University of Massachusetts Amherst

Assembly Systems Project

Cleo Hein
Janhavi Palkar
Stefanie Reineke
Revati Borkhade

The goal is to develop a practical tool that the firm can use to streamline the production at each level of the supply chain with that of the bottleneck resource in order to optimize profits. The following steps are suggested to systematically address all aspects of the problem.

1. Write an AMPL data file that captures the given information on the BOM and on demand.

```
param n:= 10;

set I:= 1, 2, A, B, C, D, E, F, G, H, I;
set K:= C, D, E, H, I;

param C:= 10080;
#param C:= 20160;
#param C:= 30240;

param M:= 999;

param:  H P :=
C    4    40
D    2    20
E    2    20
A    15   150
B    15   150
1    100  1000
2    200  2000
F    50   500
G    20   200
H    5    50
I    2    20;

param: R  S:=
C  30  120
D  30  120
E  30  120
H  30  120
I  60  120;


param B:=
A 1 4
B 1 2
C A 2
D A 1
C B 3
E B 2
A 2 3
F 2 1
G 2 2
H G 3
I G 2;

param D: 1  2  3  4  5  6  7  8  9  10:=
1    5    5    5    8    8    8    8    8    5    5
A    0    0    0    0    0    0    0    0    0    0
B    0    0    0    0    0    0    0    0    0    0
C    0    0    20   0    0    0    0    0    0    0
D    0    0    0    0    8    0    0    0    0    0
E    0    0    0    0    0    0    0    0    0    0
2    5    5    5    8    8    8    8    8    5    5
F    0    0    0    0    0    0    2    0    0    0

;
```

Here,
n :- number of weeks = 10
I :- Includes the subparts and end items
K :- subset of I where K shares a production resource with finite capacity of Ct at time t.
H :- Holding cost
P :- Delay Penalties
R :- Processing time
S :- Setup time
B :- The Bill of Material, number of units of part i required to build part j

2. Write and run an AMPL model to calculate all of the parts that will need to be produced and when to satisfy those demands assuming zero lead times and no capacity constraints.

Output:

```
objective production = 3605.
X [*,*]
:    1     2     3     4     5     6     7     8     9    10      :=
1    5     5     5     8     8     8     8     8     5     5
2    5     5     5     8     8     8     8     8     5     5
A   35    35    35    56    56    56    56    56    35    35
B   10    10    10    16    16    16    16    16    10    10
C  100   100   120   160   160   160   160   160   100   100
D   35    35    35    56    64    56    56    56    35    35
E   20    20    20    32    32    32    32    32    20    20
F    5     5     5     8     8     8    10     8     5     5
G   10    10    10    16    16    16    16    16    10    10
H   30    30    30    48    48    48    48    48    30    30
I   20    20    20    32    32    32    32    32    20    20
;

ampl:
```

This output explains without any lead time and capacity constraint, the number of production of each subparts(A,..I) and end products 1 and 2. In the first week of production, to meet the demand of 1 and 2 which is 5 products of each end items, assembly system produces 35 units of A, 10 units of B, 100 units of C, 35 units of D, 20 units of E, 5 units of F, 10 units of G, 30 units of H and 20 units of I.
Every week, based on the demand of end items 1 and 2, the production of subparts changes to assemble the end items 1 and 2. Since , there is no capacity constraint and lead time, it is easy for the Assembly system to meet the demand.

3. Assume now a lead time of one week for each step. Change your model to consider this. Will your data file need to change as well?

Yes, our data file will change because we now added “default 1” which tells our model that the lead time is 1 week for each part.

