A COMPARATIVE STUDY OF LIFE CYCLE COSTS FOR SELECTED ELECTRIC POWERED GROUND SUPPORT EQUIPMENT AND INTERNAL COMBUSTION ENGINE POWERED GROUND SUPPORT EQUIPMENT

By

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FOR SELECTED ELECTRIC POWERED GROUND

SUPPORT EQUIPMENT AND INTERNAL

COMBUSTION ENGINE POWERED

GROUND SUPPORT EQUIPMENT

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This doctoral degree program started fast and furious. I worked full time and took classes full time. A had completed the majority of the required credit hours in the first year and a half. Then… when I tried to give blood as a benefit to my church, the blood institute wouldn't let me donate because of high blood pressure. Not long after, I went to my annual dentist appointment. My dentist asked if I had been under an unusual amount of stress lately. "No", I replied, "I've been too busy to be stressed". I'm not sure if he was laughing at me or laughing with me, but he recommended I see my doctor because of my very high blood pressure. I would like to acknowledge my dentist and friend Dr. Larry Leemaster for possibly saving my life and definitely prolonging it. My blood pressure was, it seems, very high indeed.

My pace of work and study has since slowed considerably and maybe would have stopped altogether except for my family and coworkers who ask seemingly every day, "Are you Doctor Dano yet?" I give you all a heartfelt thank you.

I would like to thank Dr. Marks for taking time for me even though he has the NASA educational program to administer. I'd also like to thank Dr. Ehrlich who opened my eyes to the wonders of the earth and universe beyond. Dr. Kutz, my dissertation advisor, also deserves a special thank you for steering this dissertation in the proper direction. Dr. Key taught me the value and application of research. Without this knowledge of qualitative and quantitative statistics this dissertation would not be possible.

I give eternal love and thanks to my loving wife Sandy. Her cool reception to the idea of me starting another degree program quickly turned to wholehearted acceptance and support. Her patience has raised her to near sainthood in my eyes. I hope the graduation party "luau" is a success. Sandy truly believes in electric vehicles and the future potential for clean energy. Our grandchildren's grandchildren will thank her.

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CHAPTER I

INTRODUCTION

The fact that the air transportation industry is large enough to have a significant impact on the economy as a whole was tragically evidenced by the terrorism of September 11, 2001 in that air transportation aircraft were directly involved. Because of the use of commercial airliners as tools of terrorism and destruction, the air transportation industry has suffered far-reaching setbacks. These setbacks have, in turn, caused major economic setbacks to the economy of America and the rest of the world.

This study is directed toward the use of self-propelled ground support equipment (GSE) used at airports, in particular baggage tractors and the belt loaders. The baggage tractor and the belt loader GSE are the subjects of this study because of their popularity as electric-powered mobile equipment. The baggage tractor pulls baggage-filled trailers between aircraft and the passenger terminal as well as between aircraft. The belt loader is used to move luggage to and from aircraft and ground level. Pushback tractors primarily used to push aircraft away from the terminal have been the subject of research and development for alternate propulsion systems, but real-world data is not widely available.

The Federal Aviation Administration Office of Airports Community and Environmental Needs Division, administers the Inherently Low Emission Airport Vehicle (ILEAV) program. "In April 2000, Congress authorized the Inherently Low Emission

Airport Vehicle Pilot Program (ILEAV) as part of the Wendell H. Ford Aviation Investment and Reform Act for the 21st Century (AIR-21). Following program development and the application process, the Federal Aviation Administration (FAA) implemented the ILEAV Program in September 2001 through grant agreement with 10 airports. The pilot program offers the opportunity to evaluate low emission vehicle technology, refueling infrastructure, and how well they work in the airport environment. ILEAV grants to selected airports were up to $2 million each with a 50-50 cost-share. The FAA encourages airports to leverage additional support from local government, airlines, equipment manufacturers, and operators. The total commitment to the program was $48 million initially but this projected investment level has fallen to $41 million due to the events of September 11, 2001 and the financial uncertainties in the aviation sector" (Plante, 2003). The ten airports chosen to participate in the ILEAV program are Atlanta Hartsfield International (ATL), Baton Rouge Metropolitan (BTR), Baltimore-Washington International (BWI), Denver International (DEN), Dallas/Fort Worth International (DFW), John F. Kennedy International (JFK), LaGuardia (LGA), Chicago O'Hare International (ORD), San Francisco International (SFO), and Sacramento International (SMF) (Plante, 2003). Airlines are not currently mandated by federal government legislation to increase fuel economy or reduce emissions for their ground support equipment (U.S. Department of Energy [DOE], 2003), but are obviously encouraged by the ILEAV program to participate in the Government's emphasis on clean air.

While reducing emissions is an important goal, our dependence on oil in general and specifically foreign oil has recently become a national concern. "The Energy Policy Act (EPAct) was passed by Congress on October 24, 1992 with the goals of enhancing our nation's energy security and improving environmental quality. Several parts of the Act were designed to encourage use of alternative fuels, not derived from petroleum, that could help reduce dependence on imported oil for transportation" (DOE, 2001).

According to the Department of Energy Transportation Energy Data Bank, as reported in a presentation by the Electric Power Research Institute (EPRI), the projected number of barrels of oil used for transportation purposes will increase by 50 percent in the next thirty years in the U.S. (Duvall, 2000). Reducing our use of foreign oil therefore, becomes increasingly difficult as our population increases, which, in turn increases our use of vehicles for transportation.

Ground support equipment is used to service aircraft in many capacities including: luggage loading and unloading, food service, refueling, mobile electric power, air conditioning, and ground maintenance transportation. Airlines have thousands of pieces of GSE on their inventories. At the 10th annual National Aviation Environmental Management Conference, David Terrell, manager of GSE for American Airlines reported that they have approximately 9500 pieces of powered GSE (Terrell, 2001). Beginning in 1996, American Airlines has purchased $35 million in electric powered GSE. Neil Wright, General Manager – GSE Maintenance for Delta Airlines as interviewed in GSE Today (Garetson, 2002), says there are 19,131 pieces of GSE for Delta and 6103 are motorized. GSE represents a substantial portion of equipment costs and operating costs.

The United States is not alone in the quest for cleaner air and reduction in oil usage. The Committee on Japan's Experience in the Battle against Air Pollution, for example, describes dramatic environmental damage and degradation in Japan because of its rapid industrialization. The committee names a disease called Yokkaichi Asthma as the major turning point and impetus for the creation of The Compensation Law for Pollution Related Health Damage. Japan's cost to clean their air has been astronomical at $46.7 billion from 1966-1995, but asthma related diseases have been cut to less than half (Committee on Japan's Experience in the Battle against Air Pollution, 1997).

Statement of the Problem

Because of increasing use of electric GSE due to Government mandates to reduce airport air pollution, a study was deemed timely to determine if electric GSE is becoming a more favorable alternative to gas/diesel GSE in light of changes in fuel prices and the introduction of electric GSE fast-charging systems.

Purpose of the Study

The purpose of this study was to determine the influence on baggage tractor and belt loader life cycle costs in light of changes in fuel prices and the introduction of electric GSE fast-charging systems.

Objectives

1. Collect life cycle cost data (initial cost, operating cost, maintenance cost, and disposal cost) of GSE from previous studies.

2. Collect interview data from suppliers of fast-charging technology to gain a qualitative insight into the current GSE environment.

3. Update previous GSE life cycle cost studies to reflect current fuel prices and infrastructure cost changes due to the introduction of electric GSE fast-charging systems.

4. Calculate differences in life cycle cost and break-even point after the previous studies are updated to reflect changes in fuel cost and infrastructure cost associated with the introduction of fast-charging systems.

Scope and Limitations

The scope of this study includes two common types of GSE; belt loaders, and baggage tractors. As the most common types of GSE, these two vehicles have been the subjects of most previous studies.

The researcher accepts the following limitations:

Due to the geographical dispersal of interviewees, telephone interviews will be conducted.

Another cost limitation prevents collection of data from privately funded studies associated with electric GSE.

Definitions

Ampere Hours (Ah) – A measurement of electricity use.

Baggage Tractor (Tug) – A vehicle used to move luggage to the airport terminal baggage collection area and from the airport terminal to the aircraft.

Battery Electric Vehicle (BEV) – A vehicle powered by an electric motor, which derives its electricity from onboard batteries.

Belt Loader – A vehicle and conveyor belt combination that is used to lift luggage into and out of the aircraft.

Defense Advanced Research Projects Agency DARPA) – Established as ARPA in 1958. Present mission is to develop imaginative, innovative and often high-risk research ideas offering a significant technological impact that will go well beyond the normal evolutionary developmental approaches; and, to pursue these ideas from the demonstration of technical feasibility through the development of prototype systems.

Electric Ground Support Equipment (EGSE) – Electric-powered equipment used to service aircraft before and after flight operations.

Electric Vehicle (EV) – A vehicle powered totally or in part by an electric motor.

FAA Airport Improvement Program – Established as the Federal-Air Airport Program in 1946. Provides grants to public agencies—and in some cases, to private owners and entities—for the planning and development of public-use airports that are included in the National Plan of Integrated Airport Systems.

Fuel Cell – An electricity producing device which combines hydrogen and oxygen and releases water as a byproduct.

Hybrid Electric Vehicle (HEV) – Uses an internal combustion engine and an electric motor to propel the vehicle.

Internal Combustion Engine Ground Support Equipment (ICEGSE) – Gasoline or diesel powered GSE.

Inherently Low Emission Airport Vehicle (ILEAV) Pilot Program - Authorized by Congress in 2000 and offers the opportunity to evaluate low emission vehicle technology, refueling infrastructure, and how well they work in the airport environment.

Life Cycle Costs (LCC) - A combination of initial cost plus all ongoing costs of whatever design element is under consideration. Life cycle costs may be expressed in periodical units or as cumulative summations.

National Plan of Integrated Airport Systems (NPIAS) – Identifies more than 3,000 airports that are significant to national air transportation and thus eligible to receive Federal grants under the Airport Improvement Program.

State of Charge (SOC) – The percent of the total energy that can be stored in a battery or battery pack. 100 percent equals a full charge.

Zero Emission Vehicle (ZEV) – A vehicle, which does not directly produce toxic emissions. BEVs fall into this category. A true ZEV derives its electricity from a nonpolluting source such as a hydroelectric plant, wind generators, or solar collector.

CHAPTER II

REVIEW OF LITERATURE

Early History of Electric Vehicles

"The electric vehicle is not a recent development, In fact, the electric vehicle has been around for over 100 years, and it has an interesting history of development that continues to the present. France and England were the first nations to develop the electric vehicle (late 1800s). It was not until 1895 that Americans began to devote attention to electric vehicles. Many innovations followed as interest in motor vehicles increased greatly in the late 1890s and early 1900s. In 1897 the first commercial application was established as a fleet of New York City taxis. Early electric vehicles, such as the 1902 Wood's Phaeton, were little more than electrified horseless carriages and surreys. The Phaeton had a range of 18 miles, a top speed of 14 miles per hour and sold for $2,000" (U.S. Department of Energy, 1997).

"In 1898, the Electric Vehicle Company of New York used this unique station to load batteries into its vehicles. Battery packs were built up on wooden trays and then pushed into place and removed by a hydraulic ram. Ironically among today's most advanced proposals for electric vehicles is the idea of battery cassettes" (Kobe 1998).

"The years 1899 and 1900 were the high point of electric vehicles in America, as they outsold all other types of cars. Electric vehicles had many advantages over their competitors in the early 1900s. They did not have the vibration, smell, and noise associated with gasoline cars. Changing gears on gasoline cars was the most difficult part of driving, while electric vehicles did not require gear changes" (DOE 1997). "Electric vehicles enjoyed success into the 1920s with production peaking in 1912" (DOE 1997). "The decline of the electric vehicle was brought about by…The initiation of mass production of internal combustion engine vehicles by Henry Ford made these vehicles widely available and affordable" (DOE, 1997).

Related Technology: Hybrid Vehicles

Hybrid electric vehicle use is the only other widespread use of electric vehicles. Literature on hybrid electric vehicles was reviewed to quantify the overall use of electric vehicles. Toyota and Honda both produce hybrid electric vehicles.

"J.D. Power and Associates expects U.S. consumers to purchase approximately 350,000 hybrid vehicles annually by 2008…Hybrid sales are expected to reach 40,000 units in 2003 with only three hybrid electric models currently on the market. However, manufacturers are preparing to introduce a dozen new hybrid electric models over the next two years, and hybrid sales are expected to exceed 177,000 by 2005. A total of 28 models-18 truck and 10 car models-are expected to offer hybrid powertrain options in 2008" (Greywitt, 2003).

"Toyota was the first to introduce a production hybrid electric vehicle in the form of the compact Prius sedan in Japan in 1997. It made its debut in the North American market in 2000 and more than 120,000 Priuses have now been sold worldwide" (Batteries & Energy Storage Technology, 2003).

Related Technology: Fast Charging Systems

"Lack of charging infrastructure is a critical impediment to the accepted use of electric vehicles (EVs), and rapid charging stations are necessary to make EVs as practical as ICE (internal combustion engine) vehicles. Under agreements with DARPA, and DOT, the State of Hawaii, procured AeroVironment PosiCharge rapid charging stations for installation around the island of Oahu, with the goal of making the State of Hawaii "EV ready" through the installation of rapid charging infrastructure" (Quinn, Kim, Martin, 2003).

"Under the Inherently Low-Emission Airport Vehicle (ILEAV) program, the Department of Transportation (DOT) provides 50 percent of the cost of low-emission vehicles as well as the cost of refueling and recharging stations, up to a total of $2 million for each airport. "Each airport funds the remaining costs...The funds will be made available through the FAA's Airport Improvement Program..." Dewey Kulzer, Manager, GSE Technology Development, American Airlines when speaking of fast charging says, "They couldn't always make it through an operational day and needed individual chargers." The solution according to Kulzer and others lies in fast charge technology. "Parallel fast charging recharges in under one hour rather than eight hours. You can even charge during lunch breaks or run an emergency recharge for 10 minutes that can add two hours of operational life. Fast chargers also use one third of the power of conventional chargers and can charge up to 10 vehicles at one station" (Rowe, 2001).

Ground Support Equipment (GSE) Costs

Los Angeles Times

In a letter to the editor of the Los Angeles Times Alec N. Brooks, Vice President of Production for AC Propulsion Inc. writes, "Electricity costs typically a fifth as much as gasoline for a comparable vehicle" (1999).

American Airlines Study

David Woolley of American Airlines states, "Gasoline powered vehicles operate on average 4.5 hours/day for 365 days a year and consume two gallons of fuel per hour. Assuming the average fuel cost is approximately $1.15 per gallon, the yearly fuel cost for a gasoline GSE unit is $3778. Electric vehicles use on average 12 kilowatts of electricity per day. The average kilowatts/hour rate is 5 cents, for a total of 60 cents of electricity per day for 365 days per year. The yearly electricity cost for electric vehicles is $219" (Woolley, 2000).

