Bobcat: Arizona Proving Grounds

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Technical Report

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Overview

About me:

Coming from a family where doing things yourself is not an option, but a necessity, I gradually learned many of the ideas and concepts that would not only help me in the future, but propel me forward to the things that I eventually discovered I wanted to do in life. As a kid we were always working on projects, doing masonry work, building and renovating buildings and houses and working on our cars. I further honed these skills throughout much of high school.

My uncle was a contractor and I was able to work with him most summers. The jobs that we did were multifaceted, incorporating all elements of design and construction that one could think of. We constructed custom kitchens and bathrooms from scratch doing everything from framing to plumbing, electrical, drywall, and paint. While going to school and working I pursued my other hobbies, which mostly consist of auto and motorcycle restoration. I would often get a motorcycle practically given to me, fix it up, ride it for a while and sell it.

Building hands on skill was not my only pursuit. I worked hard throughout high school so that I could go to college without relying on my family to foot the bill. My parents had told me since middle school, "Son, we haven't saved a nickel for you to go to college, so do it yourself," which is exactly what I did. I was able to get into the University of Arizona with almost all of my tuition covered, although I waited until sophomore year to finally declare my major as mechanical engineering. I was able to further enhance my academic skills by working at the University's tutoring service called the Think Tank.

Training as a tutor greatly advanced my deep content knowledge of mathematics mostly in the areas of early calculus. Being a tutor also provided me with a better understanding of how to be a better student. Study habits, note taking skills, time management, and a greater appreciation of academic rigor were all ideas that I had to promote to students that I was tutoring. It was only natural that some of these habits would rub off on me as well. This varied skillset allowed me to have the most academically outstanding year of college during my junior year, which just so happens to be the year that many find the most challenging.

The academic and cognitive skills that I have learned throughout college, coupled with my background in automotive and construction, have made me particularly suited to a hands on, in the field engineering job. This is where Bobcat Arizona Proving Grounds (BAPG) comes into play

I was hired on at Bobcat after attending the fall University of Arizona career fair. I spoke with many of the companies that attended the fair such as Caterpillar, Freeport McMorran, Pepsi Co, and anybody else that I could. One of the last employers that I spoke with was Bobcat. They informed me that the internship was nearly 8 months long and that I would be working full time during that period. I also learned that the type of person they were looking for needed the background that engineering college provides, as well as a strong mechanical or construction background. It just so happened that I had all 3 of those things in just a large enough quantity that I was ultimately hired for a position as a test engineering coop from summer 2016 until December of this year.

About Bobcat:

Bobcat Company is the first manufacturer to design and construct compact loaders. The founders developed a small 3 wheeled loader for a turkey farmer to use in his pole barn that was too small for his standard equipment. Around 1960 they produced the m400, which is about what we would expect today when thinking of a skid steer loader (SSL).

M400 (left) and S650 (right) showing the evolution of the bobcat Skid Steer Loader

In 2005 Bobcat built a proving ground off of Pima Mine road. This proving ground employs about 10 operators and 3 engineers, as well as 1 or 2 interns, technicians and supervisors. The site is an accelerated wear facility that is designed to provide the harshest conditions possible. Loaders undergo testing to simulate many of the events that an owner would experience using these machines.

Another large part of the production from Bobcat is their line of small excavators. The sale of excavators has actually surpassed the sale of loaders over the last few years. Excavators go through an equally challenging set of tests.

Working for Bobcat I am expected to do a huge variety of tasks. These tasks include such things as working on machines, going into the field to diagnose problems, data collection, data analysis and reduction, and a host of other daily tasks.

