ELEMENTARY STATISTICS

Energy and the Environment: Global Challenge (MAT120)

Project
Quantum
Leap

This course serves as a study of fundamental concepts and computational techniques of elementary statistics. Among the topics studied are: measures of central tendency, standard deviation, percentiles, statistical graphs, binomial and normal distributions, probability, confidence intervals, hypothesis testing, regression, and correlation. A statistical software package will be used by students to obtain basic sample statistics, to simulate fundamental theorems, and to assist with hypothesis testing. A graphing calculator will be used by students to assist with computations, as well as with tabular and graphical displays of data.

Aircraft Emissions

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Objectives

In this activity students will examine data from the airline industry about pounds of emissions of particulate matter from jets at low power levels. The mathematical objectives for this activity are: (1) calculate the mean, (2) calculate the standard deviation, (3) perform a hypothesis test about the difference of two means, and (4) perform a hypothesis test about a single mean.

Math Topics
Measures of dispersion and central tendency, hypothesis testing about single and paired means

Purpose
Synthesis

Comments
Data based on EPA report: *Procedures for Emission Inventory Preparation* (Volume IV: Mobile Sources)

When to Introduce
Week 8

Activity Time Frame
One week

Reflection

One of the main ideas of climate change is that entire characteristics of the environment are changing over an extended period for time. Climate change is not necessarily detectable over short periods of time, but a hypothesis test can indicate broad changes over long periods of time. When a hypothesis test is significant, it indicates that whole parameters of a population have changed, and that these may not be due to chance factors alone. This exercise gives students experience with numerical results that indicate systemic changes in the population under study, and, like the problem of climate change itself, these changes cannot be attributed to chance factors, but rather to the long term effects of man-made pollutants.

One source of global warming is the emissions generated by the airline industry. Jet travel has a significant impact on global warming, but not for the reasons most people would think. Unlike the automobile engine, the turbofan engine is extremely efficient at high altitudes and at cruising speeds. Therefore, the jet engines burn fuel completely with very low particle emissions. The problem comes from the particulate matter that is put into the atmosphere during the lift-off and take-off cycle (LTO). At these lower power levels, jets put large amounts of particulate matter into the atmosphere.

The particle output of ten planes was examined to develop the data for this exercise. The CO particles for each plane were calculated based on power levels, fuel flow rates, engine type, and number of engines per aircraft. It was estimated that a particular aircraft would taxi or idle for approximately 20 minutes during a low airport traffic LTO cycle, and would taxi or idle for 60 minutes if airport traffic conditions were heavy.

In this activity, students do a hypothesis test about the difference between two means and a hypothesis test about one mean. The two tests will yield similar information, but they will also give students the experience to think about data under investigation. In this exercise, students will learn to investigate data over a short period of time and over a longer period of time. Students are asked to imagine that they are investigating at an airport for CO emissions and congestion, and they have been asked to report about what they find to the FAA for recommendations for environmental protection.

Part of this exercise is intended to show students that there is something that can be done about particle emissions that result from congestion at airports. Cutting down the idle/taxi times at large airports can help to alleviate global warming.

Activity Overview

Reading: ***Aircraft Emissions*** reading needs to precede inquiry activity handout.

1. This activity is recommended after hypothesis testing has been introduced.
2. Introduce the lesson by allowing students to read a portion of the EPA report on particulate matter emissions in the airline industry (15 minutes).
3. Students should begin the problem in class by calculating the mean and standard deviation for the emissions data (30 minutes).
4. Students review an example of a hypothesis test on the difference of two means (15 minutes).

Materials and Resources

- Handout
- Reading: United States Environmental Protection Agency Air and Radiation. (1992, December). *Procedures for emission inventory preparation volume IV mobile sources* (EPA-R-92_009. Retrieved January 30, 2009, from http://www.epa.gov/OTAQ/invntory/r92009.pdf

Reading: Aircraft Emissions

McCormack | Elementary Statistics 1 Energy and the Environment: Global Challenge (MAT120)

Source: United States Environmental Protection Agency Air and Radiation. (1992, December). *Procedures for emission inventory preparation volume IV mobile sources* (EPA-R-92_009). Retrieved January 30, 2009, from http://www.epa.gov/OTAQ/invntory/r92009.pdf

5.1.1.2 Pollutant Emissions

Aircraft pollutants of significance are hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and particulates (PM10). The factors that determine the quantity of pollutant emitted are the emission index for each operating mode (pounds of pollutant per 1000 pounds of fuel consumed), the fuel consumption rate, and the duration of each operating mode. HC and CO emission indexes are very high during the taxi/idle phases when aircraft engines are at low power and operate at less than optimum efficiency. The emission indexes fall as the aircraft moves into the higher power operating modes of the LTO cycle. Thus, operation in the taxi/idle mode, when aircraft are on the ground at low power, is a significant factor in calculating total HC and CO emissions. For areas which are most concerned about the contribution of aircraft to the inventory of HC and CO, special attention should be paid to the time the aircraft operate in the taxi/idle modes.

