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Efficiency Improvements in U.S. Manufacturing

Return on Investment for Small and Medium Establishments

Douglas Thomas

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Abstract

Manufacturers and manufacturing research organizations make investments to advance efficiency and competitiveness. Understanding the return for previously made investments can guide both manufacturers and researchers in identifying future investments with a high return. This paper examines trends in data from U.S. Department of Energy Industry Assessment Centers, which make technical assessments to reduce waste at small and medium sized manufacturers, to facilitate identifying potentially high return investments for manufacturers and researchers. The results show that the net present value is disproportionally distributed among investments, where 20 % of the investment categories represent 82 % of the net present value (i.e., net benefits). For individual investments, 20 % of the cumulative investment cost accounts for 74 % of the net present value. Regression analysis identified those investments with a high return when controlling for a selection of factors. The results suggest that over time, the average Internal rate of return (IRR) decreases, larger firms tend to receive higher IRR, and some investment categories tend to have higher IRR than others. The highest IRR investments were related to "bottleneck reduction," "scheduling," and "just-in-time" inventory. The highest concentration of net present value was found in "heat recovery" with the second highest concentration being in "cogeneration" and the third highest in "lighting." The most common high IRR investment type that was statistically significant in a regression analysis was related to "heat recovery" with the second relating to "space conditioning" and the third most common was related to "cogeneration."

Keywords

manufacturing; return on investment; net present value; internal rate of return; efficiency.

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Executive Summary

This report examines trends in the return on investment for U.S. Department of Energy Industry Assessment Centers' recommendations in order to facilitate identifying potentially high return investments for manufacturers and manufacturing industry researchers. The results show that the net present value is disproportionally distributed among investments, where 20 % of the investment categories represent 82 % of the net present value (i.e., net benefits). For individual investments, 20 % of the cumulative investment cost accounts for 74 % of the net present value (NPV). Similar distributions were found for the internal rate of return (IRR). Moreover, the investments are disproportionally distributed where a small number of investments represent a large portion of the returns. The implication is that it requires strategy and analysis (e.g., investment analysis) to get the highest returns possible, as a random selection will likely result in lower returns.

Results from a regression analysis suggest that over time, the average IRR decreases. Thus, over time, high returns may become more difficult to achieve, which reiterates the need to use strategy and analysis to identify high return investments. Larger firms were shown to have, on average, higher IRR investments. Additionally, some investment categories tend to have higher IRR than others. The results identified those investment categories with the highest IRR, the highest concentration of benefits, and those with an IRR that is statistically significant. The investment categories identified in this paper can be used to guide investments from manufacturers and manufacturing industry researchers, as they indicate areas of investment that commonly have a high return or a high level of benefits.

1. Introduction

Despite scholarly attention for the Defense Advanced Research Projects Agency (DARPA), Small Business Innovation Research Program (SBIR), and Advanced Technology Program (ATP), there is generally limited awareness of the government's role in U.S. innovation. The diversity of U.S. federal research and development programs make them difficult to categorize and appreciate (Block and Keller 2016). One goal of public innovation is to enhance economic security and improve our quality of life (National Institute of Standards and Technology 2017). This can be accomplished to some degree with advancements in efficiency. Universities, change agents, and other research organizations can do this through investment in developing technologies or improving them. Alternatively, organizations can aid firms in adopting existing technologies.

In order to move toward the largest impact possible, public entities can prioritize their investments in generating innovative solutions to improve efficiency in production by focusing on those manufacturing areas that have a high return on investment. Currently, there is limited ability to identify these research areas. This paper focuses on identifying those areas with a high return.

Previous research by Thomas and Kandaswamy (2019a) examined supply chain value added in the U.S. for producing assembly-centric products (i.e., machinery, computers, electronics, and transportation equipment). It determined that costs are disproportionally distributed and that reductions in resource consumption in some cost areas can disproportionally reduce total resource consumption. Efforts to develop and disseminate innovations for efficiency improvement can be targeted to high-cost areas. An input–output model was used for the examination combined with other data.

A paper by Thomas (2018) examines the life-cycle cost of passenger ground transportation as a proof of concept in identifying both high cost and high environmental impact areas of manufacturing. Public research that focuses on these items might be more economical than other areas. U.S. input-output analysis along with a number of datasets are used to examine the supply chain for production and use of ground transportation equipment. Another paper by Thomas et al (2017) conducted a similar analysis identifying economy-wide opportunities for efficiency improvement in manufacturing.

The papers mentioned above fit into the 5-step process for identifying and evaluating industry research investments proposed in Thomas and Kandaswamy (2019b). These steps include:

1. Identify Potential Industry Cost Research Areas
2. Measure Industry Costs using a Problem-Based Approach
3. Identify Potential Methods/Projects for Reducing Identified Costs/Impacts
4. Evaluate Costs/Benefits using a Solution-Based Approach
5. Select projects based on economics, capabilities, and other factors

Some of the papers mentioned above contribute to Step 1 and/or Step 2. Thomas and Kandaswamy (2019b) discuss a solution-based focus and a problem/cost-based focus when examining research investments. The difference is somewhat subtle or blurred but is distinguishable. A solution-based focus examines the reduced cost that might result from a particular investment or technology. For instance, the impact of adopting solar panels. A solution-based focus is a problem/cost-based examination where costs are categorized by more natural classifications without specifying solutions. An example of a problem-based category is electricity costs. The papers mentioned above (Thomas and Kandaswamy 2019a; Thomas 2018; and Thomas et al 2017) examine costs from a problem-based approach by identifying cost categories.

The level of data aggregation is also a factor in examining costs. For instance, one could measure total energy costs or break energy costs into that for building heating/cooling, machinery, lighting, and other energy consumption. More component level data provides more information for identifying means for reducing costs, but more detailed data is more costly to assemble. Aggregated data is cheaper to produce but is less useful. The level of aggregation and the type of approach are illustrated in Figure 1.1. As shown in the graph, highly detailed component level data can be infeasible due to the costs of data collection while highly aggregated data loses accuracy and/or usefulness.

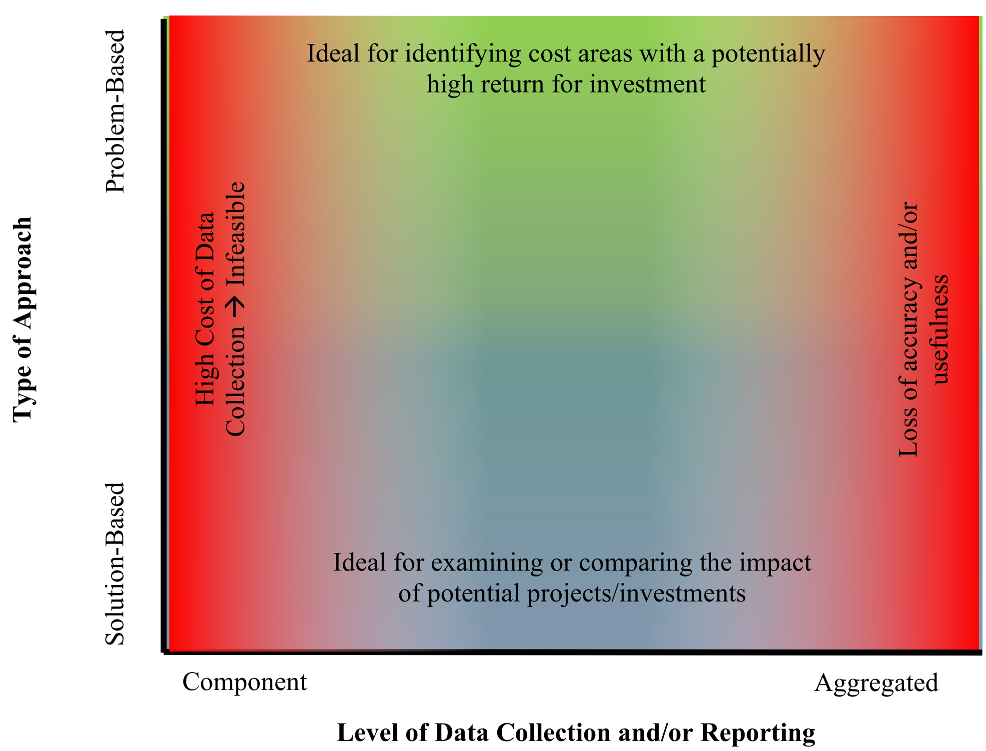


Figure 1.1: Categories of Cost Analysis (Source: Thomas and Kandaswamy 2019b)

