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The Association Between Aircraft Fleet Variety and Fuel Efficiency

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Abstract

One consideration for aircraft operators is how to have the most efficient fleet composition. Fleet makeup could be a diversified fleet makeup or a standardized fleet makeup. The decision is important because it shapes the way the fleet is operated. I examined the effect of aircraft type variety on fleet-wide fuel efficiency. The research hypothesis was that a varied fleet is more fuel efficient than a homogenous fleet. The hypothesis was tested through an analysis of academic and government literature and data. A correlation analysis through evaluation of scatterplots between number of aircraft types and fuel use per seat mile was conducted. The Master of Aeronautical Sciences core program outcomes were covered as well as the outcomes for Aviation Aerospace Management and Aviation Aerospace Operations. Fleet variety was not proven to be more important for fuel consumption than other factors. The recommendation as a result of this study is that fleet variety be considered as a tool for efficiency, but not over other measures.

*Keywords*: capstone, individual project, fleet, fuel efficiency
The Association Between Aircraft Fleet Variety and Fuel Efficiency

Airlines employ different fleet compositions as a part of overall strategy for conducting flights. One common strategy, especially for low-cost carriers, is fleet commonality. This includes using one type of aircraft or similar aircraft in order to achieve efficiencies. A different approach is using a variety of aircraft types in order to assign the most efficient aircraft to a given route. A point of academic and business interest is the success of either variety or commonality in reducing cost, of which fuel consumption plays a major part (Belobaba, 2009a; Brüggen & Klose, 2010).

This project examined the effect of airline fleet variety on fleet-wide fuel efficiency. The fuel efficiency was compared among airlines with different numbers of aircraft types in their fleet. This capstone is based on a few key assumptions. The first assumption is an airline with many aircraft types flies the most appropriate type given the route, frequency, and demand. The second assumption is that there are homogenous type aircraft fleets that fly similar route structures to diverse fleets. The third assumption is an airline cannot quickly replace aircraft for many fleet types since airlines’ orders tend to be large single-type in order to take advantage of discounts. In short, a highly varied fleet may have better route assignment, but have older less technologically advanced aircraft (Clark, 2010; de Borges Pan & Espirito Santo, 2004; Karp, 2012).

In order to accomplish the examination, the scope of this project encompassed United States registered air carriers that had complete information reported to the Bureau of Transportation Statistics (BTS) in the year 2012. The objective was to determine if a more varied fleet leads to better overall fuel efficiency. The method used was a statistical analysis using
secondary quantitative data of airlines to draw conclusions about fleet variety and efficiency (Bureau of Transportation Statistics [BTS], 2013).

The statistics performed were a correlation analysis through the evaluation of scatterplots of averaged fuel use and number of unique types in the aircraft fleet. The comparison used gallons of fuel per seat per mile for passenger carriers and gallons per available ton miles for cargo carriers over a one-year time period. The information in T2: U.S. Air Carrier TRAFFIC And Capacity Statistics by Aircraft Type is presented in available seat miles and gallons of fuel used. The equation is seat miles divided by gallons during the year 2012. The data used were from Air Carrier Summary: T2 data derived from Form 41 and 298C information under the Research and Innovative Technology Administration. Data from 2012 were chosen since that is the most recent full year available (BTS, 2013).

The data were analyzed using Microsoft Excel due to its compatibility with the database and IBM SPSS because it is able to generate correlational statistics. Analysis started with standardizing the data to compare across fleets. The standardization consisted of dividing available seat miles by gallons for each passenger carrier and using available ton miles divided by gallons for cargo carriers. Carriers with more than five percent of the line items incomplete were excluded. For example, incomplete data, such as a “0” value as fuel use but reported departures of the same aircraft type or reported flights from only one or two months of a quarter, were not included (BTS, 2013).

Once the data were summarized, each airline was plotted with gallons used per available seat mile or ton mile on one axis and number of aircraft types as tracked by the BTS on the other axis. The correlation was processed in a statistical analysis software. I examined the data for a
positive correlation or slope to disprove the null hypothesis or a negative correlation or slope to support the null hypothesis.

**Program Outcome #4: Fundamentals of Research and Problem Solving Methods**

The student was able to develop and/or apply current aviation and industry related research methods, including problem identification, hypothesis formulation, and interpretation of findings to present as solutions in the investigation of an aviation/aerospace related topic.

**Problem.** The question was whether or not having varied aircraft types in a fleet to optimize aircraft assignment reduces fuel use. Fuel conservation measures are important because fossil fuel use needs to be reduced. The problem stems from the oil-based fuel’s cost, harmfulness, and negative connotations. Fuel is one of the primary cost considerations in aircraft operations, especially for airlines (Belobaba, 2009a; Stolzer, 2002). In addition, use of aviation fuels is harmful to humans and the environment, and the transportation industry is facing political pressure to reduce their use (Marais et al., 2013).

**Hypothesis.** The hypothesis was that more variety in aircraft fleet composition reduces fuel consumption. The theory was that the more aircraft types used in a fleet the less fuel is used when measuring on a per-seat-mile or per-ton-mile basis. Put another way, the research hypothesis was that an increase in the independent variable causes a decrease in the dependent variable. The purpose of this research was to determine if a diversified fleet is an effective fuel efficiency tactic.

**Interpretation of findings.** The findings were visually described through scatterplots as well as numerically and objectively reported as the correlation coefficient. A significant correlation indicates that the diversity of aircraft types in a fleet is closely related to the fuel use. Significance for this study was set at $p < .05$. Fleet variety was not considered to be the cause of
fuel use if the variables were correlated, only that the two variables are linked. A correlational design was used rather than true experiment where cause and effect can be established. With regard to directionality, a significant negative correlation supports the hypothesis and a significant positive correlation fails to support the hypothesis.

Two broad categories exist in research for science: basic and applied science. Basic research is used to understand the foundation of a problem. Applied research is used to examine possible solutions to a problem, which was used for this study (Leedy & Ormrod, 2013). Possible solutions will be presented in the recommendations section. In order to identify some of the basic concepts surrounding the research topic as well as where this study fits in the broad scheme of research, a literature review is presented.

**Review of Relevant Literature**

A large and diverse amount of literature is available about fleets of aircraft and associated variables such as management strategies and impacts from different types of fleets; much of the literature was published recently, after 2010. Those conducting research include academic, private corporate, and government authors. The *Journal of Air Transport Management* was found to be a particularly useful resource for this study.

**Program Outcome #1: Fundamentals of Air Transportation**

The student was able to apply the fundamentals of air transportation as part of a global, multimodal transportation system, including the technological, social, environmental, and political aspects of the system to examine, compare, analyze, and recommend conclusion.

**Global multimodal transportation system.** Multimodal transportation systems have been studied using varying perspectives in the literature. Some of the prominent categories are analysis for freight or human transportation and comparison among mode types and identifying
the best use of multiple mode types for the same trip. Literature also focuses on aviation as well as in broader terms across all mode types (Janic, 2011; Miller, 2012; SteadieSeifi et al., 2014).

The global multimodal transportation system aspect was addressed by the fact that a more efficient aviation sector of a trip allows for a more efficient overall itinerary. Aviation is an especially important mode in the multimodal system considering the energy intensity required for flight. Aviation networks are an integral part of the global multimodal transportation system. Aviation is linked with other modes of transportation in order to connect people and goods to the aviation system as well as allow for the best type of transportation where mode choice is available. Aviation also plays a role in reducing congestion and demand on other intercity transportation modes (Landau, Weisbrod, & Alstadt, 2010; Miller, 2012; SteadieSeifi, Dellaert, Nuijten, Van Woensel, & Raoufi, 2014).

Multimodal trips are those that involve two or more types of equipment for transport such as using both automobile and aircraft within the same trip. Multimodal freight transport has been studied in various forms, such as through the use of different types of routes. It is characterized in both individual trip terms and transportation network terms. An individual trip is intermodal when the same container is used throughout the trip on different vehicles. From a network perspective co-modal and synchronomodal are considered to be when the best mode or modes are chosen for each logistics problem (SteadieSeifi et al., 2014).

Also prevalent in the literature is the impact of policy or the decision-making process on modal choice and mode linkages (Landau et al., 2010; Miller, 2012). Multiple authors consider there to be a deficit in current transportation planning when it comes to linking airports with other modes, especially in the context of large metropolitan areas where railroad lines already
exist. A result of better modal connection planning could be fewer flights between geographically close cities (Janic, 2011; Landau et al., 2010).

