Rethinking Short Term Electric Load Forecasting

Experience at US Utilities

Tao Hong, PhD

Principal Engineer, Quanta Technology

tao.hong@quanta-technology.com

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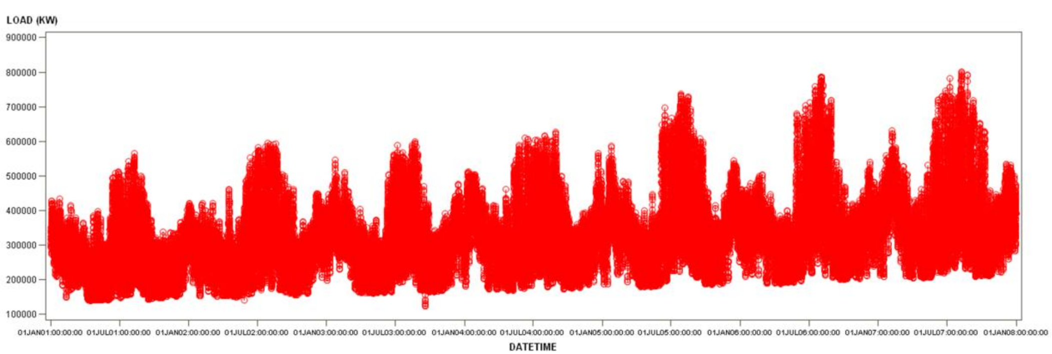
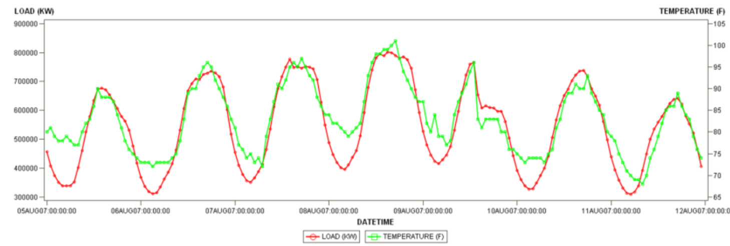
Tao Hong

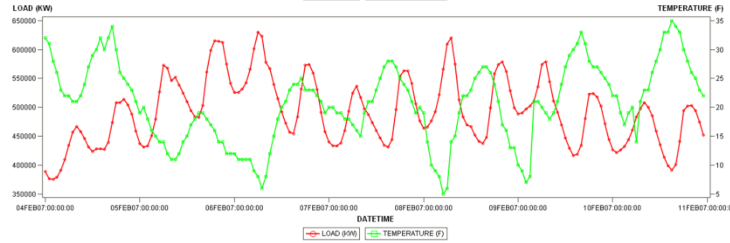
- Education
  - B.Eng, Automation, Tsinghua University, Beijing
  - M.S. E.E., North Carolina State University, Raleigh
  - M.S. O.R., I.E. North Carolina University, Raleigh
  - Ph.D. E.E. & O.R., North Carolina University, Raleigh
- Experience
  - *Engineer, Sr. Engineer, Principal Engineer,* Quanta Technology, LLC.
  - *BKS Instructor,* SAS Institute, Inc., "*Electric Load Forecasting*"
- Interest
  - Load / price forecasting, energy market
  - System planning, power engineering

Outline

- What's Electric Load Forecasting?
- A Brief Literature Review
- Building a Naïve Multiple Linear Regression Based Benchmark
- Customizing the Benchmarking Model
- 10 Ways to Screw up Your Load Forecasts