This paper examines the net present value (NPV) and internal rate of return (IRR) from a solution-based approach at a more component level, as might be illustrated in the lower left of Figure 1.1. NPV and IRR are widely accepted and used by 75 % of establishments for investment analysis in capital projects (Thomas 2017) and are used here to facilitate identifying potential investments for manufacturers and manufacturing researchers that have a high probability of having a high return on investment. The paper examines the circumstances under which high levels of NPV and IRR occur, identifies which investments tend to have higher returns, and which industries tend to experience higher return investments. It also examines the effect of investment cost, establishment size, magnitude of cost, and how the return for investments has changed over time. There are 424 solution-based categories that are used in the analysis and 20 manufacturing subsectors.

2. Data

The primary dataset for this analysis is the Industrial Assessment Center (IAC) database. It is a publicly available database of 148k recommendations for 20k facilities, as of October 2021. The data is the result of DOE technical assessments of facilities conducted by university engineering students and staff from 26 IAC centers made up of 31 universities (Industrial Assessment Center 2021; U.S. Department of Energy 2011). Each observation in the IAC database is a recommendation for an investment. It includes an Assessment Recommendation Code (discussed below), the cost to implement the recommendation, the estimated annual savings, the year, whether the recommendation was implemented, and some characteristics of the establishment including sales, various energy expenditures, and the number of employees. For the IAC to conduct an assessment, a facility must generally have the following: gross annual sales of $100 million or less, consume energy at a cost greater than $100,000 and less than $2.5 million per year, employ no more than 500 people, and have no technical staff whose primary duty is energy analysis (U.S. Department of Energy 2011). These requirements suggest that the facilities being examined are likely to have a relatively higher level of low-cost, high-return investment possibilities, as these establishments have higher costs (i.e., energy costs) and fewer resources to identify potential investments. The final selection is left up to the individual IAC centers.

Two categorization systems are used in the IAC database. The first is the North American Industrial Classification System (NAICS). The second is the Industrial Assessment Center Assessment Recommendation Codes (ARC). NAICS has several major categories each with subcategories. IAC Assessments made prior to the development of NAICS uses the Standard Industrial Classification system (SIC); however, for this analysis only those assessments with NIACS codes are used. NAICS codes have multiple levels of detail from two digits (lowest level of detail) to six digits (maximum level of detail).

The ARC codes have between one and five digits with a total of approximately 424 codes. Similar to NAICS codes, more digits represent additional detail. There are three single digit codes: ARC 2 - energy management; ARC 3 – waste minimization / pollution prevention; ARC 4 – direct productivity enhancements. Additional detail is indicated in numbers to the right of the decimal. For instance, ARC 2.4157, which is within ARC 2, is “ESTABLISH A PREDICTIVE MAINTENANCE PROGRAM.” For simplicity among standard codes used in this analysis, we remove the decimal and add zeros for place holders, making it similar to NAICS. Thus, ARC 2.4 is reported as 24000. This leaves one concept for understanding the hierarchy and reveals the maximum level of detail.

Investment and establishment sales by the number of employees is shown in Table 2.1. As shown in the table, sales increase as establishment size increases. Investments fluctuate, but to some degree they increase with employment size as well. For this analysis, only implemented investments of $1000 or greater at firms with at least 1 employee categorized by NAICS code were used, resulting in 9 247 observations being removed and 15 641 observations being used in the analysis. The years used were from 2002 through 2021, as this is when NAICS codes were used in the data.

Table 2.1: Investments and Sales by Establishment Size ($)

		Mean Investment	Mean Investment (adjusted)*	Mean Sales
Number of Employees	0-50	31 732	35 955	24 645 203
	51-100	22 451	27 436	34 295 535
	101-150	34 064	40 145	45 423 127
	151-250	32 790	40 114	73 928 745
	250+	43 440	51 258	183 604 562

*Adjusted using the Consumer Price Index from the Bureau of Labor Statistics

3. Methods

This paper uses NPV and IRR to assess the economics of an investment. In order to compare cash flows at different time periods, future cash flow is *discounted* to equate to a common time period (Thomas 2017; Ross et al. 2005; Defusco et al. 2015). NPV is calculated by summing cash inflows and subtracting cash outflows for each year and adjusting it, using a discount rate, to a common time period, which we will call time zero (Thomas 2017):

Equation 1

$$NPV = \sum_{t=0}^{T} \frac{(I_t - C_t)}{(1+r)^t}$$

I_t = Total cash inflow in time period t
C_t = Total cost in time period t
r = Discount rate
t = Time period, which is typically measured in years

The internal rate of return is a common metric for evaluating investments. It is, essentially, the discount rate at which the net present value is zero. Thus, it is calculated by setting NPV in Equation 1 equal to zero and solving for *r* (Thomas 2017; Ross 2005). A 10-year study period is used along with a 5 % discount rate. Table 3.1 and Table 3.2 provide a summary of the average NPV and IRR by industry and establishment size measured by employment. The tables are shaded so that red cells are low values of the IRR/NPV and green cells are high values.

Two analyses of covariance (ANCOVA) were conducted to examine whether certain variables affect the IRR. Model 1 includes a count for the year, three-digit ARC codes, three-digit NAICS, interaction of three-digit NAICS and three-digit ARC codes, electricity and gas expenditures per dollar of sales, investment cost, and an indicator for a rebate (e.g., a tax rebate). Model 2 has a similar set of variables except it has five-digit ARC codes in place of three-digit and does not include the interaction variable. A single model with both the interaction and five-digit ARC codes creates a large number of variables for an analysis; thus, they are examined separately. The results from this analysis were used to develop an additional regression analysis.

A regression analysis is used to examine correlations and/or trends in the IRR with respect to investment cost, establishment size (i.e., employees), expenditures on electricity and gas, rebates, ARC code, NAICS code, and trends over time, as these were found to be statistically significant in the ANCOVA analysis. Since investment costs are part of the IRR calculation, lower cost investments may tend to have a higher rate of return. This is tested by including the investment cost as an independent variable. Over time, investments with high IRR are made, leaving lower return investments. This may result in declining IRR investments over time. To test this, a trend variable is included in the model that increases by one for each year. Larger firms may experience higher returns on investment due to increasing returns to scale. To test this the number of employees at an establishment was included in the model. It has been hypothesized that investment in reducing higher cost items may tend to have a higher return on investment (Thomas and Kandaswamy 2019a; Thomas and Kandaswamy 2019b; Thomas et al. 2017; Thomas 2018). To test this, the sum of gas and electricity divided by total sales was included in the model. An indicator variable was included in the model to test whether rebates have a higher IRR. Finally, two sets of indicator variables were included in the model. The first set includes an

Table 3.1: Average Internal Rate of Return by Employees and Industry, Implemented Investments with $1000 or more invested Categorized by NAICS, 2002-2021

