Energy Performance Benchmarking for Manufacturing Plants

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ABSTRACT

Manufacturing plants, which account for two-thirds of the total energy use in the industrial sector, have seen a gradual upward trend in their energy consumption over the past decade. Understanding how an individual plant is performing relative to its peers – benchmarking – has not yet seen broad exposure throughout the manufacturing sector as a means to gauge plant effectiveness and as a basis for future action. Benchmarking energy performance as a first order of merit offers the possibilities of a quick, yet meaningful assessment of plant energy performance without the cost and rigor of a comprehensive audit or engineering evaluation. Based on a commercially available database – the Major Industrial Plant Database™ (MIPD) – containing detailed energy and plant characteristics for roughly 18,000 manufacturing plants representing 450 industries, the development of energy performance benchmarking is investigated in support of the U.S. Environmental Protection Agency's revitalized manufacturing sector effort within ENERGY STAR®. The objective of this effort is to enable plant managers, operators, and owners to easily and credibly assess and track the energy, financial, and environmental performance of manufacturing plants relative to their peers. The goal of which is to initiate more and better informed decisions toward improving plant and corporate performance.

The MIPD is used to develop benchmarking models relating *plant input* – energy consumption and energy expenditures – to *plant output* – product value. Plant level energy consumption and expenditure metrics at a 4-digit Standard Industry Classification (SIC) code resolution are investigated as functions of a variety of plant characteristics including: product type, average annual capacity, annual hours, number of employees, annual product value, and location.

The suitability of the MIPD for the task at hand is demonstrated by comparing aggregate energy use patterns and plant characteristics of the data contained in the MIPD to other known sources of data such as the Manufacturing Energy Consumption Survey (MECS) and the 1997 Economic Census along 2-digit, 3-digit, and 4-digit SIC code industry groupings. Additional analysis explores product diversity within industries, quantity and quality of individual plant data, and the relative representativeness of the MIPD data.

Results of linear regression modeling completed to date identifying the strongest determinants of manufacturing plant energy consumption and energy cost for each industry are presented. Energy performance metrics unique to each completed industry model are also presented. Finally, development of the resulting benchmarking models and subsequent placement in a publicly accessible energy tracking software is then discussed. It is anticipated that these efforts will begin to be placed in the public domain by the end of 2001.

Introduction

Since the early 1990's, the U.S. Environmental Protection Agency (EPA) has worked with U.S. corporations to reduce their energy requirements in buildings and office space through voluntary programs such as ENERGY STAR. Corporate partners within ENERGY STAR have enjoyed success by applying the principles fundamental to this program. However, a common view was held that ENERGY STAR did not fully address energy use and performance of manufacturing plants. While there are many partners working in manufacturing industries within ENERGY STAR, the program to date has focused primarily on the energy use and performance of commercial buildings rather than manufacturing plants.

In the upcoming year, the EPA is poised to deliver new program components to facilitate broader corporate participation in ENERGY STAR. The business-oriented approach for building owners central to ENERGY STAR will be expanded to accommodate the energy use of manufacturing businesses. With introduction of the enhanced industrial manufacturing offering, ENERGY STAR will have a complete group of tools that will appeal to all corporate partners.

EPA hopes to make tools available to the public that are capable of assessing the performance of individual plants relative to a national set of peer plants. The objective of these tools is to provide plant managers and corporate executives with a quick and inexpensive means to assess how their plants are performing in terms of their energy consumption. Such information can be used to prioritize corporate resources; identify good performing plants from poor performing ones; quantify opportunities for improvement; raise awareness of the need for improvement; and understand performance relative to peers as a measure of overall competitiveness.

Background

According to Energy Information Administration (EIA) estimates, the industrial sector accounted for approximately 33.5 percent of the total energy consumption in the United States in recent years. Not surprisingly, the industrial sector also produced 36 percent of the total carbon dioxide emissions in the United States due, in large part, to combustion of fossil fuels.

Within the industrial sector, defined to include the manufacturing, agricultural, mining, and construction industries, 77 percent of both the energy consumption and carbon dioxide emissions emanate from manufacturing. The EIA estimates that there are approximately 380,000 manufacturing establishments of varying sizes which consumed 16,186 trillion Btu of energy in 1994. Manufacturing energy consumption is expected to increase by over 8 percent when EIA releases its 2000 estimates and by over 19 percent by 2010.

