Developing a Multiple-Criteria Decision Methodology for the Make-or-Buy Problem

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Abstract: *Engineering design is the process of developing a system, component or process to satisfy the desired requirements. It is a decision making process, in which the basic mathematics and engineering disciplines are utilized to convert resources optimally to achieve a predetermined objective. It also includes a variety of realistic constraints such as reliability, safety, economic factors, ethical and social impacts. This work proposes a methodology and a procedure for the make-or-buy problem. Companies following this methodology are guided through a structured sequence comprising identification of factors for the make-or-buy decision, and the comparison of internal sourcing and external sourcing factors against each other. Multi-attribute decision-making is utilized to present an overall make-or-buy decision recommendation.*
Keywords: *Analytic Hierarchy Process (AHP), make-or-buy, multi-attribute decision-making*

I. INTRODUCTION

This study includes two stages. The first stage builds the conceptual model for the make-or-buy decision problem. It develops the framework of the problem with a suggested procedure that is composed of three phases. The second stage contains a case of a hypothetical company having a make-or-buy problem. The solution includes quantitative and qualitative components. Analytic Hierarchy Process (AHP) is used to determine the importance of each criterion. Sensitivity analysis and simulation tools are used which are: SensIt, RiskSim and Excel spreadsheet. One advantage of the suggested methodology is that a spreadsheet based optimizer is utilized to implement it. That it is one that provides optimal solutions and at the same time utilizes a broadly used environment for implementation. So the suggested methodology should be a practical tool for decision making. The final decision for this case is optimized and recommendations are provided.

II. STATEMENT OF THE PROBLEM

The details of the case are as follows from Ref [1]: Planners at a hypothetical company are discussing the decision whether to purchase a component that is considered as a part of the final product or to manufacture it internally. "Forecasted annual demand for this part is 3200 units. The company works 250 days per year.

The company's financial specialists established a cost of capital of 14% for the utilization of funds for investments inside the company. Furthermore, over the past year $600,000 was the average investment in the inventory of the company. Accounting information displays that a total of $24,000 was spent on insurance related to the inventory of the company. Also, an estimated $9000 was lost due to shrinkage of inventory, which comprised damaged goods besides pilferage. A remaining $15,000 was spent on overhead of warehouse, comprising utility expenses for lighting and heating.

An analysis of the purchasing operation displays that about two hours are required to process and coordinate an order for the part regardless of the quantity of the order. Purchasing salaries average $28 per hour, comprising employee benefits. Moreover, a detailed analysis of 125 orders revealed that $2375 was spent on communication tools such as telephone, paper, and postage directly related to the ordering process. A one-week lead time is necessary to get the part from the supplier. An analysis of demand during the lead time indicates it is almost normally distributed with a mean of 64 units and a standard deviation of 10 units. Service level guidelines show that one stock-out per year is satisfactory.

The company has the option to contract for purchasing the part from a supplier at random cost following normal distribution with mean $13 per unit and standard deviation 3. However, over the past few months, the company's production capacity has been expanded. Therefore, excess capacity now exists in certain production departments, and the company is considering the option of producing the parts itself.

Forecasted utilization of equipment indicates that production capacity will be available for the part being considered. The production capacity is available at the rate of 1000 units per month, with up to five months of production time available. Management relies on that with a two-week lead time, schedules can be arranged so that the part can be produced whenever required. The demand during the two-week lead time is almost normally distributed, with a mean of 128 units and a standard deviation of 20 units. Production costs are estimated to be

$6 per part. An issue of management is that setup costs will be significant. The total cost of setup is expected to be $50 per hour, and a full eight-hour shift will be required to set up the equipment for producing the part. To produce the part in-house, 5 workers are needed with wage of $4 per hour. The work day is 8 hours" [1].

The question to be answered: Should the company purchase the part from the supplier or produce the part itself?

III. MAKE-OR-BUY PROCESS

The make-or-buy process contains three phases:

Phase 1: Preparation

There are five areas for evaluating make-or-buy problem: (1) technology and manufacturing processes; (2) supply chain management and logistics (SCM); (3) support systems; (4) social and ethics impacts; and (5) costs. In this study, a quantitative area and a qualitative area will be picked, and a decision making methodology will be applied. The two areas are: costs and SCM, and the factors affecting these areas in both policies: "make" and "buy", will be examined. The scores of the two polices will be determined. The three remaining areas will be given hypothetical scores, and the final decision is chosen according these scores.

Phase 2: Data Collection

Workshops were held and they defined the weighting of the relative importance of the various factors in the framework and the rating of the performance of in-house and external supply [2]. AHP is used to find the importance of each criterion. The problem is decomposed into a hierarchy of criteria and alternatives. In our problem:

- The objective is to select the best policy
- The criteria are: (1) technology and manufacturing processes; (2) supply chain management and logistics (SCM); (3) support systems; (4) social and ethics impacts; and (5) costs.
- The alternatives are: (1) make; (2) buy; (3) make some and buy some.

