Contents

Q1b

```
clear
C = [
    0 8 6 9 1 5
    3 0 1 5 4 2
    9 2 0 3 1 1
    8 2 1 0 10 6
    6 7 10 1 0 10
    6 2 5 2 1 0]
loc = [1 5 2 6 4 3 1];
[loc, TC] = tsp2opt(loc,C);

fprintf(['The final location sequence determined after applying the'...
    'twoopt improvement procedure is %s, with total cost = %d.\n'],...
    num2str(loc), TC);
```

```
C =
     0     8     6     9     1     5
     3     0     1     5     4     2
     9     2     0     3     1     1
     8     2     1     0    10     6
     6     7    10     1     0    10
     6     2     5     2     1     0
The final location sequence determined after applying thetwoopt improvement procedure is 1  5  4  2  3  6  1, with total cost = 12.
```

Q2b

```
clear
T = [
    0 2 2 2 1 2
    2 0 3 2 3 3
    2 3 0 3 2 2
    2 2 3 0 3 1
    1 3 2 3 0 3
    2 3 2 1 3 0];
mdisp(T)
sh = vec2struct('b',1,'e',[4 2 5 3 6]);
sh = vec2struct(sh,'tU',0, 'temin',[9 9 15 18 21],'temax',[18 12 18 21 24]);
tr = struct('b',1,'e',1,'tbmin',6,'tbmax',24,'temin',6,'temax',24);
sdisp(sh)
[TC,Xflg,out] = rteTC([1 2 3 4 5 1 2 3 4 5],sh,T,tr);
TC,Xflg
sdisp(out,false);
fprintf(['The minimum total time span needed to complete all '...
    'deliveries and return to the depot is %d hours.\n'], TC)
```

```
T:  1  2  3  4  5  6
-:------------------
1:  0  2  2  2  1  2
2:  2  0  3  2  3  3
3:  2  3  0  3  2  2
4:  2  2  3  0  3  1
5:  1  3  2  3  0  3
6:  2  3  2  1  3  0

sh:  b  e  tU  temin  temax
--:------------------------
 1:  1  4   0     9     18
 2:  1  2   0     9     12
 3:  1  5   0    15     18
 4:  1  3   0    18     21
 5:  1  6   0    21     24
TC =
    15
Xflg =
     1

out:  Rte  Loc  Cost  Arrive  Wait  TWmin  Start  LU  Depart  TWmax  Total
---:----------------------------------------------------------------------
  1:   0    1     0      0      0      6      8    0     8      24     0
  2:   1    1     0      8      0      6      8    0     8      24     0
  3:   2    1     0      8      0      6      8    0     8      24     0
  4:   3    1     0      8      0      6      8    0     8      24     0
  5:   4    1     0      8      0      6      8    0     8      24     0
  6:   5    1     0      8      0      6      8    0     8      24     0
  7:   1    4     2     10      0      9     10    0    10      18     2
  8:   2    2     2     12      0      9     12    0    12      12     2
  9:   3    5     3     15      0     15     15    0    15      18     3
 10:   4    3     2     17      1     18     18    0    18      21     3
 11:   5    6     2     20      1     21     21    0    21      24     3
 12:   0    1     2     23      0      6     23    0    23      24     2
The minimum total time span needed to complete all deliveries and return to the depot is 15 hours.
```

Q3b

```
clear
r123 = [2 3 2 1 3 1];
D = [
    0 180 320 100 100 40
    180 0 140 80 240 140
    320 140 0 220 300 280
    100 80 220 0 240 60
    180 240 300 240 0 220
    40 140 280 60 220 0];
ppi = 125;
tr = struct('r',2,'Kwt',25,'Kcu',2750);
```

```
sh = vec2struct('f',[200 300 100],'s',[20 5 10],...
   'b',[6 3 2],'e',[5 1 4],'v',[20000 5000 10000],'a',1,'h',.3);
sh = vec2struct(sh,'d',diag(D([sh.b],[sh.e])));
sdisp(sh)

[TLC,q,isLTL] = minTLC(sh,tr,ppi,D,r123)
```

```
sh:   f    s  b  e     v    a   h    d
--:-----------------------------------
 1:  200  20  6  5  20,000  1  0.3  220
 2:  300   5  3  1   5,000  1  0.3  320
 3:  100  10  2  4  10,000  1  0.3   80
TLC =
   1.0550e+05
q =
    5.8929
    1.9643
    3.9286
isLTL =
  logical
   0
```

