Introduction:

Good morning. My name is Graham Duthie.

I am the Central Reliability Engineering Manager at Visteon and a major portion of my job is spent thinking about and studying how people use their vehicles.

Where do they use them, how frequently, is it raining, did it snow, how hot was it, is the sun shining, is the blower motor on… etc.

Last year I was asked by Shane Harte in Visteon’s Climate Control Engineering office to help find an average customer somewhere so that we could determine how changes in a/c system efficiency would affect vehicle fuel economy based on horsepower consumption.

This presentation will first provide you some insight into how we have developed and applied an average customer model for use in determining average horsepower consumption.
Average Mobile A/C Customer Usage Model: Development and Recommendations

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The main goals of the customer usage model were:

1) Make sure that we created a rational model that was properly weighted and not just based on the hottest place and time in the country. Customers use their vehicles across the nation and throughout the entire range of each day, not just at 2:00pm in Death Valley, CA.

2) We wanted to use publicly available climate and customer usage data so that we had a standard data set and because many of the public studies are updated regularly. Regular data updates will allow the model to evolve over time.

3) Thirdly, the model needed to be generic based on the geographical distribution of population. Consider the presentation to be that of the general model. A specific model could be easily developed by using vehicle sales data as the weighting factor instead of human population. Vehicle sales as a weighting factor would be useful for a vehicle model sold in high concentrations in certain areas; the model would then account for the specific geographic sales distribution.
This slide is intended to provide you with a flow chart of how the data was blended to result in an average customer for use in determining which specific temperature and humidity ratio points to perform vehicle testing.

The first step was to assign population to the weather stations.

Next the weighted weather stations enabled the summarization of the weather data based on where people (and their vehicles) live.

Then the weather data was weighted by the proportion of the day when people drive. This essentially gives more weight to daytime weather and less to night time.

Finally with our weighted operating conditions in hand we still need to factor in customer usage of the A/C system under the range of operating conditions. This step is in process.
Model as a Formula

\[
\text{Surface of average vehicle usage time by temperature and humidity ratio} = f \left[ \left( \text{Population weight} \times \text{weather stations} \right) \times \left( \text{hourly weather data} \right) \times \left( \text{vehicle usage by time of day} \right) \right]
\]

The above formula provides a basic outline of how the data was combined to create the surface of average vehicle usage time by temperature and humidity ratio.
Typical Meteorological Year (TMY) Background

- Designed to be a representative set of hourly weather parameter values for a single year period. One set of readings per hour (8,760 hours) at each of 237 locations. Based on 1961-1990 weather data.

- Originally intended for use in “computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations in the United States and its territories. Because they represent typical rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a location (NREL 1995).”

- Derived from the National Solar Radiation Database v1.1 and is a mixture of measured and modeled data (only solar radiation modeled).

Some background information about the weather data that was used in the model development:

The Typical Meteorological Year (TMY) dataset was designed to be a representative set of hourly weather parameter values for a single year period. One set of readings per hour (8,760 hours) at each of 237 locations in the United States. The TMY data is based on actual 1961-1990 weather data. Each hourly point was drawn from an actual reading at each location.

The original use of the dataset was for the development of (quoting the TMY documentation) “computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations in the United States and its territories. Because they represent typical rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a location (NREL 1995).” This fits well with the goals of our average customer.

References to the data are listed at the end of this presentation.
To illustrate how the model was developed I have a few slides.

This slide shows a map of estimated 1999 USA population percentages by county. It is color coded red and blue to help show where the main population centers are – the East coast and the west coast.
Next the locations of the TMY weather stations were added to the map.
Then the population data was assigned to the nearest weather station using Thiessen polygons based on the location of the center of each county.

In any Thiessen polygon the points in that polygon are closer to the weather station shown than any other weather station on the map.

So if the center of a county was closer to the Phoenix weather station as opposed to the Flagstaff weather station all of those people (and their cars) now live in Phoenix weather.

