Title: Total Cost of Ownership of a Compressed Air System

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Abstract: Compressed air is widely recognized as a versatile and essential manufacturing resource. It is however, one of the least understood cost drivers in a factory. Very few companies realize what an air leak is actually costing them. This paper gives a method to understand the total cost of ownership of a compressed air system by taking the approach of a fictional business selling air as a utility.

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INTRODUCTION

Compressed air is widely recognized as a versatile and essential manufacturing resource. There are practically unlimited applications for compressed air in today's plant. Most applications are related to some type of automation, which is increasing in all industries. So even in a stable, no-growth industrial base, compressed air usage is increasing.

Compressed air is continuously depended on. In many plants, the entire operation would come to a halt if the compressed air system failed. Any air pressure drop sometimes could cause a main failure in the plant. Many kinds of industrial plants from need it from the first day of construction to the last day of production. Compressed air like other utilities (water, electricity and gas) has its own property of how to be produced safely, used safely, and how much money should be invested for it.

Compressed air is one of the least efficient methods and most expensive ways to transfer energy from electricity to mechanical energy. By the nature of the process and the limitations imposed by thermodynamics, a compressed air system converts less than 10% of the electricity used in the main motor into usable mechanical energy. However, its versatility outweighs its costliness. Because of this, waste of compressed air has a huge cost for the plant. That is why the design and maintenance of the compressed air system in any manufacturing or any process plant needs much attention.

Compressed air is the "fourth utility" after electricity, water and natural gas. Whenever operators want to use compressed air, they just plug the pipe in with their machines as they do with water, gas, or electricity. Unlike the electricity and water, compressed air has not been sold as a normal utility. Most industrial plants either buy or rent compressed air equipment versus paying for the air as a function of usage. However, with the deregulation of utility companies in the US, opportunities are rising for the creation of new revenues without having to build new plants. Compressed air could be such a revenue source.

Whether to buy or lease a compressed air package has always been a difficult question. Each industry has to decide by using its own experience of which one is better. Some plants do all of their maintenance with in-house staff and prefer to purchase the equipment outright. However, there is an increasing trend toward leasing or renting the equipment and out-sourcing the maintenance. This option treats compressed air more as a utility than a capital expense. Whether a plant is owning an operating its own compressor or buying its output as a utility, the investment requires a similar engineering economic analysis.

ve the most accurate picture of true cost, we would apply total cost of ownership

·URE REVIEW

ı order to calculate the rate of compressed air per unit, we should know the cost of sed air system, and then relate that cost to the output of the compressor. From the about total cost of ownership (TCO), we are able to see the accurate picture of true

otal cost of ownership (TCO) is defined as " A structured approach for determining the t associated with the acquisition per se... which might include a number of non-value :tivities, service costs, failure costs, administrative costs, maintenance, disposition and cost"[1], [3]. For TCO of capital equipment might include pre-transaction costs, on costs and post-transaction costs [2]. Pre-transaction costs are all costs that are fore purchased the equipment; for example, costs are made during investigating ꞌe of equipment and educating employees for operation [2]. Transaction costs are ɔ price, order placement/preparation, delivery/transportation, tariffs, inspection, return follow-up and correction [2]. The post-transaction costs are all cost involving ıg from maintenance (special and routine maintenance costs), repairs, downtime, ence and disposal of the equipment [2], [4].

or Ellram's study [4], there are two strategies for determining TCO which are "dollar ɔroach and value base approach". Dollar-base approaches are accomplished by ȷ and allocating real cost information that is related to TCO. It also shows expending in the past and forecasting for the future. In contrast, the ~~On the contrary,~~ value base approach is the model that converts qualitative data to quantitative data. For the project, we would ɘ dollar-base approach to determine a rate of compressed air per unit.

he illustration of dollar base TCO is shown in the Figure 1[4]. Nonetheless, the details ements would need to be modified to be appropriate for each company.

Price paid, F.O.B origin (12.632/unit)		$12,000.00
Delivery charge		500.00
Quality:		
Cost to return defects	$100.00	
Inspection (in-house)	300.00	
Delay costs (downtime)	-	
Rework parts	-	
Rework finished good	200.00	
Subtotal quality costs		
Technology		**600.00**
Our engineer at their facility	$1,500.00	
<credit> Their engineer at our facility	<300.00>	
<credit> Their design change to improve yield		
Subtotal technology		
Support/Service		
Cost of delivery delays	$104.00	**$1,200.00**
Charge for not using EDI ($50.00/order)	150.00	
Subtotal support/service		
Total costs		
Units shipped		**$254.00**
TCO per unit (total costs/units shipped)		**$14,554.00**
		950
		$15.32

Figure 1. Dollar-base TCO

To implement TCO, in the case that the firm knows accurate cost information of the asset, the significant cost components which are the majority of TCO expenditure must be determined. After that, the firm gathers and summarizes all costs. Finally, it comes to analyzing the result of total cost.[2] For the result, the firm can apply the knowledge to the company's purposes.

Smytka and Clemens [5] said that "Related costs must be examined and added in to determine a realized cost." For total cost of compressed air, the first cost is initial purchase cost of compressed air. However the most cost of it is not the initial or equipment costs. Energy costs tend to dominate all others over time (particularly electrical expense)[6], [7].

To evaluate the compressed air system, the staff of the plant typically thinks of only the terms of equipment costs. Selection is made generally based on initial purchase price, even when that is the smallest category of expense. Beyond the initial cost for the first couple years, one article stated that the operation costs can vary from 1.5 to 2.5 times the initial purchase price of the equipment.[6]

For an air compressor, the major cost categories are:

1. Operating costs

- Electric energy costs, which come from the compressed air system itself and the cooling cost used to run the fan motors.
- Cooling water costs for water-cooled compressors.

2. Maintenance and repair costs
3. Initial purchase less depreciation and salvage value.

DISCUSSION OF MODEL

A spreadsheet model has been developed to provide a basis for internal costing of compressed air in a plant, as well as a method for an outside party to charge for compressed air as a commodity. Both use the same raw data as a basis. However, there are differences in approach. The internal approach is based on developing an after-tax cash flow for all of the out of pocket expenses related to compressing air in the plant. The external approach is based on using a similar but discounted cost structure, and coming up with a simple fixed and variable rate for charging for compressed air. Then the risk of using a simple rate system on the real data is analyzed.

The following steps were done to develop the model:

1. Gather air compressor size, efficiency, maintenance cost and utilization data for a large number of industrial air compressors of the same type.

2. Develop a method to annualize the major variable costs related to compressing air in an industrial air compressor. Then determine an appropriate variable cost per million cubic feet of air.

