Case Study: Diesel-Powered Loaders Compared to Hybrid Loaders in Heavy Civil Construction

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With the construction industry constantly changing, the environmental impacts of greenhouses gases have become a huge concern. Many contractors are adapting and switching over to hybrid powered systems to allow for more energy saving methods for heavy equipment, an increase in productivity, and efficient construction equipment that comply with emission regulations. The goal for this paper is to analyze the feasibility of heavy civil construction companies switching over from conventional diesel-powered wheel loaders to hybrid wheel loaders. Due to the competitive and saturated market in roadwork construction, many contractors have already begun to invest into hybrid systems. This provides cost savings in fuel efficiency and operating costs over the conventional fueled loaders. Qualitative research was conducted for this report through semi-structured personal interviews with heavy equipment experts, and the usage of primary and secondary sources. Although the switch to operating with a hybrid system it will potential have a higher up-front cost, it will have fewer operating costs and environmental impacts in the future.

Key Words: Loaders, Heavy Civil Construction, Environmental, Fuel Efficiency

Introduction

Heavy equipment in construction dates all the way back to 1886, when Benjamin Leroy Holt created the very first combine harvester for agriculture, along with a steam engine tractor four years later (Shirk, 2019). Not long after this, John Froelich invented the gas-powered tractor in 1892 which in turn helped pave the way for heavy equipment, specifically in the heavy civil industry (Shirk, 2019). These two machines have revolutionized and helped shape todays heavy equipment machinery used on many construction projects. Before these machines were invented, workers had to use labor intense methods to carry material and aggregate, which in turn slowed down the production and increased the duration of construction. One of the many drawbacks at the time was that these machines were mainly invented for agricultural use.

Benjamin Holt found a way to implement the track technology first seen on a commercial machine called the Lombard Steam Log Hauler in 1901 and run it on his gas-powered track-type tractor (Jasmin K., 2018). By implementing the continuous track technology of this Steam Log Hauler and creating more track-type or what is known today as a crawler Holt created the “Caterpillar”. As a result, these technological advancements were a huge turning point for all heavy equipment. These improvements went beyond agriculture, it in turn led to the production of metal track military equipment that would be implement on tanks and other vehicles during World War I (Jasmin K., 2018).

Due to the popularity of the track-type tractor during World War I, the emergence of the different type of heavy equipment machinery came to light. During the 1920s, the first ever bull grader or “bulldozer”, and bucket wheel excavator was manufactured (Shirk, 2019). With this time period being

known for its mining operations throughout the United States, these machines made a significant impact. Furthermore, with such an increase in popularity of heavy machinery many companies like Holt's which is now known as "Caterpillar" began to establish and grow. As a result, this heavy equipment became an essential part of the economic growth post World War II. As the economy expanded, the need for new construction emerged. Heavy equipment like the bulldozer were vital to earthwork and mining operations that took place as a result of the economic expansion.

As demand for production of more and more heavy equipment increased, so did the technological advancements of the equipment. "The Interstate Highway project was fully underway, and the heavy equipment market was thriving. Hydraulic systems gained popularity over cable-operated controls" (Shirk, 2019). During the 35-year period of Highway Construction, the new sophisticated hydraulic system made its way to the United States, replacing the cable operated system. As a result, manufacturers began producing heavy equipment with the new technological advancements (Shirk, 2019).

The completion of the Interstate Highway Project that occurred in the past 3 decades, led to a significant decrease in demand for heavy equipment in the 1980's. As a result, many of the companies merged to form a bigger and strong company, but many did not survive the recession (Jasmin K., 2018). It was not until the 1990's where these companies began to face new environmental regulations. These regulations forced all heavy equipment manufactures to change their engines in order to reduce the carbon footprint.

Since these environmental regulations were enacted, the increase in design and innovation for more clean powered heavy equipment originated. On May of 2007, Komastu was the first to launch the world's first ever hybrid electric forklift truck, as well as the world's first ever hybrid electric excavator in May 2008 (Lin & Wang & Hu & Gong, 2010). Since then the development of more hybrid and technological advanced heavy equipment like have been produced across the world.