	Number of Employees					
NAICS	0-50	51-100	101-150	151-250	250+	Total Employment
311	221.0%	355.5%	239.0%	337.1%	302.5%	299.1%
312	121.2%	171.2%	216.2%	301.6%	462.0%	250.4%
313	135.7%	184.7%	301.4%	286.9%	262.8%	238.6%
314	123.8%	119.6%	123.3%	209.3%	150.1%	144.6%
315		166.9%	104.1%	158.3%	151.3%	145.9%
316			25.2%	73.8%	182.1%	75.7%
321	169.4%	230.4%	298.1%	328.2%	317.4%	265.6%
322	245.9%	303.6%	265.3%	299.2%	440.9%	292.7%
323	140.6%	255.2%	240.1%	431.4%	419.1%	313.3%
337	98.8%	234.1%	235.7%	144.2%	205.0%	195.1%
324	234.0%	396.2%	1616.5%	113.2%	2674.5%	551.3%
325	369.1%	330.7%	443.2%	768.5%	352.9%	437.0%
326	229.3%	209.9%	299.3%	267.8%	360.3%	269.6%
327	237.4%	187.4%	1024.7%	432.2%	225.5%	404.5%
331	311.7%	323.4%	301.8%	383.6%	573.6%	383.6%
332	163.7%	241.9%	257.5%	258.1%	343.2%	248.7%
333	205.8%	230.7%	161.9%	255.1%	273.5%	236.2%
334	78.0%	143.8%	125.8%	454.6%	1364.3%	651.5%
335	425.8%	216.6%	265.8%	269.5%	353.1%	301.8%
336	203.0%	231.6%	178.1%	269.1%	309.5%	264.1%
339	125.7%	257.7%	184.8%	263.5%	306.4%	262.3%
	223.8%	234.9%	324.4%	304.6%	392.0%	483.2%

NOTE: Green indicates a high return while red indicates low return.

indicator variable for each of the ARC codes. This will identify those investments that are statistically associated with higher IRR. The second set of indicator variables is for each of the three-digit NAICS manufacturing codes. This will identify if investments in any industries tend to have higher NPV and/or IRR.

As illustrated in Figure 3.1 and Figure 3.2, the NPV and IRR appear to grow exponentially; therefore, a similar form to a Cobb-Douglas production function was used to examine factors that affect the NPV and IRR, as the relationship between the dependent and independent variables in this model is multiplicative and exponential. Generally, a Cobb-Douglas production function is a model of real output as a function of research and development capital, labor, capital stock, and technological progress (Greene 2008).

Table 3.2: Average Net Present Value by Employees and Industry, Implemented Investments with $1000 or more invested Categorized by NAICS, 2002-2021 ($Thousands 2020)

NAICS	0-50	51-100	101-150	151-250	250+	Total Employment
311	174.9	134.3	206.5	185.4	397.4	195.9
312	74.3	117.4	193.2	150.0	257.3	133.8
313	103.6	91.8	276.9	205.8	217.3	145.2
314	18.8	89.5	74.8	85.1	216.8	102.4
315		74.6	37.6	191.8	101.3	88.6
316			-1.4	20.0	20.0	12.1
321	198.3	130.2	144.0	301.5	337.5	171.5
322	145.3	194.4	324.6	410.8	524.9	227.8
323	47.2	108.9	98.6	110.6	268.8	112.1
337	40.5	93.1	159.4	128.7	114.9	96.8
324	104.4	610.9	267.8	423.0	3831.3	412.0
325	213.0	307.3	269.2	526.2	324.9	261.3
326	105.6	114.0	150.6	125.1	329.6	135.3
327	213.8	85.2	301.6	304.1	249.1	174.4
331	174.4	177.6	164.3	304.9	457.6	205.6
332	44.5	90.8	119.5	198.2	261.0	107.0
333	194.2	100.7	134.9	193.0	157.2	124.6
334	55.6	81.8	76.4	200.3	482.0	198.6
335	150.8	119.5	153.9	181.9	123.8	117.0
336	79.0	181.4	77.8	135.4	208.1	132.3
339	67.8	55.8	88.1	113.5	151.8	96.2
	86.8	87.4	161.5	194.1	257.8	162.0

NOTE: Adjusted to 2020 using the Consumer Price Index from the Bureau of Labor Statistics
NOTE: Green indicates a high return while red indicates low return.

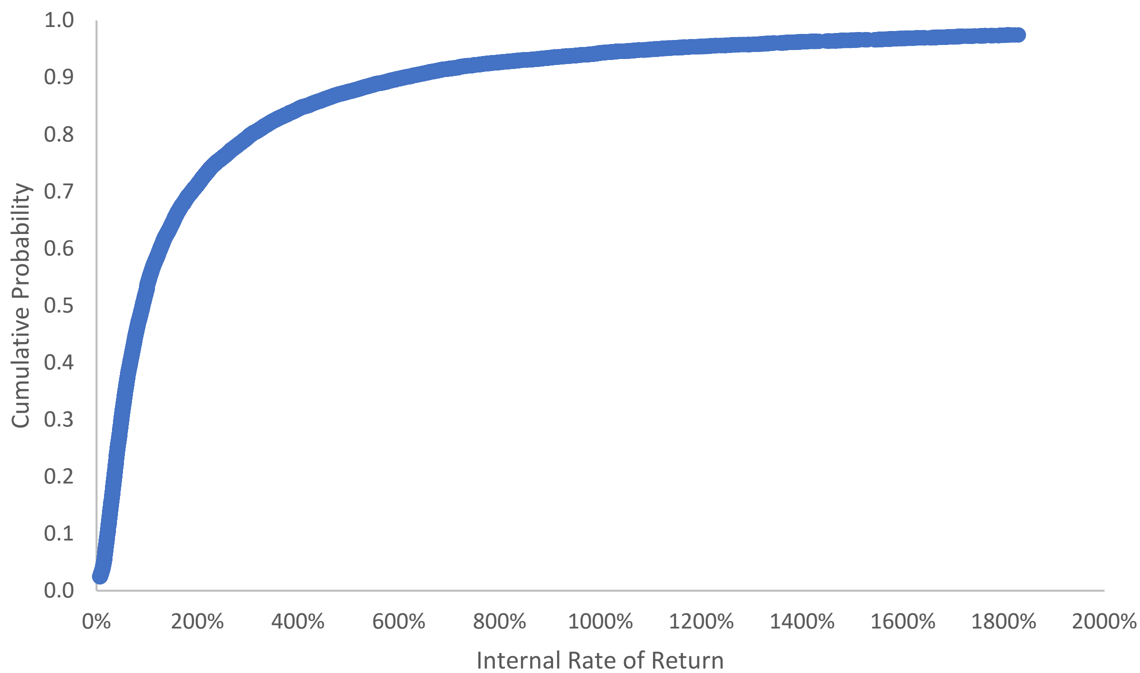
The Akaike Information Criterion was used to confirm that the form of a Cobb-Douglas production function performed better than a linear form:

$$ln(IRR) = \beta_1 \ln(INV) + \beta_2 \ln(YR) + \beta_3 \ln(EMP) + \beta_4 \ln(ENRGY) + \beta_5 RBT + \sum_{ARC=6}^{429} \beta_{ARC} IND_{ARC} + \sum_{NAICS=430}^{450} \beta_{NAICS} IND_{NAICS} + \mathcal{E}$$

Where
IRR = Internal rate of return
INV = Cost of the investment
YR = Year of investment
EMP = Number of employees at the firm making the investment
$ENRGY$ = Electricity and gas expenditures per dollar of sales
RBT = Indicator variables for whether there was a rebate