3. Correlate maintenance costs with age.

mine the fixed costs. To do this, determin[illegible]mine optimum service life and annual equivalent of ip cost, including maintenance and capita[illegible]ital equipment costs.

lop after-tax cash flow for user of compres[illegible]essed air.

lop a pricing strategy for selling compress[illegible]ssed air by the million cubic feet that uses the fixed and variable costs.

lop after-tax cash flow for seller of compre[illegible]ressed air. Test strategy against actual costs and e risk.

ions and analytical approach will be desc[illegible]scribed in each section. A flowchart of the model is in Appendix A.

poor choice of words,

HER & MANIPULATE DATA

A domestic supplier of industrial air co[illegible]compressors, Firm A, offers a "Factory Service" for monitoring and preventive maintenan[illegible]ance of air compressors that it has manufactured. cular class of air compressors, detailed da[illegible]data including size, efficiency, maintenance cost, ation hours data was available for 50 com[illegible]mpressors. These compressors varied in age from ears old, and from 50 to 350 HP in size. [illegible] See Appendix B. It was assumed that sors on factory service would also be mai[illegible]aintained by Firm A for non-routine or breakdowns. rs who expect preventive maintenance wi[illegible]will most likely call have the equipment supplier l maintenance. Therefore, the accumulat[illegible]ated maintenance data logged by Firm A was seen ing the total maintenance cost associate[illegible]ed with those compressors.

In addition to maintenance data, Firm [illegible]m A has running hours and loaded hours data for ressors, giving us the ability to know how[illegible]w much time that the compressor is actually g its full output, how much time running id[illegible]idle (unloaded), and how much shut off.

Finally, Firm A is the manufacturer of t[illegible]of the compressors, so they have accurate capacity, , and utility requirement information for a[illegible]all of the compressors. With all this data, we able to construct a complete picture of c[illegible]compressor ownership cost, less the logistics and ent cost, which is not analyzed of lack of[illegible]of data.

The compressors were in three size ranges, which we call "A", "B", and "C":

COMPRESSOR SIZES									
SIZE	COUNT	AGE		LOADED BHP		ACFM		INITIAL COST	
		AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
A	31	5.5	2.4	68	15	249	62	$ 33,322	$ 3,385
B	10	5.4	2.8	123	21	531	80	$ 54,352	$ 3,767
C	9	7.9	3.4	330	59	1431	247	$ 88,683	$ 7,871

Figure 2. Summary Of Size A, B, &C

The data is not perfect, however. There are definitely some accounting errors in posting costs to service work orders, as well as compressors that might not have all the maintenance done by Firm A. This data is much more accurate than any other source available, particularly through direct questionnaires. There is a strong incentive for Firm A to have accurate cost data, profitability.

2. ANNUALIZE VARIABLE COSTS AND DEVELOP COST PER USAGE

Loaded And Unloaded Percentages

To calculate the input energy and water requirements of the compressors, the percentage of the time running loaded and unloaded is necessary. However, the data includes "run hours" and "loaded hours", and the date when the latest meter readings were taken. With the start-up date, the hour meter read date, and the meter reading, we calculated the percentages as follows:

%LD = Tload/((Tmeter - Tstartup)*24)

%UL = (Trun - Tload)/((Tmeter - Tstartup)*24)

Where

%LD = average percent of time that the compressor is running loaded

%UL = average percent of time that the compressor is running unloaded

Tload = meter reading for loaded time, hours

Trun = meter reading for accumulated run time, hours

Tmeter = date meter is read, Julian days

Tstartup = date compressor is started up, Julian days

This is all summarized in Appendix B also.

Size And Efficiency

The class of air compressors that are being analyzed run in the "load/unload" mode. That is, when they are "loaded" they are producing their full capacity of compressed air output, and when "unloaded" they are not producing any output. The power usage is a step function. When running loaded the compressor requires full load brake horsepower (BHP) plus auxiliary power (cooling fan and oil pump), and it produces full capacity of compressed air in "actual cubic feet" or ACFM. Note that ACFM is output air flow corrected back to inlet conditions, based on the ideal gas law.

When running unloaded these compressors require unloaded BHP plus the same auxiliary power and produce no air. The remainder of the time the compressor is off, with no energy consumption and no output. Energy consumption was calculated in kilowatt-hours (KWH), which is related to BHP by a constant. The utility company charges for electrical consumption by KWH. The calculation is as follows:

KWH/yr = (%LD*(BHPld+BHPaux)+%UL*(BHPul+BHPaux))*365*24*.7457/EFF

and

KWH$/yr = KWH/yr * RATEe

Where

BHPld = BHP loaded

BHPul = BHP unloaded

BHPaux = auxiliary BHP

EFF = motor efficiency (assumed to be the same for main and aux. motors)

RATEe = electrical rate in $/KWH

Both air and water-cooled compressors were in the data. Water consumption for water-cooled compressors is constant while the compressor is running, whether loaded or not. Note that auxiliary BHP is higher for units with no water costs Almost all of this class of compressor are running on chilled water systems, not city water. Based on a limited study at a local high tech company, chilled water were estimated to be $.63/100 cubic feet. This is another TCO calculation actually, but done much more simply. Initial purchase and annual costs were estimated for one system, and then divided by the volume of water cooled per year.

Water$/yr = (%LD + %UL)*GPM*365*24*60/100/7.48*RATEw

Where

RATEw = water rate in $/100 cu.ft.

GPM = water consumption in gallons/minute.

Now that variable costs are calculated on a yearly basis, we attempted to derive a method to determine cost of compressed air per unit of output. For an air compressor, the critical output is compressed air ACFM, defined above. All of the compressors analyzed operated with different utilization rates. We considered them typical rather than forcing them to some arbitrary load percent. This is critical, because %LD is a critical independent variable in the overall cost of ownership. The actual data, which show a relatively low utilization (from 30% to 48%), creates a higher variable cost due to the higher %UL (from 20% to 32%), during which time the air compressor is consuming energy but not producing output. The customers that own this type of high-value air compressor typically have a pair of compressors running "lead-lag", with only one running at a time and the other as backup, then reversing the order. This explains the %LD being under 50%.

In light of this actual data, we calculated the total variable cost (power + water) per million actual cubic feet of air delivered (MACF) per year, which is calculated as follows:

MACF/yr = %LD * ACFM * 365*24*60

Then variable cost per unit of output is as follows:

VAR$/MACF = (KWH$/yr + Water$/yr)/(MACF/yr)

See Appendix C.

User vs. Seller Costs

The user does not have the same cost structure as the seller. The user only owns a few air compressors, and uses a tiny fraction of the utility company's power and water. The seller, presumed to be a division of a de-regulated utility company, will be purchasing a huge number of compressors, contracting a large amount of maintenance, purchasing a high volume of replacement parts, and generating or purchasing a vast amount of water and electricity. This will generate a significant discount due to their volume. We put a "volume factor" in the model to multiply all costs by. So the seller uses the same basic costs as the user, except multiplied by a factor less than one. We used 0.9 for this analysis, but the model lets you change it.