Output:

```
3 presolve messages suppressed.
X [*,*]
:     1     2     3     4     5     6     7    8    9   10     :=
1     0     0     8     8     8     8     8    5    5    0
2     0     0     8     8     8     8     8    5    5    0
A     0    56    56    56    56    56    35   35    0    0
B     0    16    16    16    16    16    10   10    0    0
C   160   180   160   160   160   100   100    0    0    0
D    56    56    56    64    56    35    35    0    0    0
E    32    32    32    32    32    20    20    0    0    0
F     0     8     8     8     8    10     5    5    0    0
G     0    16    16    16    16    16    10   10    0    0
H    48    48    48    48    48    30    30    0    0    0
I    32    32    32    32    32    20    20    0    0    0
;

ampl:
```

Lead time represents the duration between placing an order and receiving the product, impacting production scheduling and inventory management. With lead time, production must commence earlier to compensate for the delay in product availability. For A, we need C and D, for B, we need C and E. in the first week, we are producing C,D and E. Then we are producing A and B in the second week. Finally, in the third week, we are producing end items 1. Because of lead time, end items 1 and 2 get produced in the 3rd week.

4. Change your model to incorporate the processing times and capacity constraints. Find the lowest cost production schedule given the holding costs (H) and penalties (P) for each part.

In our data file, we added the parameters for holding cost, processing time, and capacity. The output shown below signifies how much of each assembly part is demanded, unfulfilled, and fulfilled. X represents the production of part i that started at time t. F is fulfilled customer demand of part i at time t. U represents cumulative unfulfilled demand of part i and time t. V is an inventory of part i at time t. For example, 5.04545 units of part 1 were produced in week 5. In week 1, 5 units of part 1 are unfulfilled. In week 6, 5.04545 units of part 1 are fulfilled. We can conclude that we do not have inventory for any of the parts given that V is 0 throughout the production cycle.

Output:

89 dual simplex iterations (0 in phase I)

:	X	U	F	V
1 0	.	.	.	0
1 1	0	5	0	0
1 2	0	10	0	0
1 3	0	15	0	0
1 4	0	23	0	0
1 5	5.04545	31	0	0
1 6	6.90909	33.9545	5.04545	0
1 7	6.90909	35.0455	6.90909	0
1 8	10.0455	36.1364	6.90909	0
1 9	10.0455	31.0909	10.0455	0
1 10	0	26.0455	10.0455	0
2 0	.	.	.	0
2 1	0	5	0	0
2 2	0	10	0	0
2 3	14.6087	15	0	0
2 4	14.6087	8.3913	14.6087	0
2 5	9.78261	1.78261	14.6087	0
2 6	8	0	9.78261	0
2 7	8	0	8	0
2 8	5	0	8	0
2 9	5	0	5	0
2 10	0	0	5	0
A 0	.	.	.	0
A 1	0	0	0	0
A 2	43.8261	0	0	0
A 3	43.8261	0	0	0
A 4	49.5296	0	0	0
A 5	51.6364	0	0	0
A 6	51.6364	0	0	0
A 7	55.1818	0	0	0
A 8	55.1818	0	0	0
A 9	0	0	0	0
A 10	0	0	0	0
B 0	.	.	.	0
B 1	0	0	0	0
B 2	0	0	0	0
B 3	0	0	0	0
B 4	10.0909	0	0	0