**Technology.** The technological aspects were reflected in the study since the idea for the comparison is technological in nature. If new technology brings sufficient efficiency gains, using sub-optimal aircraft assignment is overcome with more efficient equipment. Technology also enables and places limitations on the efficiency measures that can be taken for an airline fleet.

In terms of fleet composition and new technology, more aircraft types became available for operators over time. This has been echoed in airline fleets as they have slowly gained in variety of types. It should also be noted when considering the increased number of types in fleets that most airlines also have grown in total number of aircraft (Kilipi, 2007; Kuilman & Kim, 2013). In terms of fuel consumption, many leaps in fuel efficiency have come through implementation of new technology (Babikian, Lukachko, & Waitz, 2002; Lee, 2010).

Some literature attempts to forecast technology improvements. Looking forward, studies predict that incremental fuel efficiency increases are most likely for the near term. Aircraft technology, especially engine technology, is advanced and shows no promising large breakthroughs in efficiency or reduced environmental impact in the immediate future when compared to other modes of transportation or historic aviation breakthroughs (Lee, 2010). At a fast or slow pace, technology enables new aircraft types and subtypes. This in turn increases fleet diversity since airlines take a phase in and phase out approach to replacing old fleet types (Kilipi, 2007).

**Social aspects.** Technology is not driven by purely economic factors. One of the drivers for better technology is the social insistence on fewer emissions for a better environment and better health (Lee, 2010). The many social aspects of air travel were considered through the
social and economic benefit of reduced fuel use. Fuel use is costly, creates physically harmful impacts, and has negative connotations for the public. An outcome of increased fuel efficiency is reduced negative social impacts.

When air carriers keep or expand routes intercommunity connections increase. Increased connectivity, especially with remote airports, increases business and personal travel influencing the overall economy. Increased connectivity is often accomplished with government subsidies to reduce the cost of running the routes suggesting that the markets simply need a lower cost base (Smyth, Christodoulou, Dennis, AL-Azzawi & Campbell, 2012).

Fuel use is a large cost in aircraft operations (Belobaba, 2009a; Brüggen & Klose, 2010). Increased fuel expenditure also means increased overall pollutants for those living in the vicinity of an airport (Givoni & Rietveld, 2010). Airlines recognize the negative connotation fuel use has as evidenced by airlines marketing their aircraft as fuel efficient. New aircraft are perceived as the most effective environmental measure (Mayer, Ryley, & Gillingwater, 2012).

Broadly, air travel may be the only viable form of travel for certain remote communities (Cowper-Smith & de Grosbois, 2011; Miller, 2012). Aircraft types are assigned to certain routes, but the capabilities of the aircraft also influence the types of routes and networks an airline can operate. This may have impacts on geographic connections and economic ties between communities (Derudder, Witlox, Faulconbridge, & Beaverstock, 2008).

Within individual operations, it has been suggested that operationally related corporate social responsibility initiatives improve overall airline efficiency (Lee, Seo, & Sharma, 2013). Management decisions in a corporation that are not made for strictly financial or legal reasons and are for the betterment of employees and society can be considered corporate social responsibility. The link to fuel use is that higher oil prices discourage investment in corporate
social responsibility initiatives (Lee et al., 2013). One of the most common types of corporate social responsibility practices is environmental initiatives (Cowper-Smith & de Grosbois, 2011).

**Environmental impacts.** Environmental aspects were addressed through the discussion of how fuel expenditure and emissions is harmful to the environment. Aviation and the use of fossil fuels has been linked to numerous negative environmental impacts. The broad category of climate change is incorporated into much literature. Specific results of aviation operations and fossil fuel use include emissions of carbon dioxide, nitrogen oxides, sulfate, soot, unwanted noise, as well as changes in the atmosphere’s reflectivity through water emissions and contrail or cloud formation. Both emissions and climate change are harmful to living things (Givoni & Rietveld, 2010; Lee et al., 2009).

Links between aircraft fleet composition and environmental impacts have also been studied. One of these links exists on routes that are short enough and high enough density that a fleet choice exists between operating more numerous smaller aircraft or fewer flights of larger aircraft. Using larger aircraft on fewer frequencies reduces overall climate change impacts but also concentrates the negative environmental impacts. In reality, the widespread model is currently higher frequency with smaller aircraft (Givoni & Rietveld, 2010).

Introducing new aircraft and phasing out old aircraft in a fleet can reduce fuel consumption and emissions. Recent fuel prices tend to encourage better fuel consumption, which has been accomplished through younger fleets. However, it is not enough of an incentive to be in line with minimum environmental impacts of air fleets. The best fleet replacement plan financially costs a few percentage points less than an emissions optimized fleet. One way to change the economic model to favor emissions optimized fleets are legislated incentives and disincentives (Rosskopf, Lehner, & Gollnick, 2014).
Political aspects. Social, environmental, and political aspects are highly related. A factor in one aspect tends to be a factor in all three. I addressed political aspects as they relate to outside influence on aircraft fleet choice. On a national level, some airlines face political pressure to buy aircraft and engines manufactured by companies with strong ties to the airline’s country of origin (Belobaba, 2009b). This procurement issue may change fleet composition strategies. Political influence on aviation may also foster innovation and technology gains that lead to improved efficiency. This can be seen in the origin of the EADS/Airbus. There is also continued funding for research from governments such as in the United States and European nations (Francis & Pevzner, 2007).

A different type of political factor spanning many aspects is the taxation of airlines for environmental impacts. A prime example of this is with the European Union’s Emissions Trading Scheme. These taxes change the economics for the airlines and therefore management decisions such as those related to fleet composition (Lu, 2008; Tsai et al., 2012). The overall results of taxes have been studied. Additional environmental taxes would have a higher impact on travel demand for low-cost carriers than traditional major carriers regardless of the overall efficiency of the fleet (Lu, 2008).

In addition to the international or national level, another area where politics may influence airline management decisions is at the local or airport level. Many airports have noise control measures, but few have tailpipe emissions controls. This influences aircraft selection towards a quieter aircraft versus one efficient in a different way (Lu, 2008).

Program outcome #3: Fundamentals of Human Factors in Aviation and Aerospace

The student was able across all subjects to use the fundamentals of human factors in all aspects of the aviation and aerospace industry, including unsafe acts, attitudes, errors, human
behavior, and human limitations as they relate to the aviators adaption to the aviation environment to reach conclusions.

**Unsafe acts.** Hazardous actions were discussed as they relate to the types of aircraft in the fleet. Unsafe acts are actions taken by individuals that degrade the margin of safety (Dismukes, 2010). If air and ground crew are utilized on multiple types of aircraft, they may not be familiar with all types. A result of this may be a higher chance for unsafe actions to occur (Wenner & Drury, 2000).

Unsafe acts are generally considered a broad category that encompasses multiple subcategories. Studies use subcategories such as errors and violations or even a more detailed recurring violations, one-time violations, skill based errors, and mistakes. Unsafe acts alone do not necessarily lead to incidents (Hobbs & Williamson, 2002; Wenner & Drury, 2000).

To increase speed or efficiency, people working with aircraft may violate procedure and do things with a lower safety margin than they should. A common example of this is towing an aircraft without the required number of wing walkers or spotters. A ground operations and maintenance issue that relates to fleet variety is increased likelihood of using incorrect ground service equipment, personal protective equipment, or tools for the job when working on a different aircraft than is normally serviced (Wenner & Drury, 2000).

The type of fleet itself is related to the type of unsafe acts that occur. Different types of unsafe acts are correlated with differences in major airlines, regional carriers, charter carriers, and general aviation maintenance. Work on aircraft with more seats at major airlines included more recurring violations while regional airlines and charter operations included more one-time violations (Hobbs & Williamson, 2002).
**Attitudes.** Attitudes were considered through how decisions made by managers affect both personnel as well as fleet-wide efficiency. An aircraft operator addressing attitudes towards safety can result in a change in fuel efficiency. Deviations from normal scheduling cause inefficiencies. When there are fewer irregular operations an air fleet can operate more efficiently since the original schedule was optimized when planned (Thengvall, Bard, & Yu, 2000).

Recovery from irregular operations also depends on aircraft and crew availability. Fleet composition is a part of the constraints within which schedule recovery must work (Abdelghany, Abdelghany, & Ekollu, 2008). Working with and servicing a varied fleet could reduce boredom and complacency. This is because a person’s mental state may be improved with a variety of job tasks. Low stimulation leads to poor job satisfaction and performance, poor performance due to boredom can lead to safety lapses (Game, 2007).

