Analyzing Fuel Efficiency versus Car Transmission

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Package Dependencies

The analysis requires the `dplyr`, `ggplot2`, and `mosaic` packages. See the **Appendix** for code.

Data Preprocessing

The `mtcars` data set was transformed for easier analysis. New columns were created in order to more easily identify the engine and transmission variables. Also, these new variables `engine` and `transmission` were coerced to factor variables. See **Appendix** for code.

Introduction

This project seeks to analyze and identify any association between fuel efficiency and transmission. These traits were analyzed directly and by adjusting for other factors. The data came from the `mtcars` data set native to R and all analysis was performed within R version 4.4.1.

Summary

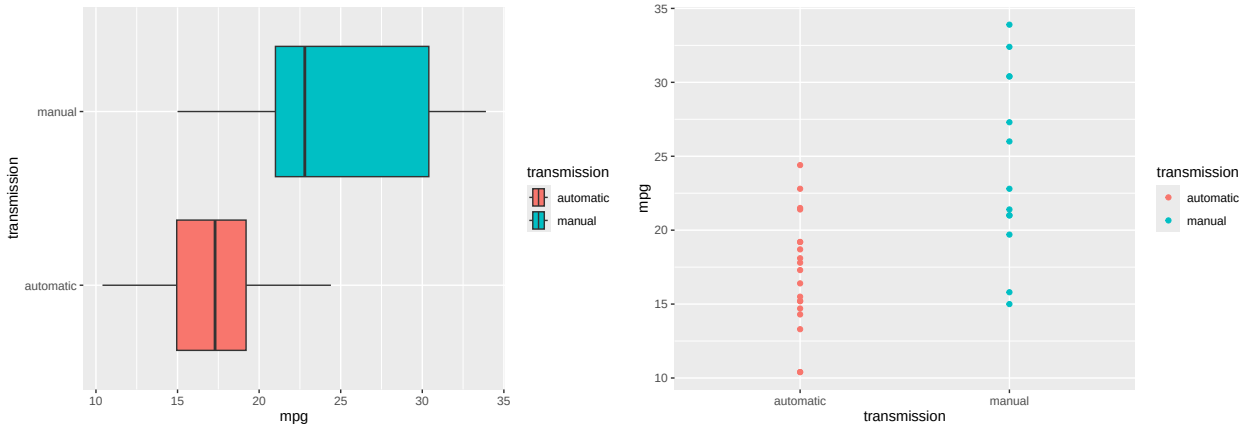
Nested ANOVA model fit testing **concluded no difference between fuel efficiency**, `mpg`, based on `transmission`. There were observed differences in average `mpg` based on `transmission`. However, these differences did not appear significant when adjusted for other car traits.

The *95% confidence interval* for the *automatic transmission* coefficient was *28.6 mpg to 39.4 mpg*, while the interval for the *manual transmission* coefficient was *32.5 mpg to 39.6 mpg*. Based on these confidence intervals the **fuel efficiency of automatic transmission cars could be up to 11 mpg better than or up to 6.9 mpg worse than the efficiency of manual transmission cars**.Coefficients are interpreted in more detail in the **Regression Analysis** section.

A caveat of this analysis is that the chosen model arguably violates some conditions for linear regression models. In particular in relation to *residuals*. This is discussed later in the **Regression Analysis** section.

Exploratory Data Analysis

Two plots `mpg` vs `transmission` are included below. These plots shows that manual cars have a higher median `mpg` and a larger spread than automatics. The plots also indicate that `mpg` increases from automatic cars to manual cars. See the **Appendix** for additional plots and statistics. These plots provide a baseline for model selection.



Model Selection

Initially a regression of `mpg` ~ `transmission` was conducted. This naive model showed significant differences in the coefficients for *automatic* (*17.15 mpg*) and *manual* transmission (*24.39 mpg*), but the residual plots violated the model assumptions. Next a regression was run with `mpg` against all other variables; however, the full model found no statistically significant predictors. Due to space constraints further details for these models have been excluded.

Since weight (`wt`) has a known causal influence on `mpg`, it was included in the model. The correlation matrix for each predictor was consulted in choosing variables for a **nested ANOVA** model fit. I elected not to use available *automated* stepwise regression after encountering these notes. The notes question the diagnostics and inference that result from automated model selection. **Ultimately, the nested ANOVA procedure compared 8 models**.