General Background

The Hydraulic Wheel Loader

The hydraulic wheel loader is a four-wheel earthmoving machine that is primarily used to load loose material. It is used in all types of construction, but you mainly see it in the heavy civil industry moving stockpile aggregates or loading up a truck. The hydraulic wheel loaders include the cab, the front mounted bucket, the boom, the bell crank or tilt, and the cylinder. Depending on soil or terrain conditions, there are track and wheel loaders offered, but for the sake of this report we will be focusing on wheel loaders.

The hydraulic wheel loader offers a single tilt or a parallel tilt loader. The main difference in these two is the form in which the tilt or lift works in conjunction with the bucket. In the parallel hydraulic ram, it would lift the bucket in the same form as lifting a heavy object with two hands. It would lift the bucket from both sides simultaneously using two different rams working as a pair. This allows for more efficient loading, smoother retraction when dumping and a leveled bucket throughout production. In comparison, a single tilt would only have one central ram connecting to the bucket, which runs a risk of a seesaw effect when loading material.

The cab of a wheel loader consists your typical gas and brake pedal, responsive steering wheel, full 80-degree articulation, levers and joysticks that control different functions of your hydraulic system. Depending on which hydraulic wheel loader you are operating, it typically is equipped with technologically advancements like load sensing hydraulics. In addition, the cab comes equipped with buttons to set bucket and boom levels, which essentially just allows you to move it up or down. Lastly, the wheel loader is powered by its engine, where many important components are stored in order to allow the equipment to operate. Although the hydraulic wheel loader is equipped with different features depending on size, there is not much flexibility on the tasks that it can perform in the construction industry.

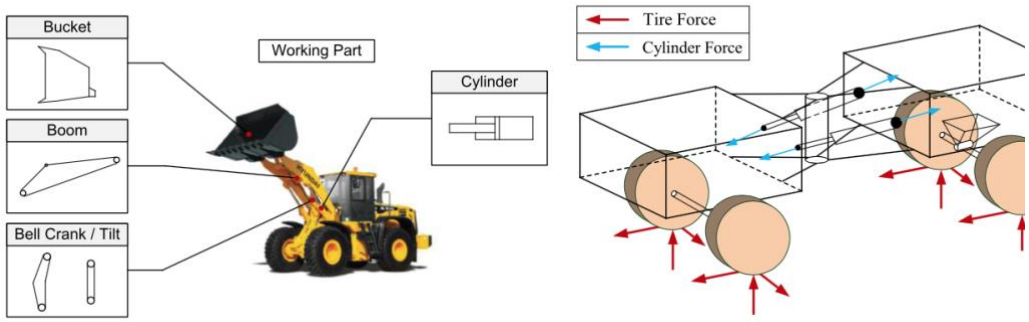

Figure 1. Wheel Loader Working Parts Component (Oh & Kim & Ko & Kim & Yi, 2015)

Hybrid Performance in Wheel Loaders

The new technological advancements of hybrid systems in wheel loaders has been a rising topic of interest in the past decade. "With hybrid construction machinery (HCM) attracting more attention, the powertrain configurations, energy management strategies, and energy storage devices have been presented by many scholars for HCM (Wang & Yang & Liu & Zhang & Han, 2016, p.1). Since the release of the very first hybrid powered heavy equipment, many companies have been competing to produce the top of the line hybrid wheel loader. In the last few years, heavy equipment companies like John Deere have been producing hybrid machinery that not only increases energy consumption, but reduces the overall fuel consumptions, costs, and many of the carbon emissions going into our atmosphere.

Wheel loaders require a significant amount of power in order to function properly. With many frequent starts and stops, it begins to generate a large amount of breaking energy which damages the braking system much faster (Wang et al., 2016, p.2). In efforts to mitigate this frequent issue, engineers have designed different hybrid powered drivetrain configurations. It is extremely common for wheel loaders to have different configurations of hybrid powertrain technology, which determines the features that will be included in the machinery. The wheel loader currently offers 3 different hybrid drivetrain options: series, parallel, and series-parallel (Wang et al., 2016, p.2). One of the main characteristics that separate these 3 hybrid powertrain options have to do with oil and fuel efficiency, as well as power sourced used to power up the heavy equipment.

