Compressed Air Systems Evaluation and Improvement

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Executive Summary

This project was centered on recommending a new air compressor system for the Fluid System Connectors division of Parker Hannifin in Otsego, Michigan. The recommended compressor for the plant is a 250hp variable speed drive Ingersoll Rand Compressor. It is recommended that this compressor, along with two 35hp compressors already purchased by Parker be tied together using an automated system. In addition to the compressor, a flow controller was recommended to be implemented into the system.

Given that leaks are also a problem in the system, it is recommended that the majority of air leaks in the system be fixed and maintained. These solutions, combined will have a payback period of 1 year and 4 months.

In addition to these recommendations, an AutoCAD layout of the main compressor room was created for Parker. A corresponding machine sheet providing details on the machines in the compressor room was also created to ease maintenance by reducing the amount of time it takes to locate and identify the machine being maintenance.
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Introduction

Problem Statement

Energy consumption due to compressed air production is extremely high in the Parker Hannifin plant in Otsego, Michigan. As shown in the pie chart below, compressed air is costing the company $152,649 annually.

![Figure 1. Compressed Air Electrical Consumption](image)

The compressed air system accounts for almost 28% of the plants annual electric bill, something that Parker desired to reduce. In addition to the high energy usage, the room where the compressor is housed is dirty, disorganized and poorly lit. Machine specifications were not known. Due to the lack of knowledge of what was in the compressed air system, along with the fact that the room itself is cramped and cluttered made maintenance difficult.

Parker’s main goal for the project is to replace the main compressor system to reduce its energy cost, and convert the old main compressor into the back-up.
Significance

Parker Hannifin requested several deliverables from the team throughout the duration of the project.

1. Layout of the main compressor room
   a. Parker requested that an AutoCAD diagram be created for an easy visual diagram of what is being housed in the compressor room.
   b. In addition, it was requested that the specification of each machine in the room be tracked down, either by contact with the manufacturer or via an internet search.

2. System analysis: a full quantification of the air flow demand of the system, and what certain factors influence air flow demand. These factors can include leaks, as well as production levels.

3. Growth capacity: How much room is provided for growth with the current compressed air system, as well as the recommended replacements?

4. Three quotes from air compressor dealers: These are necessary for Parker’s approval of funds for a given project. These quotes will be from outside vendors, and will be compiled by the team.

5. The team’s recommendation for replacement: this recommendation will be based off air flow data from Parker’s Scout sensor system. Being the focus of the project, this recommendation includes a facilities layout and capital budgeting analysis.

Background

In the plant, there are two main air compressors; a main unit and a backup unit. The main compressor is a Sullair 300hp dual stage steady state air compressor. This compressor runs during all three shifts, 7 days per week. It is the primary source for all machines and
workstations in the plant that require compressed air. Due to the seemingly large demand for compressed air, this air compressor is constantly running, and thus is costing the company a large amount of money. It is estimated that this compressor costs around $150,000 to run each year.

The backup compressor is an Ingersoll piston compressor. This compressor is quite old, as it was built in 1969. Nothing on this machine is automated, and so everything must be turned on manually. When the Sullair compressor broke down this past summer, the Ingersoll was employed to keep the plant running. However, the cooling system was not turned on, and thus the machine overheated and turned off within minutes. The plant was without compressed air and a rental compressor had to be brought in to run the plant at a large cost.

The machines in the compressor room have been primarily painted blue, to give the room a uniform look. The machine tags were painted over, and thus there was no solid consensus about the machinery in the air compressor room. Since it is unclear what is in the room, it makes maintenance difficult, and gives the room an unorganized feeling. Machine specifications are necessary for recommending a new compressor system. This is due to the fact that the recommended compressor should be compatible with the current system, and also not overwhelm the capabilities of the current system.

**Methodology**

**First Steps**
The project began at a meeting with Anil Verma, who would become the industrial sponsor of the project. Anil is a manufacturing engineer, and the division’s energy savings leader. The meeting took place at the Parker Hannifin plant in Otsego, Michigan. This plant is part of the
Fluid System Connectors Division, responsible for machining and assembling fittings for applications ranging from transportation to healthcare. Compressed air is a primary method of powering the machines necessary for manufacturing each fitting. During the meeting, Anil walked the team through some of the problems the plant faces with compressed air. Problems ranged from an unorganized compressor room, to unknown compressed air demands, to aging equipment. These problems interested the team, and thus the project to improve Parker’s compressed air systems began.