Sacramento Airport Project

Kevin Morrow of Electric Transportation Engineering Corporation (ETEC) reports, "Funding for the project was provided by it's participants including California Air Resources Board (CARB), Defense Advanced Research Projects Agency (DARPA), Southwest Airlines (SWA), Sacramento Municipal Utility District (SMUD), Sacramento County Airport System, and ETEC. The project replaced Southwest's gasoline baggage tractors with twelve DC drive and one AC drive electric tractors. All vehicles relied on

ETEC's SuperCharge GSE-400MP, Multi-Port Fast Charge System for their recharging needs.... During the course of this project, ETEC demonstrated that fast charging reduced the average annual cost of "fueling" tractors. Southwest realized an annual savings of $1227 per tractor; between the cost of fuel and the cost of electricity...ETEC's SuperCharge system minimized the cost of electricity by charging up to 20 tractors from a single 100 amp, 480VAC circuit"(Morrow, 2002).

Major Air Carrier Studies cited by Bill Dean of Charlatte GSE

According to Charlatte's VP, Sales and Marketing, Bill Dean, studies by major air carriers show that the maintenance costs for such equipment is roughly half that of internal combustion engine vehicles. "Depending on use, this can result in savings from $1,000 to $4,000 per vehicle annually," he says, "When these savings are added to the various governmental incentives that promote zero emissions vehicles, the numbers are very attractive and estimates of capital return have shown payback in less than 36 months"(Rowe, 2001).

California Air Resources Board (CARB) Study

According to a major GSE study prepared for the California Air Resources Board called Assessment of Airport Ground Support Equipment Using Electric Power or Low-Emitting Fuels, by a research company called Arcadis Geraghty & Miller, 20 July 1999, Emissions of hydrocarbons (HC) and oxides of nitrogen (NOx) are especially problematic because they combine in the atmosphere to form ground-level ozone, or smog. In the South Coast Air Basin (California), the GSE contribution of 9 percent of the total HC and 14 percent of the total NOx shows that reducing emissions from this equipment sector would make an important contribution to California's air program. Improvements to airports suggested or required by tenants, for example addition of electric vehicle charging stations are subject to the approval of the airport's property management staff. Costs of improvements are often the tenants' responsibility, although at times airports will agree to share the cost. Another reason to switch to electric GSE, according to GSE manufacturers, is employee health and safety. "Baggage handler associations complain about the amount of emissions they are exposed to from the diesel and gasoline engines of baggage tractors, belt loaders and lifts while working in baggage handling facilities and in cargo holds of aircraft. GSE emissions are also seeping into the terminals and bothering travelers" (Charlatte, 1998).

TABLE 1

Life Cycle Costs from CARB Study

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Diesel Baggage Tractor	19000	2991	1461	4452		63520
Gasoline Baggage Tractor	16000	3342	1461	4803		64030
Electric Baggage Tractor	24250	4214	1522	5736		81610
Diesel Belt Loader	29000	2749	908	3657		65570
Gasoline Belt Loader	27000	2990	908	3898		65980
Electric Belt Loader	30000	2585	1154	3739		67390

Diesel vs. Electric baggage tractor LCC - Electric is: $18,090 higher
Diesel vs. Electric baggage tractor break-even point is: - 4.09 years
Gasoline vs. Electric baggage tractor LCC – Electric is: $17,580 higher
Gasoline vs. Electric baggage tractor break-even point is: - 8.84 years
Diesel vs. Electric belt loader LCC – Electric is: $1,820 higher
Diesel vs. Electric belt loader break-even point is: -12.20 years
Gasoline vs. Electric belt loader LCC – Electric is: $1,410 higher
Gasoline vs. Electric belt loader break-even point is: 18.87 years

The data for this analysis step was collected from a study prepared for the California Air Resources Board 1999. It will be referred to as the CARB study. A professional research company named Arcadis Geraghty & Miller, Inc. prepared the CARB study. The Non-Road Electric Vehicle Applications (NREVA computer model beta version) software organized and computed their data based on inputs provided by their researchers. The CARB study provides life cycle costs for baggage tractors and belt loaders, then goes on to relate the life cycle costs to emission reductions. The CARB study concludes that while electric GSE is more expensive than gas/diesel GSE, electric GSE becomes the less expensive option when pollution reductions are quantified with dollar amounts. The life cycle cost numbers in the CARB study portray electric GSE as more expensive to purchase and more expensive to operate. No valid break-even point exists in the CARB study because cumulative life cycle costs never become equal at any point during the life of the vehicles that are being compared.

This example depicts electric GSE life cycle costs as greater than gas/diesel GSE. Three of the examples reflect a negative number as a break-even point. This result means a break-even point will not occur during the vehicle lifetime. The fourth example computed a break-even point of 18.87 years, which also will not occur during the vehicle lifetime. According to the CARB study electric GSE will not pay for itself in the short-term or the long-term since electric GSE life cycle costs are initially higher than gas/diesel GSE and stay higher during the useful life of the vehicle.

As one of the first life cycle cost studies concerning electric GSE, the CARB study presented cost in a format that has changed over time. While contemporary thought acknowledges the fact that electric GSE requires recharging equipment and an initial set of batteries, the CARB study annualized these costs as maintenance costs whereas these costs are now capitalized along with the initial cost of the vehicle. The very recent developments in fast charging technology have greatly complicated the process of assigning charger equipment costs to individual electric GSE vehicles. Charger costs are shared among stakeholders, and one fast-charger can charge up to 20 vehicles at a time. The cost of the technology is significant, but it is becoming much less significant when calculating total life cycle costs of individual vehicles (Kamakate, Pera, & Unnasch, 1999).

Sierra Research Inc. Study

According to Sierra Research Inc., today total emissions from these three source categories hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and particulate matter (PM)) comprise on the order of 2-3 percent of total manmade emissions in a typical metropolitan area. Since there are no registration requirements for GSE or any other national organization charged with tracking GSE activity, there is no reliable database from which accurate GSE populations can be determined. Although there is an increase in offsite power generating station emissions resulting from the increased electrical demand required to recharge electric GSE, conversion to electric power or replacement with electric GSE can be a very effective emission reduction strategy. The majority of GSE continue to emit pollutants at essentially uncontrolled rates. Equipment that is in continuous or near-continuous service throughout the day will require quick turnaround battery replacement facilities, quick recharge capability or the availability of fully charged backup equipment. Initial purchase costs for electric GSE are high relative to their fossil fueled counterparts. The cost premium is almost entirely associated with the required battery pack and recharger. In addition to reduced fuel costs, the latest generation of electric GSE has demonstrated significantly reduced maintenance requirements. Costs could be reduced by a much as two-thirds relative to gasoline and diesel powered GSE.

TABLE 2

Life Cycle Costs from Sierra Research Study

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Diesel Baggage Tractor	22000	1712	2943	4655		68550
Gasoline Baggage Tractor	17000	3718	2943	6661		83610
Electric Baggage Tractor	30000	348	981	1329	4500	47790

Diesel vs. Electric baggage tractor LCC - Electric is: $20,760 lower
Diesel vs. Electric baggage tractor break-even point is: 2.83 years
Gasoline vs. Electric baggage tractor LCC – Electric is: $35,820 lower
Gasoline vs. Electric baggage tractor break-even point is: 2.69 years

The Sierra Research study was performed in 1998, during the same time period as the CARB study. These studies, both performed during the infancy of widespread electric GSE purchase, presumably were written to encourage electric GSE use and to encourage tax incentives for the purchase of electric GSE. Sierra Research and Energy & Environmental Analysis, Inc. prepared this study for the U.S. Environmental Protection Agency. The computer spreadsheet based computer program used in the Sierra Research study is called the GSE Model. The model was developed for use by metropolitan planning organizations, airports and other agencies interested in evaluating potential emission benefits and cost savings resulting from available GSE emission control technologies.

The CARB study was based on 6-8 years of useful life for GSE vehicles. The Sierra Research study was based on 16 years of useful life (Sierra Research Inc., 1998). This wide variation in vehicle lifetimes offers the possibility of using many different standards of useful life. This study uses a 10-year life cycle to standardize the life cycle.

EVS-17 Presentation on Southern California Edison Study

In a presentation at EVS-17 an Electric Vehicle Symposium in Montreal Canada, Dean Taylor summarizes findings from an Arthur D. Little – Acurex Environmental report. The report was prepared for Southern California Edison. The study used a computer software model provided by Energy Research Group and Boston Systems and Solutions, Inc. for EPRI. The model name is Non-Road Electric Vehicle Applications (NREVA). This model helps agencies estimate life cycle costs when submitting application for tax credits. The model includes costs not included in this study. Two costs that were relevant before fast charging are the battery cost for extra batteries, and the cost of the charger equipment. We presently find that fast charging deletes the requirement for extra batteries and that the fast charging system costs are shared among the airline, airport and electricity providers (Taylor, 2000).

Southern California Edison Study

Southern California Edison (SCE) studies show that electric vehicles convert 60 percent of energy into motion, internal combustion engine (ICE) 10 percent. ICE engine idling 20-70 percent of the operating time and 10-50 percent of fuel consumption. $3.97 to fuel EV belt loader/day. $8.18 to fuel ICE belt loader/day.

Maintenance Cost according to the SCE study are: Electric belt loader- $2.68/day or $978/year; Electric tug- $3.85/day or $1406/year; Gas Belt Loader- $3.19/day or $1165/year; Gas tug- $5.19 day or $1893/year (www.sce.com, 2003).

TABLE 3

Life Cycle Costs from SCE Study - Gasoline

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Gasoline Baggage Tractor	16000	2986	1893	4879		64790
Electric Baggage Tractor	30000	1449	1406	2855	2425	60975
Gasoline Belt Loader	27000	2986	1165	4151		68510
Electric Belt Loader	34000	1449	978	2427	2900	61170

Gasoline vs. Electric baggage tractor LCC - Electric is: $3,815 lower
Gasoline vs. Electric baggage tractor break-even point is: 7.98 years
Gasoline vs. Electric belt loader LCC – Electric is: $7,340 lower
Gasoline vs. Electric belt loader break-even point is: 4.99 years

This section provides calculations based on data from literature provided by Southern California Edison, and a study for Southern California Edison that was summarized in a presentation during EVS-17. The SCE study adds $10,000 to the cost of electric baggage tractors as incremental capital cost, $4,000 as cost of the charger, and $2425 as replacement battery cost. The SCE study adds $3,000 to the cost of electric belt loaders as incremental capital cost, $4,000 as cost of the charger, and $2,900 as replacement battery cost. The charger cost is capitalized and the cost of replacement batteries is added as disposal cost.

TABLE 4

Life Cycle Costs from SCE Study - Diesel

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Diesel Baggage Tractor	19000	2986	1893	4879		67790
Electric Baggage Tractor	33000	1449	1406	2855	2425	63975
Diesel Belt Loader	29000	2986	1165	4151		70510
Electric Belt Loader	36000	1449	978	2427	2900	63170

Diesel vs. Electric baggage tractor LCC - Electric is: $3,815 lower
Diesel vs. Electric baggage tractor break-even point is: 7.98 years
Diesel vs. Electric belt loader LCC – Electric is: $7,340 lower
Diesel vs. Electric belt loader break-even point is: 4.99 years

This step compares diesel baggage tractors and belt loaders to electric. The SCE study adds $10,000 to the cost of electric baggage tractors as incremental capital cost, $4,000 as cost of the charger, and $2425 as replacement battery cost. The SCE study adds $3,000 to the cost of electric belt loaders as incremental capital cost, $4,000 as cost of the charger, and $2,900 as replacement battery cost. The charger cost is capitalized and the cost of replacement batteries is added as disposal cost. The significant initial cost difference is the result of capitalizing the charger and battery cost into the purchase price. This was a standard practice when each vehicle needed its own charger.

AeroVironment Study

TABLE 5

Life Cycle Costs from AeroVironment Study

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Gasoline Baggage Tractor	20000	6023	5680	11703		137030
Electric Baggage Tractor	31749	887	2810	3697	4537	73256

Gasoline vs. Electric baggage tractor LCC - Electric is: $63,774 lower
Gasoline vs. Electric baggage tractor break-even point is: 2.03years

The total initial cost of the electric baggage tractor at $36,286 includes the cost of batteries at $9,074 plus the battery charger cost at $3,212 plus the base price of $24,000. The $20,000 initial cost of the gasoline baggage tractor does not include any additional costs. The operating cost of the electric baggage tractor uses an electricity cost of $0.09 per kilowatt hour (KWH). The operating cost of the gasoline baggage tractor uses a gasoline cost of $1.50 per U.S. gallon. The maintenance cost of both vehicles uses a labor rate of $45 per hour (AeroVironment, 2004).

Harlan Corporation Study

GSE Today reports current trends of all types of GSE including EVGSE. For example, an article by Judi Kaplan-Tauber, a Harlan Corporation employee estimates the ownership costs of a standard Ford 300 gas powered engine tractor over a 20 year life will be about $12,580 per year while the comparable Harlan electric powered tractor costs only $2255 per year. These size tractors can push/pull a fully loaded Boeing 737-300 up a 2 percent grade" (Kaplan-Tauber, 2001).

Summary

Electric Vehicles have seen limited and varied use since the late 19th century. The gasoline automobile however had better range and production costs were less than electric vehicles. Through recent computer technology advancements, two types of electric vehicles (the hybrid electric automobile and electric ground support equipment) have become a viable alternative to gasoline and diesel powered vehicles. The computerized charging systems of modern electric vehicles enable the vehicle technology to attain real-world usefulness. Fast charging systems allow 24-hour electric GSE operations at even the busiest airports. American Airlines, Delta Airlines, and Southwest Airlines own over 15,000 pieces of powered ground support equipment. The most common types of electric powered GSE are the baggage tractor (tug) and the belt loader, and are the subject of this study to compare life cycle costs.

CHAPTER III

PROCEDURES

Objectives

1. Collect life cycle cost data (initial cost, operating cost, maintenance cost, and disposal cost) of GSE from previous studies.

2. Collect interview data from suppliers of fast-charging technology to gain a qualitative insight into the current GSE environment.

3. Update previous GSE life cycle cost studies to reflect current fuel prices and infrastructure cost changes due to the introduction of electric GSE fast-charging systems.

4. Calculate differences in life cycle cost and break-even point after the previous studies are updated to reflect changes in fuel cost and infrastructure cost with the introduction of fast-charging systems.