This forms the basis of the model’s ability to weight the time spent at any given condition by where people live.

In essence we are tying the model to the ground.
The 1995 Nationwide Personal Transportation Survey or NPTS is a very large survey conducted every five to seven years that is designed to quantify the travel behaviors of the American public. Participants in the study are asked to record all of their travel characteristics on their specific travel day.

The survey is sampled systematically for day of the week and month of the year.

Some of the metrics the NPTS is designed to measure or record are:
- Trip purpose
- Trip length
- Number of occupants
- Trip time
- Driver characteristics (sex, age, worker status, etc)
- Vehicle characteristics (make, model, year, yearly mileage, etc)
To help visualize what the data looks like and what the general characteristics of daily trips look like I have created a multi-panel chart to show how trip length and duration vary depending on the time of day and the day of the week.

Each row of the chart shows 20% of the number of trips in the sample classified by trip duration in minutes. Note that most trips are under 30 minutes in length.

You can clearly see the morning and evening commuting regime in the 15-30 minute and the 30-960 minute rows. You can also see that people are out late Saturday evening and sleep-in late on Sunday morning – or at least their cars are still sleeping. My kids usually have me up before 8:00am on Sunday, but my cars sleeps.

The main point behind this slide is that people do not use their vehicles uniformly across all hours of the day. There are clearly times when almost no activity occurs and times when there is a tremendous amount of activity – every night when I drive home at 5:00pm.
The first output from the weighting and summarization of population, weather data and vehicle usage by time of was this plot.

The plot shows temperature on the x-axis vs. relative humidity on the y-axis.

The size and color of the dots represent the number of hours a fictional average customer might spend at at each particular operating point given that the customer uses their vehicle for 500 hours per year.

The vehicle that actually lives through this surface would be very difficult to find since it is a blend of all vehicles, the weather where the vehicle lives, and the time when the vehicle is used during the day.

Shown on the chart are Recommended points for horsepower loss testing derived from this model along with the SAE test points.
Same input data as the previous slide, but this time we have calculated the humidity ratio from the temperature and relative humidity numbers to arrive at the final plot.

Again, the dots vary in size and color depending on how many hours per year the “average” customer spends at each operating point.

Note how much time is spent in the lower left portion of the surface between –5C and 10C.
In three dimensions the humidity ratio – temperature plot looks like this. You can better see the ridge and the peaks are the left. I have also placed the Recommended test points and the SAE points in the chart to allow comparisons.
To enable calculation of the horsepower consumption at each of the new test points a percentile curve of temperature with temperature zones around the recommended test points was created.

Each zone has a weight which is then used to compute the weighted horsepower consumption across all temperature zones.

The sum of the temperature zones do not add to one since about 10% of the time the customer will not be using their A/C system due to cold temperatures.
The power loss worksheet looks like this. On the left are the test conditions and on the right the vehicle conditions – blower setting and vehicle speed - and the test result column – A/C System horsepower.

Further enhancements to this model will more fully develop the time spent at each blower setting based on temperature and vehicle speed.
Additional weighting of the horsepower consumption should include vehicle speeds.

Shown here is a summary of time spent at the average speeds computed from the NPTS data.

Unfortunately, the resolution of the NPTS is only at the trip level – meaning all we know is the duration and the distance characteristics of each trip. The best we can do is to compute the average speed of each trip and then create a plot to learn the general shape of the distribution of average trip speeds. As you can see there is a large peak in the “commuting zone” (highway speeds) at 60 mph. A few lucky cars somehow managed to average 90mph! I would expect the distribution to look very different in other countries.
This plot shows that same data as the previous slide, but as a cumulative percent of the total time spent at each average trip speed.

The data summary displayed in this plot will appear later as the speed weighting values. However, it should be known that this is NOT the recommended average speed distribution only an example.

The problem is that it is not possible to tell how much time was really spent at each speed due to averaging of the entire trip– higher resolution data is needed.