NOx emissions, on the other hand, are low when engine power and combustion temperature are low but increase as the power level is increased and combustion temperature rises. Therefore the takeoff and climbout modes have the highest NOx emission rates. If NOx is a primary concern for the inventory area, special effort should focus on determining an accurate height of the mixing layer, which affects the operating duration of climbout.

Sulfur emissions typically are not measured when aircraft engines are tested. In evaluating sulfur emissions, it is assumed that all sulfur in the fuel combines with oxygen during combustion to form sulfur dioxide. Thus, sulfur dioxide emission rates are highest during takeoff and climbout when fuel consumption rates are high. Nationally the sulfur content of fuel remains fairly constant from year to year at about 0.05% wt. for commercial jet fuel, 0.025% wt. for military fuel, and 0.006% wt for aviation gasoline. This is the basis for the sulfur dioxide emission indexes in the tables included in this methodology. If the sulfur content of fuel varies significantly on a local basis, the emission index can be adjusted according to a ratio of the local value to the national value.

Particulates form as a result of incomplete combustion. Particulate emission rates are somewhat higher at low power rates than at high power rates since combustion efficiency improves at higher engine power. However, particulate emissions are highest during takeoff and climbout because the fuel flow rate also is high. It is particularly difficult to estimate the emissions of this pollutant. Direct measurement of particulate emissions from aircraft engines typically are not available, although emission of visible smoke is reported as part of the engine certification procedure. Particulate emission factors for only a few aircraft engines are included in this chapter.

Handout: Aircraft Emissions

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Introduction

From the EPA report you have just read you learned that emissions from jet engines are at their highest during low power levels of the lift-off and take-off cycle (LTO), or when fuel consumption levels are the highest, such as during take-off. Typically, low power levels occur when a jet is preparing to take off, such as when it is taxiing to the runway or idling while waiting to take off. Therefore, the key to limiting emissions from aircraft is to limit the time spent at lower power levels. Eliminating airport congestion can go a long way toward controlling the harmful emissions that occur during taxi/idle times of aircraft on their approach to the runway.

Round trip taxi/idle times, from the gate to the runway and back, should not take more than an average of 20 minutes in an airport with light traffic. Airports that have enough runways and gates for the aircraft they service have low taxi/idle times because they are less congested. Airports that service more aircraft than there are facilities for exhibit higher taxi/idle times.

The table below shows pounds of CO emitted during heavy traffic and hence high taxi/idle times.

Problem A

Aircraft	**Heavy Traffic lbs CO/High Taxi/ Idle times**
Boeing 727	106.60
DC-10	211.86
Boeing 737	68.67
Boeing 747	356.67
DC-9	25.38
L-1011	478.44
DC-8	109.44
B 737-300	29.85
B747 F	356.91
A-310	30.96

1. Calculate the mean and standard deviation for both heavy and light traffic pounds of CO particulate matter.

2. Imagine you are conducting an investigation of an airport for CO particulate matter based on taxi/idle times. The airport you are investigating reports a mean pound particulate idle/taxi time of CO to be 59.16 lbs, but the mean pounds of CO that you, the investigator, calculate is: _______________ (*calculated mean for the above ten aircraft in heavy traffic/high taxi/idle times*). The standard deviation you record is: ______________ (*calculated standard deviation for the above ten aircraft in heavy traffic/high taxi/idle times*). Using the 5% significance level can you conclude the mean number of pounds of CO particles for this airport is still 59.16 lbs?

3. Long taxi/idle times in heavy traffic pollute the first 3000 feet of the atmosphere. From your

calculation what can you conclude is happening to the atmosphere closest to the ground?

4. What are some of the reasons that an airport might have heavy traffic?
5. What are some of the ways an airport might be able to reduce traffic?
6. Can you think of some economic reasons why an airport might not want to reduce congestion?

Problem B

As an FAA airport congestion investigator you want to know if CO particulate emissions have increased from 1998 to 2005 based on idle/taxi times. The following table gives the CO particulate emissions in pounds for 1998 and 2005. These data are calculated for the years 1998 and 2005 on the same aircraft.

In your textbook look up *inferences between two population means for paired samples*. Using 5% significance level, can you conclude that the number of pounds of CO particulate emission has increased between 1998 and 2005? Assume that the population of paired differences has a normal distribution. Based on this test what would you recommend to the FAA about congestion at this airport

1998	35.53	70.62	22.89	118.89	8.46	159.48	36.48	9.95	118.97	10.32
2005	106.60	211.86	68.67	356.67	25.38	478.44	109.44	29.85	356.91	30.96

1. Does this test indicate that there are fundamental changes in CO_2 emissions at this airport over the period in question?
2. Could the time of year these samples were taken affect the results of the test?

Reference for all data:

United States Environmental Protection Agency Air and Radiation. (1992, December). *Procedures for emission inventory preparation volume IV mobile sources* (EPA-R-92_009). Retrieved January 30, 2009, from http://www.epa.gov/OTAQ/invntory/r92009.pdf (p. 171)