Given these trends in energy consumption and carbon dioxide emissions within the manufacturing industry, the EPA has begun investigating the usefulness of metrics that relate plant energy consumption to plant production as a means to enable plant managers to assess their performance. Having an understanding of the energy performance relative of a particular plant to its peers can be a convincing indicator for the need and the potential impact of improvements. Currently, only a handful of industries have the capability to assess plant performance relative to their peers. The objective of the effort described herein is to develop and promote an energy performance benchmarking capability for many more unique industries.

While the EPA is currently pursuing the development of plant productivity indices at a four-digit Standard Industrial Classification (SIC) level, EPA is also exploring simpler energy operating ratios, also at a four-digit SIC level, relating plant energy input to plant production measures. Though simpler and less robust than the plant productivity indices under consideration, the analysis behind the energy operating ratios is no less rigorous. Two particular metrics are being explored: 1) Energy Output Ratio; and 2) Energy Cost per Plant Hour. The Energy Output Ratio (E$OR) is simply a ratio of an individual plant's annual energy cost to its annual shipment value; both measured in dollars ($). The Energy Cost per Plant Hour (E$/HR) is just the annual energy cost in dollars per plant hour.

By examining how these metrics relate to various plant operating characteristics through regression analysis, it is hoped that statistically significant relationships can be found. These relationships can then be used to construct models that may act as the basis for assessing individual plant performance relative to a peer group.

Database

Manufacturing Energy Consumption Survey

The Manufacturing Energy Consumption Survey (MECS), administered by the EIA, is the most comprehensive source of published national-level data on energy-related information for manufacturing establishments. EIA obtains information from a national representative sample of manufacturing establishments classified in SIC 20 through 39 of the U.S. economy as defined by the Office of Management and Budget. With a sample size of 22,173 establishments, the MECS was undertaken to represent approximately 250,000 of the largest manufacturing establishments which translates to roughly 98 percent of the U.S. economic output from the manufacturing industry.

The SIC system, on which the MECS is based, is a hierarchical system that divides the manufacturing sector into 20 major industrial groups (two-digit codes), 139 industry groups (three-digit codes), and 459 industries (four-digit codes). MECS provides aggregate results for all 20 major industrial groups, 3 industry groups, and 49 industries. The Census Bureau serves as the collecting and compiling agent for EIA in conducting the MECS. As such, all data reported are considered confidential under the provisions of Title XIII of the U.S. Code. While data is made available to the public in the form of selected tables published by EIA, the public cannot access the micro data directly. Instead, the Census Bureau accepts proposals to conduct research to analyze the data for specific interests. All approved research activities must be accomplished by official agents of the Census Bureau.

While the MECS database is quite large and comprehensive, access is very limited. Despite a large sample size, only 49 of the 459 four-digit SIC code industries have a sufficient number of data records to warrant the publishing of results. Furthermore, the most current, published version of the MECS was conducted in 1994 and published in 1997. Thus, the data contained in the current survey is over six years old at this point. The next MECS survey was conducted for reporting year 1998, with publication expected to be in late 2001. Because of these limitations, the MECS dataset was eliminated from consideration as the basis for simple, energy performance benchmarks.

Major Industrial Plant Database

The Major Industrial Plant Database (MIPD) contains data for approximately 18,000 manufacturing establishments spanning 454 of the 459 individual, four-digit SIC industries and can be purchased by the public. Data is collected in a 3-year rolling cycle format where 1,500 records are updated per quarter, or 6,000 per year. Thus, at any given point, the MIPD contains data as current as 3-months old and as old as 33 months old. Unlike the MECS, the MIPD collects a limited number of variables. However, the variables include the several major operating characteristics, energy consumption and cost – a measure of the input, shipment value information – a measure of the plant output, and other plant characteristics. The MIPD also identifies specific product information within four-digit SIC industries. See Figure-1 for sample record showing some, but not all, of the characteristics collected by the MIPD survey for one plant.