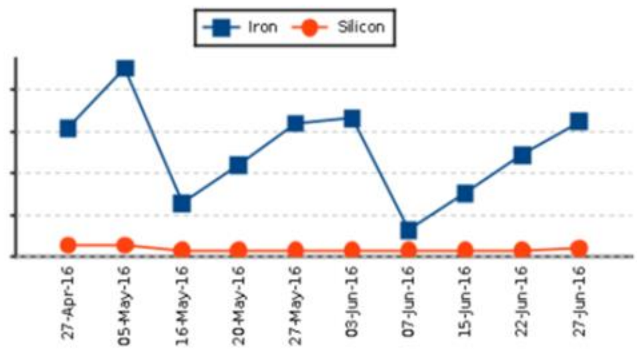
Working with the ESET machines:

One of the daily tasks of an intern at Bobcat is maintaining the various ESETs on site. During my employment at Bobcat there have been 2 of these machines to oversee. The ESET is basically a loader without wheels—like an engine on a dyno stand. Hydraulic fans are used to load the engine at known intervals for 20 hours every day, 5 days per week. Because the engines run so many hours, they need maintenance almost every day. The daily tasks at minimum were an exhaust system inspection a recording of the intake delta pressure, an inspection for leaks/wear, and a recording of the hydraulic, coolant and engine oil levels. Other standard procedures for the ESETs were taking oil samples, inspecting the fans, air intake, engine mounts and battery.

During one morning inspection I noticed a pool of oil underneath one of the machines. Once I opened the machine it was a horrible sight. The oil dipstick had dislodged and sprayed oil all over the engine compartment. Being that these machines are here for product validation this became a challenge since the same failure happened once before. Was this the fault of a poorly designed or failing dipstick, or is this the fault of the engineer not fully seating the dipstick in the tube. Of course there is no way to know for sure so the solution was to take a picture before starting the machine every day and add it to the log. One of my main takeaways from this experience is to do all of the maintenance completely focused and very methodical. It is easy to get carried away on a project moving too fast and miss a small, seemingly minor step or procedure. Sometimes these small mistakes can cause major consequences. We were fortunate that the machine did not have a complete failure by running too low on oil.

An interesting aspect of maintaining the ESETs is taking oil samples and inspecting the data that this provides. This is especially important if a failure has just occurred, such as the dislodged dipstick. Because of the failure, it was necessary to find out if there were any excess metals present in the oil which would indicate worse damage than what can be seen through a visual inspection. Thankfully there were no excess metals in the oil that was sampled after the failure.

Consider the iron-silicon concentration graph below; as the engine ages through its oil, it is clear that the iron content in the oil is increasing. This is an indication of the wear that the engine is facing. This sort of wear is expected though, and as long as there are no obvious spikes in the data the engine is operating as expected. Other wear indicators include aluminum, copper, chromium and nickel, but these elements are seen in much lower concentrations. The silicon shown in the graph is a contaminant metal, and mostly appeared at the beginning of the engines life cycle. Both ESET machines on site exhibited nearly identical wear metal and contaminant metal levels.



The daily check of air intake delta pressure yeilded interesting results towards the beginning of the experiment. An unexpected pattern of air filters becoming clogged was noticed by one of the engineers in North Dakota. It was determined that the likely cause of this was the exhaust gas coming from the exhaust pipe that was not very far from the air intake. It was left up to us to come up with a way to route the exhaust away from the intake in a manner that would still allow easy access to all of the internal components. We came up with an easy slip fit bendable exhaust that was easy to remove and routed all of the necessay gases away from the intake.

ESET Machine (Rear) with fan stand and controller (front)

The best part of the ESET project was receiving a prototype machine identical to the model that we are testing on the stand. The prototype machine that we received looks exactly the same on the inside as these test engines, Already being familiar with the engine platform of this loader helped me to more efficiently work on the real life machine when it arrived at the accelerated testing facility. It was great to see something go from a simple engine test to a more serious product validation test.

Data Collection and Data Analysis

One of the hardest parts of my internship so far has been data analysis. Working with and learning multiple programs that I have never seen before and using them to provide reliable analysis is very challenging. I was given a basic overview for the use of infield, ncode glyphworks, minitab, vector logger and CANalyzer. These programs are very specific to test engineering, and are used extensively for analysis. I have been doing extensive work with infield and ncode, as well as excel.