This information is then arranged in a hierarchical tree as in Fig.1.

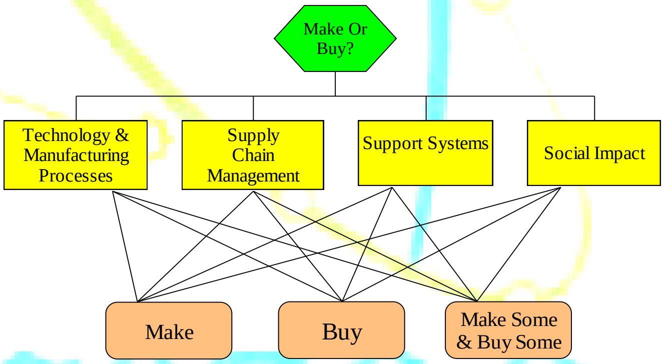


Fig.1: AHP for the make-or-buy problem.

We use judgments to determine the ranking of the criteria [3]. In this problem, the assigned team decided that:

- Technology & Manufacturing Processes are 2 times important as SCM
- SCM is three times important as support systems
- and so on as shown in Table 1.
-

Table 1: The relative importance of the areas

	Tech. & Manu. Processes	SCM	Support Systems	Social Impact
Tech. & Manu. Processes	1/1	2/1	1/5	4/1
SCM	1/2	1/1	3/1	5/2
Support Systems	5/1	1/3	1/1	8/3
Social Impact	1/4	2/5	3/8	1/1

After manipulations and matrix calculations, the computed eigenvector gives us the relative weights of our criteria as follows:

Criteria	Weights
Tech. & Manu. Processes	0.242
SCM	0.325
Support Systems	0.375
Social Impact	0.076

It is shown that “support systems” is the most important criterion, and the social impact is the least important criterion.

Phase 3: Analysis and Results

In the third phase, a complete picture of the SCM and costs will be visualized. The ratings of supplier and in-house would be determined based on costs calculation, while the area of SCM will be evaluated by a questionnaire developed and scored by a team. After that, the findings of the weightings and ratings are combined to present a single figure which gives an indication of the relative merits of making or buying options [4].

IV. SUPPLY CHAIN MANAGEMENT ANALYSIS

In this section, the SCM which is a qualitative area will be examined. A team composed of four members has met and agreed six factors affecting SCM. These factors are shown in Fig.2.

Factor	Ratings: 5	4	3	2	Ratings: 1	Why?	Evidence
1. Formal supplier selection procedure	Formal supplier selection procedure fully implemented for all suppliers.				No formal supplier selection procedure.		✓ Supplier selection procedure
2. Cost reduction activity with suppliers	Pro-active in implementing cost reduction initiatives with clear and measurable results.				No cost reduction initiatives.		✓ Cost reduction initiatives/ results
3. Collaboration with suppliers (e.g. joint programmes).	Long established collaboration with key suppliers.				No collaboration with key suppliers or not willing to investigate opportunities in this area.		▲ Examples of joint programmes
4. Delivery performance	Always achieves delivery targets.				Never achieves delivery targets.		✓ Delivery reports
5. Stock targets achievement	Always meets stock targets.				Never meets stock targets.		✓ Stock figures
6. Inventory control	Maintains optimum buffer stock with the right items.				No buffer stock/ or never holds the right items.		▲ Reports/ Records

Fig.2 Factors of SCM area [5].

After setting these factors, the weightings have been determined. Each individual member in the team has scored the factors for the two policies: “make” and “buy”. This process is summarized in Tables 2 and 3.

Table 2: Scores of “make” SCM.

Factor	Score 1	Score 2	Score 3	Score 4	Score Average	Weight	Score Weighted Average
1	5	5	5	5	5	0.1	10
2	5	5	4	5	4.75	0.2	19
3	4	5	5	5	4.75	0.1	9.5
4	5	5	4	4	4.5	0.15	13.5
5	5	5	5	5	5	0.25	25
6	4	5	4	5	4.5	0.2	18
					Total	1	95

Table 3: Scores of "buy" SCM.

Factor	Score 1	Score 2	Score 3	Score 4	Score Average	Weight	Score Weighted Average
1	2	5	4	5	4	0.1	8
2	5	3	5	3	4	0.2	16
3	3	5	1	4	3.25	0.1	6.5
4	5	4	3	4	4	0.15	12
5	3	5	5	5	4.5	0.25	22.5
6	5	5	4	4	4.5	0.2	18
					Total	1	83

We can see from Tables 2 and 3 that the "make" option is given 95 out of 100 score, and "buy" option is given 83 out of 100 score. This means that the "make" policy is better than "buy" policy in terms of SCM.