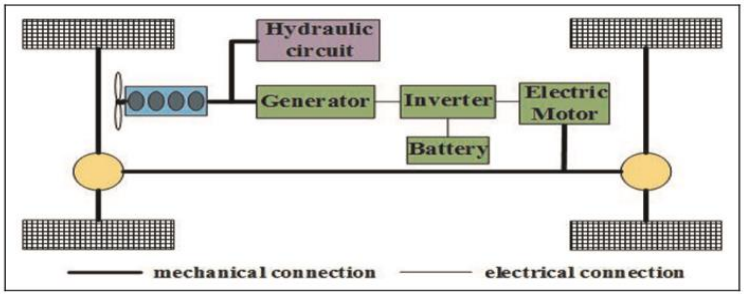

Figure 2. Series Powertrain Configuration (Wang et al., 2016, p.3)

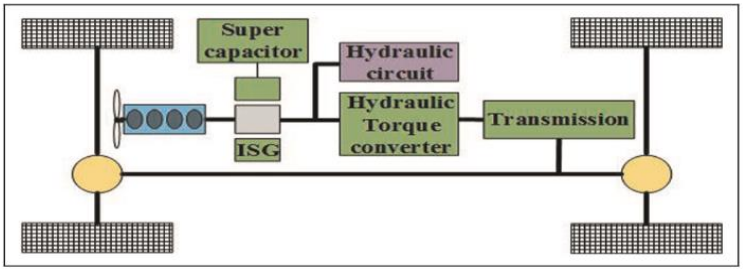

Figure 3. Parallel Powertrain Configuration (Wang et al., 2016, p.3)

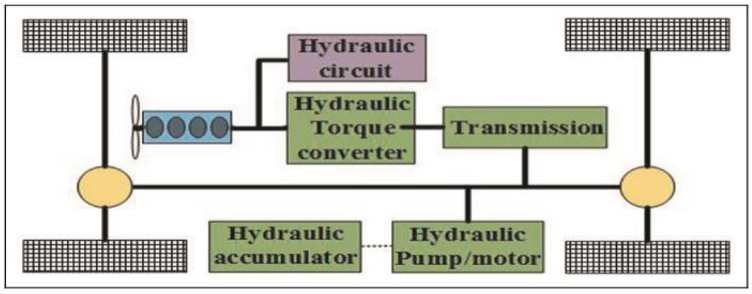

Figure 4. Series-Parallel Powertrain Configuration (Wang et al., 2016, p.3)

Engineers have implemented these different hybrid powertrain configurations into different heavy construction equipment (HCM), depending on its use and function. For example, the modern-day wheel loader that is equipped with the series hybrid powertrain configuration as seen in Figure 2, is one of the simplest configurations. In this configuration, the engine is going to power the electric generator, which as a result causes the generator to drive the electric motor (Wang et al., 2016, p.2). Although, this is one of the simple configurations, it is quite often used for large-tonnage wheel loaders. Figure 3 shows an example of a parallel powertrain hybrid configuration. This configuration quite different from the other, because of it is powered by two separate power sources. It may sound like a great hybrid configuration, but it may not be the best configuration when trying to have a high oil-saving cost (Wang et al., 2016, p.2).

Hybrid technology systems in wheel loaders do not only have the option of selecting the most efficient powertrain system, but in addition one is allowed to choose an energy storage device that will produce the maximum efficiency. Engineers have found different ways to power heavy

construction equipment or HCM, through the use of batteries, supercapacitors, hydraulic accumulator and flywheel (Wang et al., 2016, p.6). Batteries are a popular energy device in recent hybrid electric vehicles, but they have not been as popular in heavy construction equipment due to their high costs. In contrary, the hydraulic accumulator has gain popularity in HCM due to having a higher round-trip efficiency, and low mechanical issues as well the energy recovery system that comes equipped with it. This is mainly ideal for frequent short-stop cycles, which is going to be the case in most highway construction (Wang et al., 2016, p.7).

Advantages of Hybrid Powertrain Systems

When one thinks about HCM, the first type that comes to their head is the conventional diesel-powered equipment that has an internal combustion engine (ICE). Just in the European Union, heavy equipment is responsible 2% of their total emissions (Szamocki & Kim & Ahn & Brilakis, 2019). Now if you begin to look at the contributions that heavy equipment has globally, the number quickly begins to add up. For several years now, many environmentalists have been concerned with the amount of pollution output and greenhouse emissions. In order to decrease these emissions, experts have been pushing for hybrid powertrain systems to replace the conventional diesel-powered systems. The hybridization benefits that these systems provide are slowly attracting contractors due to the decrease in greenhouse emissions and fuel consumption, as well as the increase in energy efficiency.