Data collection

A major aspect of my internship with Bobcat was data collection. The vast quantity of data that is collected on site comes in many forms such as manually collected measurements from machines, various data loggers, weather loggers, oil samples, fuel logs, inspection reports and simple operator or technician comments. All of this information is invaluable in keeping the site operational and learning more about the machines that are under test. Most of the day to day data collection and storage is done in the form of machine logs. These are reports that describe in detail anything that has happened to a machine and the time that it occurred.

Bobcat T650 with EDAQ processor connected to roof and many sensors attached.

Data for most of the analysis projects that I worked on was collected in December and January. The data is collected by rigging a machine with sensors to measure parameters such as: stress, strain, accelerations, gps coordinates, engine parameters including temperature, rpm, oil pressure and others, hydraulic pump sensors to measure pressures, speeds, and flows, all connected to a very rugged processing unit called the EDAQ. An engineer follows the machine while it operates to view a live feed of the data being processed by the EDAQ, and then uploads all of the data that has been gathered. The sheer quantity of data that is collected is overwhelming, but it is impossible to know exactly what data will be needed when everything is analyzed. It is better to have more information than needed rather than to find out later on that something is missing. The machine that was tested was a 2 speed Bobcat T650.

Major data analysis project: Operator Calibration and Consistency

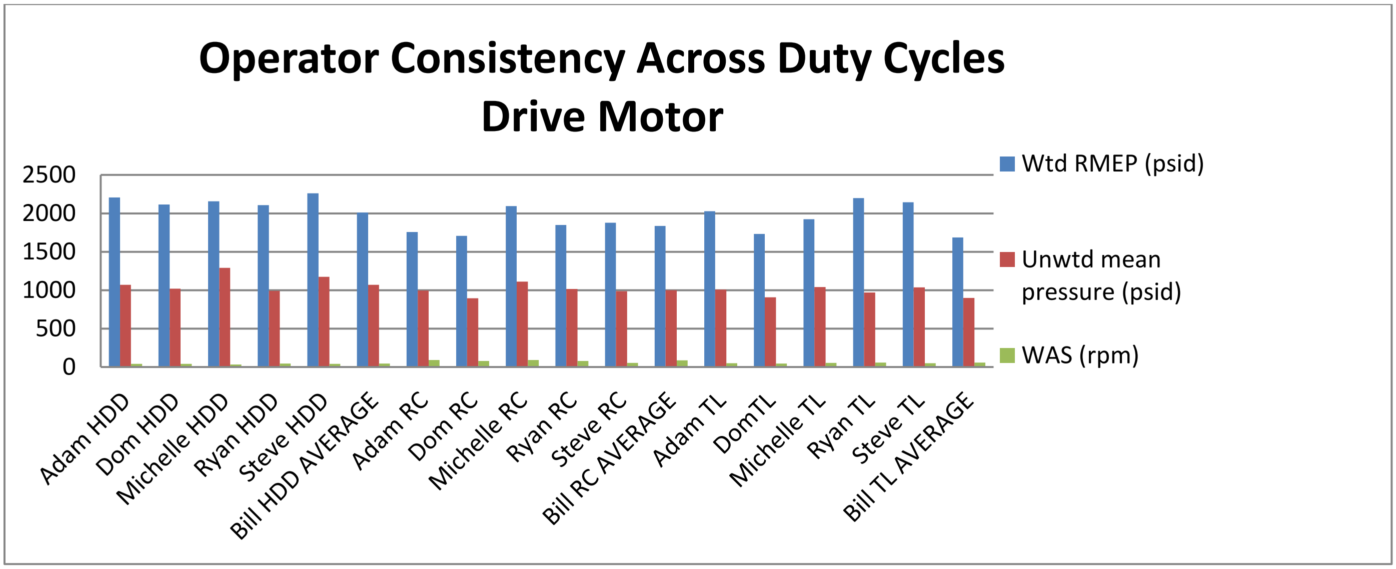
One of my major data analysis projects was operator consistency. It is important for us to know that all of our operators are performing the duty cycles as similarly as possible to each other. If one operator is working his machine much harder than the average operator, or if the operator does not work their machine nearly as hard, this will provide an inaccurate estimate of the life that we would expect the machine to survive in real life. The accelerated nature of our machine testing means that every hour is important and that deviation from our standard operation will provide debatable results at best. The operator consistency project has 3 major analyses; hydraulic, structure and acceleration.