V. COSTS ANALYSIS

The following factors will be considered in evaluating the alternatives:

1. An analysis of the holding costs, including the appropriate annual holding cost rate
2. An analysis of ordering costs for "Buy" policy, and an analysis of setup costs for the "Make" policy.
3. A development of the inventory policy for the following two alternatives:
   - Ordering a fixed quantity Q from the supplier
   - Ordering a fixed quantity Q from in-plant production
4. An analysis of the following in the policies of parts 3:
   a. Optimal quantity Q*
   b. Number of order or production runs per year
   c. Cycle time
   d. Reorder point
   e. Amount of safety stock
   Under probabilistic conditions, when demand and/or lead time vary, the reorder point often includes safety stock.
   f. Expected maximum inventory
   g. Average inventory
   h. Annual holding cost
   i. Annual ordering cost
   j. Annual cost of the units purchased or manufactured
   k. Total annual cost of the purchase policy and the total annual cost of the production policy [1].

5.1. Study of "Buy" Option

5.1.1. Economic Order Quantity (EOQ) Model

The assumptions of the EOQ model are as follow:

1) The daily demand rate, d, is constant and independent.
2) The order quantity, Q, is constant for each order and the entire order is received at one time.
3) The cost per order, C_o, is constant and does not depend on the size of the order.
4) The unit cost, C, of the inventory item is constant and does not depend on the size of the order.
5) The inventory holding cost per unit per time period, C_h, is constant.
6) Shortages such as backorders and stock outs are not permitted.
7) The lead time for an order is constant. Lead time is the time between when an order is placed until it is received.
8) The inventory level is reviewed on a continuous basis.
9) The planning horizon consists of multiple time-periods.

The inputs that we must consider in using the EOQ model to make the order quantity decision include: the annual demand (D), number of days in the year, order lead time (m), unit cost (C), holding cost rate (I), and the order cost (C_o).

The holding cost rate, C_h, is used to compute the holding cost component.

The order cost, C_o, covers preparation expenses for the order, such as payment, communication, invoice verification, receiving and so on.

The main output variable is the **order quantity**, Q, how much to order every time an order is placed. This can be determined by the EOQ model.
The EOQ model is derived as:

$$EOC : Q^{*} = \sqrt{\frac{2DC_o}{C_h}}$$

Total Inventory Costs = Holding Cost + Ordering Cost
Reorder point (r) = m d where:
r = reorder point; d = demand per day; m = lead time for a new order in days.

Reorder Point under Conditions of Uncertainty
If normal distribution is used for lead-time demand, the general expression for reorder point, r:
Reorder Point = Mean of Lead Time Demand + Safety Stock
$r = \mu + z\,\sigma$ where:
μ is mean of demand during lead time
σ is standard deviation of demand during lead time
z is the number of standard deviations necessary to obtain the acceptable stock-out probability
$z\,\sigma$ is the safety stock[1]

5.1.2. Solution of EOQ Model:
We will follow the procedure suggested earlier to examine "Buy" policy:

1) The holding cost is made of four items, as shown below. Note that those items are converted into percent for a common unit of measurement. The holding cost applies to both making and buying options:
    - Cost of Capital = 14%
    - Taxes/Insurance = $24,000 / $600,000 = 4%
    - Shrinkage = $9,000 / $600,000 = 1.5%
    - Warehouse Overhead = $15,000 / $600,000 = 2.5%

    Total = Annual Holding Cost Rate (I) = 22%

   Supplier purchase unit cost (C) = $13
   Annual Unit Holding Cost C_h = IC = (.22)(13) = $2.86
2) The ordering cost applies to the "buy" option:
   2 Hours at $28.00 = $56.00
   Other Expenses = $2,375 / 125 = $19.00 [1]
   Unit Order Cost C_o = Total = $56.00 + $19.00 = $75.00
3) Formulas used to find the components of EOQ model are summarized in Table 4

Table 4: Formulas of EOQ model.

	Description	Formula
a	Economic order quantity	$EOC : Q^{*} = \sqrt{\frac{2DC_o}{C_h}}$
b	Number of orders per year	N = D / Q
c	Cycle time	250 / N
d	Reorder point	$r = \mu + z\,\sigma$
e	Amount of safety stock	$z\,\sigma$
f	Expected maximum inventory	$Q^* + z\,\sigma$
g	Average inventory	$0.5\,Q^* + z\,\sigma$
h	Annual holding cost	$0.5\,Q\,C_h + z\,\sigma\,C_h$
i	Annual ordering cost	$(D / Q)\,C_o$
j	Annual cost of the units purchased	C D
k	Total annual cost of the "Buy" policy	Ordering cost + holding cost
l	Annual unit holding cost	$C_h = IC$
m	Probability of stock out	#stock out per year / #orders per year

