Final Project Report

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Introduction

The United States imports over $2 trillion worth of foreign products annually with the majority of goods arriving via ocean-going container ships. Port cargo drayage operations manage the over-the-road transport of shipping containers that arrive and depart on ocean-going container vessels at a port terminal. While on land, containers are placed on wheeled chassis until they return to the port facility. The acquisition and management of these chassis are significant operational challenges. This article assumed a situation where chassis may be engaged either as daily rental or via a committed long-term lease at a lower cost. Also, long-term leases offer the ability to directly manage availability and proactively keep equipment in good working order.

Chassis Leasing and Selection Policy for Port Operations

- We present and describe the implementation of a solution methodology and addresses the two decision problems:
    - The optimal fleet size for leased chassis.
    - A real-time decision policy for selecting between rental and leased chassis as containers arrive.

Data Generation

- Our optimization model requires the arrival times of all individual containers and the container dwell time.
    - The correlation between dwell times and arrival times is -0.015, so they should be uncorrelated.
    - We used 52 weeks for a year, and divided them into 728 half-day periods.
    - In our model, we assume a chassis is a available for reuse in the period following its release from a previous order, which means that a leased chassis returned in the morning can be redeployed in the afternoon.
- Based on the history of the arrival data, the order arrival rate could be approriately modeled as three distinct regimes:
    - Regime: Busy
        - Week range: 39-44; Mean: 415; Std: 63; Range: 352-524
    - Regime: Low
        - Week range: 1-3 and 48-52; Mean: 58; Std: 19; Range: 36-100
    - Regime: Moderate

- Week range: 4-38 and 45-47; Mean: 209; Std: 59; Range: 118-337
- We fitted the weekly arrival totals as truncated normal distributions with input parameters above

```r
library(truncnorm)
library(EnvStats)

##
## Attaching package: 'EnvStats'

## The following objects are masked from 'package:stats':
##
##     predict, predict.lm

## The following object is masked from 'package:base':
##
##     print.default

library(dplyr)

##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union

library(magrittr)
library(ggplot2)
library(tidyr)

##
## Attaching package: 'tidyr'

## The following object is masked from 'package:magrittr':
##
##     extract

library(readxl)
library(ROI)

## ROI: R Optimization Infrastructure

## Registered solver plugins: nlminb, clp, glpk, optimx, symphony.

## Default solver: auto.

library(ROI.plugin.clp)
library(ompr)
library(ompr.roi)
```

```
busy <- rtruncnorm(6, a = 352, b = 524, mean = 415, sd = 63)
low <- rtruncnorm(8, a = 36, b = 100, mean = 58, sd = 19)
moderate <- rtruncnorm(38, a = 118, b = 337, mean = 209, sd = 59)
busy <- round(busy)
low <- round(low)
moderate <- round(moderate)

# Weekly order arrivals
WOA<-c(busy,low,moderate)
```

- The history data also showed that the overall day-of-week distribution for arrivals did not vary significantly across our seasons, followings are these percentages:

```
# Distribution of Orders Arrivals by Day of Week
daily_percentage <- c(0.2,0.21,0.19,0.16,0.19,0.05,0)
cum_dailyPer <- cumsum(daily_percentage)
```

- We also need to generate the dwell times according to its empirical distribution.

```
# Dwell time
prob <- c(0.105,0.209,0.156,0.116,0.076,0.074,0.056,0.056,0.033,0.030,0.025,0.021,0
.011,0.017,0.005,0.010)
a <- c(1:16)
n <- sum(WOA)
nn <- n*prob
nn <- round(nn)
```