Hydraulic Analysis

The hydraulic analysis is by far the easiest part of the data crunching that I had to do. The basic steps were as follows:

1. Filter out test channels that provide hydraulic data using ncode glyphworks
2. Pass data through a time at level analysis on infield
    - Once for the drive motor and once for the implement pump
3. Pass data through a rainflow analysis on infield
4. Copy data into an excel spreadsheet
5. Manipulate the data to provide Root mean effective pressure and weighted/unweighted speeds, torques, and power.
6. Repeat for each duty cycle and operator

By using the hydraulic analysis method we are able to distill a huge quantity of data into a few, single, easy to understand values. Without these values we would have no idea how big of a change to expect from test to test. Using these analysis methods we are able to compare and contrast each operator's consistency when compared to an average taken from one operator who did multiple runs. This helps to mitigate the amount of inconsistencies that we need to account for in the data.



This sample of the data shows a comparison of hydraulic parameters between Bill's averages of 4 runs compared to the other operators. The parameters include weighted average speed, weighted root mean effective pressure, and unweighted root mean effective pressure. Thankfully these runs look to be very similar for each of the duty. The goal of these duty cycles are to have the most consistent operation of every machine across all drivers. Having only collected data for one run of each driver except for Bill, this is an indication that the operator consistency goal is a relative success.

Root-Mean Effective Pressure

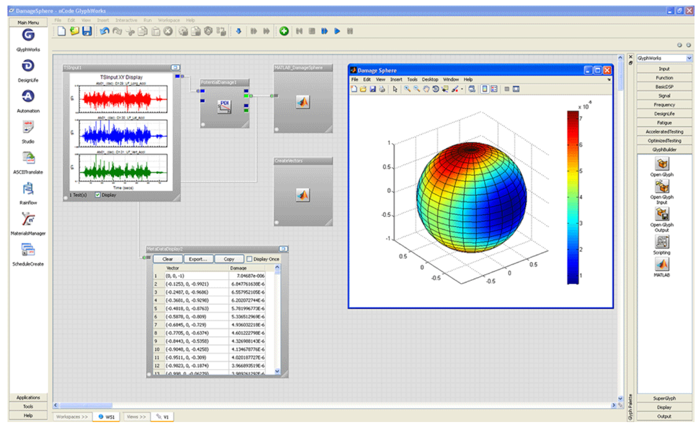
$$RMEP = \left\{ \sum_{i=1}^{i=total} \left[\frac{\%time_i \cdot n_i}{\sum_{j=1}^{j=total} \left(\%time_j \cdot n_j\right)} \cdot (\Delta p_i)^\lambda \right] \right\}^{\frac{1}{\lambda}}$$

Weighted Average Speed

$$WAS = \frac{\sum_{i=1}^{i=total} \%time_i \cdot n_i \cdot (\Delta p_i)^\lambda}{100 \cdot RMEP^\lambda}$$

The main tool for the hydraulic analysis is a program called infield. Infield's application at Bobcat ranges from real time data viewing during data collection to performing mathematical analysis on large sets of data. The analysis function is what is used for the hydraulic analysis. A time at level analysis produces the results in the above graph. Essentially a time at level analysis measures how long a parameter is at a certain level. Using these times we can calculate the root mean effective pressure and the weighted/unweighted average speed in excel. An unweighted speed is produced by using a lambda value of 1.