QUANTA TECHNOLOGY

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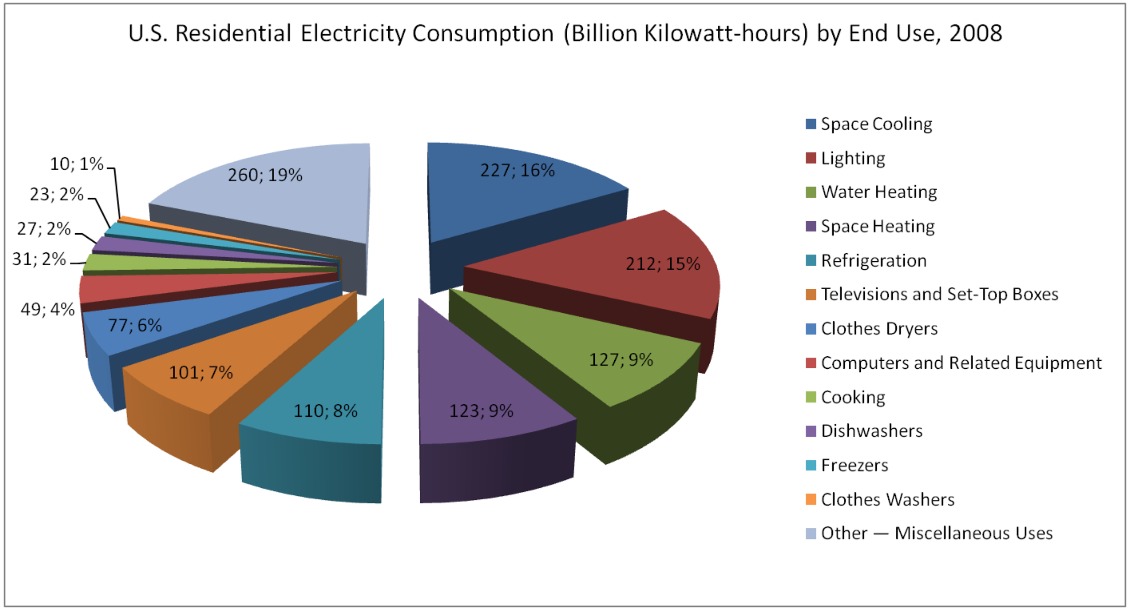
Uniqueness of Electricity

- Storage
  - Unlike fashion goods, food, airline passengers, computers, and water, electricity cannot be massively stored!!!
- End uses

Invention	Year
Air conditioner	1902
Electric washing machine	1906
Electric refrigerator	1913
Radio stations in US	1920s
Electronic television	1927
Microwave oven	1947
Personal computer	1975



Regulation and Deregulation

- Prior to the energy crisis
  - Thomas Edison (DC), Pearl station, 1882
  - Nichola Tesla (AC), Edward Dean Adams Station, 1896
  - Samuel Insull, Commonwealth Edison, 1900s
  - Abuses of holding companies, 1920s
  - Great depression, 1930s
- Energy crisis, 1970s
  - Environmental concerns, increased fossil-fuel prices, inflation
- After the Energy crisis
  - The Public Utility Regulatory Policies Act (PURPA), 1978
  - Energy Policy Act (EPACT92), 1992

Business Needs

- Generation
- Transmission
- Distribution
- Planning
- Operations & maintenance
- Market related activities

Prior to 1980s
Appliances

- Operations & Maintenance
- Planning

1990s
Deregulation

- Energy purchasing
- Rate case

2010s
Smart grid

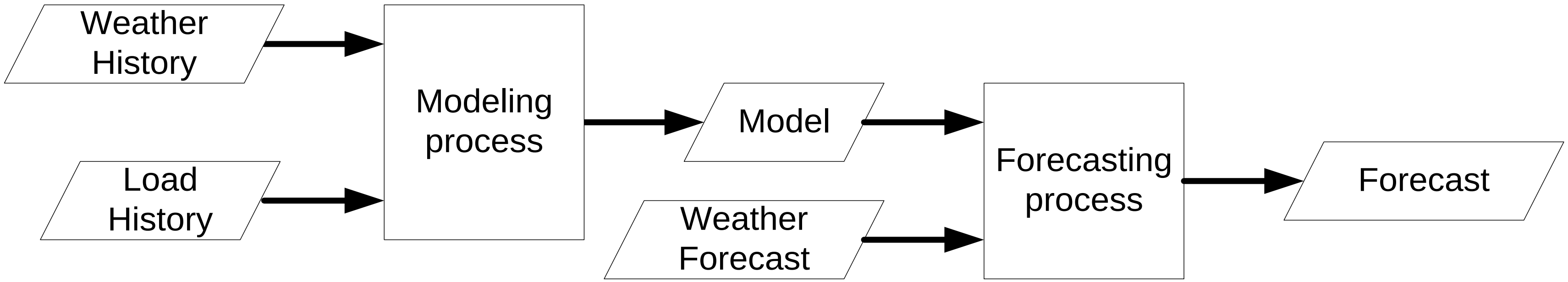
- Demand Side Management
- Electric vehicles, renewable energy