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--------------- PLANT CODE:  xxxxxx ---------------
EXAMPLE CORP                    Duns:  xxxxxxxxx
123 Main Street          Ultimate Duns:  xxxxxxxxxx
Anywhere, USA 12345-6789    Parent Co:  EXAMPLE PARENT, INC.
Plant Hours:       8736
Prod Emps:          100
Capacity Util:      65
Shipment Value:     14324
Sic Code:  3255 Industry:  Clay Refractories

Electric Utility:  ABC Power Corp
Electric Price:     .1012          Electric Use:     5280
Electric Demand:         604   % Generated on Site:          0
Cogeneration:  N

Gas Utility:  XYZ GAS DISTRIBUTION     Gas MMcf/day:          .49
Gas MMcf/yr:       180
Total Fuel:        180000  Oil (MMBtu):         0  Gas (MMBtu):   180000
Residual Oil:           0 Distillate Oil:       0 Coal Use:      0
Feedstock:              0 Furnace:       162000
Boiler (MMbtu):     18000   Boiler Capacity:        13400
Average Capacity:       0   Number of Boilers:        2
Steam Demand:        2394    Steam Temp:      270
Steam Pressure:       100   Gas Contact:
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Figure 1. Sample MIPD Record

Although the MIPD contains data on a limited number of individual plant characteristics, the characteristics that are collected appear intuitively important variables and thus well-suited for the development of regression analysis and modeling. Furthermore, although any snapshot of the MIPD contains data collected over a 30-month range versus the 6-month range in the MECS, the data is significantly more current than that found in the MECS. MECS data can be as current as 2-1/2 years old and as old as 6-1/2 years old depending on at which point in the MECS production cycle the data is obtained. Because the MIPD appeared to be relatively robust, more current, and more accessible, it was chosen as the database to serve as the basis for the analysis.

Database Comparability

One of the major concerns in using the MIPD as the basis for the regression analysis is that it is not conducted to be a representative sample as was the case with the MECS and is thus subject to self-selection bias. With that said, it was hoped that through comparisons of aggregate energy use patterns and plant characteristics of the data contained in the MIPD to MECS data, that the viability of the MIPD for the desired task could be better understood. Rather than investigating at a macro level (i.e. two-digit SIC major industrial groups), comparability was examined at the finest resolution possible – the four-digit SIC industry level. Here, though, limitations of the MECS allow for such checks on just 49 of the 459 four-digit SIC industries.

Table 1 shows results from MECS and the MIPD for one of the first industries to be examined as part of this project – SIC 2082 Malt Beverages. Another industry examined, SIC 2026 – Fluid Milk, was not part of MECS as a four-digit SIC industry. According to the MECS, in 1994 there were 140 total establishments in the Malt Beverages industry. Of these, the MECS sample included 30 compared to the 40 establishments that were contained in the MIPD snapshot covering the time period from July 1998 through January 2001.

	MECS (1994)	MIPD	Units
Sample Size	30	--	
# of Plants	140	40	
Age of Data	6.5 to 7 years	3 to 33 months	
Frequency of Non Electric Fuel Use			
Natural Gas	95%	95%	
Residual Oil	34%	25%	
Distillate Oil	25%	10%	
Coal	24%	15%	
Average Energy Rates			
Electricity	0.053	0.059	$/kWh
Natural Gas	3.37	3.75	$/MBtu
Energy Consumption			
Electricity	8	11	1×10^{12} Btu
Natural Gas	22	17	1×10^{12} Btu
Other	21	15	1×10^{12} Btu
Total	51	43	1×10^{12} Btu
Energy Cost			
Electricity	123	187	1×10^{6} $
Natural Gas	59	65	1×10^{6} $
Other	39	16	1×10^{6} $
Total	221	268	1×10^{6} $
Energy Ratios			
Energy/Employee	1694	1778	MBtu/Employee
Energy/Shipment Value	3000	2172	Btu/$
Other			
Ability to Fuel Switch	23%	25%	
On-site Generation	15%	13%	

Table 1. Comparison of MECS and MIPD for SIC 2082 Malt Beverages

In this particular case, there are several notable comparisons that suggest compatibility between the two data sets. First the prevalence of gas usage (95 percent) was equal in both the MECS and the MIPD. The ability to fuel switch and the presence of on-site electricity generation were also very similar. Given the gap in the age of the respective databases, the average fuel costs showed an increase from the MECS data to the MIPD as would be expected. Perhaps most significantly of all, the energy consumption ratio relating total annual energy consumption to the number of employees for both database were within 5 percent of one another.