3. CORRELATE MAINTENANCE COSTS WITH AGE

A work order is initiated to capture all labor and material cost for each service call. The maintenance costs in Appendix B are accumulated costs, not yearly costs. The only delineation shown in the data is between planned maintenance (coded "FS" for Factory Service) and non-planned maintenance (all other codes) and between labor, overhead and materials. All costs are actual costs incurred at the time posted. The data only includes costs since the origination of the computer system in July 1991. These costs were added and annualized as follows:

MAINT$/yr = sum(all maint costs)/((Tdata - Tmaint)/365)

Where

MAINT$/yr = all maintenance costs per year
Tdata = date that the data was downloaded, March 31, 1998 in Julian days
Tmaint = either the startup date or July 1, 1991, whichever is later, Julian days

Maintenance costs varied widely from unit to unit. Attempts were made to correlate total yearly maintenance cost with age and percent load. When all of the data was used, the awkward

correlations were low or negative. Several attempts were made to group the compressors and analyze the groups separately. The method that was used was to divide each group of compressors (A, B, and C) into 2 sub-groups, one that maintenance per age is low (group 1) and one where it is high (group 2). The slope ("M") and intercept ("B") were determined for maintenance dollars versus age. When group 1 units were analyzed, they correlated well with age, with a positive slope. Group 2 correlated with negative slopes, all sizes. A least squares calculation was done, and the results are below:

this is unusual, any further exploration or explanation?

MAINTANANCE COST VS. AGE	CORREL	M	B
A, GRP 1	0.305	$ 223	$ 1,285
A, GRP 2	(0.001)	$ (7,056)	$ 22,516
B, GRP 1	0.088	$ 31	$ 2,559
B, GRP 2	(1.000)	$ (9,414)	$ 30,585
C, GRP 1	0.636	$ 1,069	$ (250)
C, GRP 2	(1.000)	$ (46,448)	$ 126,406

Figure 3. Correlation Of Maintenance With Age

To create a more realistic relationship that incorporated both groups, the weighted average of group 2 was added to the calculated value from the least squares analysis of group 1, as a "shift factor". This spread out the high maintenance costs equally over the entire life of the compressor. Note that time value of money is not considered due to the maintenance dollars coming from accumulated costs. It is impossible to know the distribution of maintenance over time for a particular compressor in the data. See Figure 4 for final maintenance costs as a function of age.

See Appendix C for supporting information.

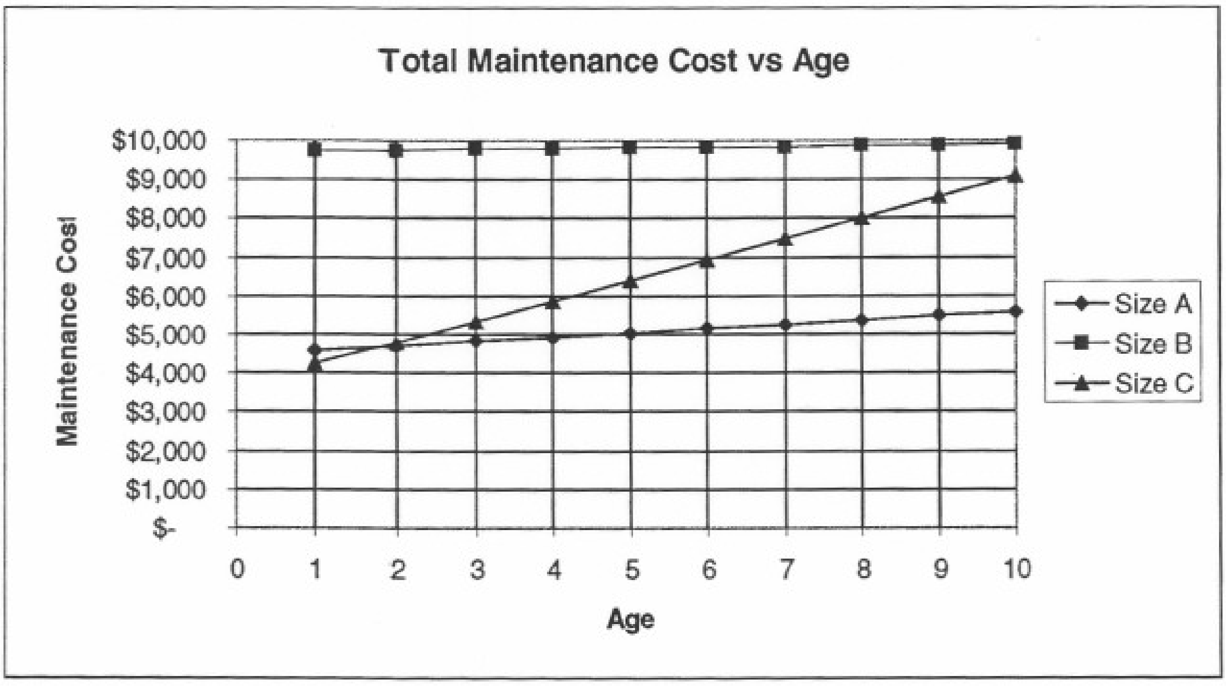


Figure 4. Maintenance Cost Versus Age

4. DETERMINE FIXED COSTS

The fixed costs related to compressing air include initial capital equipment expenditure, installation, and maintenance. Maintenance seems to be a variable cost, but since is directly related to keeping the physical asset running, we used the annual equivalent cost method to determine the yearly after-tax amount that is expended to own the asset.

The methodology starts with calculating the optimum service life, which requires the after tax salvage life calculation first. Then the annualized equivalent purchase plus operation expenses are calculated for all possible holding periods.

Capital Equipment Cost

Initial manufacturing costs were known for all of the compressors in the database, since Firm A was the manufacturer. Based on a typical gross margin, selling price was estimated (+/- 10%). Installation was assumed to be 20% of initial purchase price. This includes all foundation, water, electric, and compressed air piping installation. This became the cost basis for depreciation.

After Tax Salvage Value

The assets were considered 7 year MACRS for depreciation purposes. For all three sizes, book values, salvage values, depreciation, and tax were calculated and used to determine after-tax salvage value for holding periods from 1 to 10 years. Market value in year 1 was estimated at 8% below initial cost, and value in 10 years was estimated to be 1/3 of initial market value, with a straight-line reduction of market value between the two. See Appendix D.

A maximum service life of 10 years was chosen due to business reasons. Although air compressors of this type are often in service for much longer than 10 years, it was considered better to have good-looking and relatively technologically current air compressors in the fleet. Leased equipment should not be obsolete. Also, service parts stocking becomes more expensive as time goes on. This was modeled by the "inflation rate" of maintenance costs. In addition, maintenance data was only available for 7 year. Due to this extrapolating costs past ten years would have introduced too much uncertainty in the analysis.

The market values and after-tax salvage values were used in the service life calculations for each size. Maintenance costs per year came from the correlation between cost and age, discussed above and illustrated in Figure 4. In addition, an overhaul was added. The overhaul costs for sizes A, B, and C were estimated based on maintenance data. Overhaul times were estimated based on the average running hours and average bearing life. This overhaul was brought to present value and back out to an annual equivalent. It was then subtracted from the yearly maintenance in the service calculation and added back in as a lump in the overhaul year.

When all was said and done, the compressors still had service lives over 10 years. The annual equivalent cost was minimum at ten years, and still declining. ~~But since~~ the decision was made to not go over 10 years, the optimum service life stayed at ten years.

but this economic analysis did not account for the intangible but significant "cost" of having older, less impressive, and less reliable equipment on customer premises. Therefore

5. DEVELOP AFTER-TAX CASH FLOW FOR USER OF COMPRESSED AIR

Summary of Costs

An analysis was performed on the cash flow over 10 years from the user's point of view. For all of the actual compressor data points the after tax cash flow was calculated. See Figure 5 for an example of one compressor and Appendix E for all of the compressors. The costs described above were determined for each individual compressor and the average compressor of each size category, A, B, and C. The average tables are below. From this cash flow the average present value and annual equivalent cost was calculated for sizes A, B, and C.