Classification

- By horizon
  - Hour / day / week / month / year / 10 years / 30 years ahead
- By resolution
  - 5 minutes / 30 minutes / Hourly /daily / weekly / monthly / seasonal / annual
- By engineering concepts
  - Load (kW) / peak / valley / energy
- By levels
  - System, nodal, transmission substation, distribution substation, feeder
- Terminology
  - Long term: 30 years, annual
  - Medium term: 3 years, monthly
  - Short term: 2 weeks, hourly
  - Very short term: 1 day, hourly*

A Big Picture

- A load forecasting process



- Modeling process
  - Statistics: linear regression, Box-Jenkins, nonparametric regression
  - A.I.: ANN, fuzzy logic, neuro-fuzzy system, SVM
  - Others: hybrid approach, multi-stage approach

Counterexample #1

$$L = \delta_0 C + \delta_1 M + \delta_2 T_a + \delta_3 ENDL + (\beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + \beta_4 t^4 + \beta_5 t^5 + \beta_6 t_0 + \beta 7 t_s)* (\alpha_0 + \alpha_1 I + \alpha_2 I^2 + \alpha_3 I^3 + \alpha_4 * I^0)$$

Table 1: R^2 values for each sub-model.

Rutherford	10:00-18:00	18:00-20:00	20:00-23:00
M-F model	.983	.927	.918
T-W-T model	.975	.943	.830

Davidson	10:00-18:00	18:00-20:00	20:00-23:00
M-F model	.978	.891	.739
T-W-T model	.966	.945	.904

Statistics for the models as a whole.

	Rutherford	Davidson
Global R^2	.952	.948
PE	-.863 %	-.763 %
APE	5.770 %	9.142 %
RMSE	2.39 %	2.72 %

C = Base load initial condition

M = initial load slope condition

T_a = average temperature, first hour

I^0 = Temperature/100

I^1 = Temp - 0.55*(1 - Humd)*(Temp - 58)

I^2, I^3 = I^1 squared and I^1 cubed

t^1 = (TIME-10*3600)/(23-10)/3600 !normalized time

t_0 = $1/(1-t^1)$

$t^2 ... t^5$ = t^1 raised to the power of 2...5

t_s = Sin(2π*(TIME-12)/24)

ENDL = Average load during the period of 22:30 to 23:00 (which is the end of the period to be studied)

Counterexample #2

3.1.1. Fuzzy winter model

The fuzzy winter model can be written in a fuzzy form as

$$\underline{Y}_j(t) = \underline{A}_0 + \underline{A}_1 T_j(t) + \underline{A}_2 T_j^2 + \underline{A}_3 T_j^3 + \underline{A}_4 T_j(t-1) + \underline{A}_5 T_j(t-2) + \underline{A}_6 T_j(t-3) + \underline{A}_7 W_j(t) + \underline{A}_8 W_j(t-1) + \underline{A}_9 W_j(t-2);$$

$j = 1, \ldots, m$ (18)

3.1.2. Fuzzy summer model

The summer fuzzy model for the short-term load forecasting can be written as

$$\underline{Y}_j(t) = \underline{A}_0 + \underline{A}_1 T_j(t) + \underline{A}_2 T_j^2 + \underline{A}_3 T_j^3 + \underline{A}_4 T_j(t-1) + \underline{A}_5 T_j(t-2) + \underline{A}_6 T_j(t-3) + \underline{A}_7 H_j(t) + \underline{A}_8 H_j(t-1) + \underline{A}_9 H_j(t-2);$$