B 5	13.8182	0	0	0
B 6	13.8182	0	0	0
B 7	20.0909	0	0	0
B 8	20.0909	0	0	0
B 9	0	0	0	0
B 10	0	0	0	0
C 0	.	.	.	0
C 1	87.6522	0	0	0
C 2	87.6522	0	0	0
C 3	129.332	20	0	0
C 4	144.727	20	0	0
C 5	144.727	20	0	0
C 6	170.636	20	0	0
C 7	170.636	20	0	0
C 8	20	20	0	0
C 9	0	0	20	0
C 10	0	0	0	0
D 0	.	.	.	0
D 1	43.8261	0	0	0
D 2	43.8261	0	0	0
D 3	49.5296	0	0	0
D 4	51.6364	0	0	0
D 5	51.6364	8	0	0
D 6	55.1818	8	0	0
D 7	55.1818	8	0	0
D 8	8	8	0	0
D 9	0	0	8	0
D 10	0	0	0	0

```
E 0        .          .          .         0
E 1      0          0          0          0
E 2      0          0          0          0
E 3     20.1818     0          0          0
E 4     27.6364     0          0          0
E 5     27.6364     0          0          0
E 6     40.1818     0          0          0
E 7     40.1818     0          0          0
E 8      0          0          0          0
E 9      0          0          0          0
E 10     0          0          0          0
F 0        .          .          .         0
F 1      0          0          0          0
F 2     14.6087     0          0          0
F 3     14.6087     0          0          0
F 4      9.78261    0          0          0
F 5      8          0          0          0
F 6     10          0          0          0
F 7      5          0          2          0
F 8      5          0          0          0
F 9      0          0          0          0
F 10     0          0          0          0
G 0        .          .          .         0
G 1      0          0          0          0
G 2     29.2174     0          0          0
G 3     29.2174     0          0          0
G 4     19.5652     0          0          0
G 5     16          0          0          0
G 6     16          0          0          0
G 7     10          0          0          0
G 8     10          0          0          0
G 9      0          0          0          0
G 10     0          0          0          0
H 0        .          .          .         0
H 1     87.6522     0          0          0
H 2     87.6522     0          0          0
H 3     58.6957     0          0          0
H 4     48          0          0          0
H 5     48          0          0          0
H 6     30          0          0          0
H 7     30          0          0          0
H 8      0          0          0          0
H 9      0          0          0          0
H 10     0          0          0          0
I 0        .          .          .         0
I 1     58.4348     0          0          0
I 2     58.4348     0          0          0
I 3     39.1304     0          0          0
I 4     32          0          0          0
I 5     32          0          0          0
I 6     20          0          0          0
I 7     20          0          0          0
I 8      0          0          0          0
I 9      0          0          0          0
I 10     0          0          0          0
;
```