During the second meeting with Anil, the discussion centered on how to make this project successful. From the industrial side, Anil asked several things of the team. Over time, it was realized that there was more to do than could be accomplished in the time allotted for this project. The scope of the project was narrowed down to the following items:

1. An organized AutoCAD layout of the compressor room and accompanying specifications for the equipment contained within.
2. A detailed statistical analysis of the compressed air demands of the current system.
3. To acquire three quotes from outside vendors for a new air compressor.
4. The team’s recommendation for air compressor replacement

The plan for accomplishing the above tasks, as well as other milestones for the project, can be seen on the Gantt chart below with their projected start and finish dates.
Figure 2. Gantt chart

After getting started on the above list, the team realized that they had a lack of knowledge about compressed air and the related equipment. To gain knowledge, the team attended various classes and webinars which taught the basics of compressed air. The first opportunity presented to the team was to take the Compressed Air Challenge. The Compressed Air Challenge is a certification program that educates employees of manufacturing facilities on the costs of compressed air, as well as the basics on how the system works. One of the team members completed the course, and became level 1 certified in compressed air. The second learning opportunity took the form of a webinar, which described the process in depth of how to size a compressor for a system. This webinar was very helpful for the team, given the fact that sizing a compressor is in fact the end goal.

Initial Layout of the Compressor Room

After the educational phase was complete, the team then started poking around the compressor room. The overall dimensions of the room were noted on the first visit. Due to time constraints,
very rough layout was drawn by hand, and then transformed into a rough AutoCAD diagram. During the next visit to the compressor room, the team carefully measured and catalogued each piece of equipment in the room. The footprint of each machine was recorded, along with the description of the machine, and if the machine was required to stay in the room. The AutoCAD diagram was updated based off of these more careful measurements.

Layers were created in the drawing to distinguish between what equipment was being stored there, and what equipment was essential to the room and could not be removed. It was difficult to clearly and effectively show the dimensions and specifications of each piece of machinery in the AutoCAD diagram. Additionally, the technicians who would be referencing the diagram would not have AutoCAD, and thus this file would be useless.

Due to these two constraints, an excel spreadsheet was developed to pair with the layout created. Each machine was given a number, and that corresponding number appeared on the AutoCAD layout. Along with the diagram number, the sheet also gave the description of the object and its footprint. If a machine had a Parker Hannifin assigned machine number, this was also recorded, along with the manufacturer of the machine. Some other specifications also noted were that of the output/capacity of the machine, and the power requirements.

Both sheets would then be printed out and hung next to each other in the compressor room. Combined, these two sheets would help maintenance locate the desired equipment in the room, as well as any additional information necessary for maintenance.

This excel sheet also detailed whether the equipment could be removed from the room, or if it needed to stay. From this, a new AutoCAD diagram was created, with only the necessary equipment shown in the room.
It was desired to know how much of the room had in fact been cleaned out, so the excel sheet was once again employed. The total square footage of the original layout shown in the first AutoCAD file was 511.71 sq ft. The unnecessary equipment took up 360.48 sq. feet of that space, so once it was removed, there was only 151.24 sq. feet being used in the room. This amounted to an additional 70.45% of footprint space being open in this room.

External Quotes
Throughout the duration of the project, the team played host to various air compressor vendors to conduct air audits. These vendors came into Parker and hooked up data loggers to the main compressor. These loggers recorded the amount of power pulled by the compressor for a minimum of a week. From there, the vendors used an industry standard linear relationship between power consumed and air produced to recommend the appropriate sized compressor. The vendors each then recommended the size and type of compressor that would meet the requirements of a system. Each vendor also performed a capital budgeting analysis on the proposed compressor. A payback period was determined based on the necessary investment and the amount of annual energy savings would be incurred.