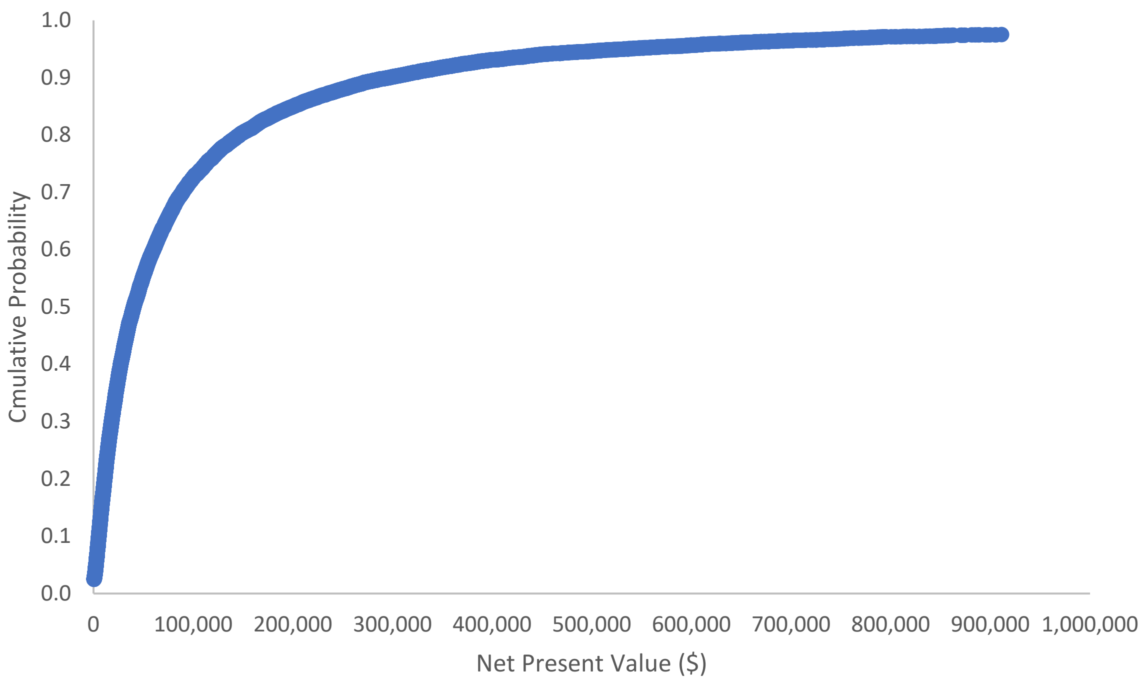
IND_{ARC} = Indicator variable for the 5-digit ARC code
IND_{NAICS} = Indicator variable for the 3-digit NAICS code
β_y = the parameters to be estimated where y is 1 through 450

Note that although the format of this equation is linear, the relationship between the dependent and independent variables are multiplicative and exponential, similar to the Cobb-Douglas production function. The natural log is taken of both sides of the equation to put the equation in linear format and estimate the parameters.



NOTE: To remove outliers, the top and bottom 2.5 % are not shown in the graph

Figure 3.1: Cumulative Probability Graph of the Internal Rate of Return for Investments of $1000 or more that were Implemented



NOTE: To remove outliers, the top and bottom 2.5 % are not shown in the graph

Figure 3.2: Cumulative Probability Graph of the Net Present Value of Investments of $1000 or more

4. Results

This paper examines trends in the return on investment for efficiency improvements in small to medium U.S. manufacturing establishments. Calculations of the IRR and NPV are used to evaluate the investments. The sum of all the positive net present values for all recommendations implemented is approximately $2.6 billion. Approximately 20 % of the recommendations represent 82 % of the net present values, as illustrated in Figure 4.1. Approximately 80 % of the investment IRR estimates are 299.6 % or lower, as seen in Figure 3.1. Figure 4.2 presents the cumulative percent of net present value by the cumulative percent investment cost ordered by IRR. That is, the investments with the highest IRR are on the left. The top 20 % of investment cost categories represent 74 % of the net present value (i.e., benefits). To advance manufacturing competitiveness, these are the investments that one might focus. Figure 4.2 presents a similar graph; however, each point represents the average for one of the ARC codes. At the societal level, it would be desirable for the investment types toward the left to be prioritized as they have higher returns. The top 47 % of investment costs represent 80 % of the net present value.

The internal rate of return and net present value for the IAC investments can be useful for manufacturers to identify potential investments in their own facilities. Table 4.1 lists the top 20 % of ARC recommendations by IRR. The top three (not shown) include “purchasing gas directly” (ARC 28113), “use an alternative desulfurizing agent” (ARC 31154), and “employing modular jigs” (46230). The top three ARC recommendation categories at the three-digit level include “bottleneck reduction” (ARC 411000), “scheduling” (ARC 44500), and “just-in-time” inventory (ARC 43100), as seen in Table 4.1.