From a different angle, the ground handling contracts with airlines are generally based on the cheapest option. The contracts also tend to punish companies when performance metrics do not reach a desired level. This is considered a possible root cause for poor ramp safety since it puts contracting companies under pressure both in terms of performance and finance. Resources and personnel are subsequently strained and fewer people are doing more work with the cheapest possible equipment while under pressure. The attitudes developed around the punitive contracts are a human factors aspect. Ramp accidents cause things like delays, grounded aircraft and scheduling changes (Harris, 2006; Thengvall et al., 2000). A change in mindset of those negotiating and selecting the contract is a possible solution (Harris, 2006).

**Errors.** Errors are one of the top reasons for aircraft damage which then lead to issues like delays, grounded aircraft, and scheduling changes leading to irregular operations (Dismukes, 2010; Harris, 2006). Errors were explored in the literature as they relate to the type and diversity
of aircraft in a fleet. Errors may have a higher chance of occurring if the people operating or working around an aircraft are not familiar with the type. This is an increased risk with a varied fleet. For example, ground movements of one type of aircraft may need to use guidelines designed for another type. Human error as it relates to the flight crew is very well studied in the literature (Dismukes, 2010; Wenner & Drury, 2000).

New network fuel efficiency strategies present opportunities for air traffic improvement as well as potential for increasing certain types of errors. A theoretical way to increase the efficiency of the United States air transportation system is through increasing use of small aircraft flying into small airports. This presents potential conflict due to aircraft with a wide range of capabilities using the same airspace. Another is the Federal Aviation Administration’s (FAA) implementation of NextGen air traffic management system. This includes airspace redesign around large metropolitan areas and changes in air traffic control enabled by new technology. Both modifications present the chance for pilot error due to changes in responsibilities and procedures. New air traffic control technology presents the challenge of possible boredom or complacency based errors due to increased automation (Helbing, Spaeth, Valasek, 2006; Langan-Fox, Sankey, & Canty, 2009).

In maintenance errors, frequency of mistakes where aircraft fatigue is missed is related to communication. Lack of communication increases the error rate. This error rate is also changes with the number of aircraft in the fleet (Paramonov & Tretyakov, 2012). Communication and reporting deficiencies also hinder trend analysis of human error. An airline could report an error differently depending on the location and outcome even if the error were the same. Aggregated information about errors may be difficult to obtain or non-existent (Wenner & Drury, 2000).
**Human behavior.** Human behavior was addressed as it was related to the equipment used and variety of aircraft involved. For example, the surrounding environment can affect human behavior. One of the challenges of operating multiple sizes and weights of aircraft into an airport is the need for wake vortex separation. An example where aviation and human behavior converge is the tendency to reduce arrival spacing in visual flight rules because pilots can see the preceding aircraft. This can lead to encounters with wake vortex (Gerz, Holzäpfel, & Darracq, 2002).

Behavior is very well studied for pilots. Included in this type of investigation are challenges of changing cockpit types. One study found that pilots who obtained an instrument rating with analog cockpit gauges then transitioned to digital glass cockpit gauges performed better than those who trained in glass cockpit aircraft and transitioned to analog often called steam gauges. Training, especially the visual instrument scan, a learned behavior, plays an important role. A couple of additional factors are that training is based on steam gauge flight displays and glass cockpits are designed to be easier to scan (Itoh, Hayashi, Tsukui, & Saito, 1990; Lindo, Deaton, Cain, & Lang, 2012).

In terms of fleet variety versus commonality, the amount of training that can be transferred is important when pilots gain certifications. Automation differs among aircraft types and cockpit setups. Higher automation degrades flying skills, which is transferable across all aircraft types (Lindo et al., 2012).

**Human limitations.** The topic of human limitations was addressed as it relates to fleet strategy. For example when there is a disruption of an airline schedule, the recovery needs to take into account crew fatigue. This is in the form of crew duty limits, which are law, but for the
sake of human physiology. Crew scheduling depends on many factors including types of aircraft in the fleet (Abdelghany et al., 2008).

Regardless of the technology and engineering systems established, humans have a limit to their capabilities. Human factors are a very well researched area of literature, but most is related to safety. There are studies that relate to efficiency and schedule optimization as well (Harris, 2006).

Crew scheduling is human limited since schedule efficiency is mediated by the need for rest and a balance between flying and other activities. Scheduling constraints become especially relevant during irregular operations. During irregular operations crews need to be matched with the appropriate aircraft. This adds to an already complex issue related to the available fleet and its aircraft type in addition to efficiency and human limitations (Abdelghany et al, 2008; Harris, 2006).

**Program Outcome #7: Aviation Aerospace Management**

The student investigated, compared, contrasted, analyzed, and formed conclusions to current aviation, aerospace, and industry related topics in management, including aircraft maintenance, industrial safety, production and procurement, international policy, research and development, logistics, airport operations, and airline operations.

ASCI 642 International Aviation Policy, ASCI 643 Management of Research & Development for the Aviation/Aerospace Industry, and ASCI 644 Integrated Logistics in Aviation Management were not part of my curriculum and not addressed in this project.

**Aircraft maintenance management.** An aspect of fleet variety that evaluated for additional complexity was aircraft maintenance management. If the efficiency strategy includes the fleet equipment, aircraft type is an important part of maintenance programs. One challenge of
a varied fleet is the extra maintenance, repair, and overhaul logistics involved with multiple aircraft types (Brüggen & Klose, 2010). The materials and trained personnel are similar at every maintenance base for a homogenous fleet since the same type of aircraft is used throughout the network. This can offer efficiencies for the company conducting the maintenance (Brüggen & Klose, 2010; Sriram & Haghani, 2003).

An area studied in the literature is the tail assignment problem as it relates to maintenance planning. Tail assignment is a part of the complex process involving aircraft route assignment, and crew scheduling. Just like the other parts of the maintenance system, it increases in complexity with additional aircraft types. Like the other components it can also be disrupted by changes to the flight schedules (Lapp & Cohn, 2012; Sriram & Haghani, 2003).

Retrofits and overhaul are aspects of maintenance other than scheduling and makeup of a fleet is important for fuel efficiency modifications. Certain retrofits that decrease fuel use are more easily incorporated on certain aircraft types. For example, avionics that can ensure a more precise and efficient flight profile are more easily installed on aircraft that already have glass cockpits (Howard, 2013). Many modern aircraft have monitoring systems built in to facilitate maintenance. Certain measurements are better for estimating fuel consumption or identifying individual aircraft in a fleet that are out of normal parameters and need servicing. Identifying issues through the monitoring systems can also be useful from a safety perspective (Stolzer, 2002; Stolzer & Halford, 2007).

**Aviation/aerospace industrial safety management.** Due to its importance, safety in aviation and aerospace operations, maintenance, and other settings is well studied. Aviation and aerospace industrial safety management was discussed as it relates to fleet diversity and familiarity with the aircraft. Safety management is of concern to fleet planners since extra
training is needed for personnel working with varied fleets including flight crew, mechanics, and ramp personnel (Brüggen & Klose, 2010). This may have an impact on safety, or there may be no effect due to the fact that much of the work is contracted out to companies that work across many fleets (Thomas, 2011).

Some of the most visible incidents are those where the aircraft are damaged in operation. Takeoff and landing are more dangerous than the cruise part of flight and can result in things such as runway overruns. If the routes served by an air fleet are set, but the operator of the fleet makes a decision on fleet types, fleet variety can be considered with regard to safety. Aircraft must be assigned to a route that are capable of operating on the available runways with an acceptable margin of safety. Fleet variety can offer options for assigning aircraft with appropriate performance characteristics to a route (Kirkland, Caves, Hirst, & Pitfield, 2003).

While aircraft variety can be a benefit, it can also pose a risk. The wake of an aircraft is a byproduct of lift. This means that the larger the aircraft the larger the wake or wake vortex. This presents the most danger when a smaller aircraft is trailing a larger aircraft. The issue is further examined through the lens of human factors above (Gerz et al., 2002).