The three quotes that the team received were from TMI Compressed Air Systems, Air Technologies, and Ingersoll Rand. These three companies measured air demand in the same way, using the data logger method. Once all three quotes were received, they were compiled and compared. At this point it was realized that the quotes differed by so much the independent analysis needed to be performed.
Leak Analysis
Given that there was a large difference between the quotes, independent data analysis was performed by the team. Before data analysis could begin, leaks in the system had to be accounted for. Based on an initial estimation in the fall, about 40% of the compressed air in the system was being lost due to leaks. This equates to about 426 SCFM of air, where SCFM is standard cubic feet per minute. Air leaks are extremely costly: even a small hole in a compressed air system can lead to large capital losses for a company. The graph below shows various air leak sizes and the cost of not fixing them.

![Cost of Leaks in a Compressed Air System](image)

**Figure 3. Cost of Leaks in a Compressed Air System**

As shown on the above graph, as the leak size increases, the cost of the leak increases at an exponential rate. It is important to note that the data from this graph assumes that the leak holes are from perfectly round air leaks.
The reason that compressed air costs as much as it does is due to the high electrical costs of compressed air productions. In a typical system, compressed air costs around $0.22-$0.40 per 1,000 cubic feet of air. The reason that the cost of compressed air is given in a range is due to the fact that the production of the compressed air costs different amounts depending on what kind of air compressor is being employed (rotary screw, reciprocating piston or centrifugal), as well as various environmental factors such as the temperature, air pressure and elevation.

Given the high cost of compressed air, and the fact that leaks were running rampant in the system, it was decided that leaks should be fixed. To fix these leaks, an ultrasonic gun was used to identify where the leaks were located, and which leaks were the largest. After the leaks were identified, a maintenance worker slowly fixed the leaks in the system, one at a time, starting in January.

After cross referencing the work logs from this maintenance worker, as well as using Scout Sensor analysis, the current estimated air loss of the system is about 20% of demand; right around 256 SCFM. The leaks were reduced up to this point by about 50%, but there is a long way to go.

To put a number on how much the leaks were costing Parker each year, the following estimates were used.

<table>
<thead>
<tr>
<th>BHP</th>
<th>320</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOURS OF OPERATION</td>
<td>8520</td>
</tr>
<tr>
<td>ELECTRICITY RATE ($/kWh)</td>
<td>$ 0.08</td>
</tr>
<tr>
<td>KW/hp</td>
<td>0.746</td>
</tr>
<tr>
<td>MOTOR EFFICIENCY FULL LOAD</td>
<td>95%</td>
</tr>
<tr>
<td>MOTOR EFFICIENCY UNLOADED</td>
<td>75%</td>
</tr>
<tr>
<td>FULL LOAD POWER DRAW</td>
<td>100%</td>
</tr>
<tr>
<td>UNLOADED POWER DRAW</td>
<td>25%</td>
</tr>
</tbody>
</table>

Table 1. Input Parameters for Energy Estimate Equation
The above table shows the BHP, which is the horsepower of the system, and the yearly hours of operation. When it is denoted that the machine is loaded, it means that the machine is producing air. When the machine is unloaded, it means that the machine is not producing air. Then, the energy estimates for each state of the machine were calculated using the following equation.

$$\text{ENERGY ESTIMATES} = \frac{(BHP) \times (\frac{KW}{HP}) \times (% \text{ FULL LOAD BHP}) \times (% \text{ TIME}) \times (HOURS) \times (RATE)}{\text{MOTOR EFFICIENCY}}$$

This equation was used in excel to calculate the cost of the current energy being used in the system right now. It was estimated that the compressor is loaded about 90% of the time, and unloaded 10% of the time. The costs, generated using the energy estimates equation are shown below in the table.

<table>
<thead>
<tr>
<th>CURRENT ENERGY COSTS</th>
<th>90% LOADED</th>
<th>$ 154,147.79</th>
</tr>
</thead>
<tbody>
<tr>
<td>10% UNLOADED</td>
<td>$ 5,423.72</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$ 159,571.50</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Current Energy Costs before Fixing Leaks

As shown, the total cost of the system in its current state is just under $160,000. After fixing the air leaks from 20%, down to about 5% of the air leaks, the compressor will load less frequently, leading to savings as shown below.