Q4

Add depot: Use end location of shipment 1 as depot for all shipments

```
clear
DC = table2array(readtable('HW8data.xlsx','Sheet', 1));
DC = flip(DC);
Cust = readtable('HW8data.xlsx','Sheet', 2);
XY_c = [Cust.Lon Cust.Lat];
XY = [DC; XY_c];
D = dists(XY,XY,'mi')*1.2;
q = Cust.Pkg;
s = 1;
maxtime = 7;

temin = [];
temax = [];
for i = 1:size(XY_c,1)
    if strcmp(Cust.T_W(i), 'M')
        temin = [temin 8];
        temax = [temax 12];
    elseif strcmp(Cust.T_W(i), 'A')
        temin = [temin 12];
        temax = [temax 17];
    else
        temin = [temin 17];
        temax = [temax 21];
    end
end

sh = vec2struct('b',1,'e',2:size(XY,1), 'q', q, 's', s);
sh = vec2struct(sh,'tU', 2/60,'temin',temin,'temax',temax);

tr = struct('b',1,'e',1, 'Kcu',99999, 'Kwt', 35);

sdisp(sh)
```

```
 sh:  b    e  q  s    tU    temin  temax
---:----------------------------------------
  1:  1    2  2  1  0.0333    12     17
  2:  1    3  2  1  0.0333    17     21
  3:  1    4  4  1  0.0333    17     21
  4:  1    5  1  1  0.0333     8     12
  5:  1    6  4  1  0.0333     8     12
  6:  1    7  2  1  0.0333     8     12
 7:  1    8  3  1  0.0333     8      12
 8:  1    9  2  1  0.0333     8      12
 9:  1   10  2  1  0.0333     8      12
10:  1   11  1  1  0.0333     8      12
11:  1   12  1  1  0.0333    17      21
12:  1   13  5  1  0.0333    12      17
13:  1   14  2  1  0.0333    17      21
14:  1   15  2  1  0.0333     8      12
15:  1   16  2  1  0.0333    12      17
16:  1   17  2  1  0.0333    17      21
17:  1   18  3  1  0.0333     8      12
18:  1   19  2  1  0.0333    17      21
19:  1   20  1  1  0.0333    17      21
20:  1   21  2  1  0.0333     8      12
21:  1   22  3  1  0.0333     8      12
22:  1   23  2  1  0.0333    12      17
23:  1   24  3  1  0.0333     8      12
24:  1   25  2  1  0.0333    12      17
25:  1   26  2  1  0.0333     8      12
26:  1   27  2  1  0.0333    12      17
27:  1   28  3  1  0.0333    17      21
28:  1   29  1  1  0.0333    17      21
29:  1   30  2  1  0.0333    12      17
30:  1   31  3  1  0.0333     8      12
31:  1   32  2  1  0.0333     8      12
32:  1   33  3  1  0.0333     8      12
33:  1   34  3  1  0.0333    12      17
34:  1   35  2  1  0.0333     8      12
35:  1   36  2  1  0.0333     8      12
36:  1   37  2  1  0.0333    12      17
37:  1   38  3  1  0.0333    12      17
38:  1   39  2  1  0.0333    17      21
39:  1   40  1  1  0.0333    17      21
40:  1   41  2  1  0.0333     8      12
41:  1   42  1  1  0.0333     8      12
42:  1   43  2  1  0.0333    17      21
43:  1   44  2  1  0.0333    17      21
44:  1   45  2  1  0.0333    17      21
45:  1   46  2  1  0.0333    17      21
46:  1   47  2  1  0.0333    12      17
47:  1   48  4  1  0.0333     8      12
48:  1   49  1  1  0.0333     8      12
49:  1   50  3  1  0.0333    17      21
50:  1   51  3  1  0.0333     8      12
51:  1   52  4  1  0.0333    12      17
52:  1   53  2  1  0.0333     8      12
53:  1   54  1  1  0.0333    17      21
54:  1   55  2  1  0.0333     8      12
55:  1   56  4  1  0.0333    17      21
56:  1   57  1  1  0.0333    17      21
57:  1   58  2  1  0.0333    17      21
58:  1   59  1  1  0.0333    17      21
59:  1   60  2  1  0.0333     8      12
60:  1   61  3  1  0.0333     8      12
61:  1   62  4  1  0.0333    17      21
62:  1   63  2  1  0.0333    17      21
63:  1   64  2  1  0.0333    17      21
64:  1   65  3  1  0.0333    17      21
65:  1   66  4  1  0.0333     8      12
66:  1   67  1  1  0.0333     8      12
67:  1   68  1  1  0.0333     8      12
68:  1   69  2  1  0.0333    17      21
69:  1   70  1  1  0.0333     8      12
70:  1   71  2  1  0.0333    17      21
71:  1   72  3  1  0.0333    12      17
72:  1   73  2  1  0.0333    17      21
73:  1   74  2  1  0.0333     8      12
74:  1   75  1  1  0.0333     8      12
75:  1   76  2  1  0.0333     8      12
76:  1   77  5  1  0.0333    17      21
77:  1   78  2  1  0.0333    17      21
78:  1   79  1  1  0.0333    12      17
79:  1   80  2  1  0.0333    17      21
80:  1   81  1  1  0.0333     8      12
```

```
 81:  1   82  1  1  0.0333    17     21
 82:  1   83  1  1  0.0333    12     17
 83:  1   84  1  1  0.0333    12     17
 84:  1   85  1  1  0.0333    17     21
 85:  1   86  1  1  0.0333    17     21
 86:  1   87  2  1  0.0333     8     12
 87:  1   88  2  1  0.0333     8     12
 88:  1   89  3  1  0.0333    17     21
 89:  1   90  2  1  0.0333    17     21
 90:  1   91  1  1  0.0333    17     21
 91:  1   92  1  1  0.0333    17     21
 92:  1   93  2  1  0.0333     8     12
 93:  1   94  2  1  0.0333    17     21
 94:  1   95  3  1  0.0333     8     12
 95:  1   96  3  1  0.0333     8     12
 96:  1   97  2  1  0.0333     8     12
 97:  1   98  1  1  0.0333    17     21
 98:  1   99  6  1  0.0333    12     17
 99:  1  100  3  1  0.0333     8     12
100:  1  101  1  1  0.0333    17     21
101:  1  102  2  1  0.0333    12     17
102:  1  103  3  1  0.0333    17     21
103:  1  104  2  1  0.0333    17     21
104:  1  105  3  1  0.0333    12     17
105:  1  106  2  1  0.0333    12     17
106:  1  107  2  1  0.0333    17     21
107:  1  108  1  1  0.0333     8     12
108:  1  109  4  1  0.0333    17     21
109:  1  110  4  1  0.0333     8     12
110:  1  111  6  1  0.0333    17     21
111:  1  112  4  1  0.0333    17     21
112:  1  113  1  1  0.0333     8     12
113:  1  114  3  1  0.0333    17     21
114:  1  115  1  1  0.0333    17     21
115:  1  116  3  1  0.0333     8     12
116:  1  117  3  1  0.0333     8     12
117:  1  118  1  1  0.0333     8     12
118:  1  119  5  1  0.0333     8     12
119:  1  120  1  1  0.0333     8     12
120:  1  121  2  1  0.0333    17     21
121:  1  122  1  1  0.0333    12     17
122:  1  123  1  1  0.0333    17     21
123:  1  124  2  1  0.0333    12     17
124:  1  125  3  1  0.0333     8     12
125:  1  126  3  1  0.0333     8     12
126:  1  127  2  1  0.0333     8     12
127:  1  128  1  1  0.0333     8     12
128:  1  129  4  1  0.0333     8     12
129:  1  130  2  1  0.0333    17     21
130:  1  131  2  1  0.0333    17     21
131:  1  132  1  1  0.0333     8     12
132:  1  133  5  1  0.0333     8     12
133:  1  134  1  1  0.0333     8     12
134:  1  135  3  1  0.0333    17     21
135:  1  136  2  1  0.0333     8     12
136:  1  137  1  1  0.0333    12     17
137:  1  138  2  1  0.0333    17     21
138:  1  139  1  1  0.0333    12     17
139:  1  140  2  1  0.0333    17     21
140:  1  141  1  1  0.0333    12     17
141:  1  142  1  1  0.0333     8     12
142:  1  143  2  1  0.0333    17     21
143:  1  144  3  1  0.0333    17     21
144:  1  145  3  1  0.0333     8     12
145:  1  146  4  1  0.0333    12     17
146:  1  147  2  1  0.0333    17     21
147:  1  148  3  1  0.0333     8     12
148:  1  149  2  1  0.0333    17     21
149:  1  150  2  1  0.0333    17     21
150:  1  151  1  1  0.0333     8     12
151:  1  152  2  1  0.0333    12     17
152:  1  153  2  1  0.0333     8     12
153:  1  154  3  1  0.0333     8     12
154:  1  155  2  1  0.0333     8     12
```

```
155:  1  156  2  1  0.0333     8     12
156:  1  157  1  1  0.0333    17     21
157:  1  158  3  1  0.0333     8     12
158:  1  159  2  1  0.0333     8     12
159:  1  160  1  1  0.0333    17     21
160:  1  161  2  1  0.0333    17     21
161:  1  162  4  1  0.0333    17     21
162:  1  163  1  1  0.0333    17     21
163:  1  164  2  1  0.0333     8     12
164:  1  165  2  1  0.0333    12     17
165:  1  166  2  1  0.0333     8     12
166:  1  167  5  1  0.0333    12     17
167:  1  168  4  1  0.0333    12     17
168:  1  169  3  1  0.0333    17     21
169:  1  170  3  1  0.0333    17     21
170:  1  171  1  1  0.0333    17     21
171:  1  172  1  1  0.0333    12     17
172:  1  173  3  1  0.0333    12     17
173:  1  174  3  1  0.0333     8     12
174:  1  175  3  1  0.0333    12     17
175:  1  176  1  1  0.0333    17     21
176:  1  177  4  1  0.0333     8     12
177:  1  178  1  1  0.0333    12     17
178:  1  179  2  1  0.0333     8     12
179:  1  180  2  1  0.0333     8     12
180:  1  181  2  1  0.0333     8     12
```