Using nested ANOVA model testing, the following predictors were selected for the final model: **horsepower, transmission, and weight**. The nested ANOVA code is located in the **Appendix**. The nested process also found `qsec` (**quarter mile time**) to be significant. However, its inclusion caused the *automatic transmission* coefficient to become insignificant. Therefore `qsec` was excluded from the model. The chosen model is labeled `fit_hp`.

Note that many models beyond those mentioned were tested. Due to the large number of significance tests performed, models that cleared especially low p-values were prioritized to limit Type I errors for the related **t-tests** and **ANOVA** tests. However, no explicit calculations were made to identify upper bounds for p-values for multiple hypothesis testing.

Regression Analysis

Below the nested ANOVA model of `mpg ~ wt + transmission + hp`, named `fit_hp`, is analyzed.

The results below give the coefficients, p-values, and 95% confidence intervals for *automatic* and *manual* transmission from the nested anova model `fit_hp`.

```
##                       Estimate     Pr(>|t|)
## transmissionautomatic 34.00288 2.824030e-13
## transmissionmanual    36.08659 1.477711e-18

##                          2.5 %   97.5 %
## transmissionautomatic 28.58963 39.41612
## transmissionmanual    32.52986 39.64331
```

The coefficients are significant at the 0.1% level, which provides some protection against Type I error. **Since the models were computed without an intercept the coefficients indicate the average miles per gallon of an automatic transmission or manual transmission car within each model**. For example, an automatic car from the `fit_hp` model would be expected to have between 28.6 mpg and 39.4 mpg of fuel efficiency. These numbers represent the average number of additional miles driven for one additional gallon of fuel.

The plot of residuals vs the fitted values arguably shows a pattern, but looks *reasonably* scattered. The residuals appear larger for extreme fitted values suggesting heteroscedasticity, but there is little data in these regions. The QQ plot is reasonably linear, though the residuals show potential influential points. This could be explored further using the influence.measures() function, but due to space constraints it is is not explored. See the **Appendix** for the residual plots of the `fit_hp` model and code for influence.measures().

Appendix

Additional figures and code are included below.

```
# code for data preprocessing
mtcars$engine <- NULL # create more informative  names for these vars
mtcars[mtcars$vs == 0,'engine'] <- 'V' # engine label
mtcars[mtcars$vs == 1,'engine'] <- 'straight' # engine label
mtcars$transmission <- NULL # create more informative  names for these vars
mtcars[mtcars$am == 0,'transmission'] <- 'automatic' # transmission label
mtcars[mtcars$am == 1,'transmission'] <- 'manual' # transmission label
mtcars$engine <- as.factor(mtcars$engine)
mtcars$transmission <- as.factor(mtcars$transmission)
```

Data Preprocessing Code

```
# install packages required for data processing and analysis

install.packages('dplyr', repos="http://cran.us.r-project.org");  install.packages('ggplot2', repos="ht
library(dplyr); library(ggplot2);  library(mosaic)
```

Package Dependencies Code

```
# linear models for sequential ANOVA TEST
wt_only <- lm(mpg ~ wt -1, data = mtcars) # weight only model
transm_wt <- lm(mpg ~ transmission + wt -1, data = mtcars) # transmission included in nesting
fit_hp <- lm(mpg ~ wt + transmission + hp - 1, data = mtcars) # horsepower included in nesting
fit_qsec <- lm(mpg ~ wt + transmission + hp + qsec - 1, data = mtcars) # 1/4 time included in nesting
fit_vs <- lm(mpg ~ wt + transmission + hp + qsec + vs - 1, data = mtcars) # engine included in nesting
fit_carb <- lm(mpg ~ wt + transmission + hp + qsec + vs + carb - 1, data = mtcars) # carburetor include
fit_drat <- lm(mpg ~ wt + transmission + hp + qsec + vs + carb + drat - 1, data = mtcars) # axel ratio
```

```r
fit_gear <- lm(mpg ~ wt + transmission + hp + qsec + vs + carb + drat + gear - 1, data = mtcars) #gears

# nested ANOVA
anova(wt_only, transm_wt, fit_hp,fit_qsec,fit_vs,fit_carb,fit_drat, fit_gear) # step wise ANOVA
```