Comparisons of energy consumption and energy cost revealed some inconsistencies on the surface. The MECS data reported a total energy consumption of 51 trillion Btu for 140 Malt Beverage establishments in 1994 while the MIPD indicated a total energy consumption of 43 trillion Btu for just 40 Malt Beverage establishments. Likewise, the MECS data showed total energy cost of $ 221 million versus the $ 267 million reported in the MIPD. These figures are seemingly inconsistent, but can perhaps be explained by two factors both of which relate to the differential in age of the two databases. First, average age of the data contained in the MECS is 6-1/2 years old while the average age of the MIPD data is roughly 1-1/2 years old. The cost of energy over those five years certainly has increased which may account for some of the difference. Secondly, and likely more significant, is the fact that the Malt Beverage industry experienced a "boom" from the early 90's to the late 90's. This boom is largely attributable to the tremendous increase in demand and subsequent supply of "micro-breweries" across the country. Thus, it is not likely that the magnitude of this market effect would have been totally picked up by the MECS survey in 1994. Further analysis is warranted before definitive conclusions can be made, however, in this particular example, one could argue that the datasets are fairly consistent with one another, though the possibility of self-selection bias remains.

Approach

Annual energy consumption in units of $ and BTUs, plant characteristics, and annual shipment value were extracted from the MIPD database for two industries: SIC 2026 – Fluid Milk; and SIC 2082 – Malt Beverages. In order to better understand the possibilities of providing the manufacturing sector with benchmarking models, three additional industries are planned to be analyzed. These include: SIC 2046 – Wet Corn Milling; SIC 2273 – Carpet and Rugs; and SIC 3711 – Motor Vehicles and Car Bodies. These unique four-digit SIC industries were selected for their ability to shed light on a variety of subjects of concern relating to plant benchmarking. In particular, product homogeneity within four-digit SIC industries, the lack thereof, energy intensity of industry relative to peers, and industry complexity were chief among these issues. Upon conclusion of the analysis for these initial five industries, it is intended that the project be re-assessed to determine what, if any, modifications to assumptions or procedure may be required.

Figure-2 is a simple block diagram illustrating the extent of the MIPD data available for each plant. On the input side, the annual energy consumption, cost, as well as demand are known. On the output side, the annual shipment value of the primary product generated by the plant as well as specific product information is known. Concerning the plant itself, the MIPD provides several core plant characteristics including annual plant hours, average plant capacity, number of production employees, number of total employees, location (zip code, latitude, and longitude) among others.

The MIPD also provides indications of the prevalence of on-site electricity generation, fuel switching, and steam use. While the plant characteristic data in the MIPD appears to include the major factors which may influence plant energy use and cost, one noticeable omission is that the MIPD does not contain information related to the process involved in making the primary product. This exclusion, however, is in keeping with the basic philosophy of this effort which is to allow plant managers to assess the performance of their plants against their peers relating energy cost (or consumption) to shipment value irrespective of process.

The basis of this philosophy is the notion that if the peer group, as defined by the four-digit SIC industry, produces a similar product, then the process by which that product is produced is in large part inconsequential to the effectiveness of the plant. Thus, to the extent that specific processes influence the input (energy) or the output (shipment $), any resultant benchmarking model should identify poor processes from efficient ones as an appropriate signal to the industry. Such signals about inferior processes are probably already understood by plant managers.