Aircraft flight operations are only a small portion of safety management in aviation. Other areas of interest include aircraft manufacturing, maintenance, and ground handling. Within these areas one workplace hazard examined by various studies is exposure to carcinogens. Aircraft assembly line work and brake pad replacement of the type used on old small Cessna and Piper aircraft were not found to contaminate the environment to harmful levels. The assembly line study encompasses many aircraft types including both commercial and military aircraft, while the break pad study is applicable to small usually general aviation piston engine aircraft (Blake, Johnson & Harbison, 2009; Lipworth et al., 2011).
Other industrial safety considerations are complicated by variety of aircraft in a similar manner to human factors and maintenance. For example, using the correct equipment and having enough space to work is important for safety, but maintenance of many aircraft types can mean one or both is not optimal at times (Wenner & Drury, 2000).

**Production and procurement management in the aviation/aerospace industry.**

Production and procurement management in the aviation and aerospace industry was addressed in terms of fleet renewal. In the aviation manufacturing process, aircraft operators and manufacturers need to use limited resources to get the most technologically efficient aircraft of the right size operating in order to have minimal fuel consumption. One reason this is tricky, especially for airliners, is the long lead-time needed for a new aircraft (Clark, 2010).

It is a part of the assumptions of this study that there are limits on renewing aircraft within a fleet or introducing new types of aircraft to a fleet. Operators tend to pay less per aircraft when placing a high volume order with a single manufacturer. The other benefit of a fleet with less variety is reduced maintenance and servicing costs (Brüggen & Klose, 2010).

Aircraft manufacturers tend to give incentives to large customers that can encourage fleet variety. These are options added to an order where the order is placed and the units under option are either affirmed or canceled. Another is the ability to switch an order or units within the order to a different type (Treanor, 2012).

Acquiring new versus used aircraft as well as the rate at which and new aircraft are introduced into the fleet dictates the fleet makeup, which has implications for maintenance, operations, and overall efficiency. Acquiring used aircraft can lead to lower fuel efficiency even if the aircraft models are modern due to the fact that performance decreases with age (Stolzer, 2002). More relevant to production and procurement management is introducing new airframes
into the fleet. Statistically, introducing new aircraft into the fleet at larger time intervals reduces the chance for error in monitoring airframes for maintenance (Paramonov & Tretyakov, 2012).

**Airport operations.** Airport operations were discussed regarding how it is affected by airline fleet choice. Airports must accommodate for the airlines that use the facilities in their certification. This includes things such as Aircraft Rescue and Fire Fighting levels and size of taxiway and gate space (“Federal Aviation Administration,” 1978).

Recently, the efficiency and environmental impact of airports has been examined based on the type of airlines and aircraft that are operated out of the airport. It was found that there was a relationship between the scale of flight operations, as well as public versus private management and efficiency. Publicly managed airports tended to have fewer environmental impacts (Martini, Manello, & Scotti, 2013; Martini, Scotti, & Volta, 2013). Larger airports have efficiency due to scale, which is consistent with analysis conducted looking at airlines rather than airports (Lozano, & Gutiérrez, 2011; Martini, Manello, & Scotti, 2013; Martini, Scotti, & Volta, 2013).

It should be noted that smaller aircraft were found to have less environmental impacts overall rather than on a per seat basis. Low-cost carriers with new aircraft and few fleet types did not enhance the efficiency of airport operations even though fleet mix can help with environmental impacts. In fact, if low-cost carriers are dominant at a given airport it lowered efficiency according to the study (Martini, Manello, & Scotti, 2013; Martini, Scotti, & Volta, 2013).

**Airline operations and management.** On the other side of the aircraft lifespan from production and procurement, airlines make decisions about which aircraft to retire. Literature covers the historic composition of airline fleets at the time of the divestiture decision and links operations and management factors with aircraft type retirement. Three contributing factors were
size and age of the aircraft as well as fleet variety. Further, newer and older airlines tend to have different strategies that make one or more of the aircraft retirement variables more important (Kuilman & Kim, 2013).

The airline operations and management program outcome was met as it was a focus of the project. The type of fleet operated is a core business decision of an airline and the primary content of this study. The overall strategy and procedures are intertwined with the type of aircraft that are used (Belobaba, 2009a, 2009b).

In addition, there is literature that examines the system-wide efficiency based on the fleet. This research seems to suggest that the size of the airline is one of the most important factors. Airlines need to reach a certain size in order to obtain high levels of efficiency regardless of composition within the fleet (Lozano, & Gutiérrez, 2011). This type of operational analysis taking into account many factors such as fleet size, type, and financial considerations is common. The ability of the airline to generate revenue after these things have been considered has also been studied (Zhu, 2011).

Contracting flights and agreements with other airlines are practices that reduce fleet variety. These strategies are becoming more prevalent. The most common example of this is the widespread use of regional airlines to fly feeder routes to the hub of major airlines. Because the major airline’s short and thin routes are covered by the regional carrier it does not need an aircraft in the fleet to accomplish the flights (Thomas, 2011).

Fuel efficiency is another driver of fleet commonality according to some literature. This is opposite of my hypothesis, but uses same reasoning. During lower demand periods older less fuel efficient aircraft, those that are more expensive to operate are parked. This in turn reduces
fleet variety. The result is lower fleet variety, but the reasoning is still partially driven by fuel use (Kilipi, 2007).

However, fuel prices may encourage increased fleet variety according to some literature. This is due to the ability to right size an aircraft on a route, or at least operate aircraft with less overhead cost on a route that will likely lose money. The pressure for variety occurs partially because fleet planning is a long-term exercise and aircraft types used in the fleet cannot change as fast as economic demand. This is in line with my hypothesis (Treanor, 2012).

Management decisions regarding operational factors can influence fuel efficiency given a set fleet. In one study, the authors developed a model for assignment of aircraft types on routes for optimal fuel efficiency. It was found that simply accounting for which would be the most fuel efficient aircraft gives significant fuel savings (Lapp, & Wikenhauser, 2012).

**Program outcome #8: Aviation aerospace operations**

The student investigated, compared, contrasted, analyzed, and formed conclusions to current aviation, aerospace, and industry related topics in operations, including simulation systems, operations research, rotorcraft operations, communication and control systems, air carrier operations, and corporate operations.

ASCI 515 Aviation/Aerospace Simulation Systems, ASCI 518 Aviation/Aerospace Operations Research, ASCI 606 Air Traffic Control and the National Airspace System (communication and control systems), were not part of my curriculum and were not addressed in this project.

**Air carrier operations.** Purely operational aspects in addition to management and operations were also considered. Air carrier operations were addressed with the decision for is the type and diversity of aircraft operated. Aircraft fleet decisions directly impact the operational
aspects of an airline such as scheduling of aircraft on routes and for maintenance as well as gate scheduling, and personnel scheduling (Belobaba, 2009b; Brüggen & Klose, 2010).

Within the constraint of the existing fleet, using the correct size of aircraft is an effective way to reduce fuel consumption and increase efficiency. The literature reaches a near consensus on this fact. This is part of the reason why optimization of scheduling is a well-studied subject (Abdelghany et al., 2008; Barbarosoğlu et al., 2002; Treanor, 2012).

Academically, there is similar research to this study. One of the similar areas is using data mining research for determining fuel consumption. Studies were conducted on finding fuel consumption on a specific type of aircraft based on inputs such as calibrated airspeed and compressor speed or identification of specific flights that consumed more fuel than other flights by the same type of aircraft within the same fleet. Fleets of a large number of the same type of aircraft could benefit from this type of analysis, but multiple types of aircraft in the fleet do not negatively impact the data mining as long as the other types are in-addition-to rather than in-place-of the type under consideration for the analysis. Like other statistical measures, the number of data points aids accuracy (Stolzer, 2002; Stolzer & Halford, 2007).

**Rotorcraft operations.** The rotorcraft operations aspect was evaluated for how rotor fleets can use some of the same fuel efficiency methods other operator types. These include technology and design, operations, as well as the combination, where the operation is matched with the equipment (Goulos et al., 2013). Rotorcraft operations must also operate along with other types of aircraft (Langan-Fox et al., 2009).

Helicopter fleets have the potential to differ even more than airline fleets due to the fact that not only are rotorcraft capable of different things, they are designed for very specific roles. Similar to fixed-wing fleets, scheduling a diverse fleet compared to a fleet of a single type adds
complexity. Mission assignment is a vital component since different helicopter configurations are capable most efficient at different things. Things such as number and placement of engines vary considerably in modern rotorcraft (Barbarosoğlu, Özdamar, & Çevik, 2002; Newman, 2006).