Get road network

```
expansionAroundXY = 0.12;
[XY2,IJD,isXY,isIJD] = subgraph(usrdnode('XY'),...
   isinrect(usrdnode('XY'),boundrect(XY,expansionAroundXY)),...
   usrdlink('IJD'));
```

Label type of road

```
s = usrdlink(isIJD);
isI = s.Type == 'I';           % Interstate highways
isIR = isI & s.Urban == ' '; % Rural Interstate highways
isIU = isI & ~isIR;          % Urban Interstate highways
isR = s.Urban == ' ' & ~isI; % Rural non-Interstate roads
isU = ~isI & ~isR;           % Urban non-Interstate roads
```

Add connector roads from cities to road network

```
[IJD11,IJD12,IJD22] = addconnector(XY,XY2,IJD);
```

Convert road distances to travel times (needs to be after ADDCONNECTOR)

```
v.IR = 70;  % Rural Interstate highways average speed (mph)
v.IU = 50;  % Urban Interstate highways average speed (mph)
v.R = 45;   % Rural non-Interstate roads average speed (mph)
v.U = 20;   % Urban non-Interstate roads average speed (mph)
v.C = 15;   % Facility to road connector average speed (mph)

IJT = IJD;
IJT(isIR,3) = IJD(isIR,3)/v.IR;
IJT(isIU,3) = IJD(isIU,3)/v.IU;
IJT(isR,3) = IJD(isR,3)/v.R;
IJT(isU,3) = IJD(isU,3)/v.U;

IJT22 = IJD22;                % road to road
IJT22(:,3) = IJT(:,3);
IJT12 = IJD12;                % facility to road
IJT12(:,3) = IJD12(:,3)/v.C;  % (IJD11 facility to facility arcs ignored)
```

Shortest time routes

```
n = size(XY,1);
[T,P] = dijk(list2adj([IJT12; IJT22]),1:n,1:n);
```

Construct & improve routes:

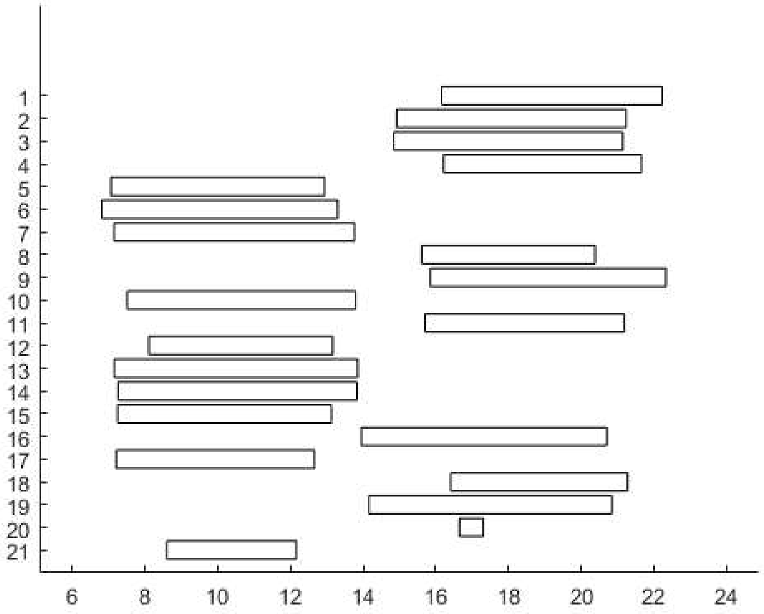
```
rTDh0 = @(rte) rteTC(rte,sh,T,tr);
rTDh = @(rte) myrteTC(rte,rTDh0,maxtime);
tic
IJS = pairwisesavings(rTDh,sh); toc
% sound(sin(1:3000));
tic
r = twoopt(savings(rTDh,sh,IJS),rTDh); toc
% sound(sin(1:3000));
```

```
Elapsed time is 132.826609 seconds.
Elapsed time is 117.664982 seconds.
```

Display route output structure

```
[TC,Xflg,out] = rTDh0(r);
Bars=[];
for i = 1:length(out), Bars=[Bars; [out(i).Depart(1) out(i).Depart(end)]]; end
gantt(num2cell(Bars,2))
fprintf('The number of vans needed for tomorrow’s deliveries is 11.\n')
```

```
The number of vans needed for tomorrow’s deliveries is 11.
```



Q5

Create Data

```
clear, close all
s = readtable('HW8data.xlsx','Sheet', 3);

Cust = uszip5('XY', 'Code5', mor([s.orig; s.dest], uszip5('Code5')));

b = [];
e = [];
```