1	**Holding cost** - Usually a percentage of the value of the item assessed for keeping an item in inventory		
2	Annual forecasted unit demand	3200	
3	Days per year operation	250	
4	Daily unit demand	12.8	
5	Inventory average annual investment	$600,000	
6	Inventory cost of capital use of company's internal investment funds	14%	14.00%
7	Inventory taxes and insurance	$24,000	4.00%
8	Inventory loss due shrinkage	$9,000	1.50%
9	Inventory warehouse overhead	$15,000	2.50%
10	**Annual Holding Cost Rate** (I)		22.00%
11	**Supplier Purchase Unit Cost** (C)		$13.00
12	**Annual Unit Holding Cost** $C_h = IC$		$2.86
13	**Annual Holding Cost** $(0.5QC_h)$		$585.83
14			
15	**Ordering Cost** - Salaries and expenses of processing an order, regardless of the order quantity		
16	Order processing hours to process part order regardless of quantity (H)	2	
17	Order processing average purchase salaries per hour (S)	$28	$56.00
18	Order processing resources directly related to the ordering process ($2,375/125 orders) (R)	$19	$19.00
19	**Unit Order Cost** $C_o = HS + R$		$75.00
20	**Annual Ordering Cost** $(D/Q)C_o$		$585.83
21			
22	**EOQ** $Q^* = SQRT(2DC_o/C_h)$		409.67
23			
24	**Part purchased from supplier**		
25	Lead time day(s) to obtain the part from the supplier	5	
26	Lead time week(s) to obtain the part from the supplier	1	
27	Approximate lead time demand mean units	64	
28	Approximate lead time demand standard deviation units	10	
29	Stock-out per year acceptable	1	
30	Purchase cost per unit from contracted supplier	$13	
31			
32	**TMS - Q/R with Probablistic Demand**	**Supplier**	
33	Annual Demand Rate (Units/Year)	3200	
34	Ordering Cost ($/Order)	$75	
35	Holding Cost Method (%)		
36	% of Unit Cost (0-100)	22%	
37	Unit Cost	$13	
38	No. Working Days / Year	250	
39	Normal Distribution of Demand		
40	Mean	64	
41	Standard Deviation	10	
42	Service Level Method (No. of Stock-Outs)		
43	Allowable Stock-Outs Per Year	1	
44			
45	**INVENTORY POLICY - Q/R with Probablistic Demand**	**Supplier**	
46	OPTIMAL ORDER QUANTITY	409.67	a. Optimal quantity Q*
47	ANNUAL INVENTORY HOLDING COST	$618.44	h. Annual holding cost
48	ANNUAL ORDERING COST	$585.83	i. Annual ordering cost
49	TOTAL ANNUAL COST	$1,204.27	
50	MAXIMUM INVENTORY LEVEL	421.073245	f. Expected maximum inventory
51	AVERAGE INVENTORY LEVEL	216.236623	g. Average inventory
52	REORDER POINT	75.4	d. Reorder point
53	NUMBER OF ORDERS PER YEAR	7.81110321	b. No. of annual orders/production runs
54	CYCLE TIME (DAYS)	32.0057223	c. Cycle time
55	SAFETY STOCK	11.4	e. Amount of safety stock
56	ANNUAL SAFETY STOCK COST	$32.60	
57	EXPECTED STOCKOUTS PER YEAR	1	
58	PROBABILITY OF A STOCKOUT PER CYCLE	0.12802289	
59			
60	k. Total annual cost of the purchase policy	$42,804.27	

Fig.3: Summary of EOQ Results.

It is found from Fig.3 that the total annual cost of the "Buy" policy = $42,804.

Now the target to examine the case of "Buy" policy in which the annual demand (D), unit cost (C), holding cost rate (I) and the order cost (C_o) are varying within certain range. This task is done with aid of SensIt.

5.1.3. Sensitivity Analysis Using SensIt

As mentioned earlier, the company is deciding whether to manufacture a part or to purchase it from a supplier. Using SensIt's Many Inputs, One Output option to see how the model's output depends on ranges specified for each of the model's input variables. Before utilizing this option, the model input cells are arranged in adjacent cells in a single column, corresponding labels in adjacent cells are arranged in a single column, Low, Base, and High input values for each input variable are arranged in three separate columns. Alternatively, the three columns containing input values can be worst case, likely case, and best case. A proper arrangement is shown in Fig.4 [6].