- Following is the histogram depicting the distribution of historical container dwell times
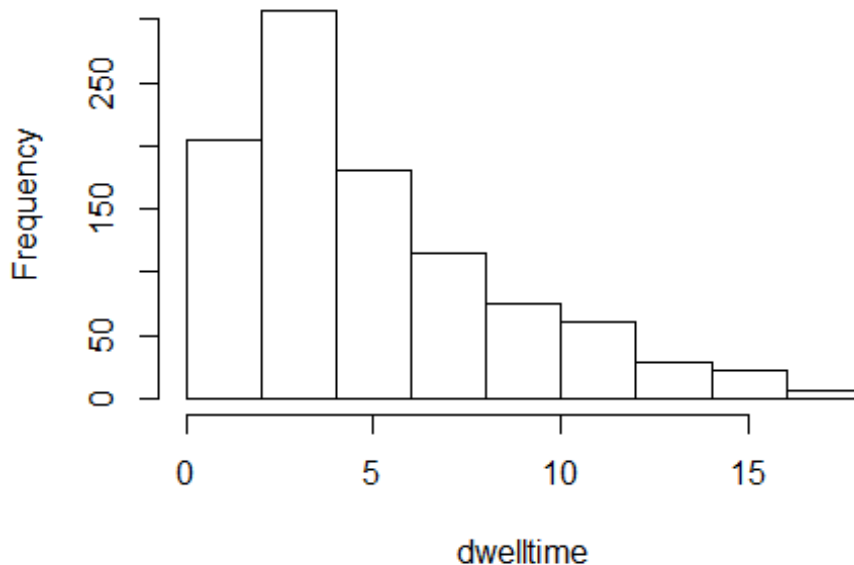
```
data <- function(nn,a){
  data <- runif(nn,a,a+1)
  data
}

result <- unlist(mapply(data,nn,a))

dwelltime<-remp(1000,result)
dwelltime <- round(dwelltime)
hist(dwelltime)
```

Histogram of dwelltime

Build the order-period incidence matrix M(i,p)

