Case Study
MSAN 631-02 Supply Chain Analytics

July 13, 2016

EXECUTIVE SUMMARY

This report outlines a production plan to meet the Specialty Packaging Corporation's (SPC) demand forecast for plastic containers over 3 years (2010-2012). The optimal production plan suggested in the report estimates the cost of production to be $12.26 Mn(approx.). As resin and outsourced plastic sheets are available in the open market and available when needed, the in-house pressing capacity puts an upper bound to the maximum demand that can be met in a month (28 Mn pounds).

The analysis also suggests to use both public and private warehousing options. Having a private warehouse space will help to keep the inventory cost under control in case the demand soars over the planning horizon.

INTRODUCTION

The production plan is geared towards meeting the demand forecast of black and clear plastic containers for 3 years (as shown in figure 1) while minimizing the total production cost. The production process broadly consists of the following steps:

1. Resin procurement from open market
2. Resin extrusion to produce plastic sheets (polystyrene).
3. Transportation of excess plastic sheets to and from warehouse (public or private).
4. Thermoform Pressing of plastic sheets that are produced in-house or purchased from subcontractors to make plastic containers.

Each process involves cost that has to be minimized subject to various constraints. SPC owns 14 extruders and 25 transforming presses producing 2850 lb of plastic sheets and lb of plastic containers per hour respectively. These machines can be operated by 6 and 1 workers respectively. Each operator can work for 63 days in a quarter, 8 hours a day and a maximum of 60 overtime hours in a quarter. This limits SPC's in-house production capacity.

As the number of extruders is less than the number of pressers, excess plastic sheet rolls extruded

are stored in warehouse to meet the demand spikes. Also, subcontracting the production of plastic sheets helps to meet the high demand in a few quarters.

The costs involved with private and public warehouses are different. Public warehouse is available on demand but is more expensive than a private warehouse. Though private warehouse is a cheaper option, it requires SPC to sign a three year lease for the area of land to be leased(i.e. over the planning horizon) and thus, becomes a fixed cost.

An aggregate production plan is suggested that meets the demand while minimizing the production cost under the the required constraints.

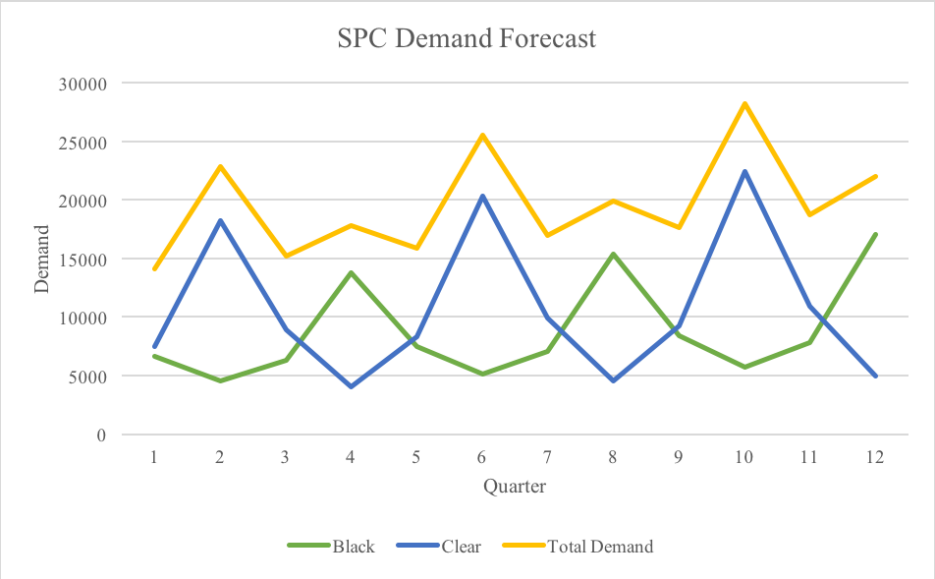

Figure 1: Demand forecast for 2010-2012 for plastic containers

METHODOLOGY

The analytical model built combines principals from network flow models and aggregate planning models (Refer figure 3 in appendix). The three parts, i.e. Extrusion, Inventory+Transportation and Pressing have been modeled as 3 separate aggregate planning models and then linked together in the end.

This analytical model allows the possibility of both public and private warehouses and let the cost minimization algorithm determine what is the ideal combination.