<table>
<thead>
<tr>
<th>PROPOSED ENERGY COSTS</th>
<th>65% LOADED</th>
<th>$ 111,328.96</th>
</tr>
</thead>
<tbody>
<tr>
<td>35% UNLOADED</td>
<td>$ 18,983.01</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$ 130,311.97</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Proposed Energy Costs After Fixing Leaks

As shown, the total cost after fixing the leaks is estimated to be that of $130,311.97. Performing this maintenance on the system would result in an energy savings of $29,259.53, annually.
Data Analysis

After quantifying the air leaks and their burden on the system, the analysis of air demand could begin. To do this, the team was given access to Parker’s scout sensor system. This system is implemented directly into the compressed air lines and measures the air flow that passes over a pedotube attached to the sensor. This air flow is measured, logged and stored in an online server. The initial data that was given to the team was in nine-hour chunks. The data that was pulled yielded the following information: max flow, average flow and min flow. Over each nine-hour chunk, the average air flow was calculated by the system, as well as the max and min value. While this data was helpful in showing long term compressed air usage, it was unclear what state the system was in during the shifts.

To fill in the knowledge gap, data over ten-minute intervals was pulled for analysis. A total of 4,500 data points were pulled; plenty of data for analysis. The first method of analysis that was employed was to see if there were differences between demands of compressed air between shifts. To do this, the data was separated in Excel by shift. Then, ANOVA was run on the data in Minitab, and the following output was gained:

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>2</td>
<td>51375</td>
<td>25687</td>
<td>16.13</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>2244</td>
<td>3573387</td>
<td>1592</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2246</td>
<td>3624762</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4. ANOVA Output for Shifts

When looking at the p-value of the output it is given as a zero in Minitab. When P<α, the null is rejected. In this case, the null is that the mean air demand is equal for each shift. From this test, it
was realized that there was a difference between shifts, and thus a Tukey test was run to find out where those differences lay.

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-15</td>
<td>749</td>
<td>549.08</td>
<td>A</td>
</tr>
<tr>
<td>23-7</td>
<td>749</td>
<td>539.31</td>
<td>B</td>
</tr>
<tr>
<td>15-23</td>
<td>749</td>
<td>538.59</td>
<td>B</td>
</tr>
</tbody>
</table>

*Means that do not share a letter are significantly different.*

Figure 5. Tukey Test Output

From the Tukey test, it was seen that the demand for first shift was significantly different from that of second and third shift. Looking at the difference between the means of shifts, there is only a small difference, but nonetheless there is a difference.

At this point, the team sat down with Anil, and talked over the data. He suggested that the difference, although small, was due to the utilization of the tool room (room where specialized parts are made) during first shift only. This increase in workers could be the cause for the increase in air demand.

Given that the difference between shifts was so small, this difference was discarded. One of the main problems that the team encountered when trying to interpret the data is the random jumps as shown below.
Figure 6. Air Demand

Given that there is a clear low from February 25th-March 25th, and high demand times on either side of that, the team wanted to find an explanation for why the air demand shifted as much as it did. Additional data was pulled from Parker’s system that detailed production hours, and the team hoped to correlate the production hours with the air demand. Data for daily production was pulled from January 1st-April 5th. Given that the production data was in a daily format, the airflow demand was averaged over the length of the day to get the data into like time frames.

After the data was transformed, regression was run on the two sets of data using Excel. The output is shown below.
Figure 7. Regression Output for Production and Air Demand Data

It is clear to see that this is not a good regression model, as the R-squared value is 0.036. This means that only 3.6% of the error in the regression model could be explained by this regression.

Given that this regression is so poor, and there were no other feasible input data options, the data was then plotted in a histogram.
As it can be seen from this graph, the data is bimodal, meaning that there are two distinct peaks in the data. The data was broken down into high and low demand events. High demand events range from 650-1,100 SCFM, and low demand events ranges from 450-650 SCFM. The system is in high demand for 70% of the data analysis window, and high demand for the remaining time. Using this information, a compressor system was recommended to meet these event requirements.

Facilities Layout Analysis
A final portion of the project that needed to be accomplished was that of the facilities layout analysis. In terms of implementation, Parker requested that the new main system be installed and fully operation before the old back-up system is removed.
The first step of the facilities layout analysis was the creation of a relationship chart between the pertinent machines. This chart is shown below.