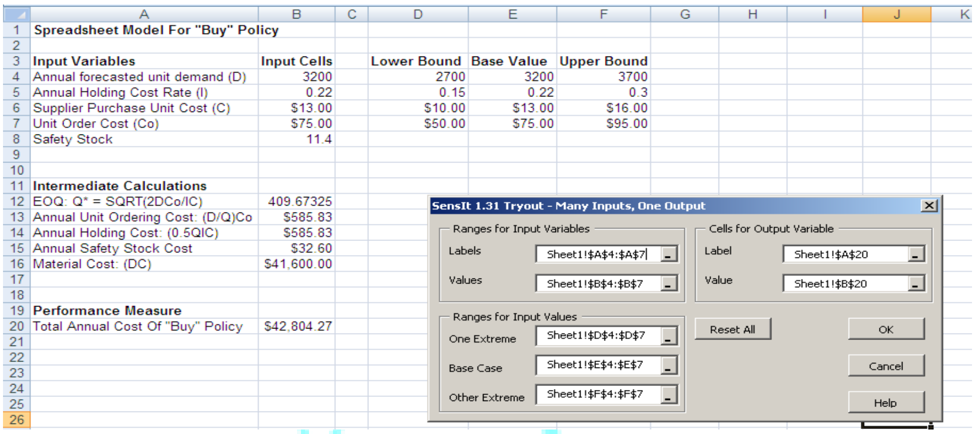


Fig.4: Model Display with Lower and Upper Bounds for "Buy" Policy in SensIt.

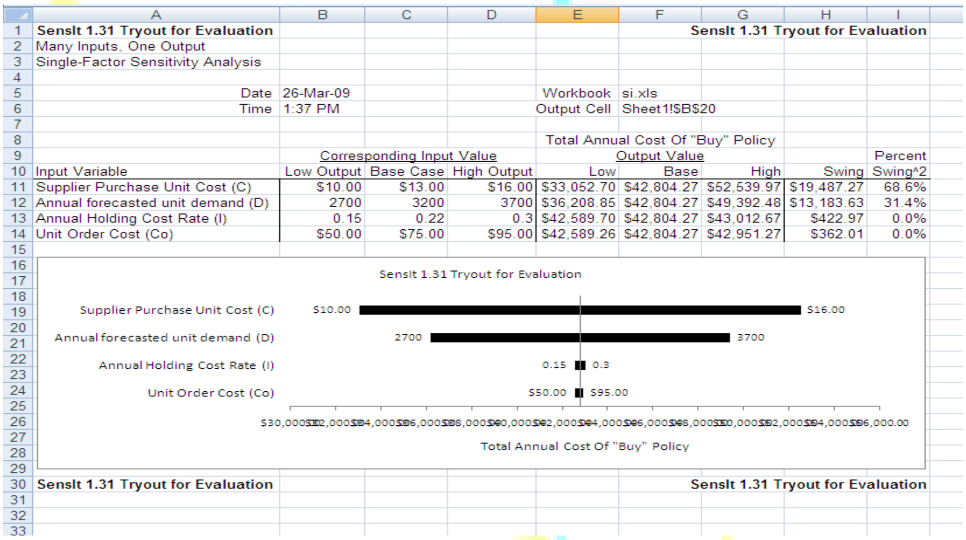


Fig.5: SensIt Tornado Numerical and Chart Output for "Buy" Policy

The uncertainty about Supplier Purchase Unit Cost (the topmost bar in the tornado chart) is associated with the widest swing in Annual cost. For each Low output value in column E, the corresponding input value is shown in column B. For each High output value in column G, the corresponding input value is shown in column D. The tornado chart shows single-factor sensitivity analysis, i.e., for each output value, only one input value is changed from its base case value [6].

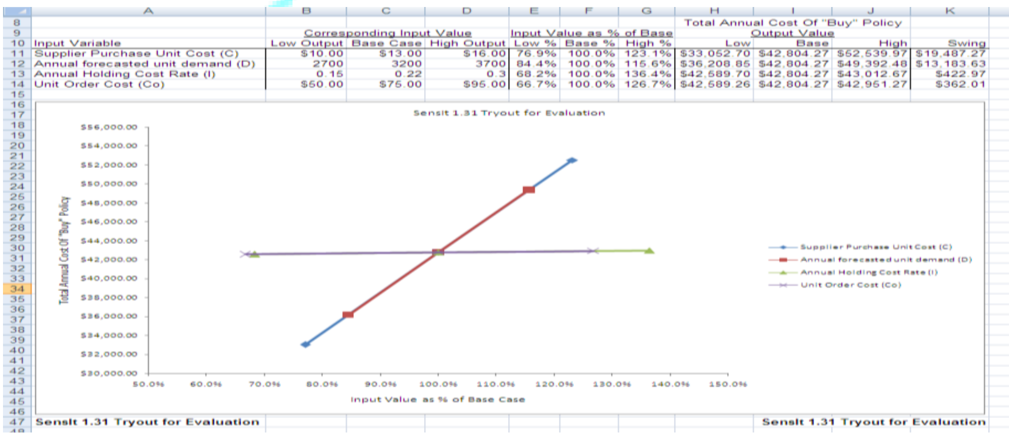


Fig.6: SensIt Spider Numerical and Chart Output for "Buy" Policy

On a spider chart, lines that are nearly horizontal generally indicate an input variable where small percentage changes do not have much effect on the output value. Lines that are more vertical indicate an input variable where small percentage changes have a greater affect on the output value [6].

