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To: Ian MacMillan
South Coast Air Quality Management District (SCAQMD)

From: Robert L. Russell & Kanok Boriboonsomsin
College of Engineering-Center for Environmental Research and Technology (CE-CERT)

Re: Analysis of High Cube Warehouse Trip Data

Between 7/30/13 and 2/12/14, inclusive, SCAQMD monitored vehicle traffic entering and leaving 36 warehouses in the Inland Empire that have 185,096 to 1,820,457 square feet of warehouse space. The monitoring consisted of 24 hours of video recording of all entrances and exits to the warehouses. The videos were analyzed and a spreadsheet created containing data about the warehouse, the number of total vehicles entering and leaving, plus a breakdown by cars, trucks, and by the number of axles for the trucks. These data are referred to as "SCAQMD Data" in this letter.

Kunzman Associates, for the National Association of Industrial and Office Properties (NAIOP) Inland Empire Chapter, performed an analysis of 2008 trip data for high-cube warehouses in the Inland Empire[1] ("NAIOP Data"). They had entrance and exit data for light-duty vehicles and heavy-duty vehicles for various time periods for 31 sites, all of which had greater than 500,000 square feet of warehouse space. The data were obtained over 24 hour periods by manual counting and was classified as cars, 2 axle trucks, 3 axle trucks, 4 axle trucks, and 5+ axle trucks. The NAIOP Data were also included in the SCAQMD Data spreadsheet on a tab labeled NAIOP 2011. SCAQMD sent the spreadsheet to CE-CERT for various statistical analyses.

While the NAIOP study only included warehouses with ≥ 500,000 sq. ft., the SCAQMD decided to include warehouses with < 500,000 sq. ft. but ≥ 200,000 sq. ft. One of the SCAQMD warehouses had less than 200,000 sq. ft. and the SCAQMD requested eliminating the data from that warehouse from the statistical analyses. There were also two warehouses which had extremely high trip rates relative to the other 33 warehouses. Analyses were performed including these two warehouses as well as excluding these two warehouses.

The summary and key findings from the statistical analyses are provided below:

- No unifying equation could be found which accounted for all of the variability in the data, whether looking at the combined SCAQMD and NAIOP Data or at the SCAQMD Data only.

[1] Kunzman Associates, Letter of July 19, 2010 to Mr. Robert Evans, Executive Director, NAIOP Inland Empire

- The equations, which were tested by regression analysis for all vehicles and for trucks only as well as with and without warehouses which had cold storage, included:

  - $T = mX + n$
  - $Ln(T) = mLn(X) + n$
  - $T = aX + bY + c$
  - $Ln(T) = aLn(X) + bY + c$

  where:

  T = number of trips (all vehicles, cars only, or trucks only)
  X = 1000 square foot gross floor area (GFA)
  m = slope of linear or logarithmic equation
  n = intercept of linear or logarithmic equation
  Y = 0 (No cold storage) or 1 (cold storage)
  a, b, c = regression coefficients for the equations with two independent variables

- Average trip rates were also determined for each of the above cases.

- The R^2 of a regression equation is a common statistical parameter used to determine the goodness-of-fit of the equation to the data. R^2 always has a value between 0 and 1 inclusive where 0 indicates that there is no correlation (0%) while 1 indicates that there is a perfect correlation (100%).

- For the equations with one independent variable, the highest R^2 values were obtained when excluding the two high trip rate warehouses and cold storage warehouses. The values were 0.34 for all vehicles and 0.33 for trucks. For the equations with two independent variables, the R^2 values were 0.43 for all vehicles and 0.52 for trucks when the two high trip warehouses were excluded.

- When only data from warehouses with cold storage were regressed, R^2 values above 0.95 were obtained for using just the SCAQMD Data, but the sample size was only 5. Inclusion of the NAIOP Data increased the sample size to 10 but the R^2 values reduced to between 0.27 and 0.54.

- For the SCAQMD Data, the average trip rates for all vehicles varied from a low of 1.34 for the data without cold storage to a high of 2.49 for the cold storage only data.

- For the SCAQMD Data, the average trip rates for trucks only varied from a low of 0.40 for the data without cold storage to a high of 1.10 for the cold storage only data.
- The 50^{th}, 75^{th}, 85^{th}, 90^{th}, and 95^{th} percentiles of trip rate for all vehicles and trucks only were determined for the SCAQMD Data with and without cold storage and for cold storage only (see Table 1).
  - If including the two warehouses with anomalously high trip rates, the percentiles ranged from 1.22 (50^{th}) to 7.05 (95^{th}) for the All Vehicle Rate and from 0.39 to 1.40 for the Truck Rate.