CASH FLOW STATEMENT, SIZE A, USER

tax rate: 40%

YEAR	0	1	2	3	4	5	6	7	8	9	10
FINANCIAL DATA											
DEPRECIATION		$ 5,714	$ 9,793	$ 6,994	$ 4,994	$ 3,571	$ 3,567	$ 3,571	$ 1,783	$ -	$ -
BOOK VALUE		$ 34,272	$ 24,480	$ 17,486	$ 12,492	$ 8,921	$ 5,354	$ 1,783	$ (0)	$ (0)	$ (0)
SALVAGE VALUE											$ 9,197
GAIN FROM SALE											$ 9,197
INCOME STATEMENT											
REVENUES		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
EXPENSES											
COSTS		$ 13,075	$ 13,467	$ 13,871	$ 14,287	$ 14,716	$ 15,158	$ 15,612	$ 16,081	$ 16,563	$ 17,060
DEPRECIATION		$ 5,714	$ 9,793	$ 6,994	$ 4,994	$ 3,571	$ 3,567	$ 3,571	$ 1,783	$ -	$ -
TAXABLE INCOME		$ (18,789)	$ (23,260)	$ (20,865)	$ (19,282)	$ (18,287)	$ (18,724)	$ (19,183)	$ (17,864)	$ (16,563)	$ (17,060)
INCOME TAXES (40%)		$ (7,516)	$ (9,304)	$ (8,346)	$ (7,713)	$ (7,315)	$ (7,490)	$ (7,673)	$ (7,146)	$ (6,625)	$ (6,824)
NET INCOME		$ (11,273)	$ (13,956)	$ (12,519)	$ (11,569)	$ (10,972)	$ (11,235)	$ (11,510)	$ (10,718)	$ (9,938)	$ (10,236)
CASH FLOW STATEMENT											
OPERATING ACTIVITIES											
NET INCOME		$ (11,273)	$ (13,956)	$ (12,519)	$ (11,569)	$ (10,972)	$ (11,235)	$ (11,510)	$ (10,718)	$ (9,938)	$ (10,236)
DEPRECIATION		$ 5,714	$ 9,793	$ 6,994	$ 4,994	$ 3,571	$ 3,567	$ 3,571	$ 1,783	$ -	$ -
INVESTMENT ACTIVITIES	$ (39,986)										
INVESTMENT											
SALVAGE											$ 9,197
GAINS TAXES											$ (3,679)
NET CASH FLOW	$ (39,986)	$ (5,559)	$ (4,163)	$ (5,525)	$ (6,575)	$ (7,401)	$ (7,668)	$ (7,939)	$ (8,935)	$ (9,938)	$ (4,718)

MARR = 15%
PW = $ (72,252)
AE = $ (14,396)

Figure 5A. Cash Flow for Size A, User Perspective

CASH FLOW STATEMENT, SIZE B, USER

tax rate: 40%

YEAR	0	1	2	3	4	5	6	7	8	9	10
FINANCIAL DATA											
DEPRECIATION		$ 9,320	$ 15,973	$ 11,407	$ 8,146	$ 5,824	$ 5,818	$ 5,824	$ 2,909	$ -	$ -
BOOK VALUE		$ 55,902	$ 39,929	$ 28,522	$ 20,375	$ 14,551	$ 8,733	$ 2,909	$ (0)	$ (0)	$ (0)
SALVAGE VALUE											$ 15,001
GAIN FROM SALE											$ 15,001
INCOME STATEMENT											
REVENUES		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
EXPENSES											
COSTS		$ 30,261	$ 31,169	$ 32,104	$ 33,067	$ 34,059	$ 35,081	$ 36,134	$ 37,218	$ 38,334	$ 39,484
DEPRECIATION		$ 9,320	$ 15,973	$ 11,407	$ 8,146	$ 5,824	$ 5,818	$ 5,824	$ 2,909	$ -	$ -
TAXABLE INCOME		$ (39,582)	$ (47,142)	$ (43,512)	$ (41,214)	$ (39,884)	$ (40,899)	$ (41,958)	$ (40,126)	$ (38,334)	$ (39,484)
INCOME TAXES (40%)		$ (15,833)	$ (18,857)	$ (17,405)	$ (16,485)	$ (15,953)	$ (16,360)	$ (16,783)	$ (16,051)	$ (15,334)	$ (15,794)
NET INCOME		$ (23,749)	$ (28,285)	$ (26,107)	$ (24,728)	$ (23,930)	$ (24,539)	$ (25,175)	$ (24,076)	$ (23,000)	$ (23,690)
CASH FLOW STATEMENT											
OPERATING ACTIVITIES											
NET INCOME		$ (23,749)	$ (28,285)	$ (26,107)	$ (24,728)	$ (23,930)	$ (24,539)	$ (25,175)	$ (24,076)	$ (23,000)	$ (23,690)
DEPRECIATION		$ 9,320	$ 15,973	$ 11,407	$ 8,146	$ 5,824	$ 5,818	$ 5,824	$ 2,909	$ -	$ -
INVESTMENT ACTIVITIES	$ (65,222)										
INVESTMENT											
SALVAGE											$ 15,001
GAINS TAXES											$ (6,000)
NET CASH FLOW	$ (65,222)	$ (14,429)	$ (12,312)	$ (14,700)	$ (16,582)	$ (18,106)	$ (18,722)	$ (19,350)	$ (21,167)	$ (23,000)	$ (14,690)

MARR = 15%
PW = $ (147,684)
AE = $ (29,426)

Figure 5B. Cash Flow for Size B, User Perspective

CASH FLOW STATEMENT, SIZE C, USER

tax rate: 40%

YEAR	0	1	2	3	4	5	6	7	8	9	10
FINANCIAL DATA											
DEPRECIATION		$ 15,207	$ 26,062	$ 18,613	$ 13,292	$ 9,503	$ 9,493	$ 9,503	$ 4,746	$ -	$ -
BOOK VALUE		$ 91,212	$ 65,150	$ 46,537	$ 33,245	$ 23,742	$ 14,250	$ 4,746	$ 0	$ 0	$ 0
SALVAGE VALUE											$ 24,476
GAIN FROM SALE											$ 24,476
INCOME STATEMENT											
REVENUES		$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
EXPENSES											
COSTS		$ 52,834	$ 54,419	$ 56,062	$ 57,734	$ 59,466	$ 61,250	$ 63,087	$ 64,980	$ 66,929	$ 68,937
DEPRECIATION		$ 15,207	$ 26,062	$ 18,613	$ 13,292	$ 9,503	$ 9,493	$ 9,503	$ 4,746	$ -	$ -
TAXABLE INCOME		$ (68,042)	$ (80,481)	$ (74,665)	$ (71,025)	$ (68,969)	$ (70,742)	$ (72,590)	$ (69,726)	$ (66,929)	$ (68,937)
INCOME TAXES (40%)		$ (27,217)	$ (32,193)	$ (29,866)	$ (28,410)	$ (27,588)	$ (28,297)	$ (29,036)	$ (27,890)	$ (26,772)	$ (27,575)
NET INCOME		$ (40,825)	$ (48,289)	$ (44,799)	$ (42,615)	$ (41,381)	$ (42,445)	$ (43,554)	$ (41,836)	$ (40,157)	$ (41,362)
CASH FLOW STATEMENT											
OPERATING ACTIVITIES											
NET INCOME		$ (40,825)	$ (48,289)	$ (44,799)	$ (42,615)	$ (41,381)	$ (42,445)	$ (43,554)	$ (41,836)	$ (40,157)	$ (41,362)
DEPRECIATION		$ 15,207	$ 26,062	$ 18,613	$ 13,292	$ 9,503	$ 9,493	$ 9,503	$ 4,746	$ -	$ -
INVESTMENT ACTIVITIES	$ (106,419)										
INVESTMENT											
SALVAGE											$ 24,476
GAINS TAXES											$ (9,791)
NET CASH FLOW	$ (106,419)	$ (25,618)	$ (22,227)	$ (26,186)	$ (29,323)	$ (31,878)	$ (32,953)	$ (34,051)	$ (37,089)	$ (40,157)	$ (26,676)