- We define $M(i, p) = 1$ if the order i container requires a chassis in period p and 0 otherwise.

```
# Generate 1000 simulated realizations of order arrivals and dwell times
numSimulated <- 1000

s_busy <- sum(busy)
s_low <- sum(low)
s_moderate <- sum(moderate)
ss <- s_busy + s_low + s_moderate

Busy_week <- seq(39, 44)
Low_week <- c(seq(1, 3), seq(48, 52))
Moderate_week <- c(seq(4, 38), seq(45, 47))

M <- matrix(rep(0, 728*numSimulated), nrow = numSimulated, ncol = 728)

for (i in 1:numSimulated) {
  regime <- runif(1)

  if(regime <= s_busy/ss){
    w <- sample(Busy_week, 1)
    hdp_0 <- (w - 1)*14
    dow <- runif(1)
    if(dow <= cum_dailyPer[1]){
      hdp_1 <- hdp_0
```

```r
    m_a <- runif(1)
    if(m_a <= 0.5){
      hdp_2 <- hdp_1 + 1
      M[i, hdp_2] <- 1
      if(hdp_2 + dwelltime[i] >= 728){
        for (k in 0:(728-hdp_2)) {
          M[i, hdp_2+k] <- 1
        }
      }
      else{
        for (k in 0:(dwelltime[i]-1)) {
          M[i, hdp_2+k] <- 1
        }
      }
    }
    else{
      hdp_2 <- hdp_1 + 2
      M[i, hdp_2] <- 1
      if(hdp_2 + dwelltime[i] >= 728){
        for (k in 0:(728-hdp_2)) {
          M[i, hdp_2+k] <- 1
        }
      }
      else{
        for (k in 0:(dwelltime[i]-1)) {
          M[i, hdp_2+k] <- 1
        }
      }
    }
  }
  else{
    for (j in 2:6) {
      if(cum_dailyPer[j] >= dow && cum_dailyPer[j - 1] < dow){
        hdp_1 <- hdp_0 + (j - 1)*2
        m_a <- runif(1)
        if(m_a <= 0.5){
          hdp_2 <- hdp_1 + 1
          M[i, hdp_2] <- 1
          if(hdp_2 + dwelltime[i] >= 728){
            for (k in 0:(728-hdp_2)) {
              M[i, hdp_2+k] <- 1
            }
          }
          else{
            for (k in 0:(dwelltime[i]-1)) {
              M[i, hdp_2+k] <- 1
            }
          }
        }
        else{
```

```
            hdp_2 <- hdp_1 + 2
            M[i, hdp_2] <- 1
            if(hdp_2 + dwelltime[i] >= 728){
              for (k in 0:(728-hdp_2)) {
                M[i, hdp_2+k] <- 1
              }
            }
            else{
              for (k in 0:(dwelltime[i]-1)) {
                M[i, hdp_2+k] <- 1
              }
            }
          }
        }
      }
    }
  }

  if(regime > s_busy/ss && regime <= (s_busy+s_low)/ss){
    w <- sample(Low_week, 1)
    hdp_0 <- (w - 1)*14
    dow <- runif(1)
    if(dow <= cum_dailyPer[1]){
      hdp_1 <- hdp_0
      m_a <- runif(1)
      if(m_a <= 0.5){
        hdp_2 <- hdp_1 + 1
        M[i, hdp_2] <- 1
        if(hdp_2 + dwelltime[i] >= 728){
          for (k in 0:(728-hdp_2)) {
            M[i, hdp_2+k] <- 1
          }
        }
        else{
          for (k in 0:(dwelltime[i]-1)) {
            M[i, hdp_2+k] <- 1
          }
        }
      }
      else{
        hdp_2 <- hdp_1 + 2
        M[i, hdp_2] <- 1
        if(hdp_2 + dwelltime[i] >= 728){
          for (k in 0:(728-hdp_2)) {
            M[i, hdp_2+k] <- 1
          }
        }
        else{
          for (k in 0:(dwelltime[i]-1)) {
            M[i, hdp_2+k] <- 1
```

```r
        }
      }
    }
  }
  else{
    for (j in 2:6) {
      if(cum_dailyPer[j] >= dow && cum_dailyPer[j - 1] < dow){
        hdp_1 <- hdp_0 + (j - 1)*2
        m_a <- runif(1)
        if(m_a <= 0.5){
          hdp_2 <- hdp_1 + 1
          M[i, hdp_2] <- 1
          if(hdp_2 + dwelltime[i] >= 728){
            for (k in 0:(728-hdp_2)) {
              M[i, hdp_2+k] <- 1
            }
          }
          else{
            for (k in 0:(dwelltime[i]-1)) {
              M[i, hdp_2+k] <- 1
            }
          }
        }
        else{
          hdp_2 <- hdp_1 + 2
          M[i, hdp_2] <- 1
          if(hdp_2 + dwelltime[i] >= 728){
            for (k in 0:(728-hdp_2)) {
              M[i, hdp_2+k] <- 1
            }
          }
          else{
            for (k in 0:(dwelltime[i]-1)) {
              M[i, hdp_2+k] <- 1
            }
          }
        }
      }
    }
  }
}

if(regime > (s_busy+s_low)/ss){
  w <- sample(Moderate_week, 1)
  hdp_0 <- (w - 1)*14
  dow <- runif(1)
  if(dow <= cum_dailyPer[1]){
    hdp_1 <- hdp_0
    m_a <- runif(1)
    if(m_a <= 0.5){
```

```r
        hdp_2 <- hdp_1 + 1
        M[i, hdp_2] <- 1
        if(hdp_2 + dwelltime[i] >= 728){
          for (k in 0:(728-hdp_2)) {
            M[i, hdp_2+k] <- 1
          }
        }
        else{
          for (k in 0:(dwelltime[i]-1)) {
            M[i, hdp_2+k] <- 1
          }
        }
      }
      else{
        hdp_2 <- hdp_1 + 2
        M[i, hdp_2] <- 1
        if(hdp_2 + dwelltime[i] >= 728){
          for (k in 0:(728-hdp_2)) {
            M[i, hdp_2+k] <- 1
          }
        }
        else{
          for (k in 0:(dwelltime[i]-1)) {
            M[i, hdp_2+k] <- 1
          }
        }
      }
    }
  }
  else{
    for (j in 2:6) {
      if(cum_dailyPer[j] >= dow && cum_dailyPer[j - 1] < dow){
        hdp_1 <- hdp_0 + (j - 1)*2
        m_a <- runif(1)
        if(m_a <= 0.5){
          hdp_2 <- hdp_1 + 1
          M[i, hdp_2] <- 1
          if(hdp_2 + dwelltime[i] >= 728){
            for (k in 0:(728-hdp_2)) {
              M[i, hdp_2+k] <- 1
            }
          }
          else{
            for (k in 0:(dwelltime[i]-1)) {
              M[i, hdp_2+k] <- 1
            }
          }
        }
        else{
          hdp_2 <- hdp_1 + 2
          M[i, hdp_2] <- 1
```

```
            if(hdp_2 + dwelltime[i] >= 728){
              for (k in 0:(728-hdp_2)) {
                M[i, hdp_2+k] <- 1
              }
            }
            else{
              for (k in 0:(dwelltime[i]-1)) {
                M[i, hdp_2+k] <- 1
              }
            }
          }
        }
      }
    }
  }
}
```