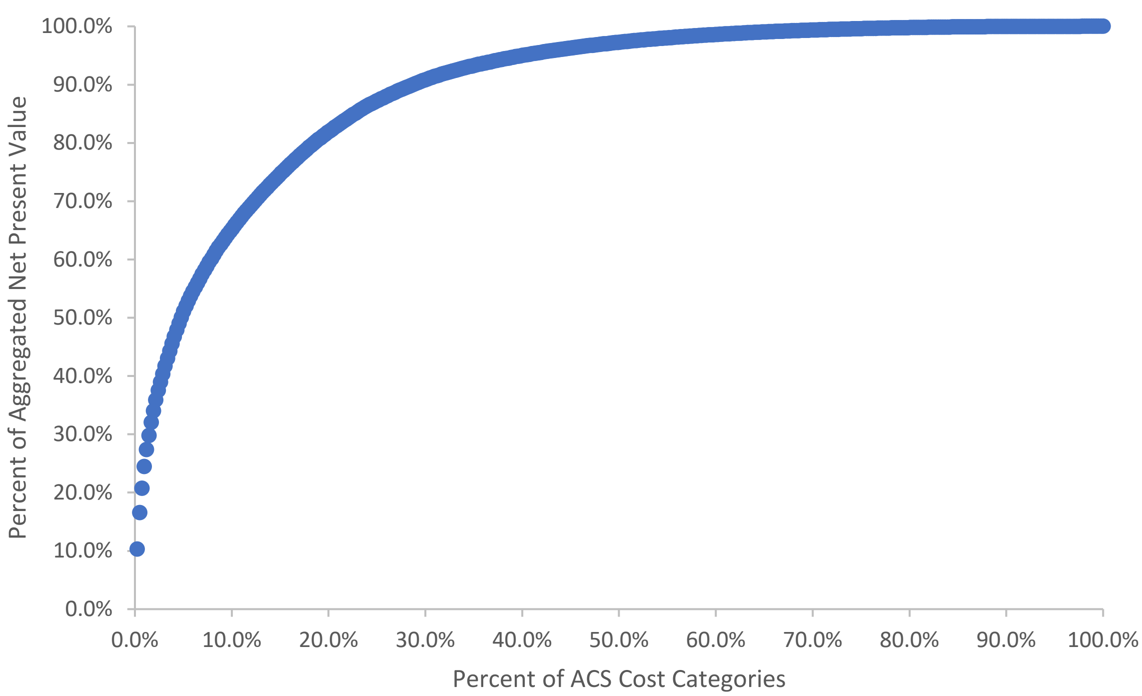


Figure 4.1: Cumulative Net Present Value by Percent of ACS Cost Categories

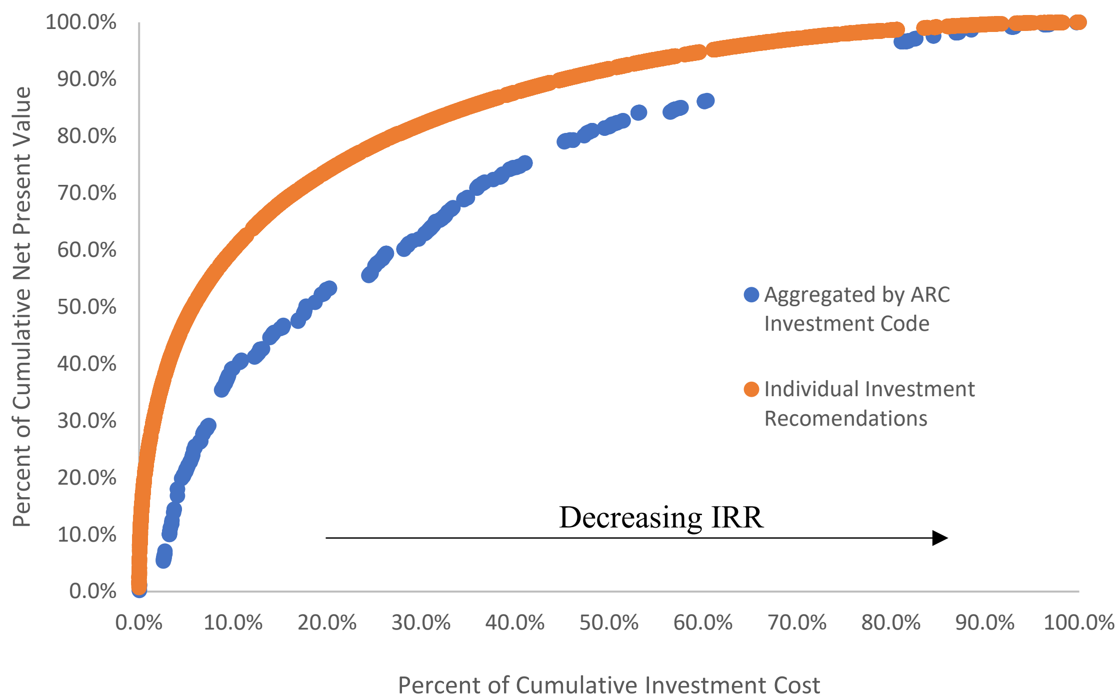


Figure 4.2: Percent of Cumulative NPV by Percent Cumulative Investment Cost – Sorted by IRR (highest on left)

Recall that although there are a number of variations shown in Table 3.1, Table 3.2, and Table 4.1, it is difficult to identify trends as other factors may confound them. For this reason, an ANCOVA analysis was conducted to see whether the ARC code, time, rebate, firm size measured in employees, gas/electricity cost, investment cost, and NAICS code had an impact on the IRR. The result suggested that they do have an impact, as shown in Table 4.2. Therefore, a regression analysis is used to examine their effect. The results are shown in Table 4.3. Two models are generated where one includes electric and gas costs divided by sales along with the investment cost to examine the trend resulting from larger investments and higher energy consumption. The second model excludes these variables to avoid potential misspecification. The results suggest that over time, the average IRR decreases. As with any correlation study, there are multiple potential reasons for a particular correlation. In this case, it could be due to energy prices or changes in the assessment process; however, a reasonable explanation is that higher return investments are selected first, leaving lower investments for the future. This likely happens at the individual establishment level and, therefore, over time at the industry level, as an industry is made up of the individual establishments. As new technologies, processes, and practices are adopted and diffused throughout an industry, it leaves fewer opportunities to achieve the same level of return. Those who do not adopt the new approaches are often competed out of the market. High-profile examples of this process might be the adoption of the assembly line or the adoption and use of computers. Once these new technologies were adopted, it becomes more difficult to achieve the same level of return.

The results from the analysis also suggest that larger firms (i.e., firms with more employees) tend to have higher IRR. Rebates also had a positive impact. Investments with higher investment costs tended to have lower IRR as did firms with higher electricity and gas costs relative to sales. A number of ARC codes were statistically significant suggesting that they were higher when controlling for other factors. The most common high IRR investment type was related to "heat recovery" (ARC 224000) with the second relating to "space conditioning" (ARC 272000) and the third most common was related to "cogeneration" (ARC 234000).

It is important to note that because we include all the six-digit ARC codes in the model, which amounts to hundreds of variables, some of these will be falsely identified as being statistically significant since we are using 90 %, 95 %, and 1 % confidence intervals. We can expect that 1 % to 10 % of the variables are falsely identified, depending on the confidence interval. We need to have awareness of this issue; however, the purpose of this analysis is to identify investments that are more likely to have a high return. Any investment category that is identified as being statistically significant has a 90 % probability or higher of actually being statistically significant, which achieves the goal of identifying investments that are more likely to have a high return.

Table 4.1: : Top 20 % of ARC Recommendations by Internal Rate of Return, Investments of $1000 or more

ARC	Description	IRR
41100	Manufacturing Enhancements: BOTTLENECK REDUCTION	4264%
44500	Labor Optimization: SCHEDULING	4180%
43100	Inventory: JUST IN TIME	3962%
47300	Management Practices: MARKETING	3125%
32100	Equipment: GENERAL	1923%
43200	Inventory: OTHER INVENTORY CONTROLS	1684%
46100	Reduction of Downtime: MAINTENANCE	1244%
46200	Reduction of Downtime: QUICK CHANGE	1231%
28100	Ancillary Costs: ADMINISTRATIVE	1051%
45200	Space Utilization: RENTAL SPACE	1044%
46300	Reduction of Downtime: POWER CONDITIONING	874%
44200	Labor Optimization: PRACTICES / PROCEDURES	815%
46400	Reduction of Downtime: ALARMS	740%
45100	Space Utilization: FLOOR LAYOUT	730%
44300	Labor Optimization: TRAINING	719%
21200	Combustion Systems: BOILERS	692%
22100	Thermal Systems: STEAM	678%
21100	Combustion Systems: FURNACES, OVENS & DIRECTLY FIRED OPERATIONS	623%
41200	Manufacturing Enhancements: DEFECT REDUCTION	598%
41300	Manufacturing Enhancements: MATERIAL REDUCTION	586%
23100	Electrical Power: DEMAND MANAGEMENT	512%
37200	Maintenance: SPILLAGE	497%
26200	Operations: EQUIPMENT CONTROL	471%
44400	Labor Optimization: AUTOMATION	445%
31100	Operations: PROCEDURES	438%
22200	Thermal Systems: HEATING	431%
34100	Water Use: GENERAL	426%
46500	Reduction of Downtime: OTHER EQUIPMENT	418%
42100	Purchasing: RAW MATERIALS	414%
31200	Operations: WASTE STREAM CONTAMINATION	412%
37300	Maintenance: OTHER	383%
38100	Raw Materials: SOLVENTS	381%
24200	Motor Systems: AIR COMPRESSORS	380%