The model is based on following assumptions:

- The production plan has been created to meet demand forecast and no error in demand has been considered.
- At the beginning of the production horizon, it is assumed that all the machines were online, i.e. SPC has workforce of 84 extruder operators and 25 press operators.
- A full time worker (ideal or not) costs $7560, whereas the cost of firing and hiring an employee is $5500. Since it is not economical to keep an ideal worker on the workforce, it is assumed that the workforce each quarter is governed by the number of machines that are brought online. Hence, the constraint of re-training an idle person when brought online is not captured.
- Extruder and presser workers are different and their overtime hours can be fractional.
- The cost of switching between the production of clear and black plastic sheets in the extrusion process has been considered.
- Since material handling and storage costs are negotiable and the production plan is sensitive to these costs, three cases are considered:
  - Material Cost of $10 and Storage cost of $4
  - Material Cost of $11 and Storage cost of $5
  - Material Cost of $12 and Storage cost of $6
- The material handling cost and storage cost for public warehouse and the operational cost of the private warehouse, subcontracting rate and material cost do not change over the entire 3 year period.

- The utility ratio for the private warehouse is assumed to be 70%. The assumption is in line with the industry standards[1].

The objective is to minimize the costs incurred in three sub-processes of the production plan - Extrusion, Inventory+Transportation, Pressing and an additional cost of subcontracting plastic sheets. The decision variables and constraints are outlined below (refer Appendix for mathematical formulation):

1. Extrusion Process:
   (a) Decision Variables
      - No. of pounds of plastic extruded each quarter (Resin purchased)
      - No. of extruders brought online each quarter
      - Size of the Work Force supporting extrusion process each quarter
      - No. of extruder operators hired each quarter
      - No. of extruder operators fired each quarter
      - No. of Overtime hours worked each quarter
   (b) Constraints
      - Workforce Balance
      - No worker is left ideal.
      - Overtime constraint: Maximum overtime per worker is 60 hours per quarter
      - Production Constraint: The number of pounds produced each quarter cannot exceed the production capacity of each of the online extruder each quarter subject to the maximum number of hours the workforce can operate the machines.
2. Pressing Process:
   (a) Decision Variables
      - No. of pounds of plastic sheets pressed each quarter
      - No. of presses brought online each quarter

[1] http://www.scmr.com/article/warehousing_efficiency_and_effectiveness_in_the_supply_chain_process

- Size of the Work Force supporting presses each quarter
- No. of press operators hired each quarter
- No. of press operators fired each quarter
- No. of Overtime hours worked each quarter
- No. of subcontracted sheets every quarter

(b) Constraints

- Workforce Balance
- No worker is left ideal.
- Overtime constraint: Maximum overtime per worker is 60 hours per quarter
- Production Constraint: The number of units/pounds produced each quarter cannot exceed the production capacity of 2000 pounds for each of the online presses each quarter.
- Demand Constraint: The forecasted demand is met each quarter

3. Warehousing and Transportation:

(a) Decision Variables

- No. of pounds of plastic sheets stored in Private Warehouse each quarter
- No. of pounds of plastic sheets stored in Public Warehouse each quarter
- Area to lease for private warehouse

(b) Constraints

- Storage Constraint: The number of pounds to be stored in the private warehouse are less than equal to the usable area of the warehouse.
- Container Production Constraint: The stored plastic sheets for any quarter are to be used up by following quarter. Hence, for any quarter, the pressing process uses sheets stored in the warehouses from previous quarter, along with subcontracted sheets and a portion of sheets produced in the current quarter.

ANALYSIS

Choice of Warehouse Option: Public v/s Private v/s Both:

For the comparative analysis, material handling cost of $11 (per 1000 lb) and storage cost of $5 (per 1000 lb) are considered for public warehouse. For private warehouse, the operation cost of $4 (per 1000 lb), lease rate of $4 (per sq. foot) and warehouse utility ratio of 0.7 are considered.

Case	Subcontracted units (Mn lb)	Area leased (sq ft)	Total Inventory (Mn lb)	Overall Cost (Mn $)
I - Only Public Warehouse	7.83	-	9.84	12.265
II - Only Private Warehouse	11.39	2003	7.6	12.311
III - Both Warehouses	**7.5**	**705**	**11.34**	**12.265**

Table 1: Analysis of choice of warehouse

Table 1 outlines the results of the three cases. Choosing Case III gives the advantages of having both warehousing housing options. The number of subcontracted units are low which results in better utilization of in-house extrusion capacity. A moderate area of private warehouse gives the advantage of having a cheaper warehousing option in case there is an unexpected rise in the demand forecast.