Research Design

To accomplish the first objective of collecting life cycle costs from previous studies, searches of topics related to ground support equipment and electric vehicles were conducted using Internet search engines. Other topics such as GSE manufacturers, battery manufacturers, and battery charging systems manufacturers were also included in the searches. Many government agencies are driving the change to alternative fueled vehicles based on the desire to reduce air pollution and decrease our dependence on foreign oil, which provided another avenue of data through the Internet. The Department of Transportation, Federal Aviation Administration, Department of Energy, and the National Renewable Energy Laboratory (NREL) are all deeply involved in energy use.

Four major GSE studies were appropriated to accomplish the first objective. The main source for the previous studies was the Mid-Del Career Technology School. The school operates an electric vehicle training program that receives basically every piece of information associated with electric vehicles and other alternative fuel vehicles. Other articles referenced in the review of literature chapter also mainly come from seemingly endless stacks of periodicals and trade journals supplied by Mid-Del Career Tech. The previous study from AeroVironment was collected by telephone contact with individuals involved in production and sales of their Posicharger, the fast-charging equipment. This study was the most current of all studies, which is quickly evident in the price of gasoline that they used in the study.

The previous studies by Sierra Research, Southern California Edison, and for the California Air Resources Board were all prepared by or prepared for government entities or public utilities and not subject to copyrighting. Other studies produced by research companies, airlines or GSE manufacturers have been produced but not publicly available at zero cost.

All quantitative data was collected through literature review. The interviews supplied qualitative data that provided insight into life cycle cost changes in the daily operations of GSE.

Population and/or Sample

To accomplish the second objective GSE industry experts were interviewed to determine how GSE costs have changed since the development of fast-charging systems. One interview source comes from Allen and Associates; a company that supplies electric vehicle batteries as well as the ETEC supercharge fast-charging system. Because this interviewee works daily with battery and charger manufacturers as well as airlines, his knowledge of electric GSE is broad based. Of the two mass produced fast-charging systems, the ETEC Supercharge system and the AeroVironment Posicharge system this interviewee represented 50 percent of the sample size of the population.

The other interviewee represents the other 50 percent sample size of the population as working for AeroVironment, the manufacturer of the other fast-charging system, the Posicharge system. This second interviewee added additional value to the interview process because he previously worked for American Airlines as a manager and procurer of ground support equipment for the airline company. These two interviewees were recommended to me by Dewey Kulzer, an often quoted and recognized expert in the ground support equipment field in general and specifically that of electric GSE. Both interviewees together represent the entire population of fast-charger system suppliers.

Situation

The geographical limits of the study pertain to the United States. Other countries on the Pacific Rim and in Western Europe are deeply involved in electric vehicle use and research, but fall beyond the scope of this research. In an effort to contain communications costs, telephone interviews were only conducted with these two experts based in the continental United States.

The previous studies pertain to U.S. based major airlines. Major airlines today purchase electric GSE as new equipment purchases and after a specified time of ownership and depreciation, sell the equipment to smaller airlines. No previous studies were discovered that included GSE after being sold by major airlines.

The interviews were conducted by telephone due to the location of the subjects. One interviewee resides in Texas, while the other interviewee resides in Florida. While electric GSE is widely used at Will Rogers World Airport, the search for industry experts dictated going beyond the bounds of Oklahoma City. Southwest Airlines, for example, operates a totally electric ground support equipment operation at Will Rogers World Airport that established the first of its kind in the country.

Methods

The two interviewees obviously do not comprise the total population of everyone involved in the fast-charging industry, however each interviewee verbally demonstrated knowledge of their own charging equipment as well as the competitor's equipment. The interview responses demonstrated such complete knowledge of the GSE industry as a whole as to be nearly identical in content. Both interviewees discussed GSE use at length eager to share their knowledge for this academic pursuit.

Sampling Techniques

Although the interview questions request specific data, the atmosphere of the interviews was unstructured in purpose and content. While the interviewees undoubtedly have access to specific life cycle cost data, their knowledge base of GSE operations, and holistic overview of the air transportation industry provided the greatest input to the study. Interview questions rather than survey questions were selected for this study because interview questions encourage discussion instead of just specific responses. Interviewee insights into electric GSE use are very beneficial to the researcher who has only academic knowledge of GSE use and costs. The interviewees, as stakeholders in the electric vehicle, GSE and air transportation industry, understand the reasons behind life cycle cost changes.

Instrument Description

Interview Questions

The remainder of this paragraph illustrates the introductory remarks by the researcher to overview the study as a basis for interviewee responses. The research for this thesis requires data collection for Ground Support Equipment life cycle costs. The study includes two types of equipment: belt loader, and baggage tractor. The belt loader and baggage tractor have been the subjects for previous life cycle cost studies, which provides baseline data for this updated study. For each type of vehicle, analysis will include the main types of cost information: Initial Cost (purchase price), maintenance cost per year (parts and labor), operating cost per year (fuel cost) and disposal cost. Once the data is collected, life cycle costs will be calculated to produce a break-even point calculated in years as well as the total life cycle cost in dollars.

The following four items are the interview questions.

1. Is electric GSE more expensive or less expensive to purchase than gas/diesel equipment? What is the initial price difference between belt loaders, and baggage tractors for the two propulsion types?

2. I'm also collecting information concerning maintenance costs. Is electric GSE cheaper or more expensive to maintain? Do you have any examples of maintenance cost differences or even a ratio between costs?

3. My next question concerns operating costs. Operating costs relate mainly to fuel and electricity costs. Is electric GSE cheaper or more expensive to operate? Do you have examples or marketing data that I can use in my life cycle costs study?

4. My last questions refer to disposal costs. How do you compute disposal costs? What is the disposal cost for baggage tractors and belt loaders?

Instrument Development

This study is descriptive research. More specifically, this study is a developmental study to evaluate a trend based on changes over time. While this study establishes GSE cost trends in the previous five years the data cannot be extrapolated into the future and still maintain its established reliability and validity. The usefulness of this study does allow predictions based on the continuance of the established trend based on the new data. Anticipation of future fuel prices enable prediction of future gasoline/diesel GSE operating costs. The technological advancement of the fast-charging system allows supposition of future technological breakthroughs, which would translate to changes in the life cycle costs of electric GSE.

The previous studies, while not comparatively consistent in their life cycle cost analyses, provide the baseline on which to update life cycle costs with the new data of current fuel prices, and infrastructure cost changes due to fast-charging efficiency.

Instrument Reliability and Validity

Numerous Internet articles quoted leaders in the GSE industry, airline industry, and electric vehicle (EV) industry. GSE and EV professional journals, and periodicals also provide pieces of related life cycle cost data to enhance the validity of data by triangulation of the data. The interviews provided the direction and scope related to change of life cycle costs. Moreover, the interviews provide reliability to the study. If a future study examined GSE life cycle costs these interviewees or their counterparts would be the most eager and valuable interview subjects. Airline representatives are not proper interview subjects because Government pressure is requiring their change to electric GSE resulting in higher initial costs. GSE manufacturers are hesitant to participate because they sell either gas/diesel GSE or electric GSE with roughly the same profit margin and the quantity of sales is dictated by the state of the airline industry profits, not by the GSE powertrain type. Battery suppliers and fast-charging systems manufacturers are the business entities that benefit from electric GSE use and therefore eager to spend valuable time informing a researcher of costs and benefits of electric GSE use which makes them the most valid source of information.

Procedures for Gathering Data, Including Confidentiality

These interview questions are to bring forth responses from experts in the field of GSE. Much of the baseline data is derived from previous studies of ground support equipment. Also, Internet data searches revealed many Government agencies associated with electric vehicle research and development, and testing. Internet searches also produced articles with partial studies. As evidenced in the introduction letter and IRB compliance documents in the appendix, the interview participants' identities will remain confidential and only known to the researcher. IRB compliance documents were sent via email, and the signed copies were returned via email and regular mail.

Data Analysis Techniques

Statistical and Mathematical Procedures

To satisfy the third objective to update the costs from previous studies based on the new data of current fuel costs, and new infrastructure costs based on the introduction of fast-charging equipment, a spreadsheet based series of formulas computed life cycle costs of gas/diesel GSE and electric GSE for data from the previous studies as well as producing the results for this updated study.

Each step of data analysis involves the following mathematical computations as well as a resulting chart to graphically depict the mathematical solutions. This type of data analysis is referred to as "Solving Systems of Linear Equations". The first computation of each separate analysis step involves presentation of the raw data, then the addition of the life cycle cost elements depicting the overall life of each vehicle. The total life of each vehicle is defined in this study as 10 years to provide service life as a constant. Various studies estimated service life of GSE to be anywhere from 6.5 years to 12 years. A standard of 10 years allows relevant visual interpretation of comparisons depicted graphically on the x – y charts. The slope of the line depicting the life cycle costs starting from year 1 costs through each annual period, and the break-even point are both computed mathematically with these two equations:

$$m = (y2 - y1) / (x2 - x1)$$

and

$$y = m x + b$$

The first equation: $m = (y2 - y1) / (x2 - x1)$ solves for "m", which stands for the slope of a line. The slope or "m" represents how quickly the line is rising or descending. This formula is solved for each type of equipment. Two types of equipment are compared in each set of computations and for each chart. The slope of each vehicle life cycle cost is required for the next step, which is to simultaneously solve the second set of linear equations for each vehicle type.

The second equation: $y = m x + b$ is called the "slope – intercept" form, and will use the results from the first formula to solve for the point where the two equations are equal. By solving the two equations simultaneously (one equation for each vehicle compared) the equality point is established. This point represents the break-even point. Starting from the point in time that each vehicle is purchased up to the break-even point, one vehicle will be more cost advantageous than the other. Beyond the break-even point, the other vehicle will be more cost advantageous.

When the two formulas are compared, the resulting information shows a comparison of total life cycle costs and the point in time where both GSE options have the same financial advantage. Purchase decisions should ultimately be based upon cash flow analysis for short term, and total life cycle costs for long term.

The following example equations depict each step of solving the systems of linear equations to first calculate the slope of the life cycle cost lines, and then the break-even point specified in years. These equations show the spreadsheet formulas that compute the break-even point for a diesel powered baggage tractor and an electric powered baggage tractor.

The first step is to find the slope of the line for each vehicle type being compared.
Diesel baggage tractor
$m = (y2 - y1) / (x2 - x1) = 3500$ = slope of the line.
Electric baggage tractor
$m = (y2 - y1) / (x2 - x1) = 1033.333$
As a built in test of the calculations as performed by the spreadsheet, "m" should equal annualized costs.

The second step is to solve both linear equations together for x (break-even point) by the addition method.
$y = m\,x + b = 3500x + 19000$
$-y = -m\,x - b = -1033.333x - 27000$
$3500x - 1033.333x = 27000 - 19000$
$2466.667x = 8000$
$x = 3.24$ years = break-even point
As a built in test of the calculations as performed by the spreadsheet, "b" should equal initial cost of each vehicle.

The values for "m" and "b" are automatically inserted into their respective equations by the spreadsheet formulas. The value for "y", which is the vehicle cost (in dollars) at the break-even point, is not a factor in this study and is removed from the calculation by multiplying one whole equation by (–1) and thereby removing "y" and "-y" from the solution.

The appendix spreadsheets depict the specifically developed tables and charts and formulas for finding the break-even point for both vehicles and the individual life cycle costs of each vehicle. The first table depicts initial cost, operating costs per year, maintenance costs per year, total annual costs, disposal cost and total life cycle costs for each specific type of GSE. The second table depicts cumulative life cycle costs from year 1 to year 10. Data from these two tables is used to develop the associated charts. The charts give a visual depiction of the total life cycle costs, the break-even point, as well as a yearly comparison of life cycle costs. Each chart is accompanied by the above mathematical computations to solve the linear equations, which produce the slope of the lines and the break-even point for that specific chart.

The source data required for input into the first table consists of the initial cost, operating cost per year, maintenance cost per year, and disposal cost. Computerized spreadsheet formulas designed specifically for this data analysis then populate the second table, produce the charts, and solve the systems of linear equations.

Initial cost is the purchase price of a piece of GSE. The purchase price varies somewhat with optional equipment such as additional instrumentation, or auxiliary lighting but variances in price are not substantial or traceable within the scope of this study. Pricing from one manufacturer to another is similar enough to not be a factor in this study.

Operating costs are annualized costs of vehicle use and are variable costs tied to hours of use or miles driven per year. This study includes fuel cost and electricity cost in calculating operating costs. Operating costs are averaged for this study, and accumulated over the standardized life cycle of the vehicle.

Maintenance costs are parts and labor for vehicle repair and preventive maintenance. Examples of preventive maintenance are oil changes for gas/diesel vehicles, or battery inspection and watering for electric vehicles. Maintenance costs are annualized costs, are averaged for this study, and accumulated over the standardized life cycle of the vehicle.

Disposal cost as reported in more than one interview is not a factor to major airlines. Once a GSE vehicle has reached a pre-specified point of operational use, the vehicle is sold to another airline that continues to use the vehicle for an unknown (to the researcher) period of time. Electric GSE batteries are disposed of at some point in the life cycle of the vehicle at significant cost. Disposal costs are depicted at the end of the standardized life cycle in this study since the actual number of hours of use and subsequent depletion of the battery varies for each vehicle type and airport of usage. The actual year of battery replacement normally falls around the 6.5-year point, but batteries sometimes last up to 8 years or longer. Some industry experts believe recent refinement in fast charging technology may allow batteries to last throughout the complete usable life of an electric GSE vehicle. The process of adding disposal costs to the last year of the life cycle cost analysis produces a nonlinear line. Since the break-even point, if a viable factor in purchasing decisions will fall far short of the last year, disposal costs are not responsible for any variation in the break-even point.

Life cycle cost is the sum of initial cost, annual operating costs, annual maintenance costs, and disposal cost. Life cycle costs are a significant factor involved in strategic GSE purchasing decisions for an airline. This study computes life cycle costs as they accumulate over the 10-year life cycle, which allows the graphical depiction and mathematical computation of the life cycle cost break-even point. The break-even point is the most important consideration for GSE purchase decision-making during these brutal financial times for America's airlines. This study shows the significance of how costs determine the break-even point. This study also illustrates graphical depiction of the difference in life cycle costs. The graphs show that a quick payback period by an early break-even point may or may not reflect a significant difference in total life cycle costs. This fact shows the importance of making purchasing decisions not only on short-term vision, but also on long-term significant financial advantages.

Limitations

One limitation of the study is the cost limitation, which precludes face-to-face interviews with the interviewees because of their geographical dispersal. Another cost limitation prevents collection of data from privately funded studies associated with electric GSE. While a funded research study may have the money and staff to directly observe and record daily GSE life cycle costs at each airport, this student-funded study is limited to motivated interview subjects and publicly available life cycle cost studies.