We can conclude from SensIt charts that the most affecting factors on cost for "buy" policy are: Supplier Purchase Unit Cost (C) and Forecasted Unit Demand (D). From this discussion, we found that the Supplier Purchase Unit Cost (C) is the most critical factor that affects the "Buy" choice. So, the variability of market price may negatively affect the total cost and this might not be suitable for risk averse. This stage of (SensIt) determines the critical inputs for the next stage (RiskSim).

5.1.4. Monte Carlo Simulation Using RiskSim

We can see in the summary output of RiskSim that the annual total cost mean of "Buy" policy is $42,886. This result is close to the one we have obtained by the former solution, $42,804. However, the solution obtained by RiskSim is more reliable in process of Make-or-Buy decision, since it takes into consideration the **randomness of demand and material cost**, which is the case in real life.

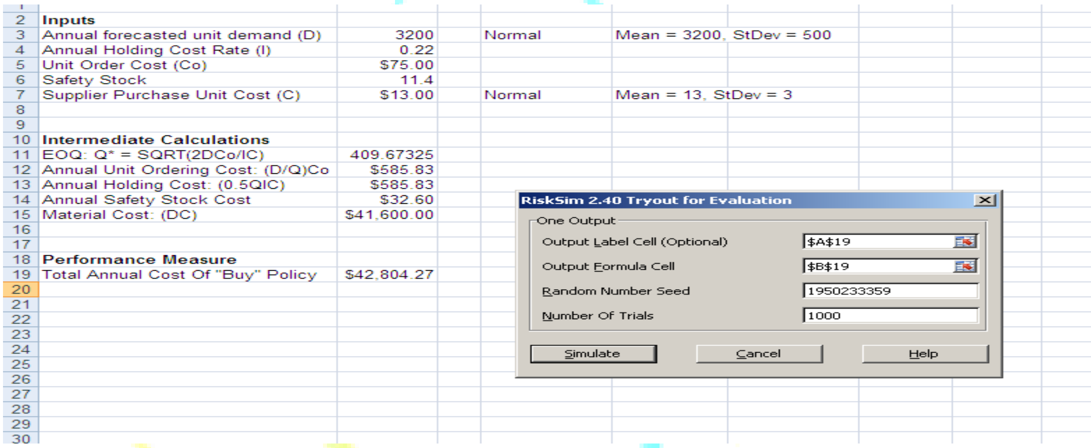
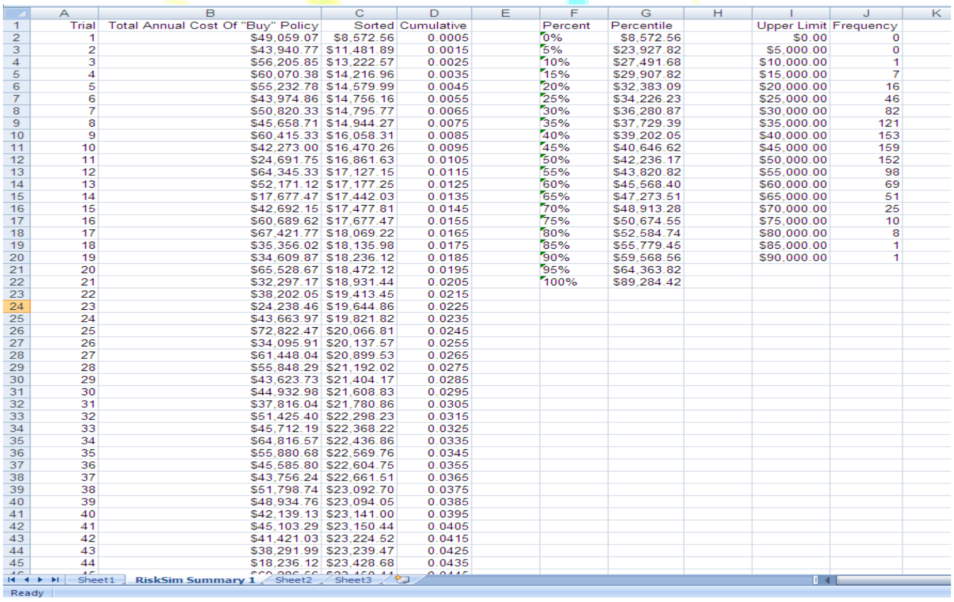