5. Change your model to incorporate the setup times and solve again.
a) Solve first assuming both X (production) and Z (setup) are non-negative continuous variables.

By solving the model by making X and Z non-negative continuous variables, we can see that the output for production and unfulfilled demand is slightly lower, which makes sense now that the setup time is taken into account. Making the production and setup times non-negative continuous means that half of a part can be produced, rather than a whole part, meaning that an **incomplete part can be produced.** As a result, having Z as a binary variable is more accurate than having it as a non-negative continuous variable because it gives a more accurate result for the setup time as either being required or not.

Output:

:	X	U	F	V
1 0	.	.	.	0
1 1	0	5	0	0
1 2	0	10	0	0
1 3	0	15	0	0
1 4	0	23	0	0
1 5	5.02997	31	0	0
1 6	6.90357	33.97	5.02997	0
1 7	6.90357	35.0665	6.90357	0
1 8	10.0397	36.1629	6.90357	0
1 9	10.0397	31.1232	10.0397	0
1 10	0	26.0835	10.0397	0
2 0	.	.	.	0
2 1	0	5	0	0
2 2	0	10	0	0
2 3	14.6039	15	0	0
2 4	14.6039	8.39613	14.6039	0
2 5	9.79226	1.79226	14.6039	0
2 6	8	0	9.79226	0
2 7	8	0	8	0
2 8	5	0	8	0
2 9	5	0	5	0
2 10	0	0	5	0
A 0	.	.	.	0
A 1	0	0	0	0
A 2	43.8116	0	0	0
A 3	43.8116	0	0	0
A 4	49.4967	0	0	0
A 5	51.6143	0	0	0
A 6	51.6143	0	0	0
A 7	55.1588	0	0	0
A 8	55.1588	0	0	0
A 9	0	0	0	0
A 10	0	0	0	0
B 0	.	.	.	0
B 1	0	0	0	0
B 2	0	0	0	0
B 3	0	0	0	0
B 4	10.0599	0	0	0
B 5	13.8071	0	0	0
B 6	13.8071	0	0	0
B 7	20.0794	0	0	0
B 8	20.0794	0	0	0
B 9	0	0	0	0
B 10	0	0	0	0
C 0	.	.	.	0
C 1	87.6232	0	0	0
C 2	87.6232	0	0	0
C 3	129.173	20	0	0
C 4	144.65	20	0	0
C 5	144.65	20	0	0
C 6	170.556	20	0	0
C 7	170.556	20	0	0
C 8	20	20	0	0
C 9	0	0	20	0
C 10	0	0	0	0
D 0	.	.	.	0
D 1	43.8116	0	0	0
D 2	43.8116	0	0	0
D 3	49.4967	0	0	0
D 4	51.6143	0	0	0
D 5	51.6143	8	0	0
D 6	55.1588	8	0	0
D 7	55.1588	8	0	0
D 8	8	8	0	0
D 9	0	0	8	0
D 10	0	0	0	0

```
E 0        .          .          .        0
E 1       0          0          0        0
E 2       0          0          0        0
E 3      20.1199     0          0        0
E 4      27.6143     0          0        0
E 5      27.6143     0          0        0
E 6      40.1588     0          0        0
E 7      40.1588     0          0        0
E 8       0          0          0        0
E 9       0          0          0        0
E 10      0          0          0        0
F 0        .          .          .        0
F 1       0          0          0        0
F 2      14.6039     0          0        0
F 3      14.6039     0          0        0
F 4       9.79226    0          0        0
F 5       8          0          0        0
F 6      10          0          0        0
F 7       5          0          2        0
F 8       5          0          0        0
F 9       0          0          0        0
F 10      0          0          0        0
G 0        .          .          .        0
G 1       0          0          0        0
G 2      29.2077     0          0        0
G 3      29.2077     0          0        0
G 4      19.5845     0          0        0
G 5      16          0          0        0
G 6      16          0          0        0
G 7      10          0          0        0
G 8      10          0          0        0
G 9       0          0          0        0
G 10      0          0          0        0
H 0        .          .          .        0
H 1      87.6232     0          0        0
H 2      87.6232     0          0        0
H 3      58.7536     0          0        0
H 4      48          0          0        0
H 5      48          0          0        0
H 6      30          0          0        0
H 7      30          0          0        0
H 8       0          0          0        0
H 9       0          0          0        0
H 10      0          0          0        0
I 0        .          .          .        0
I 1      58.4155     0          0        0
I 2      58.4155     0          0        0
I 3      39.169      0          0        0
I 4      32          0          0        0
I 5      32          0          0        0
I 6      20          0          0        0
I 7      20          0          0        0
I 8       0          0          0        0
I 9       0          0          0        0
I 10      0          0          0        0
;

 total solve time = 0
cost = 332223
```

b) Solve requiring Z to be binary variables.