Summary

The first step of the study is to collect quantitative data from previous studies. The second step is to collect qualitative data from the suppliers of the fast-charger systems. The third step is to update the previous studies with the new life cycle cost data gained by the interviews and review of literature. The new data is comprised of current fuel costs, and infrastructure cost changes with the advent of fast-charging systems. The fourth step is to calculate the differences in life cycle cost and break-even point after the previous studies are updated to reflect changes in fuel cost and infrastructure cost associated with the introduction of fast-charging systems.

Four previous studies establish the baseline of life cycle costs associated with the belt loader and baggage tractor. The two interview subjects represent both manufacturers of fast-charging systems. The mathematical computations to complete the update to the previous studies were performed by a researcher developed computer spreadsheet that uses initial cost, annual costs (operating cost, and maintenance cost), and disposal cost to compute total life cycle costs for each piece of ground support equipment. The custom formulas in the spreadsheet template also calculate the break-even point between like equipment. For example, a gas powered baggage tractor has a different life cycle cost structure than its associated counterpart that is electric powered. If the equipment with a lower initial cost also has higher annual costs than its counterpart, at some point in time their life cycle costs will be equal. This is defined as the break-even point. From the break-even point onward, the equipment with the higher initial cost has lower total life cycle costs. The comparison of life cycle costs from the previous studies to the updated studies defines the trend in life cycle cost changes.

CHAPTER IV

FINDINGS

Data Analysis: CARB study

TABLE 6

Life Cycle Costs Updated from CARB Study

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Diesel Baggage Tractor	19000	4746	1461	6207		81070
Gasoline Baggage Tractor	16000	5966	1461	7427		90270
Electric Baggage Tractor	24250	3299	1522	4740		72460
Diesel Belt Loader	29000	3686	908	4594		74940
Gasoline Belt Loader	27000	4313	908	5221		79210
Electric Belt Loader	30000	2174	1154	3234		63280

Diesel vs. Electric baggage tractor LCC - Electric is: $8,610 lower
Diesel vs. Electric baggage tractor break-even point is: 3.79 years
Gasoline vs. Electric baggage tractor LCC – Electric is: $17,810 lower
Gasoline vs. Electric baggage tractor break-even point is: 3.17 years
Diesel vs. Electric belt loader LCC – Electric is: $11,660 lower
Diesel vs. Electric belt loader break-even point is: 0.79 years
Gasoline vs. Electric belt loader LCC – Electric is: $15,930 lower
Gasoline vs. Electric belt loader break-even point is: 1.58 years

This step of data analysis is to use the CARB study data, but to update the data to more accurately reflect today's electric vehicle (EV) environment in charging technology and update fuel costs to current prices. The CARB study, which was performed in 1999, calculated electric ground support equipment costs using costs typical to that time period. Present electric GSE recharging equipment is far superior to that of only five years ago. Fast charging technology increases battery life and negates the need for extra batteries, which were needed to allow electric GSE to perform all their daily duties. A common practice in the early years of electric GSE use was to purchase three sets of batteries. One set was used in the vehicle, another set was being recharged, and the third set sat ready to be installed on the vehicle. The CARB study specified annualized charger costs for electric baggage tractors as $915 per year, and $411 per year for belt loaders. These specific costs were subtracted from the operating costs for these updates to the CARB study. The CARB study also specified annualized gasoline and diesel fuel prices as $0.806 and $0.746 respectively. Current fuel prices of $1.50 per gallon were used to update operating costs for gas/diesel GSE. These fuel prices are conservative averages considering the pricing in several large cities hovers well over $2.00 per gallon. Initial cost remained the same in the findings as with the raw data from the study. No reference was made in the CARB study that the recharger cost was capitalized into the initial cost. Rather, the charger cost was annualized. This annualized cost was deducted from operating cost in this update.

Data Analysis: Sierra Research study

TABLE 7

Life Cycle Costs Updated from Sierra Research Study

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Diesel Baggage Tractor	22000	3950	2943	6893		90930
Gasoline Baggage Tractor	17000	7435	2943	10378		120780
Electric Baggage Tractor	24000	348	981	1677	4500	41790

Diesel vs. Electric baggage tractor LCC - Electric is: $49,140 lower
Diesel vs. Electric baggage tractor break-even point is: 0.39 years
Gasoline vs. Electric baggage tractor LCC – Electric is: $78,990 lower
Gasoline vs. Electric baggage tractor break-even point is: 0.82 years

This analysis step updates the study performed by Sierra Research to delete the tax incentives for fuel, and to reduce electric GSE costs related to battery charger cost. Battery cost is listed as $4,500 in the Sierra Research study. To develop a number for charger cost, the battery replacement charge was subtracted from an average price differential between gas/diesel GSE and electric GSE initial costs. The charger cost is determined to be $6,000 for the purposes of this study. This charger cost has been removed from the initial cost of the electric baggage tractor, while the gas and diesel vehicle initial cost remains the same as in the original Sierra Research study. The Sierra Research study included repair/replacement costs, while the CARB study did not. These costs are listed as disposal costs following the practice of standardized life cycle cost analysis. To use a parallel format of other studies, repair costs of gas/diesel GSE have not been included in this update. The disposal cost for the electric baggage tractor has been changed to include only the cost of replacement batteries as defined in the Sierra Research study.

Fuel costs were updated to $1.50 per gallon for both gasoline and diesel to reflect today's price. The Sierra Research study used $0.75 for the gasoline price, and $0.65 for diesel. The charge to reflect current gas and diesel prices increased the operating cost of the gas/diesel GSE. Maintenance costs remained the same in the update to the original study.

Data Analysis: SCE study (gas)

TABLE 8

Life Cycle Costs Updated from SCE Study (gas)

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Gasoline Baggage Tractor	16000	2986	1893	4879		64790
Electric Baggage Tractor	26000	1449	1406	2855	2425	56975
Gasoline Belt Loader	27000	2986	1165	4151		68510
Electric Belt Loader	30000	1449	978	2427	2900	57170

Gasoline vs. Electric baggage tractor LCC - Electric is: $7,815 lower
Gasoline vs. Electric baggage tractor break-even point is: 5.7 years
Gasoline vs. Electric belt loader LCC – Electric is: $11,340 lower
Gasoline vs. Electric belt loader break-even point is: 2.14 years

This step of data analysis is to use the SCE study data, but to update the data to more accurately reflect today's electric vehicle (EV) environment in charging technology. The SCE study adds $10,000 to the cost of electric baggage tractors as incremental capital cost, $4,000 as cost of the charger, and $2425 as replacement battery cost. The SCE study adds $3,000 to the cost of electric belt loaders as incremental capital cost, $4,000 as cost of the charger, and $2,900 as replacement battery cost. The charger cost is capitalized and the cost of replacement batteries is added as disposal cost.

In this analysis step, Gasoline baggage tractors and belt loaders are compared to electric. The battery charger cost has not been calculated as part of the life cycle costs for electric GSE in this update to the original study. As defined in the assumptions and explained in the review of literature, chargers now service many vehicles, and the airlines as well as other stakeholders share the charging equipment costs. Operating costs were not changed because the SCE study did not address how fuel costs were calculated. Maintenance costs were not changed either. Disposal cost reflects the battery replacement costs as defined in the original study.

Data Analysis: SCE study (diesel)

TABLE 9

Life Cycle Costs Updated from SCE Study (diesel)

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Diesel Baggage Tractor	19000	2986	1893	4879		67790
Electric Baggage Tractor	29000	1449	1406	2855	2425	59975
Diesel Belt Loader	29000	2986	1165	4151		70510
Electric Belt Loader	32000	1449	978	2427	2900	59170

Diesel vs. Electric baggage tractor LCC - Electric is: $7,815 lower
Diesel vs. Electric baggage tractor break-even point is: 5.7 years
Diesel vs. Electric belt loader LCC – Electric is: $11,340 lower
Diesel vs. Electric belt loader break-even point is: 2.14 years

This step of data analysis is to use the SCE study data, but to update the data to more accurately reflect today's electric vehicle (EV) environment in charging technology. The SCE study adds $10,000 to the cost of electric baggage tractors as incremental capital cost, $4,000 as cost of the charger, and $2425 as replacement battery cost. The SCE study also adds $3,000 to the cost of electric belt loaders as incremental capital cost, $4,000 as cost of the charger, and $2,900 as replacement battery cost. The charger cost was capitalized in the SCE study and the cost of replacement batteries added as disposal cost.

In this analysis step, Diesel baggage tractors and belt loaders are compared to electric. The $4,000 cost of charging equipment has been removed from the initial cost of the electric vehicles and the initial cost of the diesel vehicles has been kept constant. As defined by the review of literature and interview comments, chargers now service many vehicles, and the airlines as well as other stakeholders share the charging equipment costs. Operating costs were not changed because the SCE study did not fully address how fuel costs were calculated. Maintenance costs were not changed either. The battery replacement costs were added as disposal costs and no changes made for this update.

Data Analysis: AeroVironment Inc.

TABLE 10

Life Cycle Costs Updated from AeroVironment Study

	Initial Cost	Operating Cost/yr	Maintenance Cost/yr	Annual Costs	Disposal Cost	Life Cycle Cost
Gasoline Baggage Tractor	20000	6023	5680	11703		137030
Electric Baggage Tractor	28537	887	2810	3697	4537	70044

Gasoline vs. Electric baggage tractor LCC - Electric is: $66,986 lower
Gasoline vs. Electric baggage tractor break-even point is: 1.14 years

This step of data analysis is to use the AeroVironment study data, but to update the data to more accurately reflect today's electric vehicle (EV) environment in charging technology. The gas baggage tractor initial cost remained the same, while the initial cost of the electric baggage tractor has been reduced by an amount equal to the stated cost of the charging equipment at $3,212. In addition, while not changing the life cycle cost structure, one half the cost of batteries as previously shown as part of the initial cost was moved to disposal cost to more accurately reflect allocation of the $9,074 cost of batteries. Operating costs remained the same in this update as in the original study since $1.50 per gallon is a current fuel price. The electricity cost for the electric GSE reflected current prices. Maintenance costs remained the same in this update as in the original study. The labor rate was specified in the original study at $45 per hour for both vehicle types.

Interviews

The interviews represent qualitative data rather than quantitative data. Due to the highly competitive airline and aircraft support markets after 9/11, interviewees were reluctant to provide cost information. The information provided by the interviewees did support the basis of this study and provided insightful qualitative remarks. The interview questions are directed at initial cost, maintenance costs, operating costs, and disposal costs of GSE.

1. Is electric GSE more expensive or less expensive to purchase than gas/diesel equipment? What is the initial price difference between belt loaders, and baggage tractors for the two propulsion types?

Interviewee 1: Cash strapped airlines still struggle with the higher initial cost of electric GSE even though in the long run electric GSE life cycle costs are lower. Whereas a gasoline powered baggage tractor costs $15,000 - $18,000 and a diesel baggage tractor is $22,000 - $23,000, the electric baggage tractor initially costs $22,000 - $24,000 not including $8,000 for the required batteries.

Interviewee 2: Airline companies alone are not totally responsible for the cost of electric GSE infrastructure costs. The ILEAV program paid for the fast charging equipment at Midway Airport in Chicago. Fast charging equipment is the required type of charging equipment to comply with ILEAV procedures.

2. I'm also collecting information concerning maintenance costs. Is electric GSE cheaper or more expensive to maintain? Do you have any examples of maintenance cost differences or even a ratio between costs?

Interviewee 1: While much of the maintenance cost increase for gas/diesel GSE is attributable to the greater number of moving parts in an ICE vehicle, a significant increase in maintenance costs is directly related to use and misuse of gas/diesel GSE. Electric vehicles normally require a drive train of some type unless the electric motor is attached directly to a wheel. The drive train of an electric vehicle is not composed of multiple belts and gears like that of an ICE vehicle. An ICE vehicle produces power in only a limited range of engine rotation. To operate the vehicle at different speeds, a transmission is required to change the overall gear ratio between the engine and the wheels. An electric motor operates efficiently and effectively in such a wide range of rotational speeds, a transmission is not normally required. The transmission of gas/diesel GSE vehicles takes a beating during normal operations. Drivers use the reverse gear to bring the vehicle to a quick stop instead of using brakes. This observation is not logical to automobile drivers and brakes are certainly less expensive to replace than transmissions. Electric GSE on the plus side must come to a full stop before the drive train can reverse itself.

Another occurrence on the airport ramp the favors electric GSE concerns the starter motor. Too often a GSE operator will run an ICE vehicle out of fuel and leave the vehicle where it sits. The operator from the next shift will sometimes completely ruin a starter motor, battery, and alternator trying to start an empty vehicle. While this does not happen every day at every airport, this problem is obvious.

Interviewee 2: Batteries last for varying time periods depending more on their design and periodic maintenance than on the type of charging technology used. Batteries that are routinely discharged below 20% state of charge do not last nearly as long as batteries that are properly charged. Fast charging does help in this respect because opportunity charging quickly charges batteries in deep discharge states and opportunity charging reduces the chance of running a battery into deep discharge. Conventional batteries require periodic maintenance more often than maintenance free or gel cells. All batteries require some maintenance since battery cables and terminals must be inspected, tightened or replaced at some point in time.

According to this source, “1000 ampere hours (ah) can’t replace 3000 ah”. What this means is that one battery being fast charged will not last longer than each of three batteries that are being conventionally charged and rotated into a vehicle every eight hours. His point is that of trade-offs again. Fast charging is one way to allow a vehicle to perform all its required duties, and battery swapping is another way. Fast charging is much more convenient and less costly in terms of maintenance costs since battery swapping is a maintenance cost.

The fast charger monitors internal battery temperature so as to keep temperature to 140 degrees Fahrenheit or less. Since they use 480 volts, 3 phase power as their input and use a 15-kilowatt transformer with 80-volt output; the power output becomes 188 amperes. The temperature monitoring technique makes the fast chargers possible.

3. My next question concerns operating costs. Operating costs relate mainly to fuel and electricity costs. Is electric GSE cheaper or more expensive to operate? Do you have examples or marketing data that I can use in my life cycle costs study?

Interviewee 1: Electric GSE is so much more cost effective in the long term that airline companies realize that when profitability increases again, vastly increased electric GSE numbers will be attainable.

A battery pack requiring 6 hours of charging time can be recharged in 1.5 hours with a fast charger station. This equates to nearly a full recharge of a vehicle while the driver is taking a lunch or dinner break. The battery pack can be brought up to at least 50% charge during a 10-minute coffee break. This "opportunity charging" is the single most important factor in the allocation of continuous use electric GSE at hub airports that require nearly 24-hour operations.