Variations can occur within each type of rotorcraft. Although not tracked in this study statistically, one important aspect of a fleet is using an engine on the airframe that is optimized for the intended mission. It is one more level of possible fleet diversity where specifications can be tailored to be most efficient (Goulos et al., 2013).

A common theme in published research and reporting about helicopter fleets is military fleet planning. This is covered in numerous types of publication including magazines and academic journals. Reports often note how the number of aircraft types will be reduced in the future and one type will perform the missions of multiple current types (Brown, Clemence, Teufert, & Wood, 1991; Downing, Chipulu, Ojiako, & Kaparis, 2011; Tunick, 2002).

System wide fuel efficiency and helicopters can also be covered from a human factors perspective, especially as it relates to air traffic control and pilot workload. Academic and government researchers cover the challenge of better incorporating rotorcraft operations into a busy aircraft environment with fixed-wing operations (Langan-Fox et al., 2009 Tobias, Lee, Peach, Willett, & Obrien, 1983).

A choke point for incorporating helicopter flights is when flights are conducted according to instrument flight procedures and helicopters as well as fixed wing aircraft are using the same instrument landing system to guide them into an airport. Due to the differences in speed between faster fixed-wing aircraft and slower helicopters separation of incoming flights needs to be
increased which in turn reduces the arrival rate and therefore the capacity and system efficiency of the airport (Langan-Fox et al., 2009 Tobias et al., 1983).

**Corporate operations.** Corporate operations were considered for how fuel consumption can be reduced by fleet variety. Fuel use is becoming an increasingly important issue for corporate aviation. Verification of this is an increasing number of strategies marketed to business jet operators such as retrofit winglet installation (Seidenman, 2005). Corporate flight departments that have a need for multiple aircraft also make the same commonality versus versatility decision as airlines (Conklin & de Decker, 1998). An additional consideration for corporate operations is airports that cater to mostly airlines. Other types of operations must not hinder the flow of traffic and routing strategies in place for fuel efficiency (Helbing et al., 2006; Langan-Fox et al., 2009).

One option for corporate flight departments and individuals that want the flexibility of a private aircraft without the cost or need to manage the asset is fractional ownership. Companies such as NetJets and Flexjet have fleets of business jets with many owners. These companies exist as almost a hybrid between airlines and corporate flight departments (Martin, Jones, & Keskinocak, 2003; Muharrem & Crossley, 2012).

Corporate operations have options to add fleet capability that airlines usually do not. This is the spectrum of ownership to one time chartering. Aircraft management companies fall on this spectrum. The total of the spectrum for adding capability includes chartering each flight, agreements that allow a certain number of hours of flight, fractional ownership, aircraft leasing, and outright ownership of the aircraft. The best option or combination of options often depends on the amount of usage and if one mission for the fleet is radically different from other missions (Conklin & de Decker, 1998; Martin et al., 2003).
Optimizing scheduling of an on-demand fleet has been studied similar to projects done for airline fleets. On-demand operations have many similarities to airlines such as the need to assign pilots to flights, schedule maintenance, and the fact that they can only charge for flights with passengers not repositioning flights. One advantage of a varied fleet unique for fractional ownership companies is the ability to offer different products. There are some of the same drawbacks of a varied fleet as with any other type of air fleet due to the increased complexity (Martin, et al., 2003; Muharrem & Crossley, 2012).

Similar to rotorcraft operations, corporate aircraft often fill a specific role. Corporate aircraft often use numerous airports other than the large FAA Part 139 certificated ones. Fleet variety may be a necessity for a fleet that flies numerous mission profiles (Budd & Graham, 2009; Conklin & de Decker, 1998).

A recent development that increases the options for corporate fleets was the introduction and certification of a new category of aircraft called very light jets. As the name implies these aircraft add potential variety to the fleet at the small end of the market. In terms of efficiency, these aircraft burn less fuel per hour than larger business jets (Budd & Graham, 2009).

Methods

In addition to a review of the relevant literature, I conducted a statistical analysis. The analysis looks for a link in quantitative data between fuel efficiency and fleet variety. This section covers the fundamentals of statistics program outcome.

Program Outcome #2: Fundamentals of Statistical Analysis in Aviation and Aerospace.

The student was able to identify and apply appropriate statistical analysis, to include techniques in data collection, review, critique, interpretation and inference in the aviation and aerospace industry.
Statistical analysis. Quantitative statistical analyses were conducted. Fuel efficiency and fleet variety data from the BTS database were used to create scatterplots, trend lines, and coefficients of determination or “$R^2$” through Microsoft Excel. Pearson’s correlation coefficient or “$r$” along with statistical significance was calculated in IBM SPSS. Pearson’s correlation is a measure used to determine the strength of correlation between the two variables. The coefficient of determination is used to explain the amount of change in one variable accounted for by change in the other variable. The cutoff for statistical significance was set at $p = .05$. The dependent variable was the fuel efficiency operationalized as gallons of fuel per seat mile while the independent variable was the number of unique aircraft types in the fleet as defined by the BTS database. The BTS database uses aircraft sub-types to classify aircraft such as the Boeing 737-800 as opposed to aircraft families such as the 737 family, which could include the 737-100 through the 737-900. A full list of aircraft included in the analysis can be found in Appendix A.

Data collection. The data came from the United States Department of Transportation and data collection was through the Transtats online database. The data set was Air Carrier Summary: T2 data derived from Form 41 and 298C information under the Research and Innovative Technology Administration. The time period used was the year 2012 since that was the most recent full year available. Schedule T2 was chosen over other Transtats data sets because it included both aircraft type and fuel use in the same data set. It also captured international flights and flights operated for the military which may not be available on other data sets (BTS, 2013).

Review. The initial data review was through Microsoft Excel due to its compatibility with the database. I used Microsoft Excel to standardize the data to compare across fleets. The standardization involved dividing gallons by available seat miles for each passenger carrier and
available ton miles for cargo carriers. Carriers with more than five percent of the rows of data containing incomplete data such as a “0” value as fuel use but reported departures of the same aircraft type or reported one or two months of a quarter were not included. Each row is a unique combination of quarter of the year, airline, and aircraft type where the service class attribute was all-inclusive. The service class category was filtered for “z” since that summarized the other data groupings. Carriers with both cargo and passenger operations were evaluated for each type of operation individually. The same type of aircraft was not reflected in both comparisons. Combination aircraft where cargo and passengers are flown on the main deck were excluded as well as floatplanes and seaplanes (BTS, 2013).

This data cleaning resulted in 22 airlines with at least 95% reported fuel use. One airline, Horizon Air, was removed from the data due to unrealistic results. The seat miles per gallon number was roughly 1,000 times more efficient than any other airline and not in line with the other operator of DHC-8-400s. This was the first year of a single report for Continental Airlines and United Airlines (BTS, 2013). Thirty-six aircraft types were captured in the analysis ranging in size from the Saab-340B to the Boeing 747-400.

Data cleaning for cargo operators resulted in even fewer airlines, only 10. Twelve aircraft types were represented. The aircraft types included a range from the 737-200 to 747-400 and represented a large proportion of older out of production models such as the 727-200 and a higher proportion of widebodied airliners to narrowbodies than passenger airlines used in the analysis. The fact that fewer and older aircraft models were represented in the cargo analysis is consistent the overall cargo airline industry. The global fleet of dedicated cargo aircraft is less numerous and older than the global passenger fleet (Lee et al., 2009).
To illustrate the difference in typical aircraft size between passenger and cargo operations, percentage of revenue departures was compared. Cargo airlines in this analysis used roughly 27% narrowbody and 73% widebody aircraft by departure. Passenger airlines used 18% regional jets or turboprops 77% narrowbodies and 5% widebodies.

Regional jets and turboprops were defined in this comparison as aircraft that generally have fewer than 100 seats and used on the shortest routes. Narrowbodies are aircraft with usually more than 100 seats and one aisle in passenger configuration. These tend to be used on short and medium length flights. Widebodies were considered to be aircraft with two aisles in passenger configuration. The categories for each specific type of aircraft found in these analyses are in Appendix A.

Critique. I assumed that the government databases used in this study have comprehensive and accurate data. The assumption was checked when incomplete data was removed in the data review stage. Each database, including the Air Carrier Summary Data, has an explanation about which information is captured by the data set (BTS, 2013). The data set has also been used in other studies (Babikian, 2002; Stolzer, 2002).