$j = 1, \ldots, m$ (23)

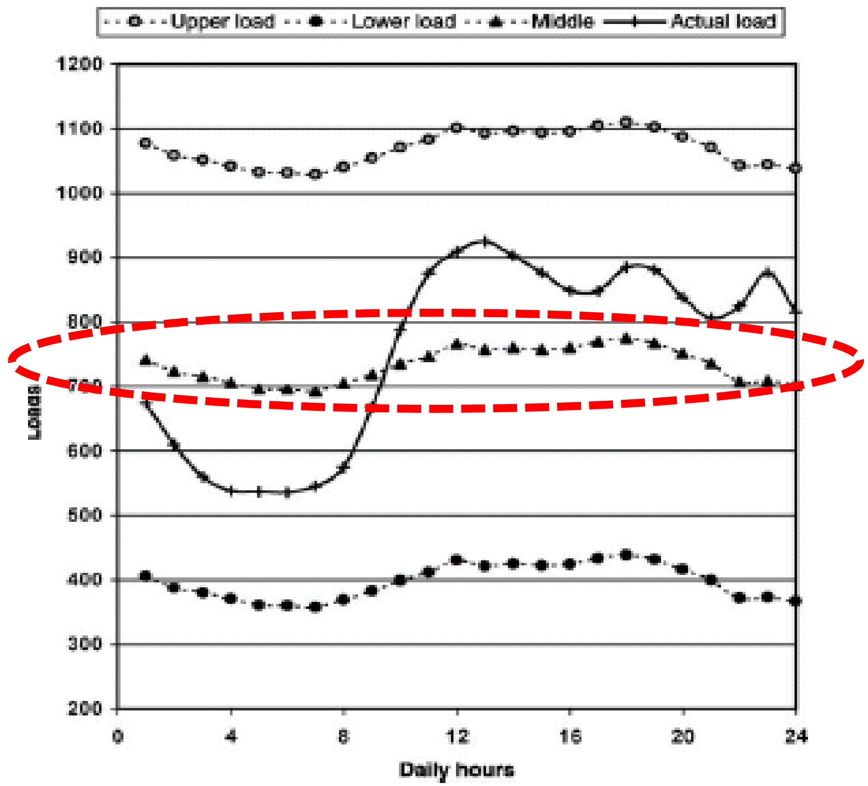


Fig. 1. Estimated load for a summer weekday, crisp load.

Issues to Face

- No benchmarking data
- No benchmarking model
- No benchmarking accuracy statistics
- Lack of comparisons
- Hard to reproduce the results
- Away from practice
- Bad interpretability of the (black box) models
- Not making use of the power of the conventional techniques
- Etc.

What to Do Next?

- Explore real-world business needs
  - Multi-region forecast
  - Probabilistic forecast
  - Outlier detection
- Quantify the economic impact of forecasting accuracy
- Establish load data pool
- Regulate reporting format
- Develop benchmarking models
- Refresh the state of the art of conventional techniques
- Increase interpretability of black-box approaches

Requirements for a Naïve Benchmark

- Simple
  - Easy to implement
- Creditable
  - Fairly accurate and theoretically sound
- Widely applicable
  - Can be used by a wide range of utilities
- Interpretable
  - Can be understood by average electrical engineers, managers, etc.
- Reproducible
  - Can be reproduced based on documented procedures

Multiple Linear Regression 101

- Simple linear regression
- General linear regression models
- Quantitative variables and qualitative variables
- Polynomial regression
- Transformed variables
- Interaction regression
- *Linear models vs. linear response surface*