23500	Electrical Power: TRANSMISSION	357%
48100	Other Administrative Savings: TAXES	351%
22500	Thermal Systems: HEAT CONTAINMENT	350%
35100	Recycling: LIQUID WASTE	342%
35300	Recycling: OTHER MATERIALS	308%
36100	Waste Disposal: GENERAL	298%
27200	Building and Grounds: SPACE CONDITIONING	289%
22700	Thermal Systems: DRYING	287%
26100	Operations: MAINTENANCE	286%
27300	Building and Grounds: VENTILATION	280%
47100	Management Practices: TOTAL QUALITY MANAGEMENT	249%
21300	Combustion Systems: FUEL SWITCHING	247%
35200	Recycling: SOLID WASTE	244%
44600	Labor Optimization: MAINTENANCE	236%
20000	Energy Management: Energy Management	223%
22400	Thermal Systems: HEAT RECOVERY	223%
24300	Motor Systems: OTHER EQUIPMENT	215%
25100	Industrial Design: SYSTEMS	196%
24100	Motor Systems: MOTORS	179%
27400	Building and Grounds: BUILDING ENVELOPE	176%
28200	Ancillary Costs: SHIPPING, DISTRIBUTION, AND TRANSPORTATION	166%
33100	Post Generation Treatment / Minimization: GENERAL	150%
37100	Maintenance: CLEANING / DEGREASING	135%
22300	Thermal Systems: HEAT TREATING	131%
22600	Thermal Systems: COOLING	121%
48200	Other Administrative Savings: FEES	94%
27100	Building and Grounds: LIGHTING	93%
23200	Electrical Power: POWER FACTOR	89%
23300	Electrical Power: GENERATION OF POWER	89%
38200	Raw Materials: OTHER SOLUTIONS	82%
23400	Electrical Power: COGENERATION	61%
42300	Purchasing: CAPITAL	54%
46600	Reduction of Downtime: INDUSTRIAL INTERNET OF THINGS SENSORS (IIOT)	40%
29100	Alternative Energy Usage: GENERAL	18%

The IAC data focuses on investments that might be made by the manufacturer; however, the estimate of benefits can be useful for researchers to understand the trends in losses, as benefits are often the result of reduced losses. Organizations focused on conducting research to advance manufacturing competitiveness might focus on investment areas with high potential for savings, as they are target rich environments. The ARC with the highest amount of savings (not shown) was to "utilize higher efficiency lamps and/or ballasts" (ARC 27142) followed by "use adjustable frequency drive or multiple speed motors" (ARC 24146). The third one was to "reduce bottlenecks" (ARC 41110). At the three digit ARC level (See Table 4.4), the highest concentration of benefits was in "heat recovery" (ARC 22400) with 9 % of the total with the next highest in "cogeneration" (ARC 32400) and the third highest in "lighting" (ARC 27100).

Table 4.2: Results from ANCOVA Analysis of IRR

	Model 1		Model 2	
Variable	F Statistics	Prob>F	F Statistics	Prob>F
Model	24.85	0.000	12.57	0.000
Year count	34.89	0.000	20.22	0.000
Natural Log of Employees	369.75	0.000	451.91	0.000
3 Digit ARC Code			15.93	0.000
5 Digit ARC Code	11.14	0.000		
3 Digit NAICS Code	7.81	0.004	3.26	0.000
Interaction of ARC Code and NAICS Code			1.56	0.000
Rebate	0.20	0.655	3.03	0.082
Nat. Log of Elect. Expenditures per $sales	122.4	0.000	129.41	0.000
Nat. Log of Investment Cost	1958.79	0.000	3096.83	0.000

Table 4.3: Regression Results, IRR for Manufacturing Energy Efficiency Investments of $1000 or more that were Implemented

Variable	IRR Model 1	IRR Model 2	Average IRR
Investment Cost	-0.315***		
Trend	-0.019***	-0.017***	
Employees	0.116***	0.06***	
Elect and gas per $ sales	-0.002**		
Rebate	0.295***	0.264***	
ARC 31154: USE AN ALTERNATIVE DESULFURIZING AGENT TO ELIMINATE HAZARDOUS SLAG FORMATION	3.835***	4.045***	6431%
ARC 27262: SEPARATE CONTROLS OF AIR HANDLERS FROM AC/ HEATING SYSTEMS	3.371***	3.722***	3109%
ARC 46230: EMPLOY MODULAR JIGS TO REDUCE PROCESS SET-UP TIME	3.162***	3.504***	5781%
ARC 46410: ELIMINATE SHUTDOWNS OF CONTROLS DUE TO OVERHEATING	2.456*	3.18**	1342%
ARC 47310: ADVERTISE PRODUCT OR SERVICE	2.553**	3.087**	3125%
ARC 43110: SCHEDULE DELIVERIES ACCORDING TO DEMAND	2.938***	3.041***	3962%
ARC 41230: REDUCE DEFECTS BY REDUCING PRODUCT TIPPING	2.581*	3.013*	32933%
ARC 44520: ELIMINATE SHIFT	2.747***	2.853***	2161%
ARC 32123: CONVERT TO HIGH VOLUME LOW PRESSURE (HVLP) PAINT GUNS	3.048***	2.847***	4637%
ARC 28113: PURCHASE GAS DIRECTLY FROM A CONTRACT GAS SUPPLIER	2.591***	2.694***	23440%
ARC 31223: USE FOG NOZZLES / SPRAY RINSING INSTEAD OF IMMERSION RINSING	2.363*	2.58*	1267%
ARC 38113: PREVENT EXCESSIVE SOLVENT USAGE (OPERATOR TRAINING)	2.084	2.561*	1204%
ARC 44510: ADD ADDITIONAL PRODUCTION SHIFT	2.543***	2.351***	4050%
ARC 46310: INSTALL AN UNINTERRUPTIBLE POWER SUPPLY	2.12*	2.279*	909%
ARC 45210: CLEAR AND RENT EXISTING SPACE	2.191***	2.165***	1743%
ARC 28111: CHECK FOR ACCURACY OF UTILITY METERS	1.982*	2.081*	998%
ARC 38125: REMOVE ROLLERS FROM THE MACHINES AND CLEAN IN A CLOSED SOLVENT CLEANER	1.492	1.943*	906%
ARC 44320: CROSS-TRAIN PERSONNEL TO AVOID LOST TIME	2.538**	1.882*	761%
ARC 44540: MODIFY STARTUP/SHUTDOWN TIMES	1.679**	1.838**	3785%
ARC 46320: CHANGE OPERATING CONDITIONS	1.957**	1.834*	4148%
ARC 46250: DEVELOP STANDARD OPERATING PROCEDURES	1.903***	1.828***	1318%
ARC 43220: ELIMINATE OLD STOCK AND / OR MODIFY INVENTORY CONTROL	1.604**	1.703**	2291%
ARC 34156: USE FLOW CONTROL VALVES ON EQUIPMENT TO OPTIMIZE WATER USE	1.463**	1.665**	1687%
ARC 43230: OPTIMIZE LOT SIZES TO REDUCE INVENTORY CARRYING COSTS	1.977**	1.611*	3984%
ARC 37311: MAINTAIN MACHINES WITH TO REDUCE LEAKS	1.671**	1.609**	2798%
ARC 44260: MODIFY WORKLOAD	1.682***	1.573**	3508%
ARC 35145: RECOVER AND REUSE SPENT ACID BATHS	1.571**	1.487*	856%
ARC 28114: CHANGE RATE SCHEDULES OR OTHER CHANGES IN UTILITY SERVICE	1.449***	1.482***	5817%
ARC 34155: SUB-METER / QUANTIFY WATER USE	1.235**	1.47***	775%
ARC 24156: ESTABLISH A PREVENTATIVE MAINTENANCE PROGRAM	1.034*	1.468**	1515%
ARC 35316: CONTRACT A WOOD PALLET RECYCLING COMPANY	0.909	1.436**	3287%
ARC 46110: BEGIN A PRACTICE OF PREDICTIVE / PREVENTATIVE MAINTENANCE	1.286***	1.424***	1983%
ARC 28121: APPLY FOR TAX-FREE STATUS FOR ENERGY PURCHASES	1.178**	1.374***	9230%
ARC 22525: ELIMINATE COOLING OF PROCESS STREAMS WHICH SUBSEQUENTLY MUST BE HEATED AND VICE VERSA	1.008	1.368*	2681%
ARC 27221: LOWER TEMPERATURE DURING THE WINTER SEASON AND VICE-VERSA	1.104**	1.309***	7917%
ARC 24157: ESTABLISH A PREDICTIVE MAINTENANCE PROGRAM	0.73	1.221***	651%
ARC 22135: REPAIR AND ELIMINATE STEAM LEAKS	1.03**	1.195**	6116%
ARC 22113: REPAIR OR REPLACE STEAM TRAPS	1.149**	1.182**	1275%
ARC 34116: METER RECYCLED WATER (TO REDUCE SEWER CHARGES)	0.952*	1.16**	2095%
ARC 41310: MODIFY PROCESS TO REDUCE MATERIAL USE/COST	1.379**	1.151**	2414%
ARC 45120: CONDENSE OPERATION INTO ONE BUILDING	1.448**	1.124*	1287%
ARC 44310: TRAIN OPERATORS FOR MAXIMUM OPERATING EFFICIENCY	1.25**	1.111**	711%
ARC 45130: REARRANGE EQUIPMENT LAYOUT TO REDUCE LABOR COSTS	1.084*	1.074*	1091%
ARC 21133: ADJUST BURNERS FOR EFFICIENT OPERATION	0.762	1.008**	2687%
ARC 21231: ESTABLISH BURNER MAINTENANCE SCHEDULE FOR BOILERS	0.837	1.007*	2998%
ARC 26218: TURN OFF EQUIPMENT WHEN NOT IN USE	0.791*	0.996**	4548%
ARC 21135: REPAIR FURNACES AND OVEN DOORS SO THAT THEY SEAL EFFICIENTLY	0.634	0.98**	393%
ARC 41110: ADD EQUIPMENT/ OPERATORS TO REDUCE PRODUCTION BOTTLENECK	1.413***	0.946*	16216%
ARC 21233: ANALYZE FLUE GAS FOR PROPER AIR/FUEL RATIO	0.652	0.921**	1232%