Impact of Material handling and Storage costs:

Material handling and storage costs for public warehouse are negotiable and affect the optimal solution. The effect of these costs has been analyzed and tabulated in table 2. It is observed that negotiating these costs do not make a significant change in the production cost, however, the inventory allocation to public and private warehouse changes significantly.

- **Case I**: If the costs are negotiated well, the public warehouse storage option becomes economically favorable and the optimal solution allocates most of the inventory to public warehouse requiring to lease only 13 sq. ft of area for private warehouse. The overall reduction in the production cost is only 0.17% from Case II.

- **Case II**: If average costs are considered for material handling and storage, the optimal solution assigns inventory to the two options in a balanced manner. In this case, an area of 705 sq. ft. is leased and utilized to the tune of 55%.
- **Case III**: If SPC is not able to negotiate the material handling and storage costs, then the public warehousing option becomes very expensive and the optimal solution in this case allocates most of the inventory to private warehouse. To meet demand, 1530 sq. ft. of area needs to be leased over for years but only 46.5% actually gets utilized, unnecessarily increasing the fixed cost for SPC.

Case	Material Handling Cost (per 1000 lbs)	Storage Cost (per 1000 lbs)	Extruder workers laid off	Pressing workers laid off	Area leased (sq ft)	Total utilized area	Sub-contracted units (mn lbs)	Overall Cost (Mn $)
I	$4	$10	18	29	13	66.6%	4.9	12.244
II	**$5**	**$11**	**18**	**29**	**705**	**55.05%**	**7.5**	**12.265**
III	$6	$12	18	29	1530	46.51%	7.8	12.275

Table 2: Effect of Material Handling ans Storage Cost

Thus, Case II is an optimal solution to meet SPC's demand. The detailed production plan is outlined in Appendix in tables 3 and 4. With this plan, the cost incurred by SPC is very reasonable and also has a buffer capacity for storage (leased private warehouse space) in case of demand fluctuation. The extruder and presser utilization during the production plan is given in figure 2.

Outstanding Issues

1. Availability of error rate in demand forecast from previous planning horizons can help account for any changes in demand in the current planning horizon.
2. The scenario that every time a worker is brought online after an idle period, he is re-trained needs to be investigated further as this increases costs for SPC.

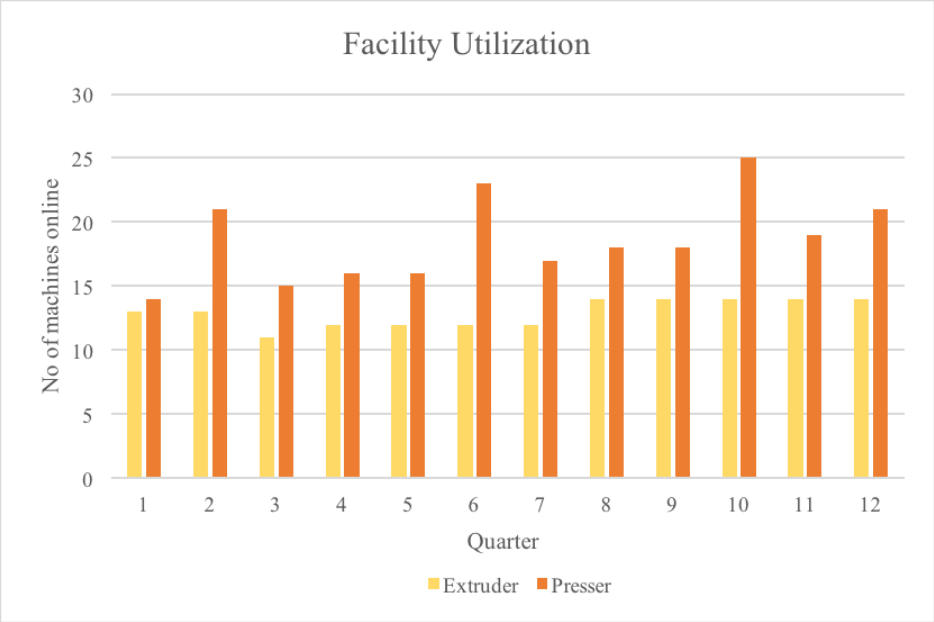

Figure 2: Facility Utilization each quarter

CONCLUSION

The analysis suggests that a mix of public and private warehousing option helps reduce overall cost, reduces the number of units subcontracted and gives buffer capacity for unexpected demand fluctuations. The production plan suggested considering these options incurs a cost of $12.265 Mn. For private warehouse, 705 sq. ft. area should be leased. The material handling and storage charges should be negotiated to $11 and $5 per 1000 lb respectively.