:	X	U	F	V
1 0	.	.	.	0
1 1	0	5	0	0
1 2	0	10	0	0
1 3	0	15	0	0
1 4	0	23	0	0
1 5	2.68182	31	0	0
1 6	6	36.3182	2.68182	0
1 7	6	38.3182	6	0
1 8	9.13636	40.3182	6	0
1 9	9.13636	36.1818	9.13636	0
1 10	0	32.0455	9.13636	0
2 0	.	.	.	0
2 1	0	5	0	0
2 2	0	10	0	0
2 3	13.913	15	0	0
2 4	13.913	9.08696	13.913	0
2 5	11.1739	3.17391	13.913	0
2 6	8	0	11.1739	0
2 7	8	0	8	0
2 8	5	0	8	0
2 9	5	0	5	0
2 10	0	0	5	0
A 0	.	.	.	0
A 1	0	0	0	0
A 2	41.7391	0	0	0
A 3	41.7391	0	0	0
A 4	44.249	0	0	0
A 5	48	0	0	0
A 6	48	0	0	0
A 7	51.5455	0	0	0
A 8	51.5455	0	0	0
A 9	0	0	0	0
A 10	0	0	0	0
B 0	.	.	.	0
B 1	0	0	0	0
B 2	0	0	0	0
B 3	0	0	0	0
B 4	5.36364	0	0	0
B 5	12	0	0	0
B 6	12	0	0	0
B 7	18.2727	0	0	0
B 8	18.2727	0	0	0
B 9	0	0	0	0
B 10	0	0	0	0
C 0	.	.	.	0
C 1	83.4783	0	0	0
C 2	83.4783	0	0	0
C 3	104.589	20	0	0
C 4	132	20	0	0
C 5	132	20	0	0
C 6	157.909	20	0	0
C 7	157.909	20	0	0
C 8	20	20	0	0
C 9	0	0	20	0
C 10	0	0	0	0
D 0	.	.	.	0
D 1	41.7391	0	0	0
D 2	41.7391	0	0	0
D 3	44.249	0	0	0
D 4	48	0	0	0
D 5	48	8	0	0
D 6	51.5455	8	0	0
D 7	51.5455	8	0	0
D 8	8	8	0	0
D 9	0	0	8	0
D 10	0	0	0	0

```
D 10     0          0          0          0
E 0        .          .          .        0
E 1      0          0          0          0
E 2      0          0          0          0
E 3      10.7273    0          0          0
E 4      24         0          0          0
E 5      24         0          0          0
E 6      36.5455    0          0          0
E 7      36.5455    0          0          0
E 8      0          0          0          0
E 9      0          0          0          0
E 10     0          0          0          0
F 0        .          .          .        0
F 1      0          0          0          0
F 2      13.913     0          0          0
F 3      13.913     0          0          0
F 4      11.1739    0          0          0
F 5      8          0          0          0
F 6      10         0          0          0
F 7      5          0          2          0
F 8      5          0          0          0
F 9      0          0          0          0
F 10     0          0          0          0
G 0        .          .          .        0
G 1      0          0          0          0
G 2      27.8261    0          0          0
G 3      27.8261    0          0          0
G 4      22.3478    0          0          0
G 5      16         0          0          0
G 6      16         0          0          0
G 7      10         0          0          0
G 8      10         0          0          0
G 9      0          0          0          0
G 10     0          0          0          0
H 0        .          .          .        0
H 1      83.4783    0          0          0
H 2      83.4783    0          0          0
H 3      67.0435    0          0          0
H 4      48         0          0          0
H 5      48         0          0          0
H 6      30         0          0          0
H 7      30         0          0          0
H 8      0          0          0          0
H 9      0          0          0          0
H 10     0          0          0          0
I 0        .          .          .        0
I 1      55.6522    0          0          0
I 2      55.6522    0          0          0
I 3      44.6957    0          0          0
I 4      32         0          0          0
I 5      32         0          0          0
I 6      20         0          0          0
I 7      20         0          0          0
I 8      0          0          0          0
I 9      0          0          0          0
I 10     0          0          0          0
;

 total solve time = 0.09375
cost = 357144
```

Incase Z becomes Binary taking value 1 or 0, meaning if a changeover happens for i t time t , there is a changed observed in the production quantity X. For instance the production was 2.68 when Z was 0 the production of engine 1 in week 5 was reported 5.02. Similarly , the unfulfilled demand when Z was 0 was 36.31 in week 6 for engine 1 and reduced to 33.97 in week 6 for engine 1 which justifies the concept as the time invested in the changeover for the limited shift we observed lesser production (X) which resulted in increased unfuldiled(U) demand resulting in decreased in fulfilled demand(F) and no Inventory (V)

c) Solve requiring in addition the production X to be integer. Compare the production schedule, cost and solution time of the three solutions and explain the differences. Hint: You can calculate the CPU time taken by the AMPL solution process by adding the command display _total_solve_time;