MARR = 15%

PW = $ (252,516)

AE = $ (50,314)

Figure 5C. Cash Flow for Size C, User Perspective

It is interesting to note that the annualized equivalent cost is a large percentage of the initial purchase price, from 57% for size A to 82% for size C. The reason that the larger compressor has a higher annual cost is because it is putting out proportionally more air per $ initial purchase, and the power costs related to that increased air delivery dominates. Most plant managers probably don't realize how much their air compressor really costs them. If they did, they would be implementing more aggressive energy efficiency and preventive maintenance measures.

6. DEVELOP PRICING STRATEGY

Using the seller's discounted annual equivalent cost and usage based cost, a linear equation was developed to set pricing, based on the compressor size and usage. The fixed portion is an annual payment based on the size range of the compressor (A, B, or C), independent of usage. The variable is based on a metered usage of compressed air. Recall that the cost for the seller is 0.9 times the user's cost. To develop the fixed and variable factors, we applied a "profit" to the annual equivalent cost and the usage-based cost. "Profit" was essentially the difference between the target IRR and the MARR, as described below:

ANNUAL FEE = ANNUAL EQUIV. COST/(1-IRR+MARR)

USAGE FEE = USAGE COST/(1-IRR+MARR)

These fees came from the costs in the actual data. Changes done for sensitivity analysis change costs, but not selling rate.

To test the strategy, the model was used to predict cash flows for all of the compressors in the database, had they been on such a program from the seller's perspective. The present value was then computed (from the point of start-up, looking forward ten years) and IRR. Averages and standard deviations were calculated for the present worth of each size, A, B, and C. Cash flow predictions were developed for all three sizes, which is shown below:

CASH FLOW STATEMENT, SIZE A, SELLER

tax rate: 40%

YEAR	0	1	2	3	4	5	6	7	8	9	10
FINANCIAL DATA											
DEPRECIATION		$ 5,143	$ 8,813	$ 6,294	$ 4,495	$ 3,214	$ 3,210	$ 3,214	$ 1,605	$ -	$ -
BOOK VALUE		$ 30,845	$ 22,032	$ 15,737	$ 11,243	$ 8,029	$ 4,819	$ 1,605	$ (0)	$ (0)	$ (0)
SALVAGE VALUE											$ 9,197
GAIN FROM SALE											$ 9,197
INCOME STATEMENT											
REVENUES		$ 21,601	$ 22,249	$ 22,917	$ 23,604	$ 24,312	$ 25,042	$ 25,793	$ 26,567	$ 27,364	$ 28,185
EXPENSES											
COSTS		$ 11,768	$ 12,121	$ 12,484	$ 12,859	$ 13,244	$ 13,642	$ 14,051	$ 14,473	$ 14,907	$ 15,354
DEPRECIATION		$ 5,143	$ 8,813	$ 6,294	$ 4,495	$ 3,214	$ 3,210	$ 3,214	$ 1,605	$ -	$ -
TAXABLE INCOME		$ 4,691	$ 1,315	$ 4,138	$ 6,251	$ 7,854	$ 8,190	$ 8,528	$ 10,489	$ 12,457	$ 12,831
INCOME TAXES (40%)		$ 1,876	$ 526	$ 1,655	$ 2,500	$ 3,142	$ 3,276	$ 3,411	$ 4,196	$ 4,983	$ 5,132
NET INCOME		$ 2,815	$ 789	$ 2,483	$ 3,750	$ 4,713	$ 4,914	$ 5,117	$ 6,294	$ 7,474	$ 7,698
CASH FLOW STATEMENT											
OPERATING ACTIVITIES											
NET INCOME		$ 2,815	$ 789	$ 2,483	$ 3,750	$ 4,713	$ 4,914	$ 5,117	$ 6,294	$ 7,474	$ 7,698
DEPRECIATION		$ 5,143	$ 8,813	$ 6,294	$ 4,495	$ 3,214	$ 3,210	$ 3,214	$ 1,605	$ -	$ -
INVESTMENT ACTIVITIES	$ (35,988)										
INVESTMENT											
SALVAGE											$ 9,197
GAINS TAXES											$ (3,679)
NET CASH FLOW	$ (35,988)	$ 7,957	$ 9,603	$ 8,777	$ 8,245	$ 7,926	$ 8,124	$ 8,331	$ 7,899	$ 7,474	$ 13,217
MARR =	15%										
PW =	$ 7,237										
AE =	$ 1,442										
IRR=	20%										

Figure 6A. Cash Flow for Size A, Seller Perspective

CASH FLOW STATEMENT, SIZE B, SELLER

tax rate: 40%

YEAR	0	1	2	3	4	5	6	7	8	9	10
FINANCIAL DATA											
DEPRECIATION		$ 8,388	$ 14,376	$ 10,267	$ 7,332	$ 5,242	$ 5,236	$ 5,242	$ 2,618	$ -	$ -
BOOK VALUE		$ 50,312	$ 35,936	$ 25,669	$ 18,338	$ 13,096	$ 7,860	$ 2,618	$ 0	$ 0	$ 0
SALVAGE VALUE											$ 15,001
GAIN FROM SALE											$ 15,001
INCOME STATEMENT											
REVENUES		$ 44,736	$ 46,079	$ 47,461	$ 48,885	$ 50,351	$ 51,862	$ 53,418	$ 55,020	$ 56,671	$ 58,371
EXPENSES											
COSTS		$ 27,235	$ 28,052	$ 28,894	$ 29,761	$ 30,653	$ 31,573	$ 32,520	$ 33,496	$ 34,501	$ 35,536
DEPRECIATION		$ 8,388	$ 14,376	$ 10,267	$ 7,332	$ 5,242	$ 5,236	$ 5,242	$ 2,618	$ -	$ -
TAXABLE INCOME		$ 9,113	$ 3,651	$ 8,301	$ 11,793	$ 14,456	$ 15,053	$ 15,656	$ 18,906	$ 22,170	$ 22,835
INCOME TAXES (40%)		$ 3,645	$ 1,460	$ 3,320	$ 4,717	$ 5,782	$ 6,021	$ 6,262	$ 7,563	$ 8,868	$ 9,134
NET INCOME		$ 5,468	$ 2,190	$ 4,980	$ 7,076	$ 8,674	$ 9,032	$ 9,393	$ 11,344	$ 13,302	$ 13,701
CASH FLOW STATEMENT											
OPERATING ACTIVITIES											
NET INCOME		$ 5,468	$ 2,190	$ 4,980	$ 7,076	$ 8,674	$ 9,032	$ 9,393	$ 11,344	$ 13,302	$ 13,701
DEPRECIATION		$ 8,388	$ 14,376	$ 10,267	$ 7,332	$ 5,242	$ 5,236	$ 5,242	$ 2,618	$ -	$ -
INVESTMENT ACTIVITIES	$ (58,700)										
INVESTMENT											
SALVAGE											$ 15,001
GAINS TAXES											$ (6,000)
NET CASH FLOW	$ (58,700)	$ 13,856	$ 16,566	$ 15,247	$ 14,407	$ 13,915	$ 14,268	$ 14,635	$ 13,962	$ 13,302	$ 22,702
MARR =	15%										
PW =	$ 16,683										
AE =	$ 3,324										
IRR=	22%										