Fig.7: One-Output Model Display for "Buy" Policy in RiskSim



	A	B	C	D	F	G	I	J
1	Trial	Total Annual Cost Of "Buy" Policy	Sorted	Cumulative	Percent	Percentile	Upper Limit	Frequency
2	1	$49,059.07	$8,572.56	0.0005	0%	$8,572.56	$0.00	0
3	2	$43,940.77	$11,481.89	0.0015	5%	$23,927.82	$5,000.00	0
4	3	$56,205.85	$13,222.57	0.0025	10%	$27,491.68	$10,000.00	1
5	4	$60,070.38	$14,216.96	0.0035	15%	$29,907.82	$15,000.00	7
6	5	$55,232.78	$14,579.99	0.0045	20%	$32,383.09	$20,000.00	16
7	6	$43,974.86	$14,756.16	0.0055	25%	$34,226.23	$25,000.00	46
8	7	$50,820.33	$14,795.77	0.0065	30%	$36,280.87	$30,000.00	82
9	8	$45,658.71	$14,944.27	0.0075	35%	$37,729.39	$35,000.00	121
10	9	$60,415.33	$16,058.31	0.0085	40%	$39,202.05	$40,000.00	153
11	10	$42,273.00	$16,470.26	0.0095	45%	$40,646.62	$45,000.00	159
12	11	$24,691.75	$16,861.63	0.0105	50%	$42,236.17	$50,000.00	152
13	12	$64,345.33	$17,127.15	0.0115	55%	$43,820.82	$55,000.00	98
14	13	$52,171.12	$17,177.25	0.0125	60%	$45,568.40	$60,000.00	69
15	14	$17,677.47	$17,442.03	0.0135	65%	$47,273.51	$65,000.00	51
16	15	$42,692.15	$17,477.81	0.0145	70%	$48,913.28	$70,000.00	25
17	16	$60,689.62	$17,677.47	0.0155	75%	$50,674.55	$75,000.00	10
18	17	$67,421.77	$18,069.22	0.0165	80%	$52,584.74	$80,000.00	8
19	18	$35,356.02	$18,135.98	0.0175	85%	$55,779.45	$85,000.00	1
20	19	$34,609.87	$18,236.12	0.0185	90%	$59,568.56	$90,000.00	1
21	20	$65,528.67	$18,472.12	0.0195	95%	$64,363.82		
22	21	$32,297.17	$18,931.44	0.0205	100%	$89,284.42		
23	22	$38,202.05	$19,413.45	0.0215				
24	23	$24,238.46	$19,644.86	0.0225				
25	24	$43,663.97	$19,821.82	0.0235				
26	25	$72,822.47	$20,066.81	0.0245				
27	26	$34,095.91	$20,137.57	0.0255				
28	27	$61,448.04	$20,899.53	0.0265				
29	28	$55,848.29	$21,192.02	0.0275				
30	29	$43,623.73	$21,404.17	0.0285				
31	30	$44,932.98	$21,608.83	0.0295				
32	31	$37,816.04	$21,780.86	0.0305				
33	32	$51,425.40	$22,298.23	0.0315				
34	33	$45,712.19	$22,368.22	0.0325				
35	34	$64,816.57	$22,436.86	0.0335				
36	35	$55,880.68	$22,569.76	0.0345				
37	36	$45,585.80	$22,604.75	0.0355				
38	37	$43,756.24	$22,661.51	0.0365				
39	38	$51,798.74	$23,092.70	0.0375				
40	39	$48,934.76	$23,094.05	0.0385				
41	40	$42,139.13	$23,141.00	0.0395				
42	41	$45,103.29	$23,150.44	0.0405				
43	42	$41,421.03	$23,224.52	0.0415				
44	43	$38,291.99	$23,239.47	0.0425				
45	44	$18,236.12	$23,428.68	0.0435				

Fig.8: RiskSim Numerical Output for One-Output of "Buy" Policy

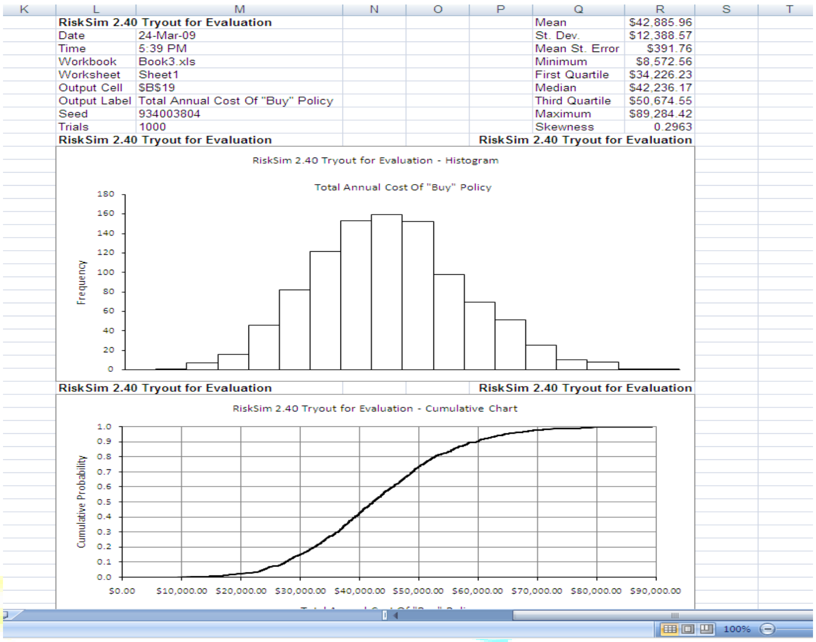


Fig.9: RiskSim Summary Output for One-Output for "Buy" Policy.