Considering the case scenarios when X and Z we continuous, when Z was binarya nd when X is strictly integer - the total solve time in these cases was

	X and Z continuous	Z binary	X is Integer
Total solve Time	0	0.093	0.562
Cost	332223	357144	350526

Very evidently when X and Z are relaxed and continuous th etime required for the solution is lesser compared to when the X is strictly integer meaning there cannot be partial production.
Moreover an interesting observation canbe studies with the cost - the cost is theleast in the case when X and Z are are relaxed and the second being when there is no partial production allowed. Whe production schedules are when Z is binary vs when X is integers wrt the schedules when X and Z are relaxed

Wrt X and Z continuous	X	U	F	V
Z Binary	Decreased	Decreased	Increased	No change
X is integer	Decreased	Increased	Decreased	No change

Output:

```
:        X     U     F     V     :=
1 0      .     .     .     0
1 1      0     5     0     0
1 2      0    10     0     0
1 3      0    15     0     0
1 4      0    23     0     0
1 5      2    31     0     0
1 6      6    37     2     0
1 7      6    39     6     0
1 8      9    41     6     0
1 9      9    37     9     0
1 10     0    33     9     0
2 0      .     .     .     0
2 1      0     5     0     0
2 2      0    10     0     0
2 3     13    15     0     0
2 4     14    10    13     0
2 5     12     4    14     0
2 6      8     0    12     0
2 7      8     0     8     0
2 8      5     0     8     0
2 9      5     0     5     0
2 10     0     0     5     0
A 0      .     .     .     0
A 1      0     0     0     0
A 2     39     0     0     0
A 3     42     0     0     0
A 4     44     0     0     0
A 5     48     0     0     0
A 6     48     0     0     0
A 7     51     0     0     0
A 8     51     0     0     0
A 9      0     0     0     0
A 10     0     0     0     0
B 0      .     .     .     0
B 1      0     0     0     0
B 2      0     0     0     0
B 3      0     0     0     0
B 4      4     0     0     0
B 5     12     0     0     0
B 6     12     0     0     0
B 7     18     0     0     0
B 8     18     0     0     0
B 9      0     0     0     0
B 10     0     0     0     0
C 0      .     .     .     0
C 1     78     0     0     0
C 2     99     0     0     0
C 3    100     5    15     0
C 4    132     5     0     0
C 5    132     5     0     0
C 6    159     5     0     0
C 7    158     2     3     0
C 8      0     0     2     0
C 9      0     0     0     0
C 10     0     0     0     0
D 0      .     .     .     0
D 1     40     0     0     0
D 2     41     0     0     1
D 3     44     0     0     0
D 4     48     0     0     0
D 5     48     8     0     0
D 6     51     8     0     0
D 7     52     8     0     0
D 8      7     7     1     0
D 9      0     0     7     0
D 10     0     0     0     0
```

```
D 10     0     0     0     0
E 0      .     .     .     0
E 1      0     0     0     0
E 2      0     0     0     0
E 3      8     0     0     0
E 4     24     0     0     0
E 5     24     0     0     0
E 6     36     0     0     0
E 7     36     0     0     0
E 8      0     0     0     0
E 9      0     0     0     0
E 10     0     0     0     0
F 0      .     .     .     0
F 1      0     0     0     0
F 2     13     0     0     0
F 3     14     0     0     0
F 4     12     0     0     0
F 5      8     0     0     0
F 6     10     0     0     0
F 7      5     0     2     0
F 8      5     0     0     0
F 9      0     0     0     0
F 10     0     0     0     0
G 0      .     .     .     0
G 1      0     0     0     0
G 2     26     0     0     0
G 3     28     0     0     0
G 4     24     0     0     0
G 5     16     0     0     0
G 6     16     0     0     0
G 7     10     0     0     0
G 8     10     0     0     0
G 9      0     0     0     0
G 10     0     0     0     0
H 0      .     .     .     0
H 1     78     0     0     0
H 2     84     0     0     0
H 3     72     0     0     0
H 4     48     0     0     0
H 5     48     0     0     0
H 6     30     0     0     0
H 7     30     0     0     0
H 8      0     0     0     0
H 9      0     0     0     0
H 10     0     0     0     0
I 0      .     .     .     0
I 1     62     0     0     0
I 2     48     0     0    10
I 3     46     0     0     2
I 4     32     0     0     0
I 5     32     0     0     0
I 6     20     0     0     0
I 7     20     0     0     0
I 8      0     0     0     0
I 9      0     0     0     0
I 10     0     0     0     0
;

 total solve time = 0.5625
cost = 360526
```