Figure 6B. Cash Flow for Size B, Seller Perspective

CASH FLOW STATEMENT, SIZE C, SELLER

tax rate: 40%

YEAR	0	1	2	3	4	5	6	7	8	9	10
FINANCIAL DATA											
DEPRECIATION		$ 13,687	$ 23,456	$ 16,751	$ 11,963	$ 8,553	$ 8,543	$ 8,553	$ 4,272	$ -	$ -
BOOK VALUE		$ 82,091	$ 58,635	$ 41,883	$ 29,921	$ 21,368	$ 12,825	$ 4,272	$ 0	$ 0	$ 0
SALVAGE VALUE											$ 24,476
GAIN FROM SALE											$ 24,476
INCOME STATEMENT											
REVENUES		$ 74,316	$ 76,546	$ 78,842	$ 81,207	$ 83,644	$ 86,153	$ 88,737	$ 91,400	$ 94,142	$ 96,966
EXPENSES											
COSTS		$ 47,551	$ 48,977	$ 50,447	$ 51,960	$ 53,519	$ 55,125	$ 56,778	$ 58,482	$ 60,236	$ 62,043
DEPRECIATION		$ 13,687	$ 23,456	$ 16,751	$ 11,963	$ 8,553	$ 8,543	$ 8,553	$ 4,272	$ -	$ -
TAXABLE INCOME		$ 13,079	$ 4,112	$ 11,644	$ 17,285	$ 21,572	$ 22,485	$ 23,406	$ 28,646	$ 33,905	$ 34,923
INCOME TAXES (40%)		$ 5,231	$ 1,645	$ 4,658	$ 6,914	$ 8,629	$ 8,994	$ 9,362	$ 11,458	$ 13,562	$ 13,969
NET INCOME		$ 7,847	$ 2,467	$ 6,986	$ 10,371	$ 12,943	$ 13,491	$ 14,044	$ 17,188	$ 20,343	$ 20,954
CASH FLOW STATEMENT											
OPERATING ACTIVITIES											
NET INCOME		$ 7,847	$ 2,467	$ 6,986	$ 10,371	$ 12,943	$ 13,491	$ 14,044	$ 17,188	$ 20,343	$ 20,954
DEPRECIATION		$ 13,687	$ 23,456	$ 16,751	$ 11,963	$ 8,553	$ 8,543	$ 8,553	$ 4,272	$ -	$ -
INVESTMENT ACTIVITIES	$ (95,777)										
INVESTMENT											
SALVAGE											$ 24,476
GAINS TAXES											$ (9,791)
NET CASH FLOW	$ (95,777)	$ 21,534	$ 25,923	$ 23,738	$ 22,333	$ 21,496	$ 22,034	$ 22,597	$ 21,459	$ 20,343	$ 35,639

MARR =	15%
PW =	$ 21,242
AE =	$ 4,233
IRR=	21%

Figure 6C. Cash Flow for Size C, Seller Perspective

The standard deviation for each compressor's present value was considered the same as that of the group of compressors in that size. Then we calculated the "risk" associated with the pricing strategy. This is the probability that the IRR for that compressor would drop below the MARR.

The model tracked well with the real data. When a target IRR of 30% and a volume discount factor of 90% , the average IRR was 21%. Size A had a lower IRR and a higher probability of going below the MARR. Risk was higher in the smaller size range due to a higher variance of maintenance costs in the database, and the relatively large proportion of costs that were maintenance costs. Size C was the most profitable and least risky, due to the smaller proportion and variance of maintenance costs. Size B was in the middle. See Figure 7.

	AVG OF PW	AVG OF STDEV	IRR	PROB OF GOING BELOW MARR
ALL SIZES	$ 11,647		21%	
SIZE A	$ 7,237	$ 19,213	20%	35%
SIZE B	$ 16,683	$ 20,538	22%	21%
SIZE C	$ 21,242	$ 21,071	21%	16%

Figure 7. Risk of selling strategy

Based on the discount factor of 90% and a target IRR of 30%, the pricing model allowed the seller to offer the compressed air to the user at an annualized cost about 12% less than they would have incurred on their own, while still providing the seller with a MARR of 21%, or a "profit" of 6% over the MARR. This assumes that the seller had a family of compressors being leased that was identical to the sample in the database. Figure 8 shows that it is a better deal for the user to pay Firm A for the compressed air as a utility, given the database of compressors available. The annualized cost to the user is higher than the annualized fee to the seller for the same amount of compressed air. See Figure 8.

	AE OF COSTS	AE OF PAYMENT
ALL SIZES	$ (23,868)	$ 21,014
SIZE A	$ (14,396)	$ 12,709
SIZE B	$ (29,426)	$ 26,321
SIZE C	$ (50,314)	$ 43,724