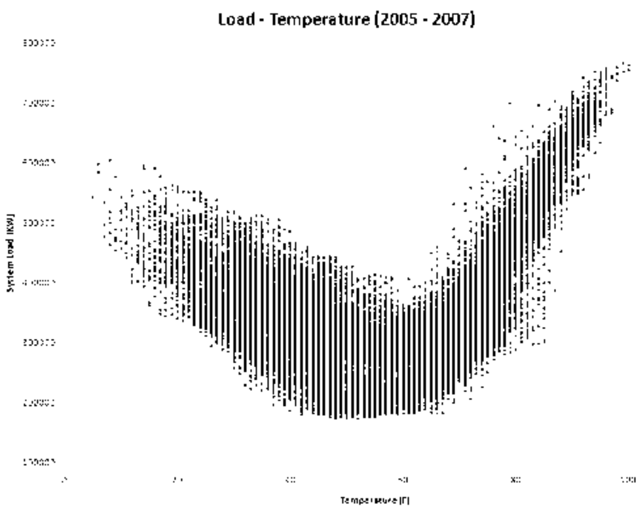
Trend and Seasonality

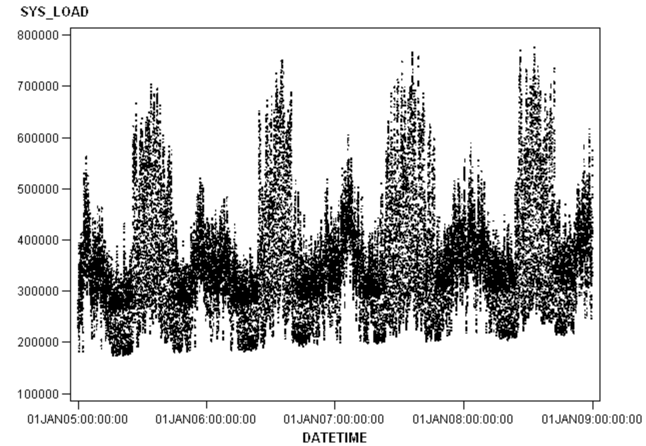
- Trend
  - Linear, macroeconomic indicators (GDP, GSP, employment, etc.)
- In a year
  - 4 seasons, 12 months, etc.
- In a week
  - Weekday/weekend, etc.
- In a day
  - 24 hours, etc.

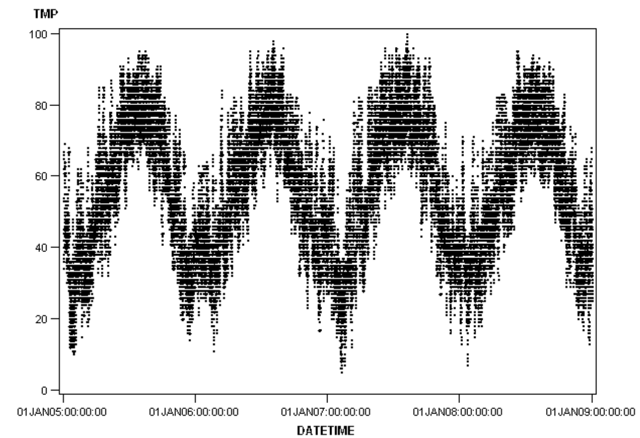
	Day Type
1	2 types: Mon – Fri; Sat, Sun.
2	3 types: Mon – Fri; Sat; Sun.
3	4 types: Mon; Tue – Thu; Fri; Sat, Sun
4	4 types: Mon; Tue – Fri; Sat; Sun
5	4 types: Sat; Sun – Wed; Thu; Fri
6	5 types: Mon; Tue – Thu; Fri; Sat; Sun
7	7 types: Mon; Tue; Wed; Thu; Fri; Sat; Sun

Temperature

- Piecewise linear
- Quadratic
- 3rd order polynomial
- Etc.







Interactions

- Temperature vs. calendar variables
  - High during the day, low at night
  - High in summer, low in winter
  - No apparent interactions across 7 days of a week
- Interactions (or cross effects)
  - "Temperature" × Hour
  - "Temperature" × Month

  "Temperature": T, T^2, T^3

$$E(\text{Load}) = \beta_0 + \beta_1 \times \text{Trend} + \beta_2 \times \text{Day} \times \text{Hour} + \beta_3 \times \text{Month} + \beta_4 \times \text{Month} \times T + \beta_5 \times \text{Month} \times T^2 + \beta_6 \times \text{Month} \times T^3 + \beta_7 \times \text{Hour} \times T + \beta_8 \times \text{Hour} \times T^2 + \beta_9 \times \text{Hour} \times T^3$$