Electric GSE operating costs are much less than gas/diesel GSE operating costs. While loading and unloading operations are taking place, the ICE belt loader engine is running because the engine must power the integrated conveyor belt, which lifts and lowers baggage to and from each aircraft. In fact, the belt loader sits idling for much of the day and night. The distinct advantage of the electric belt loader is that the drive motor only operates while the vehicle is actually in motion. An auxiliary electric motor, which requires only a fraction of the electricity of the drive motor, powers the conveyor belt only while loading and unloading operations are taking place. Energy is not wasted on an electric belt loader when it is not in motion and only a small amount of energy is used while the belt is in motion.

Interviewee 2: Conventional charging technology inputs electricity into a battery at a rate of up to 85 ampere hours per hour (ah/hour) while fast charging does up to 300 ah/hour.

4. My last questions refer to disposal costs. How do you compute disposal costs? What is the disposal cost for baggage tractors and belt loaders?

Interviewee 1: Disposal costs for GSE are not really a factor for the major airlines. They use the equipment, and then sell it to smaller airlines.

Interviewee 2: GSE normally uses three battery types. Conventional lead-acid batteries, maintenance free lead-acid batteries, and gel cells, which are another type of lead-acid battery, are the three most often used types of batteries for electric GSE. Conventional batteries last the longest, followed by maintenance free, and gel cells having the shortest life expectancy. On the average an electric GSE battery lasts 6.5 years, with some batteries lasting up to eight years or possibly more. The cost of battery replacement is $5,000 for conventional lead-acid batteries to $8,000 for maintenance free batteries.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Statement of the Problem

Because of increasing use of electric GSE due to Government mandates to reduce airport air pollution, a study was deemed timely to determine if electric GSE is becoming a more favorable alternative to gas/diesel GSE in light of changes in fuel prices and the introduction of electric GSE fast-charging systems.

Purpose of the Study

The purpose of this study was to determine the influence on baggage tractor and belt loader life cycle costs in light of changes in fuel prices and the introduction of electric GSE fast-charging systems.

Objectives

1. Collect life cycle cost data (initial cost, operating cost, maintenance cost, and disposal cost) of GSE from previous studies.

2. Collect interview data from suppliers of fast-charging technology to gain a qualitative insight into the current GSE environment.

3. Update previous GSE life cycle cost studies to reflect current fuel prices and infrastructure cost changes due to the introduction of electric GSE fast-charging systems.

4. Calculate differences in life cycle cost and break-even point after the previous studies are updated to reflect changes in fuel cost and infrastructure cost associated with the introduction of fast-charging systems.

Summary of Findings

A summarization of the findings includes a quantitative summary since most of the collected data was quantitative. A required portion of the summarization must also included qualitative tasks because of the wide variation in data as collected. A common ground of data does exist, however the conclusions cannot be made as a function of computing variance or standard deviation of the data. These results would be misleading and incomplete.

The following summary reflects the variation in life cycle costs among the previous studies from Chapter II, Review of Literature. The variation in costs stems from different methodology used in the previous studies, as well as different inputs into their respective computer models used to develop their data.

Life Cycle Cost Summary for Raw Data

Diesel baggage tractor costs ranged from:	$63,520 to $68,550
Gasoline baggage tractor costs ranged from:	$64,030 to $137,030
Electric baggage tractor costs ranged from:	$47,790 to $81,610
Diesel belt loader costs ranged from:	$65,570 to $70,510
Gasoline belt loader costs ranged from:	$65,980 to $68,510
Electric belt loader costs ranged from:	$61,170 to $67,390

The following summary reflects the variation in life cycle costs among the previous studies as specified in Chapter IV, Findings. In general comparison of the following summary with the previous summary, gas/diesel GSE costs have increased with the increase in fuel costs with updated data, and electric GSE costs have decreased with the reduction in initial cost due to removal of battery charger cost with the updated data.

Life Cycle Cost Summary for Updated Data

Diesel baggage tractor costs ranged from:	$67,790 to $90,930
Gasoline baggage tractor costs ranged from:	$64,790 to $137,030
Electric baggage tractor costs ranged from:	$41,790 to $72,460
Diesel belt loader costs ranged from:	$70,510 to $74,940
Gasoline belt loader costs ranged from:	$68,510 to $79,210
Electric belt loader costs ranged from:	$57,170 to $63,280

GSE vehicles have approximately the same initial cost today as when the previous studies were completed in 1999. Some variation in price is due to optional equipment installed on purchase. Due to the staleness of the airline industry in general and the GSE industry in particular, pricing strategy has dictated constant pricing in hopes of some vehicle sales. Variation in electric GSE pricing is mainly due to whether or not each individual study included the cost of batteries with the vehicle cost, and additionally whether or not the past study included the cost of charging equipment into the initial cost. One of the goals of this study was to subtract the cost of charging equipment from the cost of electric GSE vehicles. These cost summaries were obtained from the review of literature.

Gas/diesel GSE operating costs fluctuated greatly because this study compared life cycle costs using fleet vehicle tax credits for gasoline and diesel fuel as well as costs without the tax credits. Electric GSE operating costs varied because some studies unknowingly added battery cost and charger cost to operating costs rather than capitalizing these costs.

Belt loaders were not included into as many studies as were baggage tractors, which partially explain the standardized the maintenance costs. Incomplete data in some studies required carrying forward maintenance costs into these studies from previous studies. Baggage tractor maintenance costs varied as a function of generalized maintenance cost estimates from previous studies.

Disposal costs were not included in some studies and could not be ascertained from any narrative in the previous studies. Electric GSE disposal costs, when included, referred not to the disposal cost of the complete vehicle since the vehicles are sold, but rather to battery disposal/replacement costs. Disposal costs for gas/diesel GSE were included in this study to factor in commonality between electric and gas/diesel vehicles. Disposal costs as calculated for gas/diesel GSE included either replacement of the vehicle or major repair of the vehicle.

Life cycle costs are of course the sum of initial cost, operating cost, maintenance cost, and disposal cost. Belt loader costs varied the least and gasoline baggage tractor costs varied most. The majority of the fluctuation in gas/diesel baggage tractors comes from the fluctuation in the previous studies. Computer models were used in these previous studies without complete disclosure of all inputs into the computer models. The next most significant fluctuation in life cycle costs is from fuel costs. One of the assumptions is that fuel tax credits should be removed from life cycle cost studies to more aptly compare gas/diesel GSE and electric GSE on common ground and to compare them vehicle to vehicle without tax incentives or infrastructure costs. When current, retail fuel prices were plugged into previous studies, operating costs of gas/diesel GSE more than doubled in some cases.

Conclusions

The findings of this study in general matched expected results. Initial cost, and disposal costs are higher for electric GSE, but operating costs and maintenance costs are much lower than for gas/diesel GSE. Cost fluctuations from one study to the next were significant, and based largely on complex computer model inputs that were unexplained in these previous studies. The overall goal for the early GSE life cycle cost studies was however, to calculate a baseline life cycle cost and then use the complex computer model to relate the life cycle costs to reductions in airport air pollutants. The overall results of these previous studies showed significant cost advantages for electric GSE when taking pollutants into account, since electric vehicles emit zero pollutants during operation. Gas/diesel GSE on the other hand has historically been unregulated for tailpipe emissions, which produced in some cases, poorly tuned and poorly maintained overly polluting vehicles.

Recent innovations in charging technology have increased electric GSE advantages to allow their use on a 24-hour basis, if required. Fast charging allows opportunity charging during coffee breaks and lunch breaks, whereas conventional charging required extra batteries to be replaced during a workday. These extra battery purchases increased capital costs and maintenance costs. Fast charging also allows multiple vehicle charging simultaneously at a single charging station, while each vehicle required a single dedicated charger when using conventional charging. These advantages have reduced electric GSE life cycle costs to allow a distinct real-world advantage over gas/diesel GSE.

Another update of life cycle costs in this study, calculated gasoline and diesel fuel costs at current prices. When fuel prices and infrastructure costs were updated, the break-even point became, in many cases, almost immediate. Operating costs and reduced capitalized costs became so advantageous to electric GSE as to quickly negate the gas/diesel GSE advantage of lower initial cost. Only the studies for the California Air Resources Board and from Sierra Research included documented fuel costs that were definitely not current prices. The Southern California Edison and AeroVironment studies either reflected current fuel prices or in the case of the Southern California Edison study, did not designate the origin of fuel costs.

The differences in life cycle costs and the break-even points are significantly different between the first two studies listed and the second two studies because of the change or lack of change in fuel costs. Conclusions are achievable from all four studies even though they are much different.

As shown in the following examples, a change in fuel cost affects a significant change in life cycle costs because fuel costs are annualized. The significance of fuel cost increases applies to the future use of gas/diesel GSE and to most of our current modes of transportation at large. As reported by every study of fuel costs and fuel availability, fuel costs will continue to increase, and fuel availability is limited. Petroleum resources will someday disappear and will become very expensive before they disappear. This study illustrates that electric GSE becomes more advantageous as fuel prices increase.

Lower electric GSE maintenance also contributed to the much faster break-even point. Realistically, maintenance costs on a brand new gas/diesel vehicle and comparable electric vehicle would be similar initially. Maintenance costs are very low and possibly nonexistent during the vehicle warranty period for both gas/diesel GSE and electric GSE. Life cycle costs were averaged over the life of these vehicles for this study, but vehicle maintenance costs actually increase at a nonlinear rate. Maintenance costs increase at an increasing rate as a vehicle ages. All sources of data averaged maintenance costs over the vehicle lifetimes, which dictated the same procedures here.

The charts, as calculated by the spreadsheet tables are found in appendix E. These charts give a visual depiction of total life cycle cost differences as well as a visual depiction of the break-even point for each set of vehicles compared.

TABLE 11

Life Cycle Cost Differences in CARB Study Before and After Update

	Electric LCC was	Electric LCC is	Difference
Diesel Baggage Tractor	$18,090 higher	$8,610 lower	$26,700
Gasoline Baggage Tractor	$17,580 higher	$17,810 lower	$35,390
Diesel Belt Loader	$1,820 higher	$11,600 lower	$13,420
Gasoline Belt Loader	$1,410 higher	$15,390 lower	$17,340

TABLE 12

Break-even Point Differences in CARB Study Before and After Update

	Break-even Point was	Break-even Point is	Difference
Diesel Baggage Tractor	None	3.79 Years	Indefinable
Gasoline Baggage Tractor	None	3.17 Years	Indefinable
Diesel Belt Loader	None	0.79 Years	Indefinable
Gasoline Belt Loader	18.87 Years	1.58 Years	17.29 Years

The difference in life cycle costs and break-even points are dramatic in the CARB study. The CARB study as originally reported, defined fuel costs significantly lower than current costs, which led to a large change in life cycle costs after the update. The CARB study also annualized the cost of battery charging equipment at a rate higher than other studies. The break-even points changed from values outside the normal life cycle to meaningful numbers.

TABLE 13

Life Cycle Cost Differences in Sierra Research Study Before and After Update

	Electric LCC was	Electric LCC is	Difference
Diesel Baggage Tractor	$20,760 lower	$49,140 lower	$28,380
Gasoline Baggage Tractor	$35,820 lower	$78990 lower	$43,170

TABLE 14

Break-even Point Differences in Sierra Research Study Before and After Update

	Break-even Point was	Break-even Point is	Difference
Diesel Baggage Tractor	2.83 Years	0.39 Years	2.44 Years
Gasoline Baggage Tractor	2.69 Years	0.82 Years	1.87 Years

The study by Sierra Research that was performed for the U.S. Environmental Protection Agency also designated fuel prices lower than current prices. Average fuel prices have changed even during the preparation of this study. The $1.50 per gallon used in this study is definitely a conservative number. The cost of battery charging equipment was also significant in the original Sierra Research study. This is not to say the cost of battery charging equipment was out of line. Before the implementation of fast-charging equipment, each piece of electric GSE required a dedicated battery charger.

The Sierra Research study differs from the CARB study in that the original computations provided break-even points that fell within the normal life cycle of GSE. Notice the break-even points decrease to less than one year. Realistically, gas/diesel GSE has no advantage over electric GSE, especially upon examination of the total life cycle cost savings.

TABLE 15

Life Cycle Cost Differences in SCE Study Before and After Update

	Electric LCC was	Electric LCC is	Difference
Diesel Baggage Tractor	$3,815 lower	$7,815 lower	$4,000
Gasoline Baggage Tractor	$3,815 lower	$7,815 lower	$4,000
Diesel Belt Loader	$7,340 higher	$11,340 lower	$4,000
Gasoline Belt Loader	$7,340 higher	$11,340 lower	$4,000

TABLE 16

Break-even Point Differences in SCE Study Before and After Update

	Break-even Point was	Break-even Point is	Difference
Diesel Baggage Tractor	7.98 Years	5.7 Years	2.28 Years
Gasoline Baggage Tractor	7.98 Years	5.7 Years	2.28 Years
Diesel Belt Loader	4.99 Years	2.14 Years	2.85 Years
Gasoline Belt Loader	4.99 Years	2.14 Years	2.85 Years

The Southern California Edison study, along with the AeroVironment study, only allows a change in battery charging equipment costs. The AeroVironment study defined fuel costs using current prices and the Southern California Edison study did not define the origin of the fuel prices. The results therefore only show the difference in cost of charging equipment. The cost of charging equipment was stated at $4,000 in the SCE study, which results in the same difference in life cycle costs. The break-even point changed by more than two years, which changed the payback period for belt loaders to half the previous time period.

TABLE 17

Life Cycle Cost Differences in AeroVironment Study Before and After Update

	Electric LCC was	Electric LCC is	Difference
Gasoline Baggage Tractor	$63,774 higher	$66,986 lower	$3,212

TABLE 18

Break-even Point Differences in AeroVironment Study Before and After Update

	Break-even Point was	Break-even Point is	Difference
Gasoline Baggage Tractor	2.03 Years	1.14 Years	0.89 Years

A notable conclusion after examination of the results of the Southern California Edison study and the AeroVironment study is the high degree of influence that fuel prices have on life cycle costs. Noting the advantage of fast-charging equipment is informative and beneficial to GSE purchasing decisions, but the importance of fuel price changes is the potential to predict future life cycle cost differences. Gas/diesel prices will continue to rise over time as a function of their availability. Fossil fuel is a nonrenewable and finite resource. The price will always rise as time passes, making electric GSE an increasingly favorable option.

Recommendations

Based on this research, electric GSE is the exclusive purchase decision. Recent advancements in fast charging technology negate previous electric GSE shortcomings. This recommendation is based on the comparison of total life cycle costs as well as the computed break-even point, which was solved mathematically using systems of linear equations.

Interviews with industry leaders revealed qualitative information not accessible through research of past studies. Interview information was completely current, and although interviews were conducted over the telephone, honest insightful opinions aided the quantitative analysis of the mathematical findings.