The measures of available seat miles and ton miles per gallon were chosen because they can be compared across airlines of different sizes. Averaging in this manner is in line with other studies and common efficiency measures that average capacity with distance in order to make different aircraft operations comparable. Analyzing cargo or passenger operations exclusively is also done by other studies (Lozano, & Gutiérrez, 2011; Tsai et al., 2012; Zhu, 2011).

Results

The scatterplots and statistical values generated can be seen below. Passenger and cargo airlines were considered independently. The primary results are presented as well as an
exploratory analysis to look for additional patterns in the data. All analyses failed to reject the null hypothesis because they were not statistically significant.

Data Interpretation and Inference

Data interpretation and inference occurred by performing a correlation analysis through the evaluation of scatterplots. The results of the descriptive statistics in the form of a scatterplot can be seen in Figure 1 below. There was more variability in efficiency values for fleets with fewer aircraft types than those with the most aircraft types. There was an increasing strength of correlation from lower to higher number of fleet types or a heteroscedastic feature to the data set. Visually, the data have close to no slope. The values for each airline can be found in Appendix B.

![Figure 1. Fuel Efficiency and Fleet Variety](image-url)
The most efficient passenger airline was Miami Air International at 98.39 seat miles per gallon using two aircraft types the Boeing 737-400 and 737-800. The least efficient was Air Wisconsin Airlines with one fleet type, the Canadair CRJ-200 flying at 36.93 seat miles per gallon. This typified the overall results where there was a wider spread of efficiency values in the airlines with few fleet types. The Miami Air and Air Wisconsin values also show the overall range of fuel efficiency in the passenger analysis.

The coefficient of determination or “R^2” was calculated by Microsoft Excel to be .006. This was a very weak positive correlation. This can be seen with the slight slope of the line of best fit. Overall, number of aircraft in a fleet is a poor predictor for fuel consumption measured by seat miles per gallon. The heteroscedastic nature of the scatterplot means that fleet variety and fuel efficiency better fits the regression as the number of fleet types increase. The correlation between passenger seat miles per gallon and fuel efficiency was not statistically significant at the .05 level \( r(19) = .075 \) with \( p = .745 \).

Cargo carriers showed a similar pattern to passenger carriers. Resembling the passenger analysis, there is more variability in efficiency for fleets with fewer aircraft types than those with the most aircraft types. Results can be seen in Figure 2 and individual airline descriptive statistics in Appendix B.
Centurion Air Cargo was the most efficient cargo airline operating one aircraft type, the McDonnell Douglas MD-11, at 19.00 available ton miles per gallon. The least efficient was Northern Air Cargo with two aircraft types and an efficiency of 6.09 available ton miles per gallon. Northern Air Cargo operated 737-200 and 737-300. This is similar to the passenger airlines analyzed in that the most and least efficient were both operators of one and two fleet types.

The correlation for cargo operators was also a weak positive correlation. The coefficient of determination correlation or $R^2$ was 0.035. This showed a stronger determination than the passenger coefficient. The correlation between passenger seat miles per gallon and fuel efficiency was not statistically significant $r(8) = .187$ with $p = .605$. 

![Figure 2. Cargo Fuel Efficiency and Fleet Variety](image-url)
Exploratory Analysis

The fuel efficiency of an aircraft operator with only one fleet type has to do with the efficiency of the type chosen rather than the fleet mixture and total variety chosen. It is important to analyze the fleets with one versus multiple types when considering fleet variety, but it is also worth exploring the same analysis with only fleets that contain two or more aircraft types. The results of the same type of analyses of the same data source can be seen in Figure 3 and Figure 4. For individual airline values reference Appendix B.

![Figure 3. Fuel Efficiency and Fleet Variety for Airlines with at Least Two Aircraft Types](image)

Without the homogenous fleets, the correlation value for passenger carriers was slightly negative. The $R^2$ value is .007. The slope of the trend line was opposite of the analysis with full data but the correlation was also weak and the data were heteroscedastic. The correlation
between passenger seat miles per gallon and fuel efficiency was not statistically significant $r(16) = -.081$ with $p = .750$.

Without the homogenous fleets, the $R^2$ value for cargo carriers showed a stronger relationship than any of the other coefficients of determination calculated at $R^2 = .206$. The trend exhibited a positive slope similar to the initial cargo carrier analysis. However, the correlation between passenger seat miles per gallon and fuel efficiency was also not statistically significant $r(4) = .454$ with $p = .366$. A stronger correlation existed, but was not statistically significant.

Some limitations existed in the analysis. Externalities included the fact that mail and cargo tonnage was not included in seat analyses. Mail and cargo could affect efficiency measures by changing the weight carried by the aircraft without affecting the seat total. A related, but assumed to be small, factor is that an aircraft flying full of passengers burns more fuel over the
course of a flight than one flying close to empty. This could reduce the fuel efficiency in this analysis for airlines successful at filling their flights.

**Conclusion**

Conclusions were drawn from the relevant literature and the results of the statistical analysis. In order to address the problems presented by fossil fuel use in aviation, the hypothesis was presented that more variety in aircraft fleets reduces fuel consumption. There overall suggestion by the literature that variety in a fleet offers the flexibility to optimize aircraft assignment for each mission, but each aspect differs. However, the statistical correlational analysis through evaluation of scatterplots does not reach statistical significance. Without significant results, the **interpretation of findings** is the null hypothesis is assumed because it fails to be rejected. Each of the program aspects are considered for how they promote or are affected by more diversity or similarity of aircraft in efficient aircraft fleets since confounding variables made the statistical analyses not significant.

Regarding the statistical analysis, the primary analysis was inconclusive because none of the correlations proved to be significant to a probability of $p = .05$. That is $p < .05$ was significant and $p > .05$ was not. All $p$ values calculated were higher than .05. It is very possible that the deterministic relationship happened due to chance. The same conclusion is drawn for the exploratory analysis. One variable is not a good predictor for the other.

Statistical power could have been increase in the data **collection** by gathering more data points. **Review** of the data could have also excluded less data to increase the power. Transformations could also have been used in order to make data fit linear models, but this was not necessarily appropriate. As a **critique** the data was likely accurate since the data set is used in multiple other analyses (Babikian, 2002; Stolzer, 2002). The only issue found was the value
for Horizon Air. *Interpretation and inference* of the data could have looked at various other corralational methods to better fit the scatterplots.

Values for individual airlines may have hinted at an ideal fleet diversity for efficiency. Although a bell shaped or normal curve was not observed, it can be noted that the most efficient airlines considered in the passenger analysis tended to have two to five fleet types. This is a generalization rather than a specific conclusion since it does not take into account network type or business model of the most efficient airlines.

Flight will continue to be inherently a part of the global multimodal transportation system. There is no option other than ground transportation for the portion of the trip from door to aircraft; it is called pre-haul for freight (SteadieSeifi et al., 2014). There is a known deficiency in the current linkages between aviation and other modes as well as a push for improved travel efficiency from economic, environmental, and social standpoints. The result of the effort may be improved connections between aviation and other modes. The improved connections could alter air fleets by reducing the demand for short flights between major cities and therefore aircraft used in that capacity. Fleet commonality would be promoted with less demand for one type of mission (Janic, 2011; Landau et al., 2010). These are the same aircraft types that comprise the bulk of flights in the passenger correlational analysis.

One of the biggest confounding variables is the difference between short and long haul operations. Larger aircraft tend to have better efficiency per seat or ton partially because of operational differences between short and long haul but also because of technological aspects. New technology tends to be introduced on larger and long haul aircraft first. Another reason is that smaller short haul aircraft carry more structural weight per seat (Babikian et al., 2002; Lee, 2010).
Some examples of new technology in place on long haul aircraft before short-range aircraft are the introduction of high-bypass turbofan engines and composite carbon materials. High-bypass engines are more efficient than low bypass engines and were first introduced on widebody airliners. Carbon fiber reinforced polymers are a more recent example and offer benefits over aluminum (Babikian et al., 2002; Lee, 2010).

It is concluded that the comparison between fleet variety and fuel consumption is not technologically driven as initially thought. One of the original ideas was that fleets with fewer types tended to be more technologically advanced due to the ability to maintain a lower fleet age. In fact, the opposite is true in some fleets. Introduction of new aircraft types creates increased variety since there are two aircraft types performing the same mission as the new type is phased in and the old type is phased out (Kilipi, 2007).