The main advantage of a hybrid configuration includes the option of shutting off the combustion engine when coming to a temporarily stop, which will ensure the owner an increase in energy saving (Donateo, 2017.) In addition to this, HCM owners can see an energy saving cost anywhere from 25%-45%, in comparison to the conventional ICE. Of course, that saving cost is dependent on the type of hybrid powertrain configuration that is equipped to the wheel loader.

Objectives

- Analyze the operating & ownership costs of both the hybrid powertrain wheel loaders and the conventional diesel wheel loaders
- Analyze the environmental impacts of purchasing both type of wheel loaders in roadway construction
- Analyze the feasibility of heavy civil contractors switching over to hybrid powertrain wheel loaders
- Provide new knowledge to roadway contractors on purchasing costs of a hybrid powertrain wheel loader

Methodology

In order to ensure the best results, an extensive literature review was conducted through semi-structured interviews, as well as the usage of primary and secondary sources. This allowed me to obtain a better understanding of the complexities of the research topic. Through this extensive literature review, I will be able to analyze the ownership and operating costs of both type of heavy equipment by obtaining a rate of investment. In addition, I will be able to provide contractors knowledge on the feasibility of switching over to a hybrid system in heavy civil construction, but specifically in the sector of roadway construction.

Case Study

For the sake of this case study, I would like to focus it on all roadway construction companies, but I was lucky enough to obtain from information from Atkinson Construction. Atkinson Construction is based out of Irvine, California and focuses on all aspects of heavy civil construction. Their scope of work includes dams, underground tunnels, roadways, and bridges. I will be focusing on their roadwork production, in order to get an understanding on their future heavy equipment investments. Although they only have diesel powered equipment in their fleet, I will be comparing the John Deere 644k conventional wheel loader and the John Deere 644k hybrid wheel loader.

Data Collection

The use of primary and secondary sources allowed me to obtain useful information about the functions of hybrid and conventional wheel loaders. This alone was not enough information to allow me to complete my objective of proving roadway contractors a feasibility on switching over to hybrid powered heavy equipment. I conducted multiple interviews with different project team members, which gave me a better understanding on what the purchasing, operating, and ownership costs of both the John Deere 644k conventional and hybrid wheel loaders.

One of the first semi-structured interviews that I conducted was with Ryan Wood, Engineer with Atkinson Construction. Ryan has had experience tracking weekly cost reports on the company's fleet in that specific project. Through this interview, I was able to obtain estimates on ownerships and operating costs of the conventional 644k wheel loader. I insured myself to gather the adequate information in order to perform an accurate life cycle analysis. In addition to costs, I acquired information on upfront costs, life expectancy, routine maintenance checks, and the estimated hourly use per week. In addition, he had mentioned the possibility of renting equipment for smaller projects if no in house wheel loaders are available. It was something I had to keep in mind when performing my calculations. After gathering enough information, it was quite difficult to obtain prices on new wheel loaders, so I began looking for used wheel loaders on the market that fit the information I obtained.

In order to get a better understanding on the John Deere 644k hybrid wheel loader, I conducted a phone interview with RDO Equipment Co in Southern California. As a spoke to their General Manager Gary Bow, his knowledge and experience with the John Deere wheel loader provided valuable information on ownership cost for my life cycle analysis. In addition, as a service manager he had a great understanding of maintenance cost, life expectancy, and operating costs. Through conducted field tests, Gary ensured me that the 644k hybrid got the job done faster and burned less fuel.

Operating & Ownership Costs

Through the data the I collected, I was able to analyze both the John Deere 644k conventional and hybrid wheel loaders, by conducting a thorough life cycle analysis. As a result, this would allow me to provide the roadway contractors a detailed breakdown of all costs for both the conventional and the hybrid system. In order to ensure that my calculations are accurate, I used the Net Present Value formula which tells me a dollar value that the purchase of the wheel loaders will bring for the

company. For this formula to be accurate, I made sure to calculate the wheel loaders depreciation by using the life expectancy and salvage value that I obtained through data collection.