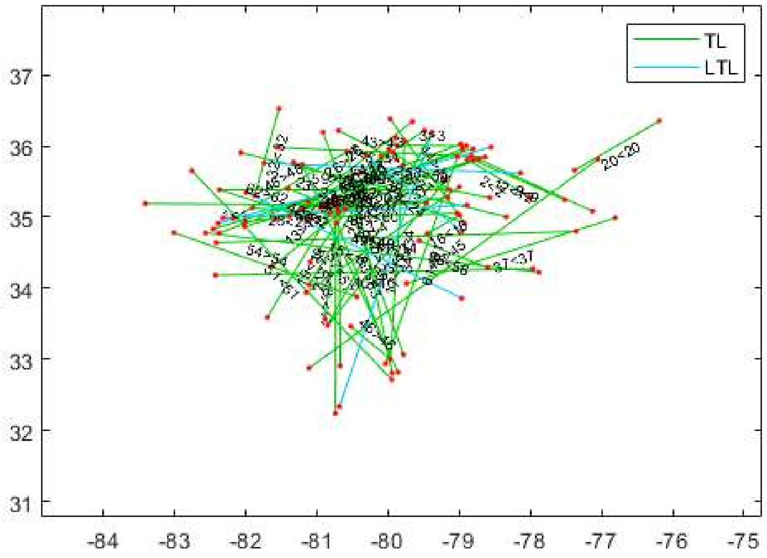
```
for i=1:length(s.orig)
    b = [b; find(Cust.Code5 == s.orig(i))];
    e = [e; find(Cust.Code5 == s.dest(i))];
end

D = dists(Cust.XY, Cust.XY, 'mi')*1.2;

ppiLTL = 193.6; % Jan 2020 (P)
ppiTL = 136.3; % Jan 2020 (P)
r = 2*(ppiTL/102.7);

tr = struct('r',r,'Kwt',25,'Kcu',2750);
sh = vec2struct('idx',1:length(s.orig),'b',b, 'e',e,...
    'f',s.ud.*s.wt/2000,'s',s.wt./s.cu,'v',2000./s.wt.*s.uc,'a',0.5,'h',.3);
sh = vec2struct(sh,'d',diag(D([sh.b],[sh.e])));
[TLC1,q1,isLTL] = minTLC(sh,tr,ppiLTL);
sh = vec2struct(sh,'TLC1',TLC1,'q1',q1,'t1',q1./[sh.f],'isLTL',isLTL);
qmax = maxpayld(sh,tr);
sh = vec2struct(sh,'qmax',qmax);
sdisp(sh)
```

```
sh:   b    e      f      s         v       a    h      d        TLC1      q1      t1    isLTL   qmax
--:-----------------------------------------------------------------------------------------------
 1:   48   75    1.25   0.45   5,132.04  0.5  0.3  169.55   1,384.39   0.62  0.4965    0      0.62
 2:   56   21   20.61  10.20  11,107.68  0.5  0.3   73.10   5,163.23   1.55  0.0752    0     14.02
 3:   16   27   38.44   3.44   2,182.55  0.5  0.3   65.70   2,962.70   4.52  0.1177    0      4.72
 4:   84   18   24.84   4.89   4,289.27  0.5  0.3  191.17   5,695.00   4.43  0.1782    0      6.72
 5:   13    1   26.10  10.59   6,027.81  0.5  0.3   63.97   4,003.69   2.21  0.0848    0     14.56
 6:   38   14   50.38  20.15   4,848.33  0.5  0.3   77.31   5,484.03   3.77  0.0748    0     25.00
 7:   74   96   17.21   0.96   6,614.36  0.5  0.3  270.37  10,698.83   1.31  0.0764    0      1.31
 8:   98   47    7.02   0.80   6,856.54  0.5  0.3  193.73   4,412.90   1.10  0.1567    0      1.10
 9:   68   23   41.70  28.23   1,990.04  0.5  0.3  131.60   4,170.55   6.99  0.1675    0     25.00
10:   28  104    5.57  13.89   1,504.30  0.5  0.3  263.71   1,876.69   4.16  0.7460    0     19.10
11:  117   46   11.45   1.69  22,424.59  0.5  0.3  252.52  10,162.74   1.51  0.1319    0      2.32
12:   65   19    2.69   2.52   1,280.75  0.5  0.3   98.31     733.90   1.91  0.7111    0      3.46
13:   79   37   57.92  10.21  27,397.99  0.5  0.3   96.88  15,646.97   1.90  0.0329    0     14.03
14:   67  107   16.07   1.24   1,773.01  0.5  0.3  344.62   9,094.36   1.70  0.1058    0      1.70
15:   99   40    4.30  16.78   7,167.62  0.5  0.3  240.88   3,038.38   0.44  0.1030    1     23.07
16:   51   59    7.94   4.28   7,622.55  0.5  0.3   37.96   1,913.26   0.84  0.1053    0      5.89
17:    5  115    5.03  14.64   5,859.56  0.5  0.3  331.71   3,889.88   0.66  0.1310    1     20.12
18:    7   85   41.54  19.33  13,811.59  0.5  0.3  151.38  11,761.21   2.84  0.0683    0     25.00
19:   45  114   19.94   5.95  63,574.29  0.5  0.3  147.59  17,261.03   0.91  0.0454    0      8.19
20:   33   31  144.22  36.46   1,717.41  0.5  0.3   98.45   6,231.86  12.10  0.0839    0     25.00
21:   81   42   92.23  32.89   2,021.85  0.5  0.3  112.23   5,773.22   9.52  0.1032    0     25.00
22:   17   86    2.91   1.46   9,304.48  0.5  0.3  190.27   2,863.69   1.03  0.3527    0      2.00
23:   34   39    1.25   3.14   3,181.82  0.5  0.3   52.29     576.46   0.60  0.4816    0      4.31
24:   61    9    2.69  14.76  23,780.06  0.5  0.3  127.44   2,306.26   0.12  0.0455    1     20.29
25:    3   92    5.28   1.56  20,833.93  0.5  0.3  261.65   6,767.95   1.08  0.2052    0      2.15
26:  112   10   33.60  32.97   1,040.29  0.5  0.3  160.27   2,986.90   9.57  0.2849    0     25.00
27:   12    8   24.73  10.34   1,421.15  0.5  0.3   69.25   1,968.75   4.62  0.1867    0     14.22
28:   50   88    6.16   4.29   4,788.13  0.5  0.3   74.14   1,865.96   1.30  0.2109    0      5.90
29:    6  110   14.88   1.99   4,566.35  0.5  0.3  148.35   4,015.67   2.74  0.1839    0      2.74
30:   89   30   29.90   6.60   1,081.81  0.5  0.3  195.38   3,181.37   9.07  0.3034    0      9.07
31:   25   50   11.98   1.85   7,928.18  0.5  0.3  155.01   4,842.63   2.04  0.1699    0      2.54
32:   71   35   14.97   4.44   2,305.77  0.5  0.3  103.38   2,384.19   3.45  0.2302    0      6.10
33:  108   52    4.30  11.32  10,867.69  0.5  0.3  233.68   3,805.43   0.37  0.0859    1     15.56
34:   15   95   40.63  19.09  18,149.68  0.5  0.3  254.71  17,295.82   3.18  0.0782    0     25.00
35:   80    5    7.70   1.58   9,047.71  0.5  0.3  246.00   5,225.63   1.93  0.2499    0      2.17
36:   87   54   24.61  10.41  15,817.76  0.5  0.3  195.29  11,004.09   2.32  0.0942    0     14.31
37:   66  100    9.78   9.08  13,933.32  0.5  0.3  214.49   6,822.95   1.63  0.1669    0     12.48
38:   69   58   19.46  31.19   2,396.71  0.5  0.3  177.04   3,626.52   5.04  0.2592    0     25.00
39:   22   73    6.20  17.56  33,188.33  0.5  0.3  242.80   5,215.78   0.17  0.0275    1     24.15
40:   62  105   13.29  12.91  11,350.61  0.5  0.3  305.72   8,570.55   2.52  0.1894    0     17.75
41:   36   29    7.95   2.71   1,188.50  0.5  0.3  159.31   1,565.60   3.73  0.4696    0      3.73
42:   49   36   25.89  10.44   1,239.04  0.5  0.3   14.17   1,100.88   2.29  0.0884    0     14.36
43:   72   26   51.46   3.37   2,369.64  0.5  0.3  195.81   7,421.28   4.63  0.0900    0      4.63
44:    2   58   25.48   2.96   5,574.97  0.5  0.3  140.11   5,629.89   3.37  0.1321    0      4.07
45:  116   32   11.53  10.04   1,980.61  0.5  0.3  369.04   3,662.81   6.16  0.5349    0     13.81
46:   82   95   11.68  13.04  22,673.10  0.5  0.3   54.50   4,794.44   0.70  0.0603    0     17.92
47:  113   53   15.63   8.82  25,556.94  0.5  0.3  148.28   9,713.58   1.27  0.0810    0     12.13
48:   90    3   42.09  19.97   3,560.84  0.5  0.3  132.73   5,628.64   5.27  0.1252    0     25.00
```

```
49:  106   63   19.99   6.26  17,363.27  0.5  0.3  323.00  13,363.35   2.57  0.1283    0     8.60
50:   55   77   73.84  13.03   2,441.11  0.5  0.3  262.57   8,681.68  11.85  0.1606    0    17.92
51:   94   76   11.84   5.99   8,876.81  0.5  0.3  310.28   7,206.14   2.71  0.2286    0     8.23
52:   24  103   12.44  13.42  17,598.77  0.5  0.3  273.65   9,680.92   0.56  0.0451    1    18.45
53:   11   80   59.99  15.04   4,303.19  0.5  0.3  202.99   9,135.21   7.08  0.1180    0    20.68
54:  109   83    1.81   4.54  22,736.13  0.5  0.3  190.91   3,538.81   0.52  0.2864    0     6.24
55:    4  102   30.85   2.13  15,458.72  0.5  0.3  192.18  12,081.95   2.61  0.0844    0     2.93
56:   64  101   15.50  33.47   3,191.63  0.5  0.3   72.92   2,396.74   2.50  0.1615    0    25.00
57:   97   70   11.69  11.22   4,396.28  0.5  0.3  259.03   4,604.34   3.49  0.2987    0    15.43
58:   41   57   37.61  15.88   6,859.29  0.5  0.3  126.49   7,209.15   3.50  0.0931    0    21.84
59:   78   12   15.76  11.61   4,852.71  0.5  0.3  218.29   5,157.05   3.54  0.2247    0    15.96
60:   60   44   56.64   5.58   3,866.42  0.5  0.3   94.53   5,741.59   4.95  0.0874    0     7.67
61:   20   93   89.29  22.95   5,587.42  0.5  0.3  251.03  14,122.61   8.43  0.0944    0    25.00
62:   78  111   26.21   4.79   3,623.21  0.5  0.3   93.65   3,763.79   3.46  0.1321    0     6.59
63:   43   95   22.08   3.48  13,099.83  0.5  0.3  191.12   9,383.40   2.39  0.1081    0     4.78
64:   91   26   17.30   7.27  17,347.14  0.5  0.3  242.68  10,768.78   2.07  0.1196    0     9.99
```