  - If excluding these two warehouses, the percentiles ranged from 1.20 to 3.33 for the All Vehicle Rate and from 0.36 to 1.34 for the Truck Rate.
  - If further excluding the warehouses with cold storage, the percentiles ranged from 0.91 to 3.38 for the All Vehicle Rate and from 0.33 to 0.98 for the Truck Rate.
  - If only warehouses with cold storage were analyzed, the percentiles ranged from 2.53 to 3.24 for the All Vehicle Rate and from 0.96 to 1.40 for the Truck Rate.

- A critical assumption of linear regression analysis is that the data is normally distributed. Therefore, the normality of the residuals for each regression analysis was determined. If the residuals do not have a normal distribution, then the regression equation is not considered to be an accurate representation of the correlation between the dependent and independent variables, and a transformation of the data may be employed to obtain a normal distribution of residuals. The natural log transform is a common transform. With the exception of the linear equations where only data for warehouses with cold storage were included, none of the residuals for the linear equations had a normal distribution. Some of the logarithmic equations had a normal distribution of residuals while others did not. Table 2 presents summary results of all normally distributed data.

- There are multiple ways to arrive at peak daily trip rates based on the data and analysis results. For example, one could select a high percentile (e.g., 75th, 95th, etc.) value to represent the peak daily trip rates. One potential percentile to use is the 85th percentile, which is also commonly used in traffic engineering practice to set the maximum speed limit of a roadway. There are also other considerations when deriving a peak daily trip rate. For example, the business survey conducted by SCAQMD found that warehouse operators on average reported a 27% increase in trucking activity between an average day and a peak day. As another example, from the eight warehouses which received trip counts both in 2008 in the NAIOP study and in 2013/2014 in the SCAQMD study, the 2013/2014 truck counts were found to be 140% higher than the 2008 counts on average.

Table 1: SCAQMD warehouse trip rate average and percentiles for various conditions

	All warehouses		Two high trip rate warehouses excluded		Two high trip rate warehouses and warehouses with cold storage excluded		Only warehouses with cold storage	
	Trip Rates		Trip Rates		Trip Rates		Trip Rates	
	All Vehicles	Trucks Only	All Vehicles	Trucks Only	All Vehicles	Trucks Only	All Vehicles	Trucks Only
Number of Warehouses	35	35	33	33	28	28	5	5
Arithmetic Mean	1.96	0.61	1.51	0.50	1.34	0.40	2.49	1.10
50th Percentile	1.22	0.39	1.20	0.36	0.91	0.33	2.53	0.96
75th Percentile	2.53	0.79	2.21	0.69	1.76	0.47	2.95	1.39
85th Percentile	3.04	0.96	2.83	0.95	2.61	0.61	3.14	1.40
90th Percentile	3.34	1.06	3.03	0.99	2.92	0.80	3.24	1.40
95th Percentile	7.05	1.40	3.33	1.34	3.38	0.98	3.24	1.40

Table 2: All regressions of SCAQMD Data which had a normal distribution

Scenario	Number of Warehouses	Slope	Intercept	R^2	
Logarithmic regression: LN(Number of Trips) = mLN(1000 sf GFA) + n					
All Vehicles	35	0.875	1.143	0.247	
Trucks Only	35	0.585	1.915	0.156	
All Vehicles with two high trip rate warehouses excluded	33	0.835	1.290	0.301	
Trucks only with two high trip rate warehouses excluded	33	0.635	1.499	0.217	
All Vehicles with two high trip rate warehouses and cold storage warehouses excluded	28	0.890	0.811	0.335	
Trucks only with two high trip rate warehouses and cold storage warehouses excluded	28	0.718	0.796	0.334	
Logarithmic regression: LN(Number of Trips) = aLN(1000 sf GFA) + b(Cold Storage) + c					
		a	b	c	R^2
All Vehicles with two high trip rate warehouses excluded	33	0.958	0.791	0.362	0.427
Trucks only with two high trip rate warehouses excluded	33	0.804	1.086	0.225	0.515
Linear regression: Number of trips = m(1000 sf GFA) + n					
All vehicles, only cold storage warehouses	5	3.386	-442.900	0.953	
Trucks only, only cold storage warehouses	5	1.665	-290.900	0.964	