Optimization Model

- **Decision Variables**
  - Nt: total number of chassis to be leased in advance for the time period spanned by the collection of orders.
  - x_i: indicator of chassis selection, $x_i = 1$ for order i is assigned to a leased chassis, and $x_i = 0$ for order i is assigned to a rental chassis
- **Problem Data**
  - D_i: dwell time (in half-day periods) of order i
  - C_R: per-period chassis rental cost
  - C_L: per-chassis annual lease cost
  - $M(i, p)$: the order-period incidence matrix
- **Objective function**
  - min $\sum_i (1 - x_i)D_i C_R + N_t C_L$
- **Constraint**
  - $\sum_i M(i, p)x_i \le N_t$

```
# Cost
rental_daily<-19
leased_annual<-2972

# Optimization Model
chassisLeasing_ompr <- MIPModel() %>%
  add_variable(chassisSelect[i], i = 1:numSimulated,
               type = "binary") %>%
  add_variable(Nt, type = "integer", lb = 0) %>%
  set_objective(sum_expr((1 - chassisSelect[i])*dwelltime[i]*(rental_daily/2), i =
1:numSimulated) +
                Nt*leased_annual, sense = "min") %>%
  add_constraint(sum_expr(chassisSelect[i]*M[i,j], i = 1:numSimulated) <= Nt, j = 1
:728) %>%
```

```
  solve_model(with_ROI(solver = "glpk"))

chassisLeasing_ompr %>%
  get_solution(chassisSelect[i])
```

```
##             variable   i value
## 1     chassisSelect   1     1
## 2     chassisSelect   2     1
## 3     chassisSelect   3     1
## 4     chassisSelect   4     1
## 5     chassisSelect   5     1
## 6     chassisSelect   6     1
## 7     chassisSelect   7     1
## 8     chassisSelect   8     1
## 9     chassisSelect   9     1
## 10    chassisSelect  10     1
## 11    chassisSelect  11     1
## 12    chassisSelect  12     1
## 13    chassisSelect  13     0
## 14    chassisSelect  14     1
## 15    chassisSelect  15     1
## 16    chassisSelect  16     1
## 17    chassisSelect  17     0
## 18    chassisSelect  18     1
## 19    chassisSelect  19     1
## 20    chassisSelect  20     0
## 21    chassisSelect  21     1
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## 23    chassisSelect  23     0
## 24    chassisSelect  24     1
## 25    chassisSelect  25     0
## 26    chassisSelect  26     0
## 27    chassisSelect  27     1
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## 29    chassisSelect  29     1
## 30    chassisSelect  30     1
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## 32    chassisSelect  32     0
## 33    chassisSelect  33     1
## 34    chassisSelect  34     1
## 35    chassisSelect  35     1
## 36    chassisSelect  36     1
## 37    chassisSelect  37     1
## 38    chassisSelect  38     1
## 39    chassisSelect  39     0
## 40    chassisSelect  40     1
## 41    chassisSelect  41     1
## 42    chassisSelect  42     1
## 43    chassisSelect  43     1
## 44    chassisSelect  44     1
```

```
## 45     chassisSelect     45     0
## 46     chassisSelect     46     1
## 47     chassisSelect     47     0
## 48     chassisSelect     48     0
## 49     chassisSelect     49     0
## 50     chassisSelect     50     1
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## 91     chassisSelect     91     1
## 92     chassisSelect     92     1
## 93     chassisSelect     93     1
## 94     chassisSelect     94     1
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## 95    chassisSelect    95     1
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## 143   chassisSelect   143     1
## 144   chassisSelect   144     1
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## 145   chassisSelect   145       1
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## 195   chassisSelect   195        1
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## 245   chassisSelect   245      1
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## 293   chassisSelect   293      1
## 294   chassisSelect   294      0
```

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## 295   chassisSelect   295      0
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## 302   chassisSelect   302      0
## 303   chassisSelect   303      1
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## 943   chassisSelect   943      1
## 944   chassisSelect   944      0
```

```
## 945    chassisSelect  945      1
## 946    chassisSelect  946      0
## 947    chassisSelect  947      1
## 948    chassisSelect  948      0
## 949    chassisSelect  949      1
## 950    chassisSelect  950      1
## 951    chassisSelect  951      0
## 952    chassisSelect  952      0
## 953    chassisSelect  953      1
## 954    chassisSelect  954      1
## 955    chassisSelect  955      0
## 956    chassisSelect  956      0
## 957    chassisSelect  957      1
## 958    chassisSelect  958      0
## 959    chassisSelect  959      1
## 960    chassisSelect  960      1
## 961    chassisSelect  961      1
## 962    chassisSelect  962      1
## 963    chassisSelect  963      1
## 964    chassisSelect  964      1
## 965    chassisSelect  965      0
## 966    chassisSelect  966      1
## 967    chassisSelect  967      1
## 968    chassisSelect  968      1
## 969    chassisSelect  969      0
## 970    chassisSelect  970      1
## 971    chassisSelect  971      1
## 972    chassisSelect  972      1
## 973    chassisSelect  973      1
## 974    chassisSelect  974      0
## 975    chassisSelect  975      1
## 976    chassisSelect  976      0
## 977    chassisSelect  977      1
## 978    chassisSelect  978      0
## 979    chassisSelect  979      1
## 980    chassisSelect  980      1
## 981    chassisSelect  981      1
## 982    chassisSelect  982      0
## 983    chassisSelect  983      1
## 984    chassisSelect  984      1
## 985    chassisSelect  985      1
## 986    chassisSelect  986      0
## 987    chassisSelect  987      1
## 988    chassisSelect  988      1
## 989    chassisSelect  989      0
## 990    chassisSelect  990      1
## 991    chassisSelect  991      1
## 992    chassisSelect  992      1
## 993    chassisSelect  993      1
## 994    chassisSelect  994      1
```