ARC 27231: USE RADIANT HEATER FOR SPOT HEATING	1.275***	0.844*	3071%
ARC 27243: IMPROVE AIR CIRCULATION WITH DESTRATIFICATION FANS / OTHER METHODS	0.833*	0.778*	2010%
ARC 23212: OPTIMIZE PLANT POWER FACTOR	-0.498	-0.812*	156%
ARC 27145: INSTALL SKYLIGHTS	-0.879*	-0.915*	271%
ARC 27142: UTILIZE HIGHER EFFICIENCY LAMPS AND/OR BALLASTS	-0.688	-0.918**	242%
ARC 21224: REPLACE BOILER	-0.384	-0.959*	132%
ARC 24133: USE MOST EFFICIENT TYPE OF ELECTRIC MOTORS	-0.925**	-0.976**	4161%
ARC 20000: Energy Management	-0.599	-0.98**	223%
ARC 22691: SHUT OFF COOLING IF COLD OUTSIDE AIR WILL COOL PROCESS	-0.739	-1.096*	167%
ARC 26221: USE MOST EFFICIENT EQUIPMENT AT ITS MAXIMUM CAPACITY AND LESS EFFICIENT EQUIPMENT ONLY WHEN NECESSA	-0.597	-1.137**	6477%
ARC 22492: USE "HEAT WHEEL" OR OTHER HEAT EXCHANGER TO CROSS-EXCHANGE BUILDING EXHAUST AIR WITH MAKE-UP AIR	-0.659	-1.155*	88%
ARC 27233: USE PROPERLY DESIGNED AND SIZED HVAC EQUIPMENT	-0.906	-1.224**	291%
ARC 27232: REPLACE EXISTING HVAC UNIT WITH HIGH EFFICIENCY MODEL	-0.874*	-1.302***	124%
ARC 29112: USE SOLAR HEAT TO HEAT WATER	-1.329**	-1.328**	42%
ARC 22622: REPLACE EXISTING CHILLER WITH HIGH EFFICIENCY MODEL	-0.567	-1.358***	57%
ARC 35318: RECYCLE FLUORESCENT LAMPS	-1.219	-1.371*	15%
ARC 27494: INSTALL STORM WINDOWS AND DOORS	-1.621**	-1.821***	38%
ARC 23415: USE A FOSSIL FUEL ENGINE TO COGENERATE ELECTRICITY OR MOTIVE POWER; AND UTILIZE HEAT	-0.138	-1.837***	29%
ARC 29141: INSTALL ANAEROBIC DIGESTER	0.387	-1.987**	19%
ARC 27225: CLOSE OUTDOOR AIR DAMPERS DURING WARM-UP / COOL-DOWN PERIODS	-1.671	-2.065*	12%
ARC 24321: UPGRADE OBSOLETE EQUIPMENT	-2.012***	-2.134***	279%
ARC 23322: USE EXISTING DAM TO GENERATE ELECTRICITY	-1.014	-2.162**	58%
ARC 29114: USE SOLAR HEAT TO MAKE ELECTRICITY	-0.922*	-2.187***	12%
ARC 29113: USE SOLAR HEAT FOR HEAT	-1.088	-2.199**	11%
ARC 25113: USE DIRECT FLAME IMPINGEMENT OR INFRARED PROCESSING FOR CHAMBER TYPE HEATING	-0.863	-2.262*	13%
ARC 22191: SUBSTITUTE HOT PROCESS FLUIDS FOR STEAM	-2.337**	-2.806***	32%
ARC 23513: CONSIDER POWER LOSS AS WELL AS INITIAL LOADS AND LOAD GROWTH IN DOWN-SIZING TRANSFORMERS	-1.558	-3.349**	4%
ARC 27446: UTILIZE SENSORS CONTROLLING ROOF AND WALL OPENINGS	-7.916***	-8.045***	1738%
ARC 41120: REPLACE OLD MACHINE WITH NEW AUTOMATIC MULTI-STATION TOOL	2.525**	1.159	291%
ARC 27424: SHADE WINDOWS FROM SUMMER SUN	2.296*	1.611	274%
ARC 22623: MINIMIZE CONDENSER COOLING WATER TEMPERATURE	2.227*	1.186	2679%
ARC 31222: REDUCE WATER USE WITH COUNTERCURRENT RINSING	1.585*	1.207	423%
ARC 41220: DEVELOP STANDARD PROCEDURES TO IMPROVE INTERNAL YIELDS	1.405**	0.923	489%
ARC 45140: REARRANGE EQUIPMENT LAYOUT TO REDUCE HANDLING COSTS	1.402**	0.841	556%
ARC 36192: USE A LESS EXPENSIVE METHOD OF WASTE REMOVAL	1.138*	1.09	2548%
ARC 31192: REDUCE SCRAP PRODUCTION	1.13*	0.706	1440%
ARC 22212: USE MINIMUM SAFE OVEN VENTILATION	-0.942**	-0.713	673%
ARC 26211: CONSERVE ENERGY BY EFFICIENT USE OF VENDING MACHINES	-1.662**	-1.267	1352%
NAICS 316: Leather and Allied Product Manufacturing	0***	0***	
NAICS 331: Primary Metal Manufacturing	1.469***	1.025**	
NAICS 327: Nonmetallic Mineral Product Manufacturing	1.352***	1.009**	
NAICS 335: Electrical Equipment, Appliance, and Component Manufacturing	1.177***	0.92**	
NAICS 325: Chemical Manufacturing	1.164***	0.802*	
NAICS 326: Plastics and Rubber Products Manufacturing	1.138***	0.779*	
NAICS 339: Miscellaneous Manufacturing	0.912**	0.69*	
NAICS 336: Transportation Equipment Manufacturing	0.909**	0.644	
NAICS 322: Paper Manufacturing	1.118***	0.617	
NAICS 324: Petroleum and Coal Products Manufacturing	1.006**	0.614	
NAICS 313: Textile Mills	0.967**	0.61	
NAICS 334: Computer and Electronic Product Manufacturing	0.854**	0.602	
NAICS 333: Machinery Manufacturing	0.905**	0.594	
NAICS 312: Beverage and Tobacco Product Manufacturing	0.903**	0.58	
NAICS 332: Fabricated Metal Product Manufacturing	0.839**	0.532	
NAICS 321: Wood Product Manufacturing	0.826**	0.53	
NAICS 337: Furniture and Related Product Manufacturing	0.653	0.381	
NAICS 314: Textile Product Mills	0.674	0.391	