As seen above, some of the objects were not in fact machines, but rather were objects/locations. It is important to note that the cement pad is the large cement area that is ringed by drainage canals. The air dryer is the one that is above the Sullair Compressor, and the Ingersoll Rand is the old backup compressor. The main thing that this relationship chart shows is where the new compressor should be put: ideally, near the air tanks, but not near the bay door, the cement pad of the Ingersoll rand. From this relationship chart, a from-to chart was formed based on the parameters shown in the chart above the from-to chart.

<table>
<thead>
<tr>
<th></th>
<th>Sullair</th>
<th>Air Dryer</th>
<th>Air Tanks</th>
<th>Ingersoll Rand</th>
<th>New Compressor</th>
<th>Cement Pad</th>
<th>Bay Door</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sullair</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Dryer</td>
<td>O</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Tanks</td>
<td>I</td>
<td>O</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ingersoll Rand</td>
<td>O</td>
<td>O</td>
<td>U</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Compressor</td>
<td>U</td>
<td>O</td>
<td>E</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement Pad</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>U</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Bay door</td>
<td>X</td>
<td>X</td>
<td>U</td>
<td>X</td>
<td>A</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Relationship Chart for Compressor Room

<table>
<thead>
<tr>
<th>Letter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
</tr>
<tr>
<td>O</td>
<td>2</td>
</tr>
<tr>
<td>U</td>
<td>1</td>
</tr>
<tr>
<td>X</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5. From-To Chart Values
This from-to chart shown above, was then input into VIP plan opt to find the optimal layout based on the given constraints. To give the room a realistic feel, all pieces of machinery that would not move in real life did not move during the optimization. This meant that every object was anchored except for that of the new compressor. The following table shows the key to identifying objects in the VIP optimization.

<table>
<thead>
<tr>
<th>Number</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sullair</td>
</tr>
<tr>
<td>2</td>
<td>Air Dryer</td>
</tr>
<tr>
<td>3</td>
<td>Air Tanks</td>
</tr>
<tr>
<td>4</td>
<td>Ingersoll Rand</td>
</tr>
<tr>
<td>5</td>
<td>New Compressor</td>
</tr>
<tr>
<td>6</td>
<td>Cement Pad</td>
</tr>
<tr>
<td>7</td>
<td>Bay door</td>
</tr>
</tbody>
</table>

The size of each object was input into VIP in inches. Then, each object was anchored in it’s true location based on the real layout. After plugging in the from-to chart into VIP as flow data, the following output was realized.
As shown, the new compressor, in block number five, is located to the left of the cement pad, and next to the air tank. Further discussion of implementation will take place in the results section.

**Constraints**

Overall this project did not provide too many constraints. Obviously, budget of the project is always of concern when it comes to the implementation of a new machine. This recommendation is under the constraint of time in the effect that the only data that could be pulled for analysis was from February 19th to the present time. If more data was available, it is possible that a different recommendation would be given.

One additional constraint is that during implementation, the new compressor must be fully installed before the old compressor can be removed. This did limit where the new compressor could be located.
Results
The results of this project will be organized into three sections according to the requests Parker stated at the initiation of the project:

1) The Machine Sheet/AutoCAD Diagram of the compressor room
2) The quotes received from vendors
3) Analysis of the flow data gathered from the scout sensors.

Machine Sheet/AutoCAD Diagram
For item number one, recording the equipment in the compressor room yielded a total of 32 unique items. The current floor plan for these items is shown below:

![AutoCAD Current State AutoCAD Layout](image)

Figure 10. AutoCAD Current State AutoCAD Layout
The cumulative footprint of the equipment housed in the compressor room amounts to almost 512 square feet. All equipment that was either unrelated to compressed air or had outlived its useful life, were identified and classified as “non-essential”. These non-essential equipment
items consumed about 360 square feet of the cumulative footprint. Clearing all of these items out of the compressor room would result in around 70% more free space and would resemble the diagram shown below:

![Figure 11. Proposed AutoCAD Layout](image)

The numbers on the AutoCAD diagrams correspond to the machine sheet shown below.