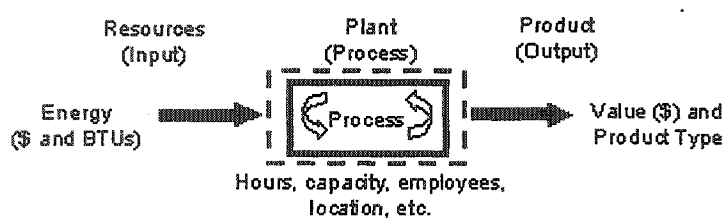


Figure 2. Simplified Data Diagram for Industrial Plants

A total of 25 variables from MIPD were selected to be examined as determinants of each metric. The rationale for selecting these variables was that the data was: a) available for all plants; and b) thought to be a possible determinant for the given metrics. Table 2 contains a list of the variables used in the regression analysis. Given the number of variables in the MIPD, there are many metrics which can examined. Based on discussions with various plant managers and owners, two were chosen that reflect their interests, E$OR and E$/HR, as described earlier.

Standard Variables		Binary Variables	
Variable	Description	Variable	Description
Energy$	Annual energy cost	*Cogen*	Presence of cogeneration
Capacity	Average annual plant capacity	*SteamUse*	Presence of steam use
Eff_Hours	Effective plant hours	*Switch*	Ability to fuel switch
Plnthr	Annual plant hours	*Generate*	Ability to generate elec. on-site
Emps	Total # of employees	*GenPct*	On-site generation percentage
Prodemps	Total # of production emp.	*Bulk*	Milk in bulk containers (SIC 2026)
CDD	Cooling degree days	*Packaged*	Milk in cartons (SIC 2026)
HDD	Heating degree days	*CottageCh*	Cottage cheese (SIC 2026)
DD	Total degree days	*IceCream*	Ice cream (SIC 2026)
Eff_Shipments	Effective shipment value	*Yogurt*	Yogurt (SIC 2026)
Shipments	Annual shipment value	*Bottled*	Beer in bottles (SIC 2082)
Site	Annual site energy use	*Kegs*	Beer in kegs (SIC 2082)
Source	Annual source energy use		

Table 2. MIPD Variables Analyzed for E$OR and E$/HR

Prior to undertaking the analysis, screening criteria were applied to each four-digit SIC industry dataset from the MIPD to produce a more internally consistent and reliable dataset. These criteria excluded only those records that demonstrated clear indications of being, at least partly, in error. The general philosophy followed was to leave in records whenever possible, and to only remove records in extreme instances. Once done, the regression analysis was undertaken to identify the primary determinants of each metric discussed above. The entire analysis included initial basic regressions which entailed examining the statistical relationship between the numerator and the denominator of each metric. So, to better understand the relationship and the magnitude of the significance of the relationship, for the case of E$OR for example, energy cost was examined as a function of shipment value. Likewise, energy cost as a function of annual plant hours was investigated to determine the significance and degree of correlation between the numerator and denominator of the E$/HR metric.

Next, log-log regressions were undertaken for each metric to identify the its primary determinants. Standard and semi-log regressions were also examined, however the log-log regression yielded the best results. In addition to utilizing log-log regressions, the White heteroskedasticity matrix was applied to further ensure consistent standard errors and covariance. The dominant and most common plant characteristics that drive plant E$OR and E$/HR were then identified. The regressions were then used to create predictive models for estimating both E$OR and E$/HR. As a final step, abbreviated look-up tables for E$OR and E$/HR values corresponding to decile and quartile gradations were developed to illustrate the range of values associated with the mean operating values.

Results

One of the first steps of the analysis was to obtain an understanding of the basic relationship between the variables comprising each of the metrics prior to undertaking the full regressions. Table 3 and Table 4 list the results of the basic analysis of E$OR and E$/HR for SIC 2026 – Fluid Milk and SIC 2082 – Malt Beverages respectively. While the R-squared value for the basic relationship between energy cost and plant hours appear low in both the SIC 2026 and SIC 2082 analyses, the approximate R-squared value for the entire metric is quite good once the other plant characteristic variables are included. The details of the approximate R-squared values follow.