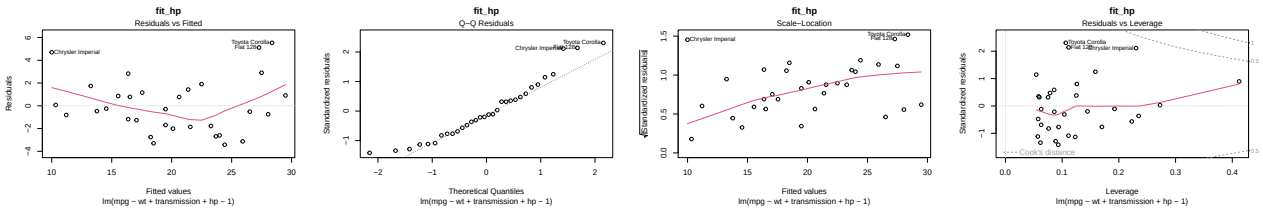
Nested ANOVA Code

```
## Analysis of Variance Table
##
## Model 1: mpg ~ wt - 1
## Model 2: mpg ~ transmission + wt - 1
## Model 3: mpg ~ wt + transmission + hp - 1
## Model 4: mpg ~ wt + transmission + hp + qsec - 1
## Model 5: mpg ~ wt + transmission + hp + qsec + vs - 1
## Model 6: mpg ~ wt + transmission + hp + qsec + vs + carb - 1
## Model 7: mpg ~ wt + transmission + hp + qsec + vs + carb + drat - 1
## Model 8: mpg ~ wt + transmission + hp + qsec + vs + carb + drat + gear -
##     1
##   Res.Df    RSS Df Sum of Sq        F    Pr(>F)
## 1     31 3936.6
## 2     29  278.3  2    3658.3 277.7379 < 2.2e-16 ***
## 3     28  180.3  1      98.0  14.8847 0.0007998 ***
## 4     27  160.1  1      20.2   3.0709 0.0930281 .
## 5     26  159.8  1       0.2   0.0377 0.8476721
## 6     25  156.4  1       3.4   0.5204 0.4779544
## 7     24  153.2  1       3.2   0.4833 0.4938789
## 8     23  151.5  1       1.7   0.2630 0.6129269
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Note that a variety of other variables were tested in a nested model fit, including an interaction term between `wt` and `transmission`. However, these model resulted in insignificance of *automatic transmission* or violated model assumptions (residual plot issues).

Residual Plots Reisdual plot of `fit_hp` model discussed in the **Regression Analysis** section.

```r
# resized due to page limit
plot(fit_hp, main = 'fit_hp')
```



```
# additional plots and statistics (#box plot not printed for space reasons)
#ggplot(mtcars, aes(x = mpg)) + geom_boxplot() + ggtitle('Fuel Efficency') +
          xlab('Miles per gallon (mpg)') + theme(plot.title = element_text(hjust = 0.5,))
```

Additional and Statistics

```
## NULL
```

```
# code for summary stats
mpg_stats <- rbind(favstats(mtcars$mpg), favstats(mtcars[mtcars$transmission == 'automatic','mpg']),
                   favstats(mtcars[mtcars$transmission == 'manual','mpg']))
row.names(mpg_stats) <- c('total_mpg','automatic_mpg','manual_mpg') # assign row names
mpg_stats
```

```
##                min     Q1 median   Q3  max     mean       sd  n missing
## total_mpg     10.4 15.425   19.2 22.8 33.9 20.09062 6.026948 32       0
## automatic_mpg 10.4 14.950   17.3 19.2 24.4 17.14737 3.833966 19       0
## manual_mpg    15.0 21.000   22.8 30.4 33.9 24.39231 6.166504 13       0
```

```
# The influence statistics for the fit_hp model are not printed due to space constraints for the assign
# However, note that dfbetas for transmission coefficients are small in comparison to the confidence in
# influence.measures(fit_hp)
```

Code for Duplicate Figures

```
# code for plots shown outside appendix

## box plot mpg vs transmission
ggplot(mtcars, aes(x = mpg, fill = transmission, y = transmission)) + geom_boxplot()
## scatter plot mpg vs transmission
ggplot(mtcars, aes(x = transmission, y = mpg, color = transmission)) + geom_point()
```