6. In exploring longer term solutions, management would like to understand the value associated with increasing capacity by a factor of 2 or 3? What would you recommend?

Assuming an annual basis to make an analysis. We assume that the production line will only be set up one time, so the setup time of 120 minutes does not change. Only changing the time in one of the setup times.

Providing Engine 1 & 2 as an example, here are the outputs (production schedule, cost, and solution time) from considering the capacity to be 10080, 20160, and 30240.

10080

:		X	U	F
1	0	.	.	.
1	1	0	5	0
1	2	0	10	0
1	3	0	15	0
1	4	0	23	0
1	5	2	31	0
1	6	6	37	2
1	7	6	39	6
1	8	9	41	6
1	9	9	37	9
1	10	0	33	9
2	0	.	.	.
2	1	0	5	0
2	2	0	10	0
2	3	13	15	0
2	4	14	10	13
2	5	12	4	14
2	6	8	0	12
2	7	8	0	8
2	8	5	0	8
2	9	5	0	5
2	10	0	0	5

```
_total_solve_time = 0.5625
cost = 360526
```

20160

:		X	U	F
1	0	.	.	.
1	1	0	5	0
1	2	0	10	0
1	3	5	15	0
1	4	21	18	5
1	5	13	5	21
1	6	8	0	13
1	7	8	0	8
1	8	5	0	8
1	9	5	0	5
1	10	0	0	5
2	0	.	.	.
2	1	0	5	0
2	2	0	10	0
2	3	23	15	0
2	4	8	0	23
2	5	8	0	8
2	6	8	0	8
2	7	8	0	8
2	8	5	0	8
2	9	5	0	5
2	10	0	0	5

```
_total_solve_time = 0.046875
cost = 113054
```

30240

:		X	U	F
1	0	.	.	.
1	1	0	5	0
1	2	0	10	0
1	3	20	15	0
1	4	11	3	20
1	5	8	0	11
1	6	8	0	8
1	7	8	0	8
1	8	5	0	8
1	9	5	0	5
1	10	0	0	5
2	0	.	.	.
2	1	0	5	0
2	2	0	10	0
2	3	23	15	0
2	4	8	0	23
2	5	8	0	8
2	6	8	0	8
2	7	8	0	8
2	8	5	0	8
2	9	5	0	5
2	10	0	0	5

```
_total_solve_time = 0.03125
cost = 93000
```

As shown, the amount of unfulfilled demand decreases and the amount of fulfilled demand increases as the capacity grows. Additionally, the time to solve and the cost decreases as the capacity increases. Therefore, we recommend increasing the capacity by a factor of at least 2. This increases the amount of fulfilled demand while keeping in mind the impact a large inventory/ storage capacity has on overall cost.

Lower costs mean greater profit, so we want to minimize costs. On the other hand, we're not taking into account that if we satisfy more demand, we will also make more profit. Based on these outputs of the production schedule, cost, and solution time, we recommend increasing the capacity by at least a factor of 2, if not 3, with the limiting factor being the logistical costs associated with increasing capacity that we are not taking into account in this model.