Energy Cost as a function of Shipment Value Dependent Variable: Ln(Energy Cost)			Energy Cost as a Function of Plant Hours Dependent Variable: Ln(Energy Cost)		
Variable	Coefficient	t-Stat	Variable	Coefficient	t-Stat
C	-0.943	-0.682	C	4.989	2.607
Ln(Shipment Value)	0.788	10.12	Ln(Plant Hours)	0.930	4.246
R-squared: 0.53 Mean Dependent Variable: 13.15			R-squared: 0.15 Mean Dependent Variable: 13.15		

Table 3. Basic Relationships between Energy Cost and Shipment Value And Energy Cost and Plant Hours for SIC 2026

Energy Cost as a function of Shipment Value Dependent Variable: Ln(Energy Cost)			Energy Cost as a Function of Plant Hours Dependent Variable: Ln(Energy Cost)		
Variable	Coefficient	t-Stat	Variable	Coefficient	t-Stat
C	-6.800	-3.794	C	-9.603	-2.968
Ln(Shipment Value)	1.120	11.95	Ln(Plant Hours)	2.757	7.295
R-squared: 0.83 Mean Dependent Variable: 14.55			R-squared: 0.45 Mean Dependent Variable: 14.55		

Table 4. Basic Relationships Between Energy Cost and Shipment Value And Energy Cost and Plant Hours for SIC 2082

Table 5 presents the results of the E$OR and E$/HR regressions for SIC 2026 – Fluid Milk. In both cases, two binary (aka "dummy") variables, each representing unique products of the industry, were found to be significant. These dummy variables addressed whether the primary product of the plant was ice cream or packaged milk, where the term "packaged" encompasses milk found in cartons and jugs. Other product-related dummy variables were investigated as well, but were not found to be significant. These included yogurt, cottage cheese, and bulk. Also common to both metrics was the significance of total degree-days (DD) and average plant capacity, albeit in an indirect fashion. Since plant capacity was highly correlated with both annual shipment value and annual plant hours, two variable transformations within the dataset were explored; specifically effective shipment value and effective plant hours. These transformations essentially involved translating the raw value, be it shipment value or plant hours, to a theoretical value if the plant were operating at 100 percent capacity. The benefit of these transformations was the inclusion of plant capacity as a variable while not adversely affecting the results of the regression. The resulting regression models for E$OR and E$/HR in SIC 2026 manufacturing plants is:

$$\text{Ln(E\$OR)} = C_0 + C_1 \times \text{Ln(Effective Plant Hours)} + C_2 \times \text{Ln(\# of Employees)} + C_3 \times \text{Ln(Degree Days)} + C_4 \times \text{(Ice Cream)} + C_5 \times \text{(Packaged)}$$

$$\text{Ln(E\$/HR)} = C_0 + C_1 \times \text{Ln(Effective Shipment Value)} + C_2 \times \text{Ln(Degree Days)} + C_3 \times \text{Ln(Plant Hours)} + C_4 \times \text{(Ice Cream)} + C_5 \times \text{(Packaged)}$$

E$OR Model Dependent Variable: Ln(E$OR)				E$/HR Model Dependent Variable: Ln(E$/HR)			
Variable	Coeff.	Value	t-Stat	Variable	Coeff.	Value	t-Stat
Intercept	C_0	-1.807	-0.946	Intercept	C_0	-0.031	-0.014
Ln(Eff_Hours)	C_1	0.174	1.137	Ln(Eff_Ship)	C_1	0.697	8.696
Ln(Emps)	C_2	-0.270	-2.793	Ln(Plant Hours)	C_2	-0.624	-3.750
Ln(DD)	C_3	-0.354	-2.149	Ln(DD)	C_3	-0.317	-1.866
Ice Cream	C_4	0.336	2.419	Ice Cream	C_4	0.440	4.201
Packaged	C_5	-1.611	-16.54	Packaged	C_5	-1.817	-14.57
R-squared: 0.16 Mean Dependent Variable: -4.733				R-squared: 0.50 Mean Dependent Variable: 4.377			

Table 5. E$OR and E$/HR Regression Summary for SIC 2026

Defining the approximate R-squared (R^2)of the entire metric as:

$$R^2_{Approximate} = R^2_{Basic} + R^2_{Metric} \times (1 - R^2_{Basic})$$

yields an approximate R-squared of 0.61 for the E$OR metric and 0.58 for the E$/HR metric. The use of approximate R-squares is helpful to understand the overall explanatory power of the model where the dependent variable is itself effectively a regression, albeit an extremely simple and arguably mis-specified one.