Independent shipments

```
plotshmt(sh,Cust.XY,[],tr,true)
```



Consolidated shipments

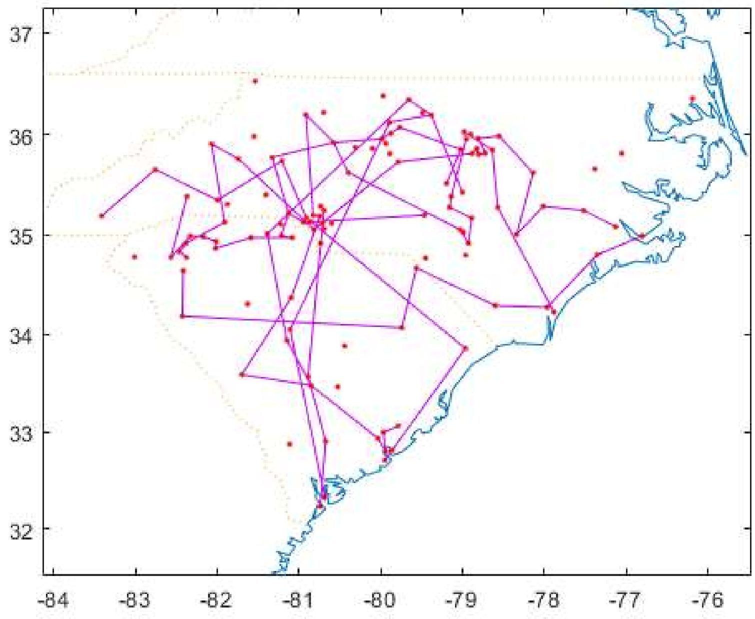
```
rTCh = @(rte) minTLC(sh,tr,ppiLTL,D,rte);
ph = @(rte) plotshmt(sh,Cust.XY,rte,tr);
IJS = pairwisesavings(rTCh,sh,minTLC(sh,tr));
```

Construct and improve routes

```
[rc,TLCc] = twoopt(savings(rTCh,sh,IJS,ph),rTCh,ph);
```

```
SAVINGS:
24496.535733: Make Rte 1 using 34 and 61
29577.318659: Add 7 to Rte 1
46473.404901: Make Rte 2 using 36 and 64
55637.424173: Add 63 to Rte 1
61074.082902: Add 47 to Rte 2
74634.917473: Make Rte 3 using 14 and 40
83323.258743: Add 53 to Rte 1
101107.247301: Make Rte 4 using 52 and 55
```