Electric GSE having a higher initial cost seems to affect buying decisions. Basic vehicle cost between gasoline, diesel and electric powered vehicles is very similar. The increased electric GSE cost originates in the battery that is required for operation. A past phenomenon that also increased vehicle cost has been the capitalization of the vehicle charger into the vehicle cost as well as up to two additional sets of back-up batteries. While the cost of the original battery and replacement battery before the end of the life cycle are still legitimate costs, the charger cost is no longer a factor when computing individual vehicle life cycle costs.

Ongoing costs such as operating costs and maintenance costs are much reduced through the use of electric GSE. A review of the studies shows a wide variation in ongoing costs, but based on interview comments gas/diesel vehicles are realistically 2-3 times more expensive to operate and maintain. Gas/diesel vehicle maintenance costs have been proven over time. Electric vehicle data collection for maintenance costs is still changing as a function of the still improving nascent technology. Battery systems account for part of the variability in electric GSE maintenance costs. Conventional lead acid batteries are the least expensive purchase option, but require regular watering. Sealed lead acid batteries are more expensive, but require less maintenance. Gel cell batteries require the least maintenance but are the most expensive lead acid option. Airlines purchase different types of batteries for electric GSE based on strategic management planning to either pay more initially for lower maintenance batteries, or buy the lesser expensive batteries and suffer the higher maintenance costs. Battery manufacturers have developed other battery options such as nickel-metal hydride batteries, lithium-ion and lithium polymer batteries. These battery options allow very large increases in performance along with a price closely associated to the performance increase.

Interviews also addressed GSE disposal costs. The universal expert opinion is that disposal costs are not a consideration for a major airline, because GSE is sold at a predetermined point in time before the vehicle usefulness is exhausted. GSE gets passed on to smaller airlines, which are not the subject of this research. Disposal costs as included in this study include only battery disposal and replacement costs, and in those studies including these costs, associated repair or replacement costs of gas/diesel GSE.

To support the recommendation of electric GSE purchase comes as much from the personal interviews than the previous studies. Previous studies were performed for tax credit appropriation. Interview sessions quickly became one-on-one conversations of how the industry as a whole is fairing.

Additional research is recommended related to airport planning and management to assess the impact of increased electricity use on the airport ramp area. While fast charging equipment makes efficient use of the electricity grid, the increase in electric GSE will soon overstress existing electrical infrastructure.

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APPENDIXES

APPENDIX A

INSTITUTIONAL REVIEW BOARD

APPROVAL FORM

Oklahoma State University
Institutional Review Board

Protocol Expires: 10/30/2004

Date: Friday, October 31, 2003 IRB Application No ED0449

Proposal Title: A Comparative Study of Life Cycle Costs for Electric/Internal Combustion Engine GSE

Principal
Investigator(s):

Daniel W. Stephens	Steven Marks
12512 Shire Lane	300 Cordell North
Okla. City, OK 73170	Stillwater, OK 74078

Reviewed and
Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

Dear PI :

Your IRB application referenced above has been approved for one calendar year. Please make note of the expiration date indicated above. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved projects are subject to monitoring by the IRB. If you have questions about the IRB procedures or need any assistance from the Board, please contact me in 415 Whitehurst (phone: 405-744-5700, colson@okstate.edu).

Sincerely,

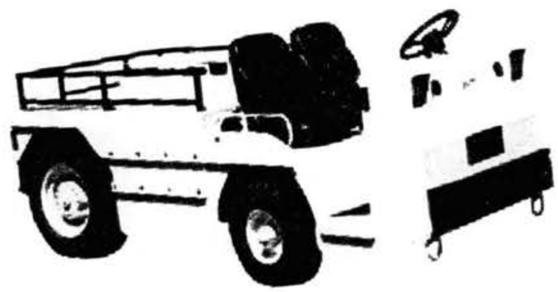
Carol Olson

Carol Olson, Chair
Institutional Review Board

APPENDIX B

A BAGGAGE TRACTOR AND A BELT LOADER

Baggage Tractor



Belt Loader

APPENDIX C

PARTICIPATION LETTER

Introduction Letter

My name is Daniel Stephens. I am a doctoral student at Oklahoma State University working toward my doctorate of Education (Ed.D.) in Aviation and Space Education. I am presently in the process of gathering information for my doctoral dissertation on ground support equipment life cycle costs. The title of my dissertation is:

A Comparative Study of Life Cycle Costs of Selected Electric Powered Ground Support Equipment and Internal Combustion Engine Powered Ground Support Equipment.

The research interview questions for my dissertation are not personal in nature and my thesis will make no written connection between you and the information that you provide. Ensuring confidentiality is a standard procedure for conducting research with educational goals. This is not a funded study but is for completion of my academic requirements for the Doctorate of Education degree. The information that I need only involves GSE cost information that you may have available and that which you are able to share with me. Thank you for your participation in this research.

Daniel W. Stephens
Doctoral student
Oklahoma State University

APPENDIX D

CONSENT FORM

INFORMED CONSENT DOCUMENT

A. AUTHORIZATION

Example:

I,______________________, hereby authorize or direct Daniel Stephens,
or associates or assistants of his or her choosing, to perform the following treatment or procedure.

B. DESCRIPTION OF RESEARCH AND ASSOCIATED RISKS/BENEFITS

1. The title of the research project is A Comparative Study of Life-Cycle Costs for Electric Powered Ground Support Equipment and Internal Combustion Engine Powered Ground Support Equipment.
2. This study involves research and is being conducted through Oklahoma State University. My name is Daniel Stephens and I am a doctoral student at OSU conducting this research into ground support equipment costs.
3. The purpose of this research is to gather information concerning initial cost, maintenance cost, and operating cost of GSE to compare costs between electric GSE and gas/diesel powered GSE. The interview process should last twenty minutes or less.
4. The interview procedure utilizes open-ended questions concerning general or specific cost information related to GSE. The interviewer realizes that some participants will have general information while others will have more specific information concerning cost data.
5. None of the procedures are experimental.
6. Subjects will not have any foreseeable risks or discomfort.
7. The benefits of this study to the subjects while not direct in nature may prove over time to be beneficial to electric GSE use. Society also benefits from the cleaner air from decreased use of gas/diesel engines to power GSE at airports.
8. N/A
9. The researcher will ensure protection of interview responses by maintaining personal possession of all responses. The researcher will maintain the confidentiality of research records and subjects. Subjects will not be directly cited in the research paper, but their respective industry and a number will identify each subject.
10. N/A
11. If the subject requires information about the research, contact: Daniel Stephens, OSU doctoral student, Phone: 405-692-9639. Additional contact for information concerning the research subjects rights or related injury to the subject: Sharon Bacher, IRB Executive Secretary, Oklahoma State University, 415 Whitehurst, Stillwater, OK 74078. Phone: 405-744-5700.

C. VOLUNTARY PARTICIPATION

Example:

I understand that participation is voluntary and that I will not be penalized if I choose not to participate. I also understand that I am free to withdraw my consent and end my participation in this project at any time without penalty after I notify the project director. Contact: Daniel Stephens, OSU doctoral student, Phone: 405-692-9639.

D. CONSENT DOCUMENTATION FOR WRITTEN INFORMED CONSENT

Example:

I have read and fully understand the consent form. I sign it freely and voluntarily. A copy has been given to me.

Date: ______________________________ Time:
(a.m./p.m.)

____

Name (typed) Signature

____

Signature of person authorized to sign for subject, if required

Witness(es) if required: ____

____

I certify that I have personally explained all elements of this form to the subject or his/her representative before requesting the subject or his/her representative to sign it.

Signed: ____

Project director or authorized representative

APPENDIX E

TABLES AND CHARTS

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Diesel Baggage Tractor	19000	2991	1461	4452		63520
Gasoline Baggage Tractor	16000	3342	1461	4803		64030
Electric Baggage Tractor	24250	4214	1522	5736		81610
Diesel Belt Loader	29000	2749	908	3657		65570
Gasoline Belt Loader	27000	2990	908	3898		65980
Electric Belt Loader	30000	2585	1154	3739		67390

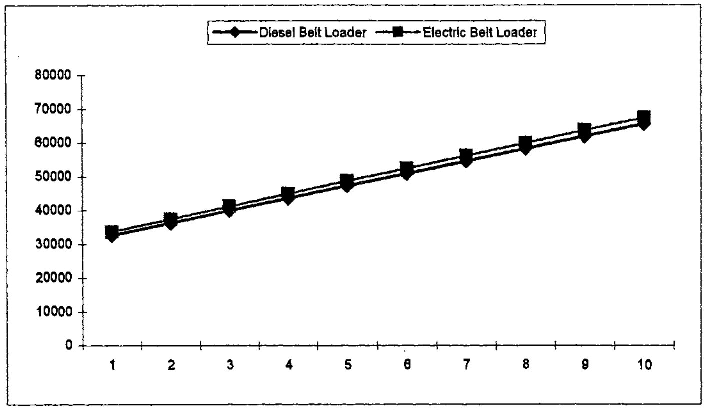
Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Diesel Baggage Tractor	23452	27904	32356	36808	41260	45712	50164	54616	59068	63520
Gasoline Baggage Tractor	20803	25606	30409	35212	40015	44818	49621	54424	59227	64030
Electric Baggage Tractor	29986	35722	41458	47194	52930	58666	64402	70138	75874	81610
Diesel Belt Loader	32657	36314	39971	43628	47285	50942	54599	58256	61913	65570
Gasoline Belt Loader	30898	34796	38694	42592	46490	50388	54286	58184	62082	65980
Electric Belt Loader	33739	37478	41217	44956	48695	52434	56173	59912	63651	67390

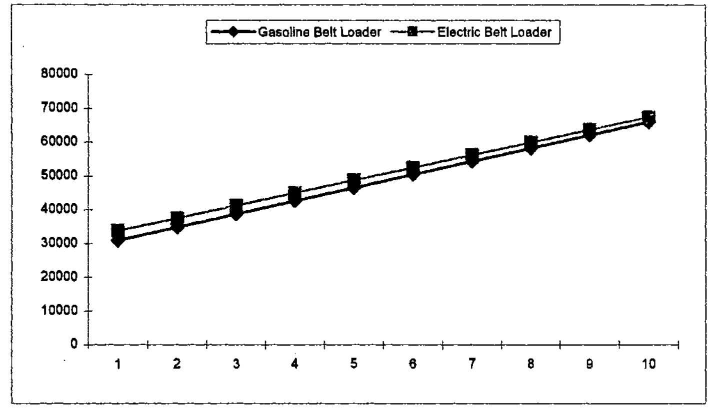
Table for Charting Cumulative Costs

CARB Study Raw Data

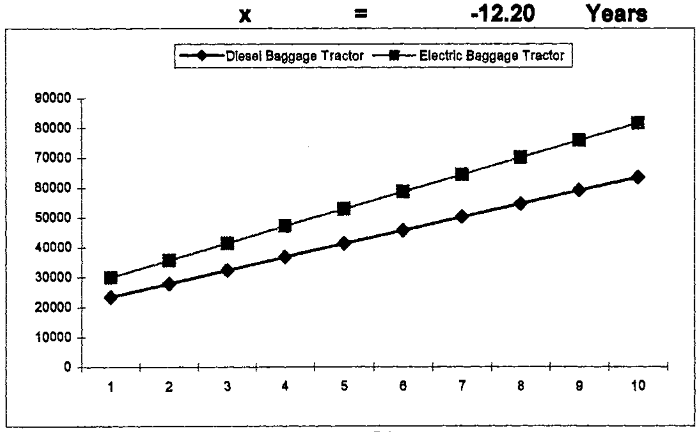
CARB study Raw Data



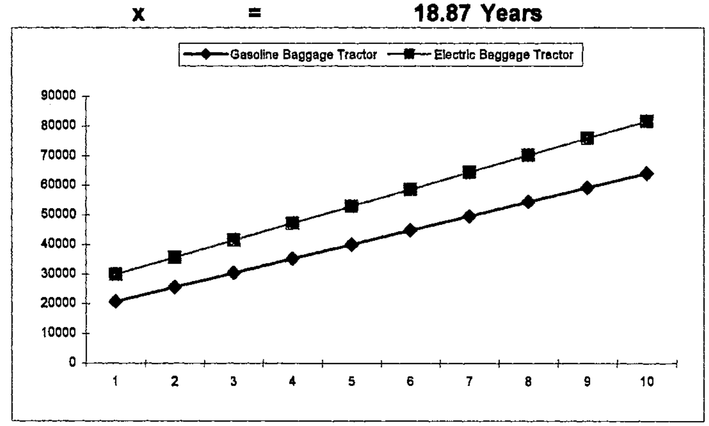
Diesel				Electric		
m= (y2-y1)/(x2-x1)				m= (y2-y1)/(x2-x1)		
m= 3657				m= 3739		
3657 x	+	29000	=	3739 x	+	30000
-82 x			=	1000		
		x	=	**-12.20**	**Years**	



Gasoline				Electric		
m= (y2-y1)/(x2-x1)				m= (y2-y1)/(x2-x1)		
m= 3898				m= 3739		
3898 x	+	27000	=	3739 x	+	30000
159 x			=	3000		
		x	=	**18.87 Years**		



Diesel				Electric		
m= (y2-y1)/(x2-x1)				m= (y2-y1)/(x2-x1)		
m= 4452				m= 5736		
4452 x	+	19000	=	5736 x	+	24250
-1284 x			=	5250		
		x	=	**-4.09 Years**		



Gasoline				Electric		
m= (y2-y1)/(x2-x1)				m= (y2-y1)/(x2-x1)		
m= 4803				m= 5736		
4803 x	+	16000	=	5736 x	+	24250
-933 x			=	8250		
		x	=	**-8.84 Years**		

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Diesel Baggage Tractor	22000	1712	2943	4655		68550
Gasoline Baggage Tractor	17000	3718	2943	6661		83610
Electric Baggage Tractor	30000	348	981	1329	4500	47790