After extensive research for used wheel loaders in the market under the same conditions, I was able to find two different 2017 John Deere 644k to compare. The first one I found was the 2017 John Deere 644k hybrid wheel loader. This specific one is in great conditions with 2,536 hours used, selling for $222,500. Since this loader is located in Idaho, I was able to get a quote for freight charges, which increased the price by $4,340. In comparison, the 2017 conventional 644k loader, has 2,054 hours used, with an asking price of $225,000. I also contributed the cost of transportation from Georgia, to California and received a quote of $4,200. Given that these two loaders are very similar in all aspects, and in good conditions, I did not factor out a huge portion for their life expectancy in my calculations. I did manage to focus on factors like brake system expectancy, fuel consumption, maintenance repairs, and their operating efficiency of short start-stop hauls. After conduction my calculations for I obtained the following results.

2017 John Deere 644k Hybrid Wheel Loader	2017 John Deere 644k Diesel Wheel Loader
Purchasing Cost: $222,500 **Operating Cost** • Fuel: $1,560/Month • Repairs: $790/Month • Maintenance: $410/Month **Total Costs:** $2,760/Month **Ownership Costs** • Equipment Cost: $3,739/Month • Depreciation: $880/Month **Total Costs:** $4,619/Month **Net Cost:** $7,379/Month	**Purchasing Cost: $225,000** **Operating Cost** • Fuel: $2,290/Month • Repairs: $530/Month • Maintenance: $278/Month **Total Costs:** $3,098/Month **Ownership Costs** • Equipment Cost: $3,781/Month • Depreciation: $930/Month **Total Costs:** $4,711/Month **Net Cost:** $7,809/Month

Upon completion of my calculation on operating and ownership costs, it is quite evident that the conventional diesel 644k loader has a higher up-front cost, and monthly cost. There are in savings in any aspects associated with the conventional wheel loader. In comparison, the 644k hybrid wheel loader has some significant savings in both up-front costs and monthly ownership/operating costs. This yields to a saving of $430 a month, which in turn saves you $5,160 per year. Depending on usage of the loader, and operations of construction, over the years the hybrid wheel loader could potentially yield and even higher cost savings.

One of the most notable savings that I noticed right away between the 644k hybrid and diesel loader was the fuel savings. On a monthly basis, the hybrid wheel loader saves the owner $730. That is quite a significant difference when comparing the two. Due to the hybrid powertrain system, repairs and maintenance is a bit more expensive than the diesel wheel loader. At the end of the month, the savings in fuel and depreciation of the hybrid wheel loaders, offset the repairs and maintenance cost. As a result, the return on investment and payback period would be more beneficial on a hybrid wheel loader.

Conclusion

Given the results from the research and calculations conducted on this case study, I would encourage Atkinson Construction, along with many other roadway contractors to invest in the John Deere 644k hybrid wheel loader over the diesel powered 644k loader. The life cycle analysis provided, along with other qualitative data used shows the feasibility of switching over to the hybrid powertrain system would be a better investment for many roadway contractors in California. Given that field tests have been conducted on both the John Deere 644k wheel loaders, the hybrid wheel loader has proven its ability to not only get the job done faster and burn less fuel. The 644k hybrid loader used its break 75% less than the diesel wheel loader. With a high demand in the roadway sector, Atkinson Construction along with other companies in Southern California need heavy construction equipment that will increase productivity and decrease costs. In conclusion, with the hybrid technological advancements the John Deere 644k hybrid wheel loader seems to be the more feasible option for roadway contractors to invest into.

Future Research

With the construction industry changing on a daily basis, the production of heavy construction equipment needs to remain to date with the environmental regulations. While hybrid systems are not completely emission free like many electric construction equipment, it still has a significant reduction in emissions compared to diesel wheel loaders. As of today, the 644k diesel wheel loader has a large Final Tier 4 engine which is complaint with E.P.A standards. Meanwhile the 644k hybrid loader only has an Interim Tier 4 engine and are yet to come out with a bigger Final Tier 4 engine. The production of a hybrid 644k loader with a bigger Final Tier 4 engine to reduce 95% of emissions, is set to release late 2020. Due to the fact that California has such strict regulations, this will ultimately be the deciding factor on choosing the 644k hybrid loader of the 644k diesel powered loader.

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