**Social aspects** tend to be impacted by fuel efficiency measures rather than a driver of fuel efficiency through fleet variety. Social considerations benefit greatly from improved efficiency in aviation (Lee, 2010). Social connections in some ways steer aircraft fleets since fleets are tailored to the missions they perform and missions performed are based on the demand for that mission. Social aspects can also influence efficiency and fleet variety when considered along with environmental and political aspects. These other aspects are interwoven with social aspects and are difficult to assess individually (Derudder et al., 2008).

**Environmental** aspects also tend to be impacted by current efficiency rather than a driver of improved efficiency efforts. The environment benefits greatly from decreased fuel use and subsequent reduced emissions (Lee, 2010). A conclusion drawn from the environmental aspect is that ecological considerations are increasing in importance as a driver of fleet types. One area is through social awareness of the environmental impacts of aviation and another is by
including environmental impacts in the fiscal economy (Lu, 2008; Tsai et al., 2012). The environmental aspect promotes fleet variety due to the ability to right size aircraft with missions for fuel conservation (Abdelghany et al., 2008; Barbarosoğlu et al., 2002; Treanor, 2012).

**Political aspects** have historically had more of an influence on aircraft fleets than environmental aspects (Belobaba, 2009b). Political pressure will also have an increased influence on both fleets and efficiency in conjunction with environmental impacts. Overall, politics tend to be something that influence fleet variety and efficiency rather than something that is affected by it. Whether government influence promotes fleet variety or commonality depends on the specific policy (Lu, 2008; Tsai et al., 2012).

According to the literature increased variety adds complexity to human factors and harmfully impacts **unsafe acts, errors, human behaviors, and human limitations**. These are consequently drivers of fleet commonality. However, the low cost model associated with less diverse fleets also has a negative impact, especially with regards to **attitudes**. Human factors and fleet complexity is mediated by the fact that aircraft operators often do not perform things such as maintenance and ground handling in house. The fleet strategy of one air operator only has a partial impact on the aircraft contract employees are working with (Thomas, 2011). Another factor that makes generalizations difficult is the fact that the type of unsafe act that is most common varies among types of operators (Hobbs & Williamson, 2002).

Human factors influences fleet variety in the sense that it is a consideration when selecting aircraft type. Training, especially flight crew training, is a large component of this (Lindo et al., 2012). Things like unsafe acts, attitudes, errors, and behavior are affected by fleet variety in the sense that the fleet is a part of the human machine interaction.
**Aircraft maintenance management** tends to drive owners of aircraft fleets to less variety. The logistics of a varied fleet are more difficult than the logistics of a homogenous fleet (Brüggen & Klose, 2010). Maintenance management is mediated by one of the same things as human factors in that contracting out work make the logistics an issue external to the aircraft operator (Thomas, 2011).

In **aviation and aerospace industrial safety management** many hazards are shared among multiple aircraft types and environmental exposure issues exist universally (Blake et al., 2009; Lipworth et al., 2011). When considering the hazards flying an aircraft, safety considerations come into play as something that can influence fleet types (Kirkland et al., 2003). In terms of employee safety in settings other than flight, industrial safety management tends to conform to aircraft types used rather than determine the types used.

Optimal **production and procurement management in the aviation/aerospace industry** for the sake of fuel efficiency may not be completely reflected with current air fleets because the best financial decision about fleet replacement is not necessarily the best decision for fuel consumption. The best practices from a fuel consumption standpoint would involve a slightly faster fleet turnover than is best economically. Fleets in a transition period have more variety because each role is duplicated. If regulatory or market pressures made fuel efficiency an even larger consideration the market pressure would be an influence to increase fleet variety (Kilipi, 2007; Rosskopf et al., 2014).

From the current purchasing and strategic planning standpoint there are many benefits to reducing the variety of the fleet. These include reduced capital expense for aircraft orders and fewer operational complexities. Procurement considerations tend to drive a fleet towards less variety (Brown et al., 1991; Brüggen & Klose, 2010).
For **airport operations**, fleet variety is mostly a non-factor since airlines with different fleet mixtures operate side by side. The exception is if the airport is dominated by a single type of airline. A common issue with variety is the challenges of sequencing and accommodating the large range of aircraft capabilities (Gerz et al., 2002, Langan-Fox et al., 2009). With a small variety, such as airports dominated by a single low-cost carrier, there are in some cases decreased efficiency as well (Stolzer, 2002; Stolzer & Halford, 2007).

Because **airline operations and management** is driven by factors additional to efficiency, fleet variety is driven by additional factors as well. One of the larger factors other than airline route and market strategy or aircraft financing available appears to be demand for air travel. High demand creates the need for capacity slowing retirements of older aircraft types. These older types may have comparable replacements already in the fleet but are retained for use rather than retired which lowers efficiency and increases the number of fleet types (Belobaba, 2009a, 2009b; Kilipi, 2007). This can be seen in the analysis where airlines operated older aircraft as well as possible replacement aircraft during the year 2012. Some examples of this are Southwest operating the 737-300 along with Boeing’s direct replacement the 737-700 and Kalitta Air operating multiple generations of the Boeing 747 (BTS, 2013).

The mix of smaller versus larger aircraft is a management decision that may have influenced results. On a per seat basis, smaller aircraft usually burn more fuel per seat mile than larger aircraft but larger aircraft typically have a higher fuel burn when not averaged by number of seats. An airline with the best number of types of aircraft for its routes could have a lower fuel efficiency on a per seat basis than an airline operating larger aircraft on average (Babikian et al., 2002).
Passenger airlines in the analysis that operated with the most efficiency had two to five narrowbody types from the same manufacturer. In addition to the previously mentioned Miami Air, Virgin America was second most efficient using Airbus A319 and A320. Third was Sun Country Airlines using Boeing 737-700 and 737-800.

The most efficient cargo airlines in the analysis used widebody types. In addition to Centurion Cargo the next most efficient was World Airways using McDonnell Douglas MD-11s and Boeing 747-400. National Air Cargo Group was third most efficient. National Air Cargo used Boeing 747-400s, Douglas DC-8-71s, and DC-8-73s. Although the DC-8s are narrowbody airliners, the bulk of the available ton miles and departures were performed by the 747s. This shows that although widebodies are more efficient on a seat mile basis when compared one to one with narrowbodies, it does not overcome the business and operational strategies used by airlines on the scale of a whole fleet. Aircraft size does lead to economy for cargo airlines.

When analyzing for efficiency, air carrier operations benefit from fleet variety. The literature does not necessarily agree with whether good or bad economic conditions lead to increased fleet variety and the results of this statistical analysis were inconclusive. However there is consensus that increased fleet variety gives operators more flexibility and in turn more opportunities for efficiency. The other evidence of this comes from the number of studies conducted that look at optimizing tail assignments or other routing and scheduling problems (Abdelghany et al., 2008; Barbarosoğlu et al., 2002; Treanor, 2012).

Within the constraint of the existing fleet chosen by management, operational procedures can be implemented. Operational efficiency options include one engine taxi, better timed push back from gates to avoid congestion, use of ground power instead of the auxiliary power unit on an aircraft, and better communication and data sharing for rerouting or irregular operations.
These offer potential improvements that can be implemented quickly when compared to introducing new fleet types (Marais et al., 2013). Operational differences between short haul and long haul operations may have also contributed to weak correlation between fuel efficiency and variety. A large part of this is that more fuel is used per unit of time during climb out than cruise and a higher proportion of time is spent on the ground at airports (Babikian et al., 2002).

Large differences in capabilities of rotorcraft mean that those conducting rotorcraft operations do not have much flexibility in fleet variety. The large fuel consumption of helicopters per hour does mean that fuel efficiency measure including fleet variety has a large potential impact (Barbarosoğlu et al., 2002; Newman, 2006). Where a varied fleet and varied types of flights exist there is certainly a place for matching rotorcraft type with the mission (Goulos et al., 2013).

A similar situation exists in corporate operations as in rotorcraft operations. Due to the very specific roles demanded of aircraft in corporate aviation, variety of fleet may be less of a choice and more of a necessity. Corporate operators also have options available for aircraft outside their own fleet such as using aircraft management companies. For aircraft management companies, operations would be simplified with a common fleet type, however, the company would miss out on the sales option of offering different types of aircraft for customers to buy into. Management companies also cater to numerous clients that have different travel demands that may not be met without numerous types of aircraft in the fleet (Budd & Graham, 2009; Conklin & de Decker, 1998).