<table>
<thead>
<tr>
<th>Diagram #</th>
<th>Description</th>
<th>Length (*)</th>
<th>Width (*)</th>
<th>Area (ft^2)</th>
<th>Machine Number</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ingersoll Rand Compressor</td>
<td>119</td>
<td>73</td>
<td>603.257</td>
<td>300 XLE</td>
<td>Ingersoll Rand</td>
</tr>
<tr>
<td>2</td>
<td>Lockers beneath Air Exchange</td>
<td>156</td>
<td>102</td>
<td>110.5</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>DI Water (Four of These)</td>
<td>42</td>
<td>31</td>
<td>9.041666667</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>DI Water Control Pump</td>
<td>60</td>
<td>36</td>
<td>15</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>Electrical Panel</td>
<td>42</td>
<td>31</td>
<td>9.041666667</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

**Table 7. Machine Sheet**

This machine sheet will be hung in the compressor room in accordance with the AutoCAD diagram to ensure clarity in maintenance.
Additionally, the machines were labeled using a bright orange label maker. They were numbered as shown in the picture below.

![Figure 12. Atlas Copco Air Filter Label](image)

Each machine that was staying in the room, or was permanently affixed to the floor were labeled. Items such as the laundry cart, and clothes rack were not labeled.

**Air Vendor Quotes**

For the second request, contact was made with three separate air compressor vendors. These vendors were hosted at the Parker facility for the purpose of gaining their recommendation on a new air compressor. The visits from all three vendors followed the same pattern. They came into the plant, installed data loggers on the Sullair, recorded the energy usage for the Sullair for a
week, compiled a report and then came back to consult on their findings. The recommendations from each air vendor is as follows:

- **TMI:** 300 HP Steady State Sullair
- **Air Technologies:** 200 HP VSD Atlas-Copco
- **Ingersoll-Rand:** 300 HP VSD Ingersoll-Rand

The energy savings claimed by each of the above vendors is summarized in the below graph:

![Figure 13. Energy Savings per Year for Each Vendor](image)

None of the vendors were able to measure air flow directly; this is the reason why they instead measured the KW consumed by the Sullair for a week. They assumed that the relationship between the KW used and the air flow produced was linear, and used this to extrapolate air flow estimates from the energy usage they recorded. The example graphic below illustrates this relationship:
On average, the air flow estimates Parker received from the three vendors ranged from 1100-1400 SCFM when they used this method of extrapolating flow data.

**Air Demand Data Analysis**

The third item, analysis of the compressed air demands of the plant, is also the last item. Air flow needed to be quantified as accurately as possible and this required the direct measurement of flow instead of an estimation through measurement of a related metric. For this, Parker’s Scout Sensor system was used. These small sensors are tapped directly into the pipes and a pedotube is placed in the center of the pipe. Air flows over the pedotube and is recorded in real time and the data is stored on Parker’s server. From this server, data was pulled in ten-minute intervals going back several months. The readout of this data is shown below:
This data pull resulted in around 4500 data points to work with. The data was then plotted in a histogram:

![Figure 15. Raw Scout Sensor Graph](image)

From the histogram above, it can be clearly seen that the data is bi-modal. Further inspection shows the lower end of the distribution ranges from around 450-650 SCFM, and the system
spends around 70% of the time in this window. The higher end of the distribution accounts for the other 30% of time and includes values from 650 up to 1100 SCFM. Not all of the air produced went to power the machines however. An analysis performed by MYESKO about a year ago showed that an estimated 40% of the air produced by the compressors was lost due to leakage in the system, whether it be bad connections or holes in the compressed air lines. A technician has been working on fixing these leaks since that time. By cross-referencing his work logs with scout sensor data from a weekend when no machines ran, the current estimate for air loss due to leakage is 20%.