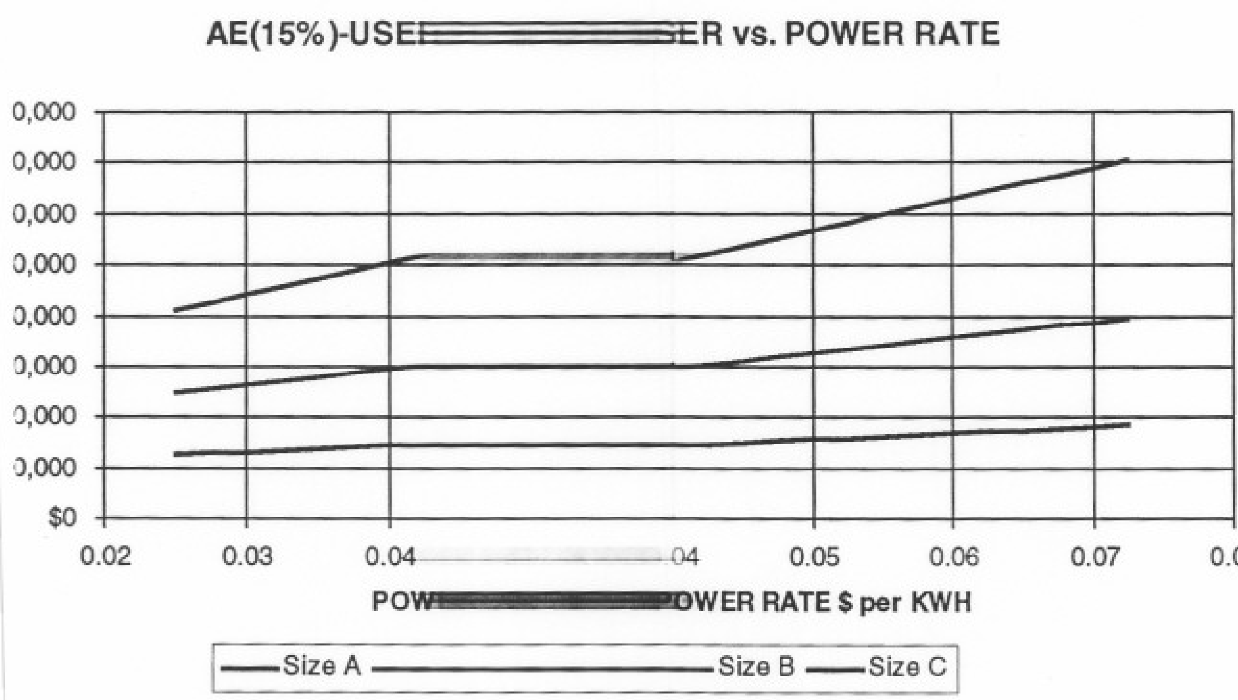
Figure 8. Comparison Between User's Internal Cost And Paying Seller

y Analysis

The major inputs to the mode[redacted]del that make the most difference in the cost of ownership r rate, percent load (%LD), mainte[redacted]aintenance costs. The major output for the user is annual t cost. The major output for the [redacted]e seller is IRR.

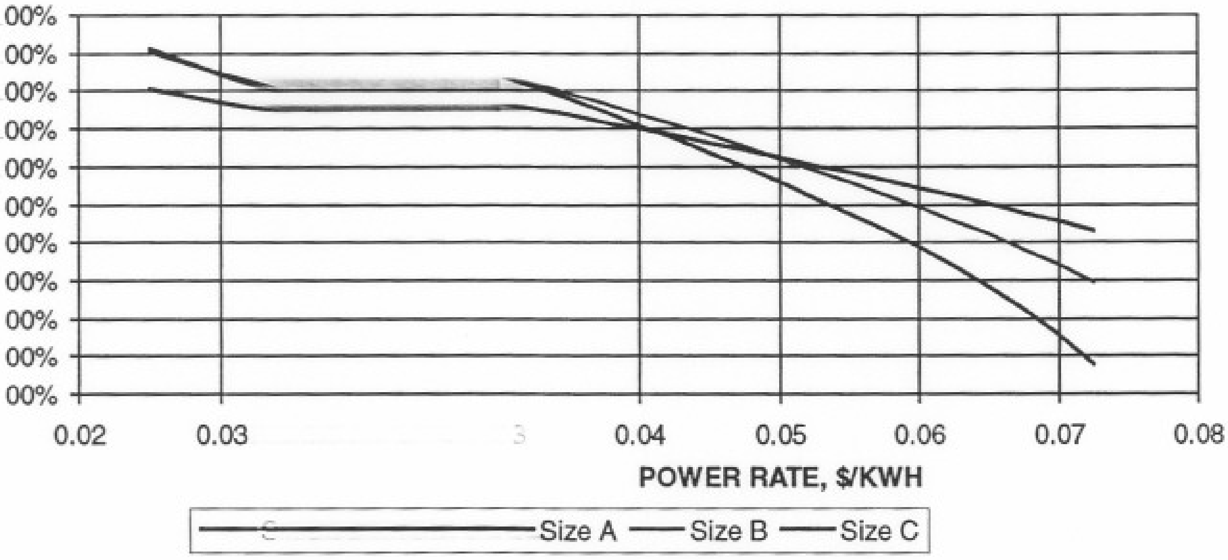
ate:

Higher power rates will increas[redacted]ease costs and reduce the seller's profitability, since the e is fixed for a geographical area[redacted]rea and a period of time. If the power rate changes during the seller incurs a higher cost du[redacted]due to the large percentage that power costs are. That in ases the annual equivalent cost a[redacted]st and reduces the seller's profitability and IRR. See and 10. Both figures show that s[redacted]at size A is the least sensitive to power rate changes, with next sensitive, and size C the m[redacted] most. This makes sense, due to the larger proportion of ng into electrical energy as the co[redacted]compressor gets larger. See Figure 11 for proportion of ll three sizes.



Annual Equivalent Cost for Us[redacted]User Versus Power Cost

IRR[illegible]R- SELLER vs. POWER RATE



). IRR for Seller Ver[illegible]versus Power Cost

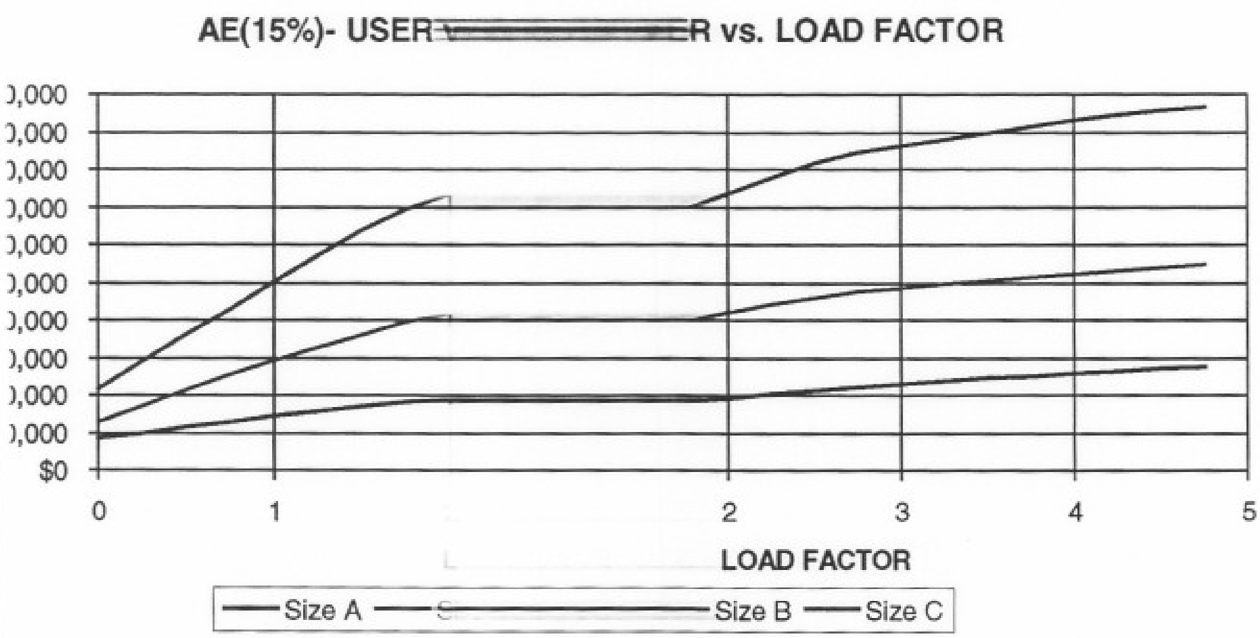
	% POWER COSTS	[illegible]R	% WATER COSTS	% MAINT COSTS	POWER/ MAINT
SIZES	56%		9%	26%	2.15
E A	50%		8%	29%	1.70
E B	64%		10%	27%	2.39
E C	70%		12%	15%	4.72