Table 6 presents the results for SIC 2082 – Malt Beverages. As was the case with SIC 2026, dummy variables representing unique products of the industry and unique plant characteristics were included in the analysis. Two product-related dummy variables represented beer in bottles and beer in kegs, and three plant-characteristic dummy variables were represented: the ability to fuel switch; the usage of steam; and the on-site generation of electricity. None of these dummy variables were found to be significant in both the E$OR and the E$/HR analysis. The number of employees and plant hours were also common to both models as being significant. The E$OR model also revealed the significance of effective shipment value even though shipment value was also part of the metric itself. On the surface this may appear to be an oddity, however there are some analogous situations with commercial buildings where, in some cases, a building's area (in square feet) is a determinant for energy intensity defined as energy per square foot. The resulting regression models for E$OR and E$/HR in SIC 2082 manufacturing plants is:

Ln(E$OR) = $C_0 + C_1$ x Ln(Effective Shipment Value) + C_2 x Ln(# of Employees) + C_3 x Ln(Plant Hours)

Ln(E$/HR) = $C_0 + C_1$ x Ln(# of Employees) + C_2 x Ln(Shipment Value) + C_3 x Ln(Capacity)

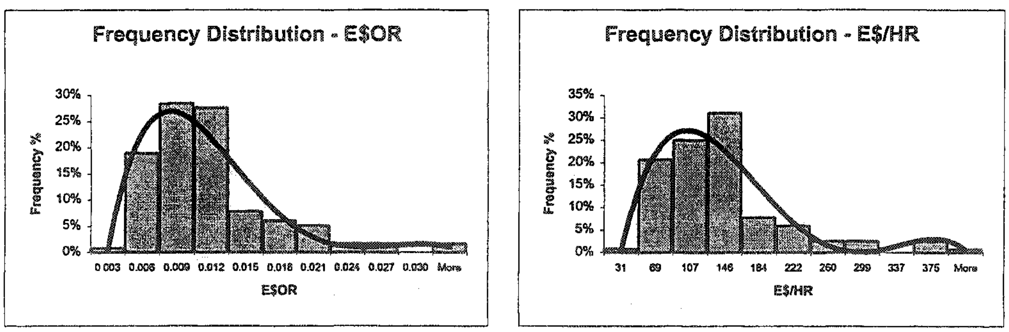
E$OR Model Dependent Variable: Ln(E$OR)				E$/HR Model Dependent Variable: Ln(E$/HR)			
Variable	Coeff	Value	t-Stat	Variable	Coeff	Value	t-Stat
Intercept	C_0	-7.462	-2.517	Intercept	C_0	-6.668	-1.604
Ln(Eff_Ship)	C_1	-0.807	-3.216	Ln(Emps)	C_1	0.729	2.210
Ln(Emps)	C_2	0.851	3.065	Ln(Shipments)	C_2	0.258	0.937
Ln(Plant Hours)	C_3	0.721	2.201	Ln(Capacity)	C_3	0.786	1.085
R-squared: 0.36 Mean Dependent Variable: -4.509				R-squared: 0.84 Mean Dependent Variable: 5.790			

Table 6. E$OR and E$/HR Regression Summary for SIC 2082

Using the equation referenced previously, based on these results the approximate R-squared for the E$OR model is then 0.89 and 0.91 for the E$/HR model.

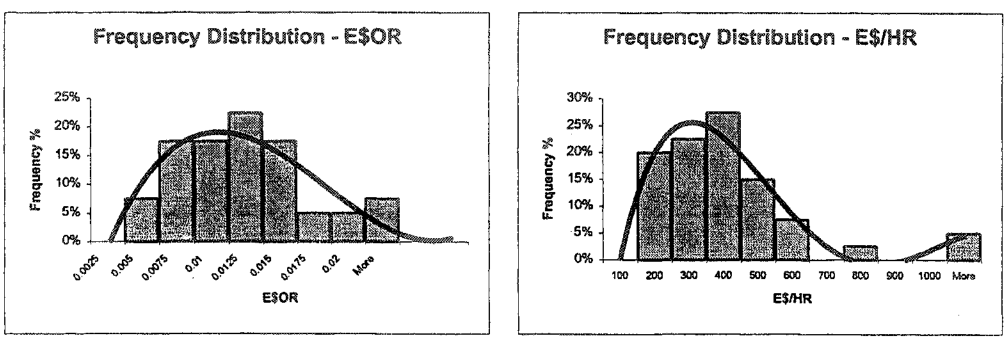
To illustrate the models created above, frequency distribution plots for both metrics were developed. The frequency distributions that follow represent the normalized data values, which is to say that the raw data records were run through the respective models prior to plotting. Trend lines are included on each frequency distribution as a reference. Figure-3a and Figure-3b are the frequency distribution plots relating to SIC 2026 for E$OR and E$/HR respectively. Likewise, Figure-4a and Figure-4b are the frequency distribution plots for SIC 2082. The shape of the trend lines approximating these distributions generally took the form of classical gamma distributions common to such analysis.