```
## 995   chassisSelect  995      1
## 996   chassisSelect  996      1
## 997   chassisSelect  997      1
## 998   chassisSelect  998      1
## 999   chassisSelect  999      0
## 1000  chassisSelect 1000      0

chassisLeasing_ompr %>%
  get_solution(Nt)

## Nt
##  8
```

Observations and Conclusion

```
cs <- chassisLeasing_ompr %>%
  get_solution(chassisSelect[i])
n_t <- chassisLeasing_ompr %>%
  get_solution(Nt)

# Orders using leased chassis
Olc <- sum(cs$value)
# Orders using rental chassis
Orc <- numSimulated - sum(cs$value)

# Optimized cost
opCost <- 0
for (i in 1:numSimulated) {
  opCost <- opCost + (1-cs$value[i])*dwelltime[i]*(rental_daily/2)
}
opCost <- opCost + n_t*leased_annual

print(n_t)

## Nt
##  8

print(Olc)

## [1] 704

print(opCost)

##      Nt
## 34881.5
```

- We have also tried 100 simulations, which shows us only one leased chassis.
- For 1000 simulations, we can have 8 leased chassis, and it would be used for 704 orders.
- The rest of the orders can use rental chassis.
- For our 1000 simulations, the optimized cost is $34881.5

Predictive Model

- We built a logistic regression model investigating the relationship between the choice of chassis leasing and the following predictor variables on the day the order (container) arrived and was processed:
  - Estimated dwell for each order (dwelltime)
  - Total daily orders for pick up (DOP)
  - Whether the planned chassis drop is morning(1) or afternoon(0) (MA)

```
## Predictive Model
Opt <- cs$value

startDate <- rep(0, numSimulated)
for (i in 1:length(startDate)) {
  startDate[i] <- min(which(M[i,] == 1))
}

# Total daily orders for pick up
DOP <- rep(0, numSimulated)
for (i in 1:numSimulated) {
  DOP[i] <- sum(M[,startDate[i]])
}

# Whether the planned chassis drop is morning(1) or afternoon(0)
MA <- rep(0, numSimulated)
for (i in 1:numSimulated) {
  if(startDate[i]%%2 == 1){
    MA[i] <- 1
  }
}

preModel <- glm(formula = Opt ~ dwelltime + DOP + MA, family = binomial())
summary(preModel)

##
## Call:
## glm(formula = Opt ~ dwelltime + DOP + MA, family = binomial())
##
## Deviance Residuals:
##     Min       1Q   Median       3Q      Max
## -3.0670  -0.6449   0.3725   0.7148   2.3463
##
## Coefficients:
##              Estimate Std. Error z value Pr(>|z|)
## (Intercept)  2.82747    0.28821   9.810   <2e-16 ***
## dwelltime    0.28648    0.03191   8.978   <2e-16 ***
## DOP         -0.30436    0.02380 -12.787   <2e-16 ***
## MA          -0.04917    0.16654  -0.295    0.768
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
##
## (Dispersion parameter for binomial family taken to be 1)
##
##     Null deviance: 1214.87  on 999  degrees of freedom
## Residual deviance:  888.17  on 996  degrees of freedom
## AIC: 896.17
##
## Number of Fisher Scoring iterations: 5
```

- The result illustrates that the selection policy for the chassis leasing is highly related with the dwell time of the oder and the total daily orders for pick up of its start date.
- We can use this predictive model to help us make the selection policy for chassis leasing.

Reference

[1] T. Gifford and R. Gremley, "Chassis Leasing and Selection Policy for Port Operations", *INFORMS Journal on Applied Analytics*, vol. 49, no. 4, pp. 239-248, 2019. Available: 10.1287/inte.2019.0991 [Accessed 5 December 2019].