Discussion

Based on the results of the analysis, it was concluded that the air flow estimates provided by the air compressor vendors were inflated and the compressor recommendations were oversized. The data shown by Scout Sensor analysis did not correlate with the numbers presented by the vendors. This was due to the vendor’s assumption that whenever the compressor is using energy it is producing air. When dealing with steady-state compressors, such as the Sullair, this is not true. The graphic below illustrates the difference between the performance curve of a steady-state compressor (top line in blue) versus a variable speed drive compressor (bottom line in orange):
Figure 17. Performance Curve Comparison between Steady State and VSD Compressor

As shown on the performance curve, a steady-state compressor pulls a percentage of its fully loaded power consumption even when it is producing zero air. This was not accounted for by any of the vendors and it was concluded that their air flow estimates were higher than the actual demand of the system.

None of the vendors mentioned how leaks impact the demand for compressed air either, as leaks will create artificial demand. These leaks are very expensive due to the energy costs required to produce compressed air are lost when the compressed air is not put to good use. According to the Compressed Air Challenge, it costs between $.22 and $.40 to produce 1000 cubic feet of compressed air. With leaks in the Parker plant at the current level of around 20% lost, annual savings of $29,253 could be achieved if the leak level were to be improved and held around 5%.
Moving forward with analysis, a recommendation was desired based on data analysis and findings from the Scout Sensor data pull. This includes stating the benefit of proposed solutions. Estimated savings for each of the solutions proposed in this report were calculated using the equation shown below from the Compressed Air Challenge. As an example, the specifications for the current Sullair compressor are also shown:

**ENERGY ESTIMATES**

$$
\text{ESTIMATED ENERGY} = \left(\frac{\text{kW}}{\text{hp}}\right) \times \left(\% \text{ FULL LOAD BHP}\right) \times \left(\% \text{ TIME}\right) \times \left(\text{HOURS}\right) \times \left(\text{RATE}\right)
$$

<table>
<thead>
<tr>
<th>BHP</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOURS OF OPERATION</td>
<td>8520</td>
</tr>
<tr>
<td>ELECTRICITY RATE ($/kWh)</td>
<td>0.08</td>
</tr>
<tr>
<td>kW/hp</td>
<td>0.746</td>
</tr>
<tr>
<td>MOTOR EFFICIENCY FULL LOAD</td>
<td>95%</td>
</tr>
<tr>
<td>MOTOR EFFICIENCY UNLOADED</td>
<td>75%</td>
</tr>
<tr>
<td>FULL LOAD POWER DRAW</td>
<td>100%</td>
</tr>
<tr>
<td>UNLOADED POWER DRAW</td>
<td>40%</td>
</tr>
</tbody>
</table>

Table 8. Energy Equation Inputs

It was discovered that the largest opportunities to save money when operating an air compressor occur in two places; 1) Optimizing the compressor so it spends more time in an unloaded state where it pulls less energy 2) Fitting the compressor to the system so the power draw is as efficient as possible. The following recommendations for the system at Parker will encompass both money saving opportunities.

The first part of the recommendation would be to continue fixing leaks in the system. This will never be perfect, meaning some air will always be lost, but the current state of 20% can be improved upon. With fewer leaks adding artificial demand to the system, the compressor will not
need to produce as much air and spend more time in an unloaded state. The benefits of improving leakage from 20% to 5% have already been discussed, and since this is an attainable state this is the number used for any cost capitalization moving forward.

In addition to controlling leaks, an educational program is recommended to teach employees the basics of compressed air. Air is free, and many people believe the same is true for compressed air. However, this could not be further from the truth. Consequently, in the Parker plant, compressed air is used poorly as a part mover, as well as a personal cleaner. Additionally, holes are intentionally put into compressed air lines to cool down a worker. Education is necessary to show that there are better, more energy-efficient methods to perform all these actions.

The second part of the recommendation is to implement a flow/pressure controller. Thanks to a motivated employee, this has already been implemented as seen in the following picture:

![Flow Controller Implementation](image)

Figure 18. Flow Controller Implementation
A flow/pressure controller regulates the volume of air allowed to flow out of the storage tanks.

This helps to hold pressure in the plant constant and removes the burden from the compressor of
responding to flash, high demand events, such as a large machine kicking on. Instead, the compressor only loads in response to the air level in storage being low. Due to the removal of the delay between pressure drop and compressor kicking on, the “safety margin” on the pressure setting for the plant can be lowered. These operational characteristics lead to two main benefits;

1) A lower, more controlled pressure setting in the plant will force less air out of any leak paths. Thus, the leaks currently present in the system will consequently cost less.