. Cost Proportions[illegible]ns

tor: It is theorized th[illegible]that higher load percentages are better, due to better utilization of a t. The air compress[illegible]ssors in the database were operated from 2% to 100% loaded, distributed. A "load f[illegible]d factor" was applied to the loaded percentages for all of the ors to linearly amplify[illegible]plify the loaded percent. So if a compressor was operating at 30% oaded, and the load f[illegible]d factor is increased to 2.0, it goes to 60% loaded. If the compressor dy at 60%, it would o[illegible]only go to 100%. The unloaded percentages stay the same until the load percentage plus[illegible]plus existing unloaded % adds to 100%. Then the unloaded % is d to maintain a constant sum of 100%. The MACF, power cost, and water cost are all ally updated when the load percentage changes.

Air compressors that are running loaded longer should have higher maintenance. The umb for rotating machinery is that bearing life is related to hours of rotation at a particular wever, the data we had did not show a correlation between load percentage and nce costs. It would take more measurement under more controlled circumstances to the actual correlation. For the sake of this analysis, we will assume a one-to-one n. That is, when the load percentage for a compressor is doubled, the maintenance costs e. The model can accommodate any correlation factor for future analysis.

When the user's costs are analyzed, size A is the least sensitive to load factor, while B nd C is the most sensitive. See Figure 12. As discussed above, power costs are the roportion of costs, with that percentage increasing as the size increases. This would e increasing overall costs as load percentage increases. If power and maintenance costs same percentages for all three sizes, the slopes would be equal.



. **Annual Equivalent Cost for User Versus Load Factor**

When the seller's IRR is analyzed, the rankings in the linear range are different than ıkings. Then they peak at different points. In the relatively linear range of load factors 2.0, the sensitivity rankings change. Size B is the least sensitive, followed by A, and then C as the most sensitive. Then all three sizes peak and start decreasing. B peaks first at an IRR of 26.2% at a load factor of about 2.25. Then C peaks at 34.9% at a load factor of about 3.0. Finally, A peaks at 28.3% at a load factor of about 3.5. See Figure 13. It is not clear why they have a different ranking and peak at different points. Possibly the linkage between load factor and maintenance costs (one-to-one in the output presented here), causes size A to be more sensitive than size B. Size A has a lower power/maintenance cost ratio (higher maintenance/power ratio) than the size B. This ratio might dominate rather than the power/total cost ratio that drives most of the analysis.

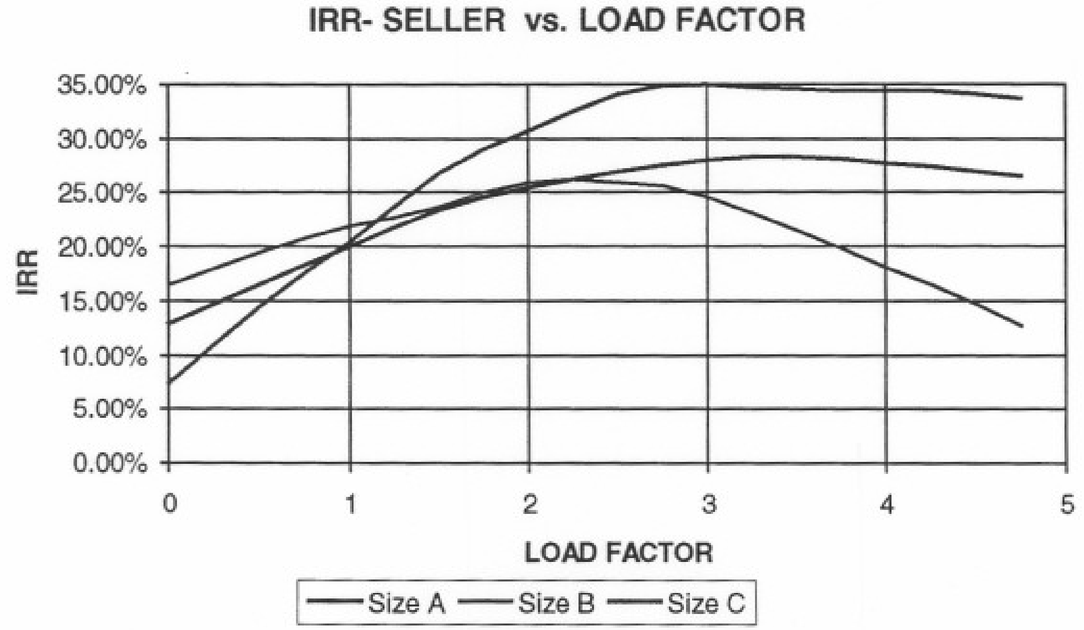


Figure 13. IRR for Seller Versus Load Factor

CONCLUSION

This analysis has shown that compressed air cost is primarily dominated by electrical power usage, and then influenced fairly strongly by maintenance costs. The dominance of power costs makes the cost of compressed air from larger compressors more sensitive to load factor and power cost than smaller compressors. Maintenance costs are seen to be somewhat related to age of the compressor. However, they do not drive the analysis in the big picture. The optimum service life of this type of compressor is greater than the time that most operators would want the compressor in service.

From a business perspective, this analysis shows that there is validity to the concept of selling compressed air as a commodity. If the right maintenance and monitoring infrastructure is in place, a utility company can take advantage of their economies of scale and sell compressed air to a user at a lower cost than the user incurs, and make a good profit. However, only a large company with adequate cash resources, like a utility company, could pull it off. Also, a utility company would be able to meter the power, air, and compressed air usage, and provide one simple bill to the user. They would never have to worry about the compressor again.

From an user perspective, this analysis can be used to measure actual costs absorbed in the usage of compressed air in a particular process. Since compressed air is a significant manufacturing cost, and there are vast dissimilarities in compressed air consumption from one process to another, this analysis could provide input to an Activity Based Costing (ABC) system to distribute the compressed air cost to the processes using it.

RECOMMENDATIONS

The unit cost of compressed air ($/MACF) needs to be investigated more. How sensitive is it to load factor and power costs, or other variables? How can it be incorporated into an ABC system? Also, the practical implications of building a business to sell compressed air by the cubic foot need to be investigated. What kind of business infrastructure, technological infrastructure, financial systems, and operating procedures would be needed? Would the overhead of such a business wipe out the potential profits? Would typical users want to buy air by the cubic foot even if it's cost effective? Would there be regulatory problems for the utility to do this? Are there other financial risks that we haven't evaluated in the model? There is much fruit here for future papers!

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