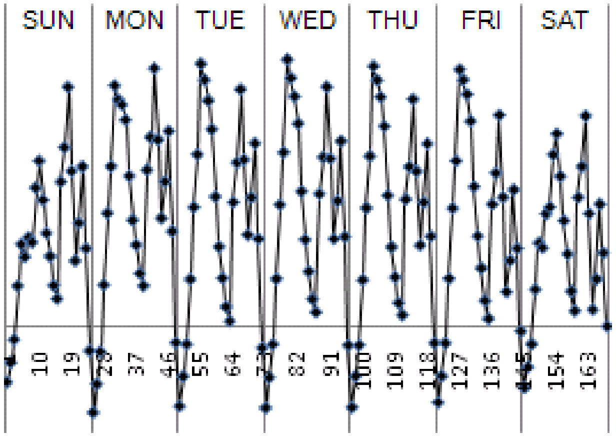
Recency Effect

- From psychology
  - This is the principle that the most recently presented items or experiences will most likely be remembered best. If you hear a long list of words, it is more likely that you will remember the words you heard last (at the end of the list) than words that occurred in the middle.
- From statistics
  - Lagged regression
  - *Load* (t+1) = $f(T(t), T(t\text{-}1), T(t\text{-}2), \ldots)$

Tao Hong, PhD (tao.hong@quanta-technology.com)

Weekend Effect

- At low resolution
  - Workdays: Monday to Friday
  - Non-workdays: Saturday & Sunday
- At high resolution, i.e. comparing with Tuesday to Wednesday
  - Monday morning: in a workday, but right after a non-workday
  - Friday evening: in a workday, but right before a non-workday
  - Saturday evening
  - Sunday evening
  - Etc.



Weekend Effect

- Principal of parsimony
  - When two models can achieve the same accuracy, pick the one with less complexity (variables, degrees of freedom, etc.)

	Day Type	MAPE
1	2 types: Mon – Fri; Sat, Sun.	3.50%
2	3 types: Mon – Fri; Sat; Sun.	3.47%
3	4 types: Mon; Tue – Thu; Fri; Sat, Sun	3.45%
4	4 types: Mon; Tue – Fri; Sat; Sun	3.45%
5	4 types: Sat; Sun – Wed; Thu; Fri	3.43%
6	5 types: Mon; Tue – Thu; Fri; Sat; Sun	3.41%
7	7 types: Mon; Tue; Wed; Thu; Fri; Sat; Sun	3.41%

Holiday Effect

- US Public Holidays Established by Federal Law (5 U.S.C. 603)

	Date	Official Name
1	Jan. 1	New Year's Day
2	Third Monday in Jan.	Birthday of Martin Luther King Jr.
3	Third Monday in Feb.	Washington's Birthday
4	Last Monday in May.	Memorial Day
5	Jul. 4	Independence Day
6	First Monday in Sep.	Labor Day
7	Second Monday in Oct.	Columbus Day
8	Nov. 11	Veterans Day
9	Fourth Thursday in Nov.	Thanksgiving Day
10	Dec. 25	Christmas Day