NAICS 315: Apparel Manufacturing	0.651	0.378
NAICS 323: Printing and Related Support Activities	0.47	0.296
Constant	1.578***	-0.649
Observations	15344	15378
R2	0.5182	0.4304

Table 4.4: Present Value Savings over 10 Years

ARC Description	Percent of Total Benefits from all Recommendations	Total 10 Year Savings ($1000s)
22400 Thermal Systems: HEAT RECOVERY	8.9%	1 112 710
23400 Electrical Power: COGENERATION	8.3%	1 038 601
27100 Building and Grounds: LIGHTING	8.1%	1 012 140
24200 Motor Systems: AIR COMPRESSORS	6.8%	846 050
24100 Motor Systems: MOTORS	6.3%	779 948
22100 Thermal Systems: STEAM	5.2%	653 500
21300 Combustion Systems: FUEL SWITCHING	4.4%	552 744
27200 Building and Grounds: SPACE CONDITIONING	4.1%	507 879
41100 Manufacturing Enhancements: BOTTLENECK REDUCTION	3.9%	488 987
21200 Combustion Systems: BOILERS	3.1%	384 899
29100 Alternative Energy Usage: GENERAL	2.6%	325 010
24300 Motor Systems: OTHER EQUIPMENT	2.4%	305 392
26200 Operations: EQUIPMENT CONTROL	2.4%	293 894
22600 Thermal Systems: COOLING	2.1%	260 037
44400 Labor Optimization: AUTOMATION	2.1%	259 120
21100 Combustion Systems: FURNACES, OVENS & DIRECTLY FIRED OPERATIONS	2.0%	255 706
28100 Ancillary Costs: ADMINISTRATIVE	2.0%	253 696
46500 Reduction of Downtime: OTHER EQUIPMENT	1.8%	222 080
34100 Water Use: GENERAL	1.8%	219 702
22500 Thermal Systems: HEAT CONTAINMENT	1.7%	217 744
31100 Operations: PROCEDURES	1.5%	182 158
23100 Electrical Power: DEMAND MANAGEMENT	1.4%	172 433
27400 Building and Grounds: BUILDING ENVELOPE	1.2%	146 981
23200 Electrical Power: POWER FACTOR	1.1%	138 912
41200 Manufacturing Enhancements: DEFECT REDUCTION	0.9%	117 253
45100 Space Utilization: FLOOR LAYOUT	0.9%	114 505
25100 Industrial Design: SYSTEMS	0.8%	102 894
41300 Manufacturing Enhancements: MATERIAL REDUCTION	0.8%	102 377
33100 Post Generation Treatment / Minimization: GENERAL	0.7%	91 163
44500 Labor Optimization: SCHEDULING	0.7%	88 751
46200 Reduction of Downtime: QUICK CHANGE	0.7%	88 428
44200 Labor Optimization: PRACTICES / PROCEDURES	0.7%	88 158
36100 Waste Disposal: GENERAL	0.7%	85 880
35200 Recycling: SOLID WASTE	0.7%	85 871
27300 Building and Grounds: VENTILATION	0.6%	79 565
32100 Equipment: GENERAL	0.6%	74 685
23300 Electrical Power: GENERATION OF POWER	0.5%	64 639
35300 Recycling: OTHER MATERIALS	0.5%	62 618
22300 Thermal Systems: HEAT TREATING	0.5%	61 145
43200 Inventory: OTHER INVENTORY CONTROLS	0.5%	60 729
44300 Labor Optimization: TRAINING	0.5%	56 615
46100 Reduction of Downtime: MAINTENANCE	0.4%	55 344
46300 Reduction of Downtime: POWER CONDITIONING	0.4%	53 092
42100 Purchasing: RAW MATERIALS	0.3%	41 709
45200 Space Utilization: RENTAL SPACE	0.3%	33 779
22200 Thermal Systems: HEATING	0.2%	30 727

28200 Ancillary Costs: SHIPPING, DISTRIBUTION, AND TRANSPORTATION	0.2%	23 704
38100 Raw Materials: SOLVENTS	0.2%	20 786
47100 Management Practices: TOTAL QUALITY MANAGEMENT	0.2%	20 718
26100 Operations: MAINTENANCE	0.2%	20 089
35100 Recycling: LIQUID WASTE	0.1%	16 808
47300 Management Practices: MARKETING	0.1%	13 183
23500 Electrical Power: TRANSMISSION	0.1%	11 615
47200 Management Practices: CERTIFICATIONS	0.1%	8082
43100 Inventory: JUST IN TIME	0.1%	7885
42300 Purchasing: CAPITAL	0.1%	7862
37300 Maintenance: OTHER	0.1%	7818
37200 Maintenance: SPILLAGE	0.1%	7344
48100 Other Administrative Savings: TAXES	0.1%	6492
37100 Maintenance: CLEANING / DEGREASING	0.0%	5766
31200 Operations: WASTE STREAM CONTAMINATION	0.0%	5496
46400 Reduction of Downtime: ALARMS	0.0%	4923
46600 Reduction of Downtime: INDUSTRIAL INTERNET OF THINGS SENSORS (IIOT)	0.0%	4276
22700 Thermal Systems: DRYING	0.0%	3302
48200 Other Administrative Savings: FEES	0.0%	3224
44600 Labor Optimization: MAINTENANCE	0.0%	1807
38300 Raw Materials: SOLIDS	0.0%	1187
42200 Purchasing: ANCILLARY MATERIALS	0.0%	1065
38200 Raw Materials: OTHER SOLUTIONS	0.0%	111
30000 Waste Minimization / Pollution Prevention: Waste Minimization / Pollution Prevention	0.0%	63

5. Summary and Conclusion

This paper examines trends in data from U.S. Department of Energy Industry Assessment Centers to facilitate identifying potentially high return investments for manufacturers and manufacturing industry researchers. The results show that the net present value is disproportionally distributed among investments, where 20 % of the investment categories represent 82 % of the net present value (i.e., net benefits). For individual investments, 20 % of the cumulative investment cost accounts for 74 % of the net present value. Similar distributions were found for the IRR. Moreover, the investments are disproportionally distributed where a small number of investments represent a large portion of the returns. The implication is that it requires strategy and analysis (e.g., investment analysis) to get the highest returns possible, as a random selection will likely result in lower returns.

Results from a regression analysis suggest that over time, the average IRR decreases. Thus, over time, high returns may become more difficult to achieve, which reiterates the need to use strategy and analysis to identify high return investments. Larger firms were shown to have, on average, higher IRR investments. Additionally, some investment categories tend to have higher IRR than others. The results identified those investment ARC categories with the highest IRR, the highest concentration of benefits, and those with an IRR that is statistically significant. The ARC investment categories identified in this paper can be used to guide investments from manufacturers and manufacturing industry researchers, as they indicate areas of investment that commonly have a high return or a high level of benefits.

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