**Recommendation**

Existing literature, statistical analysis, and conclusions were drawn from in order to make recommendations. Each operator of aircraft has a unique set of considerations, but broad
suggestions can be made. Offering recommendations and solutions are a part of the learning objectives.

**For Aircraft Fleet Operators**

Using a variety of aircraft types in a fleet is one possible strategy for fuel efficiency. The literature suggests a varied fleet is a consideration in fleet wide fuel efficiency but the analysis failed to reject the null hypothesis that no difference existed. Fleet variety is not more important than other efficiency measures since some of the most efficient carriers were those that operated two or three fleet types of modern aircraft. Fleet commonality has benefits, but does not lead to fuel used per seat mile efficiencies either. Some of the least efficient airlines operated a single fleet type. In terms of managing a fleet, the number of aircraft types in the fleet should be considered within the constraints for each individual fleet and mission types rather than goal in and of itself.

**Future Prediction**

Conclusions about different aspects were taken into consideration in order to predict future relationship between fleet variety and fuel efficiency. Considering the fact that the number of types of aircraft offered as well as the variety of aircraft in global airlines fleets has increased it is likely that fleet variety will continue to increase from an historical perspective (Kilipi, 2007; Kuilman & Kim, 2013). The next consideration is that fuel is a large cost to airlines and has increased remarkably in recent years making it something that will continue to be weighed heavily for profitability (Belobaba, 2009a; Treanor; 2012). Another piece is that increasing social awareness and political policy surrounding the environmental impacts of fossil fuel use fuel efficiency will become a greater driver of fleet planning (Mayer et al., 2012; Tsai et al., 2012). Allowing for the outsourcing trend in operational aspects of air fleets there are fewer human
factors and maintenance issues complicated by a varied fleet (Thomas, 2011). A final piece is the fact that the phase in and phase out process of introducing new aircraft types and retiring old types increases fleet diversity (Kilipi, 2007). I predict the trend will be that airlines will increase fleet variety in pursuit of more efficient fleets.

**Further Study**

If the study were to be conducted again the data review process in the statistical analysis could be different in order to increase the power of the study. One possibility is including airlines with a lower percentage of fully reported data. This could be accomplished by using only line entries of quarter of the year, air carrier, region of operation, aircraft type, available seat miles or ton miles, fuel use, and number of months reported that were complete regardless of how many were complete for the whole airline (BTS, 2013). The researcher would then need to decide on how to treat an individual air carrier’s fleet variety if a whole type of aircraft were missing complete line items for the given carrier.

Along the lines of aircraft variety, further analyses on the same subject could treat the aircraft variety in a more comprehensive manner. This analysis treated all differences the same, as a unit of one. However, not all aircraft are equally different from one another. For example, a Saab-340 and Airbus A320 are quite different in the ground infrastructure, pilot training, and manufacturer differences. An Airbus A319 and A320 on the other hand are very similar sharing things such as pilot type certificate, engine types, ground handling requirements, infrastructure requirements, and even many subcomponents of the aircraft facilitating maintenance. However, an airline with either of the two example pairs would have been treated in this study as using two fleet types. Indexes such as that developed by de Borges Pan and Espirito Santo (2004) exist and
take into consideration subassembly units of the aircraft for standardization purposes. This model has been built upon for additional studies (Kilipi, 2007).
References


Appendix A

Table A1

*Category of Each Type of Aircraft Used in the Aircraft Efficiency and Variety Analysis*

<table>
<thead>
<tr>
<th>Regional Jet/ Turboprop</th>
<th>Narrowbody</th>
<th>Widebody</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadair RJ-200ER /RJ-440</td>
<td>Airbus A-318</td>
<td>Airbus A330-300</td>
</tr>
<tr>
<td>Canadair RJ-700</td>
<td>Airbus A319</td>
<td>Airbus A300-600/R/CF/RCF</td>
</tr>
<tr>
<td>De Havilland DHC 8-400</td>
<td>Airbus A320-100/200</td>
<td>Boeing 787-800</td>
</tr>
<tr>
<td>Embraer-135</td>
<td>Airbus A321</td>
<td>Boeing 747-200/300</td>
</tr>
<tr>
<td>Embraer-140</td>
<td>Boeing 717-200</td>
<td>Boeing 747-400</td>
</tr>
<tr>
<td>Embraer-145</td>
<td>Boeing 727-200/231A</td>
<td>Boeing 767-300/300ER</td>
</tr>
<tr>
<td>Embraer-170</td>
<td>Boeing 737-100/200</td>
<td>Boeing 767-400/ER</td>
</tr>
<tr>
<td>Embraer-175</td>
<td>Boeing 737-300</td>
<td>Boeing 777-200ER/200LR</td>
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<tr>
<td>Saab-Fairchild 340/B</td>
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<td>McDonnell Douglas DC-10-30</td>
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<td>Boeing 757-200</td>
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<td>Boeing 757-300</td>
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<td>Embraer-190</td>
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<td>McDonnell Douglas DC9 Super</td>
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<td>MD-81/82/83/88</td>
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<td>McDonnell Douglas MD-90</td>
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### Appendix B

#### Table B1

*Seat Miles, Fuel Use, and Aircraft Types for Each Carrier in Statistical Analysis*

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Total Seat Miles</th>
<th>Total Fuel</th>
<th>Seat Miles/Gallon</th>
<th>Number of Types</th>
</tr>
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<tbody>
<tr>
<td>Air Wisconsin Airlines Corp</td>
<td>2846250450</td>
<td>77065039</td>
<td>36.93309556</td>
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<tr>
<td>Alaska Airlines Inc.</td>
<td>27830883126</td>
<td>354376000</td>
<td>78.53489832</td>
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<td>American Airlines Inc.</td>
<td>152626802673</td>
<td>2435062913</td>
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<tr>
<td>American Eagle Airlines Inc.</td>
<td>12731805251</td>
<td>303402855</td>
<td>41.96336666</td>
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<tr>
<td>Colgan Air</td>
<td>850915174</td>
<td>16345758</td>
<td>52.05724776</td>
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<tr>
<td>Compass Airlines</td>
<td>3702234015</td>
<td>72839431</td>
<td>50.827333</td>
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<tr>
<td>Delta Air Lines Inc.</td>
<td>200879775915</td>
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<td>65.18620459</td>
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<tr>
<td>Frontier Airlines Inc.</td>
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<td>155170250</td>
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<td>55847845</td>
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<td>14695598652</td>
<td>199464357</td>
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<td>JetBlue Airways</td>
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<td>Miami Air International</td>
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<td>7863519</td>
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<tr>
<td>Omni Air Express</td>
<td>3289883407</td>
<td>42984591</td>
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<td>Shuttle America Corp.</td>
<td>5009820080</td>
<td>122082997</td>
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<td>Southwest Airlines Co.</td>
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<td>Spirit Air Lines</td>
<td>11299098609</td>
<td>142990528</td>
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<td>Sun Country Airlines d/b/a MN Airlines</td>
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<td>US Airways Inc.</td>
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<td>Virgin America</td>
<td>12527513227</td>
<td>148129113</td>
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<td>World Airways Inc.</td>
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<tr>
<td>Horizon Air</td>
<td>2670260608</td>
<td>44280</td>
<td>60303.98844</td>
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*Note.* Horizon Air was removed from the analysis.

#### Table B2

*Ton Miles, Fuel Use, and Aircraft Types for Each Carrier in Statistical Analysis*

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Available Ton Miles</th>
<th>Total Fuel</th>
<th>Ton Miles per Gallon</th>
<th>Number of Types</th>
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<tbody>
<tr>
<td>Amerijet International</td>
<td>176894522</td>
<td>16533814</td>
<td>10.6989544</td>
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<td>Asia Pacific</td>
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<td>Centurion Cargo Inc.</td>
<td>481570662</td>
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<tr>
<td>Florida West Airlines Inc.</td>
<td>353433591</td>
<td>19657400</td>
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<tr>
<td>Kalitta Air LLC</td>
<td>1886345735</td>
<td>179810109</td>
<td>10.49076576</td>
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<tr>
<td>National Air Cargo Group, Inc. d/b/a Murray Air</td>
<td>229307576</td>
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<tr>
<td>Northern Air Cargo Inc.</td>
<td>40593267</td>
<td>6669013</td>
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<td>1604930801</td>
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<tr>
<td>United Parcel Service</td>
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<td>735349001</td>
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