2) The compressor isn’t responding to changes in pressure in the plant and is instead simply producing to fill the tanks back up. This means it will kick on and load less frequently, resulting in less energy used.

The final part to the recommendation is for the compressor itself. Based on findings for the air flow demand from Scout Sensor analysis, a 250 HP VSD Ingersoll Rand compressor would be the ideal fit for the system along with the two 35 HP compressors already installed on the mezzanine. The net 320 HP would actually be an improvement over the current 300 HP and would allow some room for growth in the system. An automated system would be necessary to integrate all compressors into one solitary, autonomous system. This solution would meet the demands of the system in the most cost-efficient way and allow for the current Sullair compressor being used as the main compressor to be converted to the back-up. This conversion would effectively retire the old Ingersoll Rand piston compressor. Combining all the recommended solutions would result in a compressor that spends the maximum time in an unloaded state, which means that it is not pulling any power since the new main compressor is a VSD.

The complete estimated costs and annual savings were calculated using the already shown energy savings equation and are summarized in the table below:
<table>
<thead>
<tr>
<th>COSTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTOMATED SYSTEM</td>
<td>$22,000.00</td>
</tr>
<tr>
<td>LABOR TO FIX LEAKS</td>
<td>$7,200.00</td>
</tr>
<tr>
<td>COMPRESSOR</td>
<td>$93,000.00</td>
</tr>
<tr>
<td>FLOW CONTROLLER</td>
<td>$3,600.00</td>
</tr>
<tr>
<td>CONSUMERS REBATE (One Time)</td>
<td>$(27,500.00)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SAVINGS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOW CONTROLLER</td>
<td>$(11,882.23)</td>
</tr>
<tr>
<td>LEAK FIXES</td>
<td>$(29,259.53)</td>
</tr>
<tr>
<td>COMPRESSOR ENERGY USAGE</td>
<td>$(33,014.20)</td>
</tr>
<tr>
<td>TOTAL EST COST</td>
<td>$98,300.00</td>
</tr>
<tr>
<td>TOTAL EST ANNUAL SAVINGS</td>
<td>$(74,155.95)</td>
</tr>
<tr>
<td>PAYBACK PERIOD (YEARS)</td>
<td>1.33</td>
</tr>
</tbody>
</table>

Table 9. Capital Budgeting Breakdown

The final part of the discussion is the plan for implementation. Parker’s only constraint for implementation is that they always want to have two compressors that are fully operational; a main compressor along with a back-up to ensure that a compressor will always be producing air for the plant. This was noted when the facilities analysis was performed, and then plugged into VIP Plan Opt. Based off the VIP output below, the following plan was realized to implement and install the compressor.
Figure 19. VIP Output

The optimal location of the new compressor to be over by the air tanks, and to the left of the Ingersoll Rand and cement pad. In order to implement this new compressor, the equipment shown in red on the left of the AutoCAD output below would be removed. The equipment highlighted in red are non-essential items, such as a laundry cart, and oil barrels.

Figure 20. AutoCAD Diagram with Specified Machines to Remove
This removal of equipment would be allow for the grouping of storage tanks in the corner as shown in the plan below. However, if it is preferred to move storage tank 26 out into assembly, then this is also possible.

**Figure 21. Proposed Layout Pre-Removal of the Ingersoll Rand**

Once the new compressor is in place, it would be possible to remove the old Ingersoll-Rand through the bay door as shown below:
Figure 22. Proposed Removal of the Ingersoll Rand

This would result in a final proposed air compressor room layout as shown below. This room would only have equipment that is pertinent to compressed air in it at this stage of the process.

Figure 23. Final Proposed Layout
Summary

To conclude, the compressor that is recommended is a 250hp VSD Ingersoll Rand Compressor. This compressor, along with the two additional 35hp compressors can account for both the high and low demand events in the system. Additionally, the proposed compressor fits in the compressor room in an efficient manner, and will increase ease of maintenance on the system.

The project also saw that identification of the machines was pertinent and clear in the compressor room. This was important to maintenance, and will be an improvement over the old, non-existent system.