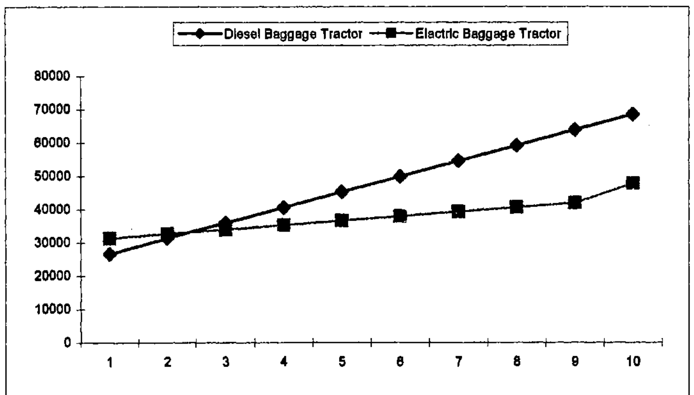
Table Depicting Life Cycle Costs

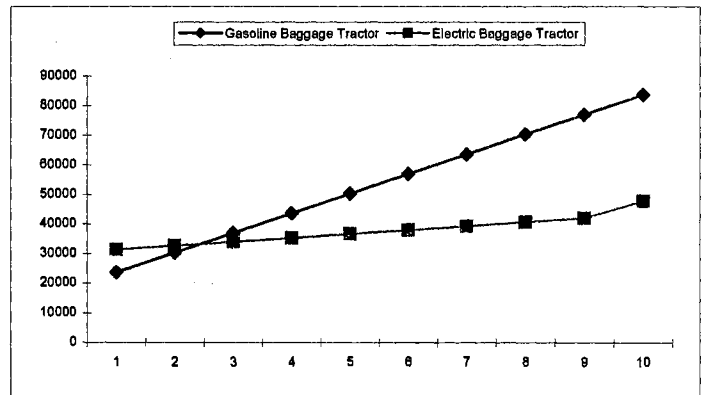
Equipment	1	2	3	4	5	6	7	8	9	10
Diesel Baggage Tractor	26655	31310	35965	40620	45275	49930	54585	59240	63895	68550
Gasoline Baggage Tractor	23661	30322	36983	43644	50305	56966	63627	70288	76949	83610
Electric Baggage Tractor	31329	32658	33987	35316	36645	37974	39303	40632	41961	47790

Table for Charting Cumulative Costs

Sierra Research Study Raw Data

Sierra Research
Study Raw Data





Diesel			Electric					Gasoline			Electric		
m=	(y2-y1)/(x2-x1)		m=	(y2-y1)/(x2-x1)				m=	(y2-y1)/(x2-x1)		m=	(y2-y1)/(x2-x1)	
m=	4655		m=	1829				m=	6661		m=	1829	
4655	x +	22000	=	1829	x +	30000	6661	x +	17000	=	1829	x +	30000
	2826	x	=	8000				4832	x	=	13000		
		x	**=**	**2.83**	**Years**				**x**	**=**	**2.69**	**Years**	

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Gasoline Baggage Tractor	16000	2986	1893	4879		64790
Electric Baggage Tractor	30000	1449	1406	2855	2425	60975
Gasoline Belt Loader	27000	2986	1165	4151		68510
Electric Belt Loader	34000	1449	978	2427	2900	61170

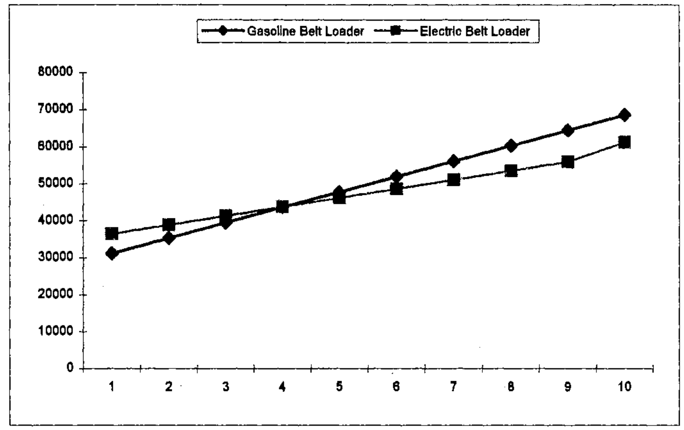
Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Gasoline Baggage Tractor	20879	25758	30637	35516	40395	45274	50153	55032	59911	64790
Electric Baggage Tractor	32855	35710	38565	41420	44275	47130	49985	52840	55695	60975
Gasoline Belt Loader	31151	35302	39453	43604	47755	51906	56057	60208	64359	68510
Electric Belt Loader	36427	38854	41281	43708	46135	48562	50989	53416	55843	61170

Table for Charting Cumulative Costs

SCE study gas/elec Raw Data

SCE gas/elec study Raw Data



Gasoline

m= (y2-y1)/(x2-x1)

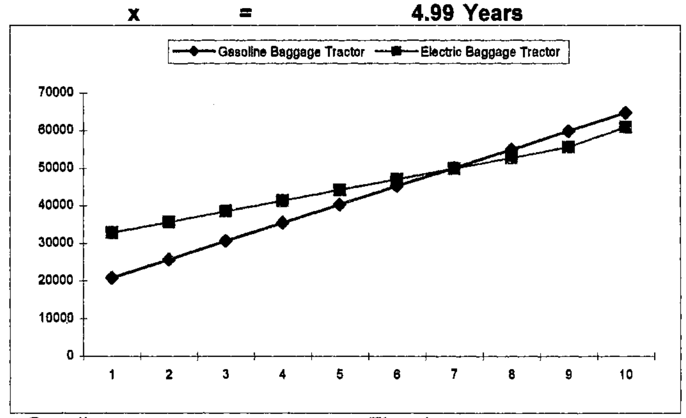
m= 4151

Electric

m= (y2-y1)/(x2-x1)

m= 2749.222

4151	x	+	27000	=	2749.222 x	+	34000
1401.778	x			=	7000		
			x	**=**	**4.99 Years**		



Gasoline

m= (y2-y1)/(x2-x1)

m= 4879

Electric

m= (y2-y1)/(x2-x1)

m= 3124.444

4879 x	+	16000	=	3124.444	x	+	30000
1754.556 x			=	14000			
x			**=**	**7.98 Years**			

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Diesel Baggage Tractor	19000	2986	1893	4879		67790
Electric Baggage Tractor	33000	1449	1406	2855	2425	63975
Diesel Belt Loader	29000	2986	1165	4151		70510
Electric Belt Loader	36000	1449	978	2427	2900	63170

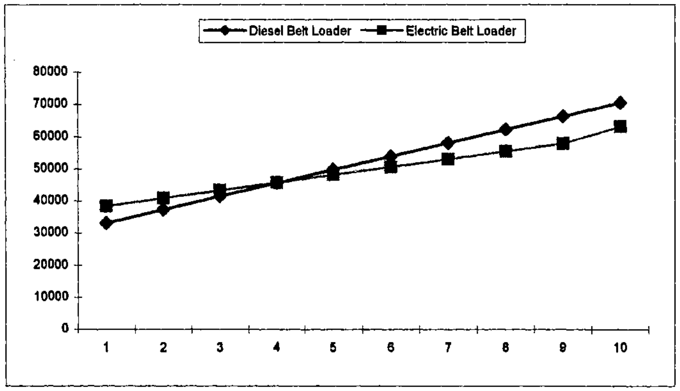
Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Diesel Baggage Tractor	23879	28758	33637	38516	43395	48274	53153	58032	62911	67790
Electric Baggage Tractor	35855	38710	41565	44420	47275	50130	52985	55840	58695	63975
Diesel Belt Loader	33151	37302	41453	45604	49755	53906	58057	62208	66359	70510
Electric Belt Loader	38427	40854	43281	45708	48135	50562	52989	55416	57843	63170

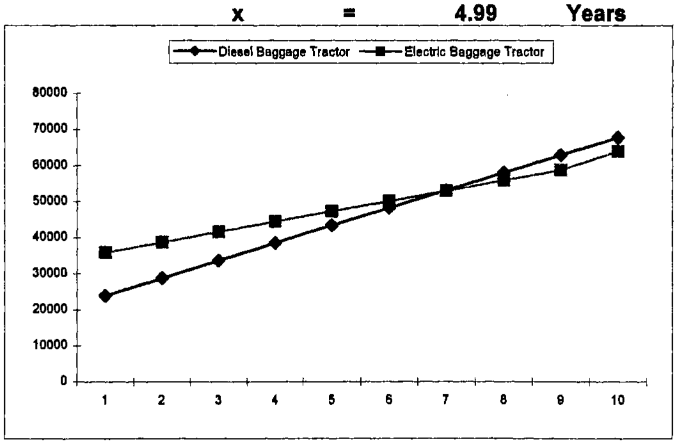
Table for Charting Cumulative Costs

SCE study diesel/elec Raw Data

SCE study
Diesel/elec Raw Data



Diesel				Electric			
	m= (y2-y1)/(x2-x1)				m= (y2-y1)/(x2-x1)		
	m= 4151				m= 2749.222		
4151 x		+	29000	=	2749.222 x	+	36000
1401.778 x				=	7000		
			x	=	**4.99**	**Years**	



Diesel				Electric			
	m= (y2-y1)/(x2-x1)				m= (y2-y1)/(x2-x1)		
	m=	4879			m= 3124.444		
4879 x		+	19000	=	3124.444 x	+	33000
	1754.556 x			=	14000		
			x	=	**7.98**	**Years**	

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Gasoline Baggage Tractor	20000	6023	5680	11703		137030
Electric Baggage Tractor	36286	887	2810	3697		73256

Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Gasoline Baggage Tractor	31703	43406	55109	66812	78515	90218	101921	113624	125327	137030
Electric Baggage Tractor	39983	43680	47377	51074	54771	58468	62165	65862	69559	73256

Table for Charting Cumulative Costs

AeroVironment Raw Data

AeroVironment study
Raw Data

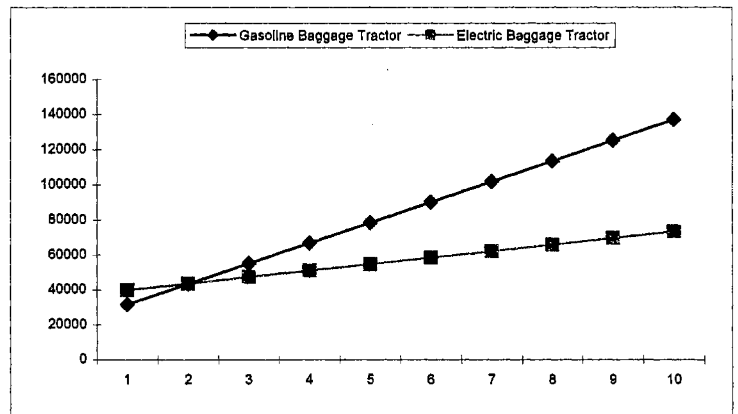


	Chart depicting Gasoline vs Electric Baggage Tractor					
	Gasoline			Electric		
	m=	(y2-y1)/(x2-x1)		m=	(y2-y1)/(x2-x1)	
	m=	11703		m=	3697	
11703	x +	20000	=	3697	x +	36286
	8006	x	=	16286		
		x	**=**	**2.03**	**Years**	

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Diesel Baggage Tractor	19000	4746	1461	6207		81070
Gasoline Baggage Tractor	16000	5966	1461	7427		90270
Electric Baggage Tractor	24250	3299	1522	4821		72460
Diesel Belt Loader	29000	3686	908	4594		74940
Gasoline Belt Loader	27000	4313	908	5221		79210
Electric Belt Loader	30000	2174	1154	3328		63280

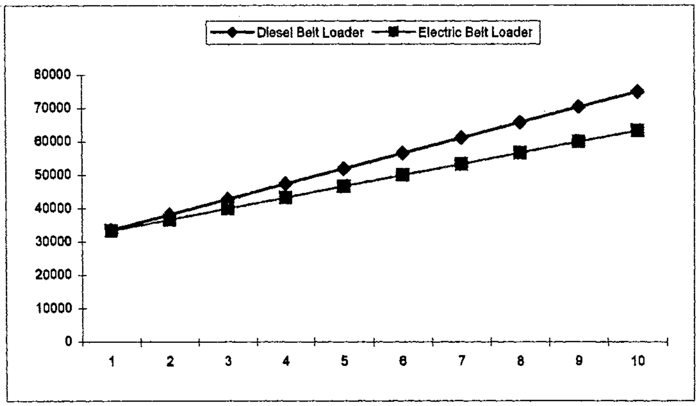
Table Depicting Life Cycle Costs

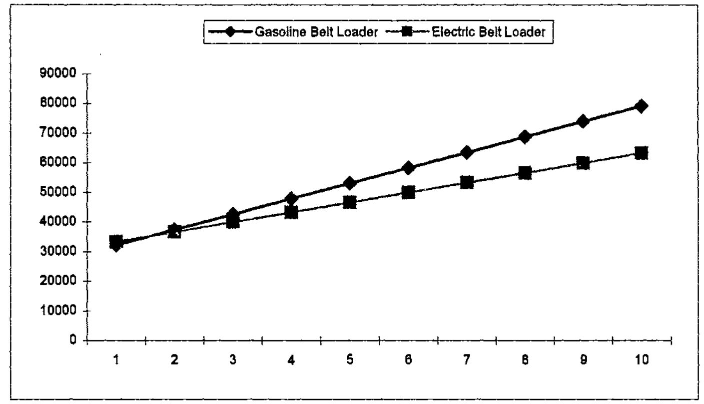
Equipment	1	2	3	4	5	6	7	8	9	10
Diesel Baggage Tractor	25207	31414	37621	43828	50035	56242	62449	68656	74863	81070
Gasoline Baggage Tractor	23427	30854	38281	45708	53135	60562	67989	75416	82843	90270
Electric Baggage Tractor	29071	33892	38713	43534	48355	53176	57997	62818	67639	72460
Diesel Belt Loader	33594	38188	42782	47376	51970	56564	61158	65752	70346	74940
Gasoline Belt Loader	32221	37442	42663	47884	53105	58326	63547	68768	73989	79210
Electric Belt Loader	33328	36656	39984	43312	46640	49968	53296	56624	59952	63280

Table for Charting Cumulative Costs

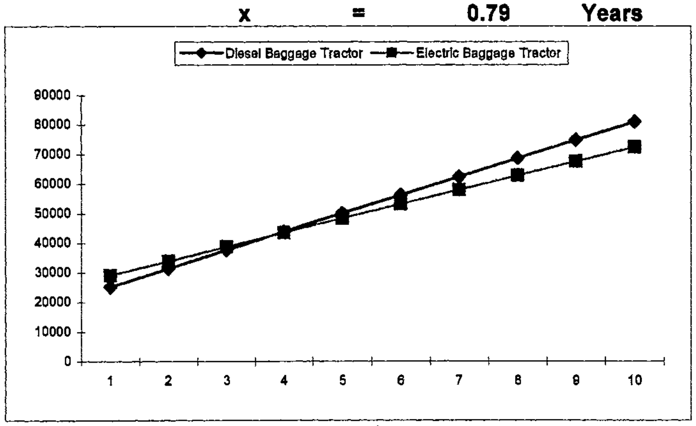
CARB study - updated

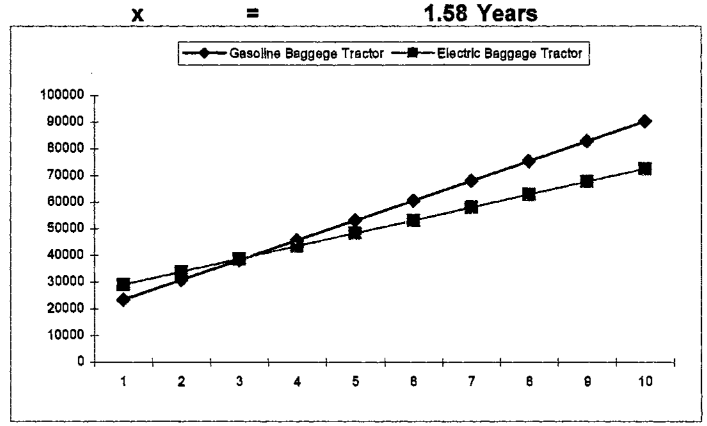
CARB study updated





Diesel		Electric		Gasoline		Electric	
m= (y2-y1)/(x2-x1)		m= (y2-y1)/(x2-x1)		m= (y2-y1)/(x2-x1)		m= (y2-y1)/(x2-x1)	
m= 4594		m= 3328		m= 5221		m= 3328	
4594 x + 29000	=	3328 x + 30000		5221 x + 27000	=	3328 x + 30000	
1266 x	=	1000		1893 x	=	3000	
x	**=**	**0.79 Years**		**x**	**=**	**1.58 Years**	