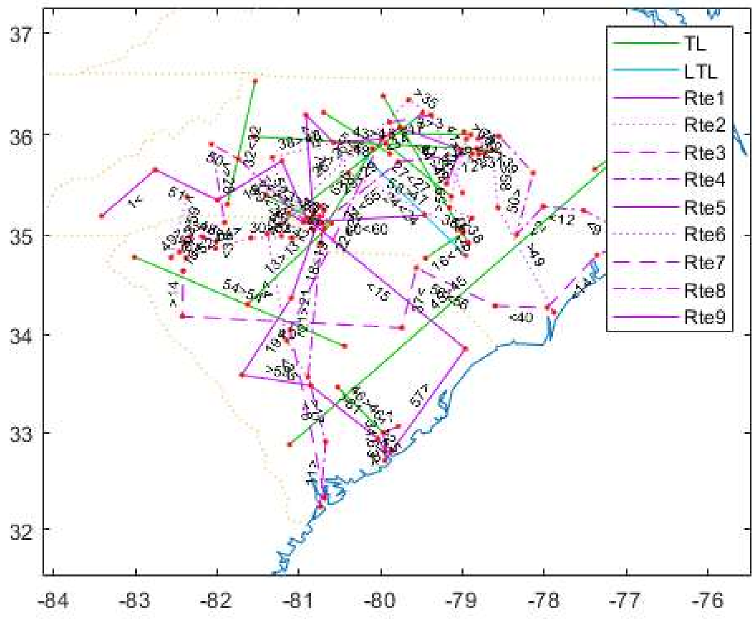
```
111530.155550: Add 49 to Rte 2
122049.715773: Add 18 to Rte 1
126749.754309: Add 39 to Rte 4
132598.205688: Add 25 to Rte 1
147337.023554: Add 19 to Rte 1
158999.336185: Make Rte 5 using 8 and 11
162923.737555: Add 31 to Rte 4
165643.574107: Add 59 to Rte 2
168585.040592: Add 21 to Rte 5
172469.118168: Add 37 to Rte 3
173638.125124: Add 33 to Rte 2
174734.722211: Add 30 to Rte 2
182884.694356: Add 50 to Rte 4
187226.443865: Add 48 to Rte 2
196883.410303: Make Rte 6 using 51 and 57
200072.370619: Add 58 to Rte 2
201144.044829: Add 10 to Rte 4
203507.205374: Add 38 to Rte 2
212983.506647: Make Rte 7 using 4 and 35
214963.698312: Add 15 to Rte 6
217520.443630: Add 62 to Rte 2
218206.232925: Add 41 to Rte 2
219378.658381: Add 28 to Rte 4
225151.605835: Make Rte 8 using 17 and 22
233506.248987: Make Rte 9 using 2 and 9
236258.420916: Add 26 to Rte 7
238536.502247: Add 56 to Rte 3
237910.200317: Combine Rte 4 to Rte 9
238412.085516: Add 12 to Rte 9
239404.751929: Add 1 to Rte 6
246180.782043: Make Rte 10 using 42 and 60

TWOOPT:
246180.782043: 1: 19 63 7 25 18 34 61 53 7 63 34 61 25 53 19 18
244595.899705: 1: 53 61 34 18 25 7 63 19 7 63 34 61 25 53 19 18
234944.689806: 1: 53 61 34 18 25 7 63 19 18 19 53 25 61 34 63 7
234710.717770: 1: 53 61 34 18 25 7 63 19 18 19 53 61 25 34 63 7
234710.717770: 2: 62 59 33 49 48 64 36 30 62 47 41 38 48 58 47 38 33 36 59 30 41 64 58 49
234628.088538: 2: 62 59 49 33 48 64 36 30 62 47 41 38 48 58 47 38 33 36 59 30 41 64 58 49
234596.424273: 2: 62 59 49 33 48 36 64 30 62 47 41 38 48 58 47 38 33 36 59 30 41 64 58 49
234596.424273: 3: 37 14 40 56 56 37 14 40
234460.941961: 3: 37 14 40 56 56 37 40 14
234460.941961: 4: 11 8 21 21 8 11
234460.941961: 5: 51 57 15 1 57 15 51 1
234460.941961: 6: 35 4 26 4 35 26
234358.619304: 6: 35 4 26 26 35 4
234358.619304: 7: 17 22 22 17
234358.619304: 8: 9 12 50 2 39 52 31 12 9 10 2 55 31 28 39 50 28 52 10 55
234274.120666: 8: 9 12 2 50 39 52 31 12 9 10 2 55 31 28 39 50 28 52 10 55
234103.499041: 8: 9 12 2 50 39 52 10 9 12 31 2 55 31 28 39 50 28 52 10 55
234070.254636: 8: 9 12 2 50 39 52 10 31 12 9 2 55 31 28 39 50 28 52 10 55
234070.254636: 9: 60 60 42 42
```



Make shipments not in routes into single-shipment routes

```
[rc,idx1,TLCc] = sh2rte(sh,rc,rTCh);
plotshmt(sh,Cust.XY,rc,tr)
```

```
ADD SINGLE-SHIPMENT ROUTES:
306611.332057: Added shipments 3 5 6 13 16 20 23 24 27 29 32 43 44 45 46 54
```



Change in TLC from indep to consol:

```
100*(sum(TLCc) - sum(TLC1))/sum(TLC1)
```

```
ans =
  -21.9894
```

Change in TLC for just multi-shipment routes

```
idxrte = find(cellfun(@length,rc) > 2);
idxsh = rte2idx(rc(idxrte));
idxsh = [idxsh{:}];
100*(sum(TLCc(idxrte)) - sum(TLC1(idxsh)))/sum(TLC1(idxsh))
```

```
ans =
  -26.9665
```

Q6

```
clear, close all
load shmtNC30
tr = struct('r',2,'Kwt',25,'Kcu',2750);
idx = [1 3 26 5];
sh = vec2struct('idx',idx,'b',b(idx),'e',e(idx),'f',f(idx),...
    's',s(idx),'v',v(idx),'a',.5,'h',.3);
sh = vec2struct(sh,'d',diag(D([sh.b],[sh.e])));
sdisp(sh)
n = length(sh)
```

```
sh:   b   e    f     s        v      a    h      d
--:----------------------------------------------------
 1:  15  42  2.13   1.17    683.19  0.5  0.3   64.97
 3:  23  40  6.27  15.23  5,843.73  0.5  0.3   59.27
26:  19  31  3.93   8.47    331.87  0.5  0.3  127.10
 5:  17  32  6.32  13.82  2,776.55  0.5  0.3  161.07
n =
     4
```

```
rTCh = @(rte) minTLC(sh,tr,[],D,rte);
[TLC1,q1,isLTL] = minTLC(sh,tr,[])
```

```
TLC1 =
   1.0e+03 *
    0.3372    1.6145    0.4462    1.8422
q1 =
    1.6148    0.9209    4.4814    2.2116
isLTL =
  1×4 logical array
   0   0   0   0
```