After completing the hydraulic analysis on a machine, we would conduct an analysis of the machine structure during a test, as well as an in depth analysis of the accelerations/vibrations that a machine experiences during a test. These analyses tests give a near complete overview of how each duty cycles compares to the other. The acceleration and vibration examination is the most challenging, requiring an extensive use of nCode, sampled above. Once all of the data analysis is complete, we will have a thorough understanding of how consistent our operators are operating their machines.



Sample of nCode. Source: http://www.mathworks.com/products/connections/product_detail/product_53245.html?requestedDomain=www.mathworks.com

Technician work

One of the major aspects of my co-op position at Bobcat has been physically working on the machines when they are in need of routine maintenance, field repairs, or any other sort of work. The main job that I had doing working on equipment was on the ESETs. Because the ESETs are a co-op only machine, we had to perform any and all maintenance, repairs, or changes that needed to be made. This included replacing filters every few hundred machine hours, installing test parts—such as a new design of starter, and fixing the fan loading stand when it was leaking. While the ESET's took up about an hour every day of work, they were not the only thing that we had to work on.

Bobcat MT-85 http://www.equipmentworld.com/bobcat-launches-mt85-mini-track-loader-with-big-power-boosts-photos/

Track replacement and inspections, shift change tasks such as greasing, tightening wheel nuts were all tasks that I had to complete. More in depth projects such as a drive belt replacement on the MT-85—which is a miniature stand behind track loader—were also completed by co-ops such as myself. Shift change tasks were usually a lesson in time management and speed. With the goal being to put as many hours on machines as possible, it becomes necessary to complete small tasks while the first shift crew swaps out with second shift. After getting used to the long time frame of most assignments like data analysis it was exciting to have a part of the day that was so hinged on getting things done in just 30 minutes.

How has my academic training helped me here

One of my instructors, Dr John Turner, explained to us in class that all of the theory and formulas that we learn are not all that useful in a bachelor's level job. He said that we would not be expected to regurgitate formulas or work some dynamics problem out on paper once we get hired. He told us that the real application of our schooling was understanding the basic principles that govern what we see around us. The critical thinking skills that we gain in class, the understanding of the physics that surround a given phenomenon, are much more important than the actual problems that we were working out. The basic principles are what we need to understand while we work on a computer model. Without the understanding of the underlying principles, we would not be able to know when a computer generated answer is correct.

I have found all of this to be true. The job that I have does not explicitly use the concepts from engineering school, but it has been instrumental in my understanding of when something is right or wrong. Take hydraulic analysis, without an in depth understanding of the math that goes into the calculations, I would not be able to look at the excel spreadsheet and see that something is off. I may not know exactly what is off at first, but that first clue, the hint that not all is well, is what my academic training has given me.

It was also true what Dr. Turner told us about the company providing the training that we would need for specific software relevant to our application. Before getting engineering training at the University, the best that I could use an excel spreadsheet for was making a single graph for a science project. When it came to word processing I was still at low speed level and I certainly wouldn't be able to help anybody though the logic of a computer code. Taking classes in math, computer programming, and matlab, as well as being exposed almost every day to the nuances of new and unfamiliar programs has greatly improved my aptitude when it comes to working through the learning curve of a new piece of software. The skills that I learned throughout my college career have greatly benefitted me in terms of speed, critical thinking and problem solving when it comes to computer related tasks.

Conclusion:

Working for Bobcat has been great experience. It has been interesting to see how my academic pursuits apply to life in the 'real world.' The daily grind of getting up and going to work for 8 hours is completely different than the student life, at times worse, but often times more fulfilling. Bobcat has opened my eyes to a side of engineering that I didn't even realize existed—test engineering. My position at Bobcat has given me a great insight into the world of engineering and I am thankful for that opportunity.