant time period) predicted EULs ranging from 7.9 to 9.5 years for Vendor A and 5.1 to 5.2 years for Vendor B.

Note: given all predicted median lifetimes are longer than the number of years covered by each vendor's dataset, a longer study period would be required to directly observe and document the median lifetime.

Effective Useful Life Analysis Results

The Evaluation Team recommends combining nonlinear and linear results to quantify the uncertainty around both EUL estimates, setting the prediction interval from 7.9 years to 11.8 years for Vendor A and 5.1 years to 5.5 years for Vendor B. Using smart thermostat program implementation data, a weighted average based on the vendor's market share produces one combined EUL interval from 7.4 years to 10.7 years.

Analysis Limitations and Recommendations

The Evaluation Team acknowledges the following as unique challenges and limitations to this approach and provides solutions and recommendations for working around these limitations:

- Vendor A, to avoid releasing protected market information, provided connectivity data for a sample of 12% of thermostats in its population of 600,000 thermostats. The Team believes the sample size was sufficient for the above-described analysis. Though Vendor A confirmed that the sample was selected randomly, the Team could not verify that thermostats in the Vendor A sample were representative of the population of thermostats sold and installed in California.
- Vendor B provided connectivity data for all of its 138,975 thermostats activated in California after 2014. Vendor B did not consistently track connectivity data for thermostats activated prior to 2014, which included 2.7% of all Vendor B thermostats activated in California. Therefore, the Evaluation Team removed thermostats activated prior to 2014 from the analysis dataset. The

Team believes available connectivity data from 2014–2018 were sufficient for the analysis as a new (first generation) product was launched in 2014, along with firmware updates for legacy models. Furthermore, Vendor B thermostats sold prior to 2014 constituted a small portion of Vendor B thermostats sold in California (2.7%).

- Internet connectivity is not a requirement to use the energy-efficient features of either Vendor's thermostats. Similarly, connectivity does not imply that energy-efficient features are used. Connectivity, however, is the only variable in Vendor A and Vendor B data that could serve as a proxy for energy-efficient feature usage. Additional data would be necessary to verify and validate the persistence of energy savings beyond the longevity of the technology's connectivity; consequently, connectivity is used as a proxy to approximate the technology's EUL. Conclusions drawn based on the above analysis should be understood to represent the EUL of connectivity for SCTs—not of the thermostats' energy efficiency feature usage or energy savings.
- EUL values are used to establish the amount of time that energy-savings will be credited for an energy efficiency measure. Therefore, future EUL studies of SCTs should explore the persistence of savings over the SCTs' lifetime. The Evaluation Team understands that this will not be feasible at this time, given available vendor data and the absence of specific data that show changes in baseline thermostat temperature setpoints over the lifetime of those thermostats. To improve this analysis, the Evaluation Team recommends determining the persistence of energy-saving features by analyzing smart thermostat setpoints over time. The Team can perform this analysis in the next study phase, contingent on the availability of historical setpoint data provided by each vendor. Note: this approach faces a primary main barrier in that any changes in smart thermostat setpoints over time should be compared to similar changes in baseline thermostat setpoints, and such baseline data are likely unavailable; they can, however, be estimated with high uncertainty using previous residential saturation studies.

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