Min incremental charge for all possible routes

```
R = perms(1:n)
R = sortrows(R,1:n)
C = zeros(size(R));
for i = 1:size(C,1)
   for j = 1:size(C,2)
      Rj = perms(R(i,1:j));  % Try all permutations to get optimal
      TC(j) = Inf;
      for k = 1:size(Rj,1)
         [~,TCj] = insertimprove(Rj(k,:),rTCh,sh);
         if TCj < TC(j), TC(j) = TCj; end
      end
   end
   C(i,:) = TC;
   TC = diff([0 TC]);
```

```
    C(i,:) = TC(invperm(R(i,:)));
end
mdisp(C,sum(R.*repmat(10.^[n-1:-1:0],size(R,1),1),2))
```

```
R =
     4     3     2     1
     4     3     1     2
     4     2     3     1
     4     2     1     3
     4     1     3     2
     4     1     2     3
     3     4     2     1
     3     4     1     2
     3     2     4     1
     3     2     1     4
     3     1     4     2
     3     1     2     4
     2     4     3     1
     2     4     1     3
     2     3     4     1
     2     3     1     4
     2     1     4     3
     2     1     3     4
     1     4     3     2
     1     4     2     3
     1     3     4     2
     1     3     2     4
     1     2     4     3
     1     2     3     4
R =
     1     2     3     4
     1     2     4     3
     1     3     2     4
     1     3     4     2
     1     4     2     3
     1     4     3     2
     2     1     3     4
     2     1     4     3
     2     3     1     4
     2     3     4     1
     2     4     1     3
     2     4     3     1
     3     1     2     4
     3     1     4     2
     3     2     1     4
     3     2     4     1
     3     4     1     2
     3     4     2     1
     4     1     2     3
     4     1     3     2
     4     2     1     3
     4     2     3     1
     4     3     1     2
     4     3     2     1

   C:     1         2        3        4
----:-----------------------------------
1234:  337.20  1,762.89  593.26  1,239.41
1243:  337.20  1,762.89  166.57  1,666.11
1324:  337.20  1,992.83  363.32  1,239.41
1342:  337.20  1,621.90  363.32  1,610.35
1423:  337.20  1,627.32  166.57  1,801.68
1432:  337.20  1,621.90  171.99  1,801.68
2134:  485.64  1,614.46  593.26  1,239.41
2143:  485.64  1,614.46  166.57  1,666.11
2314:  165.12  1,614.46  913.78  1,239.41
2341:  192.27  1,614.46  913.78  1,212.27
2413:  178.35  1,614.46  166.57  1,973.39
2431:  192.27  1,614.46  152.65  1,973.39
3124:  254.35  1,992.83  446.17  1,239.41
3142:  254.35  1,621.90  446.17  1,610.35
3214:  165.12  2,082.07  446.17  1,239.41
```

```
3241:  192.27  2,082.07  446.17  1,212.27
3412:  176.19  1,621.90  446.17  1,688.51
3421:  192.27  1,605.82  446.17  1,688.51
4123:  296.66  1,627.32  166.57  1,842.23
4132:  296.66  1,621.90  171.99  1,842.23
4213:  178.35  1,745.62  166.57  1,842.23
4231:  192.27  1,745.62  152.65  1,842.23
4312:  176.19  1,621.90  292.45  1,842.23
4321:  192.27  1,605.82  292.45  1,842.23
```

Equal charge allocation

```
TCc = min(sum(C,2))
c_equal = repmat(TCc/n,1,n)
pct_reduct = round(100*(1 - c_equal./TLC1))
```

```
TCc =
   3.9328e+03
c_equal =
  983.1913  983.1913  983.1913  983.1913
pct_reduct =
  -192    39  -120    47
```

Equal savings allocation

```
Sn = sum(TLC1) - TCc
c_eq_sav = TLC1 - Sn/n
pct_reduct = round(100*(1 - c_eq_sav./TLC1))
```

```
Sn =
  307.2837
c_eq_sav =
   1.0e+03 *
    0.2604    1.5376    0.3693    1.7654
pct_reduct =
    23     5    17     4
```

Exact Shapley allocation

```
c_Shap_exact = mean(C,1)
pct_reduct = round(100*(1 - c_Shap_exact./TLC1))
```

```
c_Shap_exact =
   1.0e+03 *
    0.2621    1.7105    0.3605    1.5998
pct_reduct =
    22    -6    19    13
```

Pairwise approximate Shapely allocation

```
[~,S2] = pairwisesavings(rTCh,sh)
c_Shap_approx = TLC1 - (Sn/n + sum(S2)/(n-1) - sum(sum(S2))/(n*(n-1)))
pct_reduct = round(100*(1 - c_Shap_approx./TLC1))
```

```
S2 =
         0         0   82.8470   40.5425
         0         0         0         0
   82.8470         0         0  153.7157
   40.5425         0  153.7157         0
c_Shap_approx =
   1.0e+03 *
    0.2654    1.5838    0.3367    1.7468
```

```
pct_reduct =
    21     2    25     5
```

Comparison

```
vdisp('TLC1,c_equal,c_eq_sav,c_Shap_exact,c_Shap_approx',true,true)
```

```
     :    TLC1     c_equal  c_eq_sav  c_Shap_exact  c_Shap_approx
-----:-----------------------------------------------------------
    1:    337.20    983.19    260.38      262.06         265.43
    2:  1,614.46    983.19  1,537.64    1,710.47       1,583.82
    3:    446.17    983.19    369.35      360.47         336.68
    4:  1,842.23    983.19  1,765.41    1,599.77       1,746.84
Total:  4,240.05  3,932.77  3,932.77    3,932.77       3,932.77
  Avg:  1,060.01    983.19    983.19      983.19         983.19
```

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