There will be further work performed on an existing database of Real World Usage Data to develop a more representative speed weighting.
During the development of the customer model there had been a few requests to determine if there were regional differences in vehicle speeds. This slide is intended to illustrate the calculated weighted average speed by Metro area.

By “weighted” I mean that the data has been scaled up to match the size of the population. In the study each person and each vehicle is given a weight so that when all the weights are added together their sum is equal to the population of either people of vehicles. The intent behind this strategy is to avoid over weighting places like New York or Oklahoma that had very large sample sizes.

However, the NPTS study also cautions against using the data at a geographic level smaller than a Census region, so I show this slide as information and as some indication that average speeds are likely to vary from place to place based on local characteristics.
### Average Cycle Power Loss Worksheet with Vehicle Speed Added

<table>
<thead>
<tr>
<th>Vehicle Speed (mph)</th>
<th>A/C System Temperature Weighting</th>
<th>Speed Ranges (mph)</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.192</td>
<td>&lt;8 mph</td>
<td>0.041</td>
</tr>
<tr>
<td>15</td>
<td>0.221</td>
<td>8 to 21</td>
<td>0.041</td>
</tr>
<tr>
<td>30</td>
<td>0.491</td>
<td>22 to 45</td>
<td>0.247</td>
</tr>
<tr>
<td>60</td>
<td>0.247</td>
<td>&gt; 46</td>
<td>0.270</td>
</tr>
<tr>
<td>0</td>
<td>0.210</td>
<td>&lt;8 mph</td>
<td>0.041</td>
</tr>
<tr>
<td>15</td>
<td>0.221</td>
<td>8 to 21</td>
<td>0.041</td>
</tr>
<tr>
<td>30</td>
<td>0.491</td>
<td>22 to 45</td>
<td>0.247</td>
</tr>
<tr>
<td>60</td>
<td>0.247</td>
<td>&gt; 46</td>
<td>0.220</td>
</tr>
<tr>
<td>0</td>
<td>0.199</td>
<td>&lt;8 mph</td>
<td>0.041</td>
</tr>
<tr>
<td>15</td>
<td>0.221</td>
<td>8 to 21</td>
<td>0.041</td>
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<tr>
<td>30</td>
<td>0.491</td>
<td>22 to 45</td>
<td>0.247</td>
</tr>
<tr>
<td>60</td>
<td>0.247</td>
<td>&gt; 46</td>
<td>0.002</td>
</tr>
<tr>
<td>0</td>
<td>0.051</td>
<td>&lt;8 mph</td>
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<td>0.041</td>
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</tbody>
</table>

Adding vehicle speed weighting from the plot on page 16 the Power Loss Worksheet will look like this. Note that the speeds weights were chosen to represent a range of speeds.
Recommendation and Improvements

Recommendation:
• Use an average A/C customer usage model that is weighted according to where people/vehicles live and when they use their vehicles. The estimation of a/c system efficiency improvements will be more representative of the geographic variation of where and when people use their vehicles.

Enhancements & Improvements:
• Weight by blower motor setting and A/C usage for each range of temperatures. (Development in process now.)
• Increase resolution of average vehicle speed distribution data.
• The model can be run using vehicle sales locations as weighting factor instead of population.
• Include solar loading effects.

It is recommended that a model like that presented today be used to determine a/c system efficiency improvements because this model accounts for the wide range of where people live and when they use their vehicles.

What can be done to improve the model?

We are working on the addition of weighting factors for blower motor usage and speed by temperature.

Higher resolution vehicle speed data will be analyzed to determine improvement opportunities.

If desired this model can be run using vehicle sales locations and volumes as a weight instead of human population distribution.

Lastly – solar loading effects need to be factored in to the model. Any enhancements that included solar loading would also be weighted based on location and time of day.

Thank you.

Questions?
Reference List

   http://www.eren.doe.gov/buildings/energy_tools/energyplus/energyplus_weatherdata.html
   http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/
   http://www.esri.com