APPENDIX

Network Diagram & Explanation

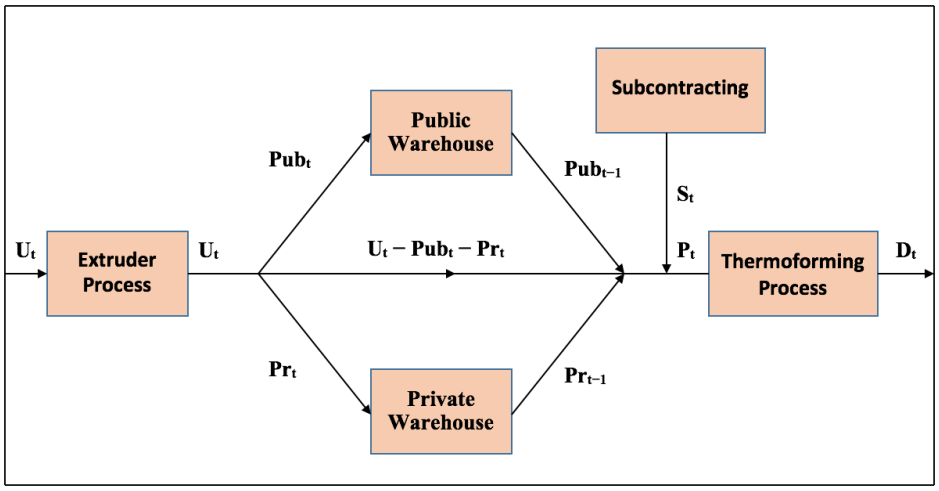

Figure 3: Production Diagram

Every quarter, SPC meets the demand for food containers. With the help of figure 3, its production process can be explained as follows:

1. The resin purchased is processed into polystyrene by the extruder. The production can also be subcontracted.

2. The polystyrene produced in-house is fed to the thermoforming process to produce containers and any excess is stored in the warehouse.

3. During the thermoforming process, first any polystyrene that is contained in the warehouse from previous quarter is used first and any remaining requirement is then fulfilled by that produced from the extruder or subcontracted.

4. Warehouse can be public or private or both.

5. At every step, the most cost effective option is chosen.

Formulation

We have identified four different costs for SPC and formulated our problem to minimize each of these costs.

Objective Function: Minimize cost
i.e. min [Extruding Cost + Pressing Cost + Subcontracting Cost + Inventory and Transportation Cost]

Inputs (common for extruder and pressing processes):
Number of working days in each quarter = 63
Number of regular working hours per day = 8
Cost of hiring a new worker = $3000
Cost of laying off a worker = $2500
Permissible overtime hours per quarter per employee = 60
Regular hourly wage per worker = $15
Overtime hourly wage per worker (150% of regular) = $22.5

1. ## Extruder Cost:

   Decision Variables:

   t: Time period. Here, t = 1, 2, ..., 12 quarters, t = 0 for initial conditions

   U_t: No. of pounds of resin procured equivalently plastic extruded in quarter t

   E_t: No. of operating extruders in quarter t

   EW_t: Total work force i.e. no. of extruder operators in quarter t

   EH_t: No. of extruder operators hired in quarter t

   EL_t: No. of extruder operators laid-off in quarter t

   EO_t: Total overtime hours for extruder operators in quarter t

   Constants:
   Effective extruder capacity = 2850 pounds per hour
   Cost of resin (raw material) = $10 per 1000 pounds

Number of extruder operators per extruder = 6

Constraints:

Work Force Constraint:

$EW_t = EW_{t-1} + EH_t - EL_t$

$EW_t - E_t * 6 = 0$

Overtime Constraint: $EO_t <= 60EW_t$

Production Constraint: $U_t <= (E_t * 63 * 8 + EO_t/6) * 2850$

Non Negativity Constraint: $U_t, EW_t, EH_t, EL_t, EO_t, E_t >= 0$

EW_t, EH_t, EL_t, E_t *are integers*

Objective Function: Extruding Cost:

$15 * 63 * 8 * EW_t + 22.5 * EO_t + 3000 * EH_t + 2500 * EL_t + U_t * \frac{10}{1000}$

2. Pressing Cost:

Decision Variables:

t: Time period. Here, t = 1, 2, ..., 12 quarters, t = 0 for initial conditions

P_t: No. of pounds of plastic containers produced in quarter t

D_t: Demand of plastic containers in quarter t

TW_t: Total work force i.e. no. of press workers in quarter t

TH_t: No. of press operators hired in quarter t

TL_t: No. of press operators laid-off in quarter t

TO_t: Total overtime hours for press workers in quarter t

T_t: No. of operating presses in quarter t

Inputs:

Effective presser capacity = 2000 pounds per hour

Number of operators required per press = 1

Constraints:

Work Force Constraints:

$TW_t = TW_{t-1} + TH_t - TL_t$

$TW_t - T_t * 1 = 0$

Overtime Constraints: $TO_t <= 60TW_t$

Production Constraint $P_t <= (T_t * 63 * 8 + TO_t) * 2000$

Demand Constraint: $P_t = D_t$

Non Negativity Constraint: $P_t, TW_t, TH_t, TL_t, TO_t, T_t >= 0$

TW_t, TH_t, TL_t, T_t *are integers*

Objective Function: Pressing Cost:

$15 * 63 * 8 * TW_t + 22.5 * TO_t + 3000 * TH_t + 2500 * TL_t$

3. ## Subcontracting Cost:

Decision Variables: t: Time period. Here, t = 1, 2, ..., 12 quarters, t = 0 for initial conditions

S_t: No. of pounds of plastic sheet production subcontracted

Constraints:

$S_t >= 0$

Objective Function: Subcontracting Cost:

$S_t * \frac{60}{1000}$

4. ## Inventory and Transportation Cost

Decision Variables: t: Time period. Here, t = 1, 2, ..., 12 quarters, t = 0 for initial conditions

Pr_t: No. of pounds of plastic sheets stored in the private warehouse

Pub_t: No. of pounds of plastic sheets stored in the public warehouse

A: Area in sq. feet to lease

Constants: M: Material handling cost at public warehouse; \$4-\$6 per thousand pounds

S: Storage cost at public warehouse; \$10-\$12 per thousand pounds

T: Transportation cost; \$4 per thousand pounds

R: Ratio of usable space at private warehouse; assumed 0.6

L: Lease Rate for 3 years; \$4 per square foot

K: No. of pounds that can be stored in 1 sq. foot of private warehouse: 1000 pounds per sq. foot

O : Operating cost of private warehouse: \$4 per thousand pounds

Inputs:

Storage Constraint:

$RAK >= Pr_t$

Container Production Constraint:

$P_t = Pub_{t-1} + Pr_{t-1} + U_t - Pr_t - Pub_t + S_t$

Non Negativity Constraint:

$Pr_t, Pub_t, A >= 0$

Objective Function: Inventory and Transportation Cost:

$Pub_t * (M + S) + T * (Pub_t + Pub_{t-1}) + (A * L) + (Pr_t * O) + T * (Pr_t + Pr_{t-1})$

Optimal Solution

Quarter	Resin procured (lbs)	No. of operating extruders	No. of extruder workers	No. of extruder workers hired	No. of extruder workers fired	No. of total extruder overtime hours	Polystyrene subcontracted (lb)
1	18,264,800	13	78	0	6	0	0
2	18,673,200	13	78	0	0	0	0
3	15,800,400	11	66	0	12	0	0
4	17,236,800	12	72	6	0	0	0
5	17,236,800	12	72	0	0	0	0
6	19,288,800	12	72	0	0	4,320	4,824,200
7	17,236,800	12	72	0	0	0	0
8	20,109,600	14	84	12	0	0	0
9	20,109,600	14	84	0	0	0	0
10	22,503,600	14	84	0	0	5,040	2,677,400
11	20,109,600	14	84	0	0	0	0
12	20,569,400	14	84	0	0	968	0

Table 3: Optimal Production Plan for SPC - 1

Quarter	Private warehouse area leased (sq ft)	Polystyrene in public warehouse (lbs)	Polystyrene in Private warehouse	No. of presser workers	No. of presser workers hired	No. of presser workers fired	No. of Total presser overtime hours
1	705	3,659,300	493,500	14	0	11	0
2	705	0	0	21	7	0	829
3	705	119,900	493,500	15	0	6	33.5
4	705	0	9200	16	1	0	856.5
5	705	894,500	493,500	16	0	0	0
6	705	0	0	23	7	0	1158.5
7	705	0	289,800	17	0	6	0
8	705	0	493,400	18	1	0	881
9	705	2,507,500	493,500	18	0	0	0
10	705	0	0	25	7	0	1491
11	705	908,100	493,500	19	0	6	0
12	705	0	0	21	2	0	401.5

Table 4: Optimal Production Plan for SPC - 2