Diesel		Electric		Gasoline		Electric	
m= (y2-y1)/(x2-x1)		m= (y2-y1)/(x2-x1)		m= (y2-y1)/(x2-x1)		m= (y2-y1)/(x2-x1)	
m= 6207		m= 4821		m= 7427		m= 4821	
6207 x + 19000	=	4821 x + 24250		7427 x + 16000	=	4821 x + 24250	
1386 x	=	5250		2606 x	=	8250	
x	**=**	**3.79 Years**		**x**	**=**	**3.17 Years**	

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Diesel Baggage Tractor	22000	3950	2943	6893		90930
Gasoline Baggage Tractor	17000	7435	2943	10378		120780
Electric Baggage Tractor	24000	348	981	1329	4500	41790

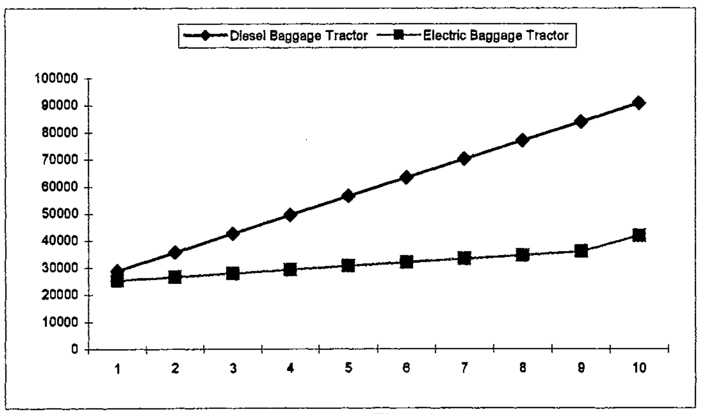
Table Depicting Life Cycle Costs

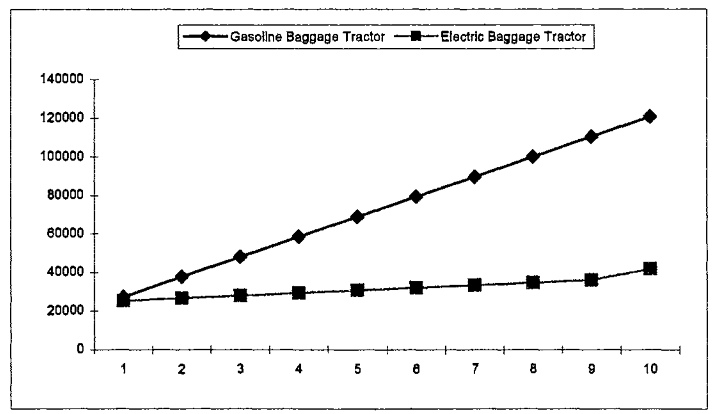
Equipment	1	2	3	4	5	6	7	8	9	10
Diesel Baggage Tractor	28893	35786	42679	49572	56465	63358	70251	77144	84037	90930
Gasoline Baggage Tractor	27378	37756	48134	58512	68890	79268	89646	100024	110402	120780
Electric Baggage Tractor	25329	26658	27987	29316	30645	31974	33303	34632	35961	41790

Table for Charting Cumulative Costs

Sierra Research study Updated

Sierra Research
Study Updated





Diesel			Electric		
m= (y2-y1)/(x2-x1)			m= (y2-y1)/(x2-x1)		
m=	6893		m=	1829	
6893 x	+	22000 =	1829 x	+	24000
	5064 x	=	2000		
	x	=	**0.39 Years**		

Gasoline			Electric		
m= (y2-y1)/(x2-x1)			m= (y2-y1)/(x2-x1)		
m=	10378		m=	1829	
10378 x	+	17000 =	1829 x	+	24000
	8549 x	=	7000		
	x	=	**0.82 Years**		

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Gasoline Baggage Tractor	16000	2986	1893	4879		64790
Electric Baggage Tractor	26000	1449	1406	2855	2425	56975
Gasoline Belt Loader	27000	2986	1165	4151		68510
Electric Belt Loader	30000	1449	978	2427	2900	57170

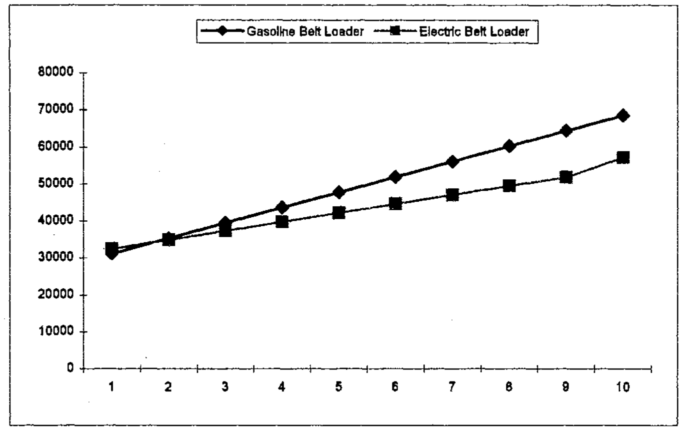
Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Gasoline Baggage Tractor	20879	25758	30637	35516	40395	45274	50153	55032	59911	64790
Electric Baggage Tractor	28855	31710	34565	37420	40275	43130	45985	48840	51695	56975
Gasoline Belt Loader	31151	35302	39453	43604	47755	51906	56057	60208	64359	68510
Electric Belt Loader	32427	34854	37281	39708	42135	44562	46989	49416	51843	57170

Table for Charting Cumulative Costs

SCE study gas/elec Updated

SCE study
Gas/Elec Updated



Gasoline

m= (y2-y1)/(x2-x1)

m= 4151

Electric

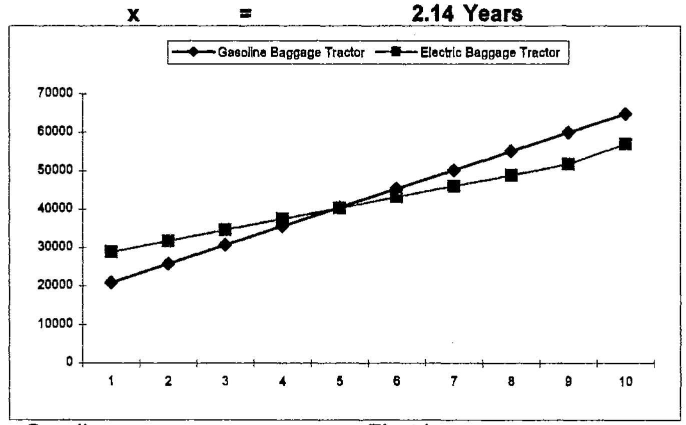
m= (y2-y1)/(x2-x1)

m= 2749.222

4151 x + 27000 = 2749.222 x + 30000

1401.778 x = 3000

x = 2.14 Years



Gasoline

m= (y2-y1)/(x2-x1)

m= 4879

Electric

m= (y2-y1)/(x2-x1)

m= 3124.444

4879 x + 16000 = 3124.444 x + 26000

1754.556 x = 10000

x = 5.70 Years

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Diesel Baggage Tractor	19000	2986	1893	4879		67790
Electric Baggage Tractor	29000	1449	1406	2855	2425	59975
Diesel Belt Loader	29000	2986	1165	4151		70510
Electric Belt Loader	32000	1449	978	2427	2900	59170

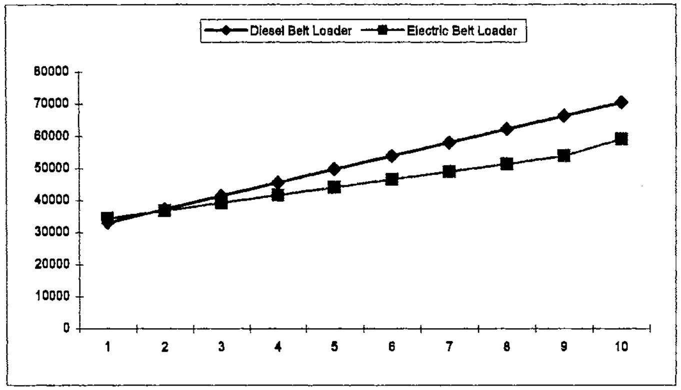
Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Diesel Baggage Tractor	23879	28758	33637	38516	43395	48274	53153	58032	62911	67790
Electric Baggage Tractor	31855	34710	37565	40420	43275	46130	48985	51840	54695	59975
Diesel Belt Loader	33151	37302	41453	45604	49755	53906	58057	62208	66359	70510
Electric Belt Loader	34427	36854	39281	41708	44135	46562	48989	51416	53843	59170

Table for Charting Cumulative Costs

SCE study Diesel/Elec Updated

SCE study
diesel/elec Updated



Diesel

m= (y2-y1)/(x2-x1)

m= 4151

Electric

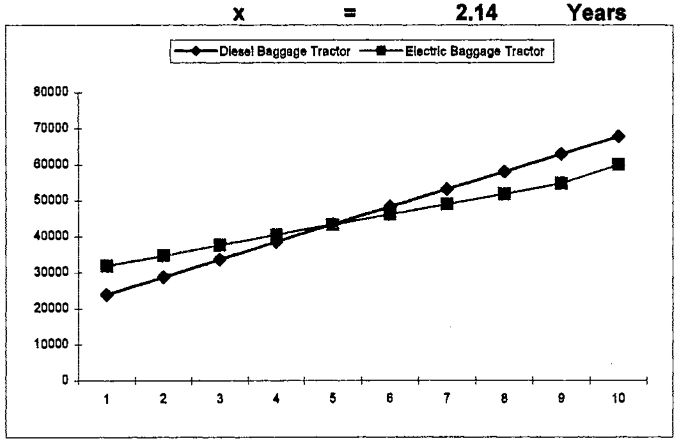
m= (y2-y1)/(x2-x1)

m= 2749.222

4151 x + 29000 = 2749.222 x + 32000

1401.778 x = 3000

x = 2.14 Years



Diesel

m= (y2-y1)/(x2-x1)

m= 4879

Electric

m= (y2-y1)/(x2-x1)

m= 3124.444

4879 x + 19000 = 3124.444 x + 29000

1754.556 x = 10000

x = 5.70 Years

Equipment	Init Cost	OperCost/yr	Maint Cost/yr	Annual Costs	Disp Cost	LCC
Gasoline Baggage Tractor	20000	6023	5680	11703		137030
Electric Baggage Tractor	28537	887	2810	3697	4537	70044

Table Depicting Life Cycle Costs

Equipment	1	2	3	4	5	6	7	8	9	10
Gasoline Baggage Tractor	31703	43406	55109	66812	78515	90218	101921	113624	125327	137030
Electric Baggage Tractor	32234	35931	39628	43325	47022	50719	54416	58113	61810	70044

Table for Charting Cumulative Costs

AeroVironment Study Updated

AeroVironment study
Updated

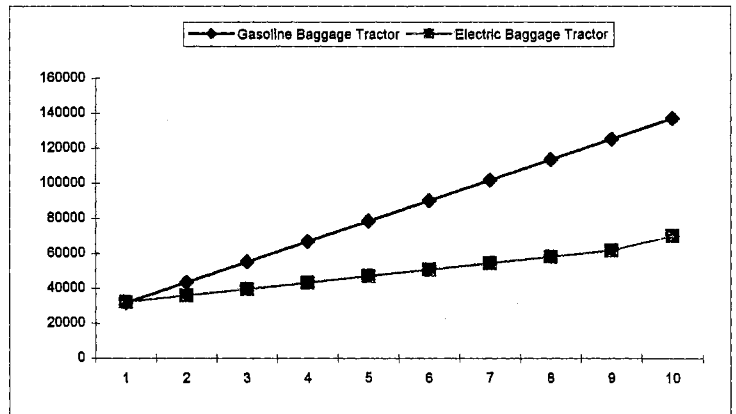


	Chart depicting Gasoline vs Electric Baggage Tractor					
	Gasoline			Electric		
	m=	(y2-y1)/(x2-x1)		m=	(y2-y1)/(x2-x1)	
	m=	11703		m=	4201.111	
11703	x +	20000	=	4201.111	x +	28537
	7501.889	x	=	8537		
		x	**=**	**1.14**	**Years**	

2

VITA

Daniel Wayne Stephens

Candidate for the Degree of

Doctor of Education

Thesis: A COMPARATIVE STUDY OF LIFE CYCLE COSTS FOR SELECTED ELECTRIC POWERED GROUND SUPPORT EQUIPMENT AND INTERNAL COMBUSTION ENGINE POWERED GROUND SUPPORT EQUIPMENT

Major Field: Applied Educational Studies

Biographical:

Personal Data: Born in Rapid City, South Dakota on June 11, 1951 to Ethel L. and Robert W. Stephens

Education: Graduated from Rapid City High School in Rapid City, South Dakota in 1969. Received Bachelor of Science degree in Business Management from University of Maryland, Heidelberg, Germany while stationed at RAF Upper Heyford, England in 1983. Received Masters of Business Administration degree from Oklahoma City University in 1992. Completed the requirements for the Doctor of Education degree with a major in Applied Educational Studies in July, 2004.

Experience: Started my working career as a paperboy in 1963. I also became an assistant manager of the local McDonalds restaurant before graduating from high school. I served in the U.S. Air Force from 1970 to 1974 and again from 1978 to 1994. I started as an Airman Basic and retired as a Captain, and never missed a promotion.

Honors and Awards: Member of Phi Kappi Phi in 2003.