The final step of the analysis involved the development of abbreviated look-up tables relating the value of the metric corresponding to deciles. The values in the look-up tables shown in Table 7, represent the metric values along decile gradations for plants operating at the mean conditions for plant characteristics, input, and output. Values corresponding to quartile gradations are also provided in Table 7 for additional reference. The creation of these look-up tables in conjunction with the predictive model equations above, allow for the customization of the look-up tables to an individual plant. Thus, plant managers can be afforded the opportunity to assess plant performance against their peers while properly accounting for the specific operating characteristics of their plant.



a) b)

Figure 3. Frequency Distributions of E$OR and E$/HR for SIC 2026



a) b)

Figure 4. Frequency Distributions of E$OR and E$/HR for SIC 2082

Conclusions and Next Steps

Although MECS data at a four-digit SIC industry level was not available for the Fluid Milk industry, the MECS data did appear reasonably consistent with the MIPD data for the Malt Beverage industry. With each future analyses of individual industries, assessing the consistency between the two databases should be considered a required step. Those industries that appear reasonably consistent, may warrant further analyses, while those that do not should be discarded as not being suitable for plant-level performance benchmarking.

	SIC 2026 – Fluid Milk			SIC 2082 – Malt Beverages	
Percentile	E$OR ($/$)	E$/HR ($/Hour)		E$OR ($/$)	E$/HR ($/Hour)
100	0.0028	31.00		0.0039	117.00
90	0.0044	54.51		0.0055	160.00
80	0.0059	65.22		0.0073	205.08
75	0.0069	84.65		0.0076	223.14
70	0.0075	90.91		0.0078	237.56
60	0.0084	101.03		0.0096	276.94
50	0.0088	109.62		0.0109	320.66
40	0.0094	118.25		0.0115	340.18
30	0.0107	129.97		0.0141	404.94
25	0.0116	141.63		0.0146	431.57
20	0.0131	153.10		0.0148	454.77
10	0.0182	214.99		0.0181	568.16
1	0.0325	413.36		0.0966	2775.37

Table 7. Abbreviated Look-up Table of E$OR and E$/HR Corresponding to Selected Percentiles for SIC 2026 and SIC 2082

Regression analyses of plant characteristics developed from the MIPD data appear useful as a means to compare the performance of individual manufacturing plants to peer groups of like plants at an individual industry level. While the results thus far seem promising, it must be understood that both industries examined to date produce products which are relatively homogeneous. Similarly, the raw product entering the plant is generally homogenous as well, both in terms of physical attributes and embodied energy. Thus, more analysis is needed for complex industries having varying product inputs and outputs to investigate the prospects for plant-level benchmarking. Upon completion of the analyses of additional industries a software tool is intended to be created to begin testing models with additional data. In future analyses, annual energy consumption instead of annual energy cost will also be examined. Both E$OR and E$/HR are financially-based metrics that may have appeal among plant managers and owners. However, energy consumption may be a more equitable manner for plant managers or owners with plants in both high and low energy cost regions of the country to objectively evaluate plant performance since plant siting decisions are not solely based on energy cost concerns.

While the quantity of variables available in the MIPD is relatively small, the intuitively significant plant characteristics and important measures of both plant input and output are included. Upon scrutiny and analysis of the data, it appears as though simple benchmarking models can be created that can provide plant managers with the capability to assess the performance of their manufacturing plants against their peers.

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