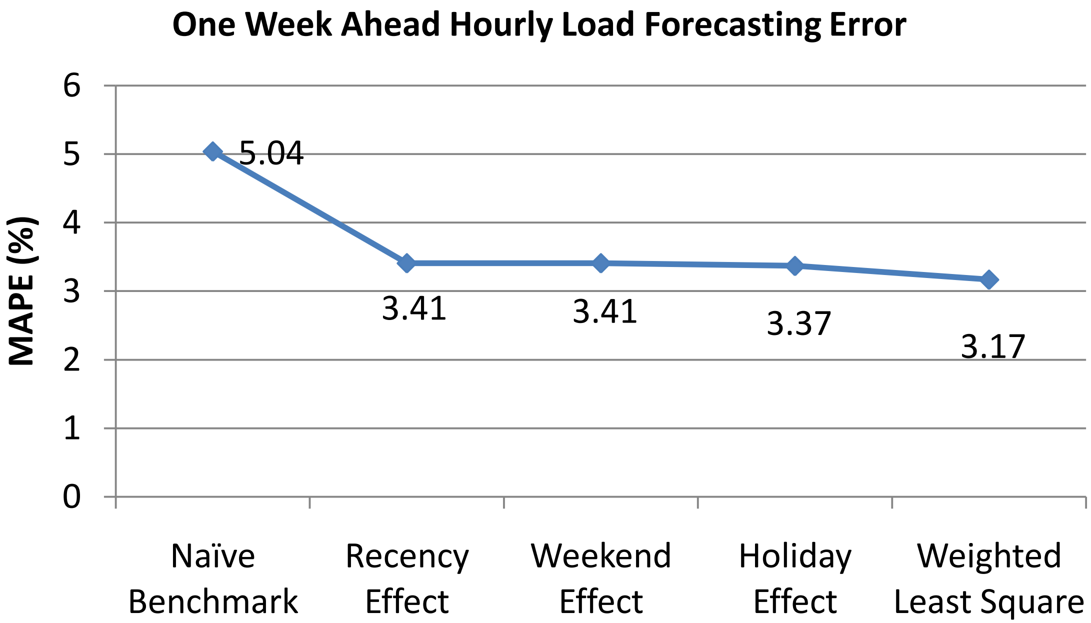
- Classes of special days
  - 4 fixed date holidays, 6 fixed weekday holidays
  - 20 surrounding days, i.e. Black Friday

Holiday Effect

- Guideline (developed for one specific utility, not all utilities)
  - Memorial Day and Labor Day are treated as Sunday.
  - The day before Memorial Day is treated as Saturday.
  - The days after Memorial Day and Labor Day are treated as Monday.
  - Thanksgiving Day and the day after are treated as Saturday.
  - New Year's Day, Independence Day, and Christmas Day are treated as Sunday when they are not observed on Friday, otherwise, treat them as Saturday.
  - The days after New Year's Day and Christmas Day are treated as Monday, when the corresponding holiday is observed on Monday, Tuesday or Wednesday.

Modeling the Time Variant System

- Weighted Least Square
  - Assign high weights to recent hours



Expectation

- Every forecast is wrong
- Some are useful – *"capture the salient features"*
  - Covering business need(s)
  - Accurate
  - Interpretable
  - Documentable
  - Reproducible
  - Defensible
- Accuracy vs. defensibility

Data

1. kW, kVar, and kVA
   - ☹ kW = kVA; $kW^2 – kVar^2 = kVA^2$
2. Time zones & DST
   - ☹ Not checking time zones, DST, etc.
3. Missing data, redundant data, & outliers
   - ☹ Incorrect treatment to missing data, redundant data & outliers
4. T&D losses
   - ☹ Not (or incorrectly) accounting transformer/line/… losses
5. Load transfer
   - ☹ Not paying attention to load transfer

Models

6. Design
   - ☹ The newer/more complicated/etc., the better
   - ☹ Not covering business needs
7. Model building
   - ☹ Verbose models: high order polynomial; over-parameterized ANN
8. Model assumptions
   - ☹ "Sampling" times series data incorrectly
   - ☹ AR w/o unit root tests
9. Comparing models
   - ☹ Models from different utilities
   - ☹ MAPE and other measures

Decisions

10. Judgmental forecast w/o DOCUMENTATION

☹ Not documenting the justifications when alternating the forecasting results.

- Not one of the "10 ways"
  - Fraud forecast

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Takeaways

- Load forecasting has to tie to utility applications
  - Fancy approach ≠ useful forecast; simple approach ≠ bad forecast
- Weather, human activities, and the interactions of the two drive the load profile
  - Discover, model, and analyze interactions
- Special attention should be paid to special effects
  - Weekend effect, holiday effect, etc.
  - Don't try to build the universally best model.
- Document every change, benchmark every major milestone
- Keep in mind some frequently made mistakes

Thank You

- Questions / comments?

Tao Hong, PhD (tao.hong@quanta-technology.com)