5.2. Study of "Make" Option

In contrast with "Bay" option, we do not have a model like EOQ for probabilistic demand in production case. Fortunately, simulation can be useful tool for getting reasonable solution for this problem. In our simulation model, we want to find:

1) Q: the size of production run
2) T_1: uptime (production time)
3) T_2: downtime
4) T: the cycle length, where: $T = T_1 + T_2$
5) Annual setup cost
6) Annual holding cost
7) Annual production cost
8) Annual labor cost
9) Total annual cost

Fig.10 shows the Excel spreadsheet we developed for production scenarios simulation.

	A	B	C	D	E	F	G	H	I	J	K
1		true			true	setup cost	holding cost	production cost	labor cost		total cost
2		3220			16	4000	1377.791184	22540	11200		39118
3											
4											
5	serial	prod/day	demand/day	inventory	#stockouts	#setups	holding cost		labor cost		
6	1	46	11	35	0	0	0.2156		160		
7	2	46	12	69	0	0	0.42504		160		
8	3	46	12	103	0	0	0.63448		160		
9	4	46	14	135	0	0	0.8316		160		
10	5	46	9	172	0	0	1.05952		160		
11	6	46	14	204	0	0	1.25664		160		
12	7	46	14	236	0	0	1.45376		160		
13	8	0	17	219	0	0	1.34904		0		
14	9	0	12	207	0	0	1.27512		0		
15	10	0	12	195	0	0	1.2012		0		
16	11	0	13	182	0	0	1.12112		0		
17	12	0	14	168	0	0	1.03488		0		
18	13	0	17	151	0	0	0.93016		0		
19	14	0	14	137	0	0	0.84392		0		
20	15	0	15	122	0	0	0.75152		0		
21	16	0	14	108	0	0	0.66528		0		
22	17	0	16	92	0	0	0.56672		0		
23	18	0	12	80	0	0	0.4928		0		
24	19	0	13	67	0	0	0.41272		0		
25	20	0	16	51	0	0	0.31416		0		
26	21	0	15	36	0	0	0.22176		0		
27	22	0	12	24	0	0	0.14784		0		
28	23	0	12	12	0	0	0.07392		0		
29	24	0	10	2	0	0	0.01232		0		
30	25	0	14	-12	1	0	0		0		
31	26	46	11	23	0	1	0.14168		160		
32	27	46	14	55	0	0	0.3388		160		
33	28	46	12	89	0	0	0.54824		160		
34	29	46	10	125	0	0	0.77		160		
35	30	46	15	156	0	0	0.96096		160		
36	31	46	13	189	0	0	1.16424		160		
37	32	46	14	221	0	0	1.36136		160		
38	33	0	6	215	0	0	1.3244		0		
39	34	0	14	201	0	0	1.23816		0		
40	35	0	12	189	0	0	1.16424		0		
41	36	0	13	176	0	0	1.08416		0		
42	37	0	15	161	0	0	0.99176		0		
43	38	0	18	143	0	0	0.88088		0		

Fig.10: Excel spreadsheet simulation.

In the model presented in Fig.10, column A represents the (days) of simulation, we run the simulation for 20,000 days, i.e. 80 years, considering one year has 250 working days. Column B shows the number of units produced every day, zeros represent days with no production (downtime). Column C shows the demand for product every day which is normally distributed with mean 12.8 and standard deviation 2. Column D represents the on hand inventory, which is inventory of the previous day plus production of the current day minus the demand of the current day. Column E represents the stock-outs. If 1 is present, it is an indicator that negative inventory happened in the neighbor cell in column D. Shortages are not lost but they are backlogged. If setup has occurred, 1 is present in column F. Column G shows the daily holding costs, it equals (0.00088) * (6) * (on hand inventory). We get the daily holding cost rate by dividing the annual rate by number of days in a year: 0.22 / 250 = 0.00088. The unit production cost is $6. Cell H2 shows the annual production cost, which is the number of parts produced in a year times the production cost. Whenever there is production, there is labor cost in column I which equals: 8 hours * 5 workers * $4 = $160. Cell E2 shows the total number of stock-outs during the simulation period which is 80 years. Since it is allowed for only one stock-out in a year, an indicator in cell E1 shows the word "true" if the total number of stock-outs in 80 years is less than 81, otherwise, the word "false" appears. Cell K2 shows the annual total cost which is the summation of: setup, holding, production and labor costs.

Note that every time we click on the spreadsheet, the values change, due the random numbers generated by Excel. The value of total cost changes accordingly, but with low variation. As we increase the simulation duration, i.e. 100,000 rather than 20,000 days, as we get more stable total cost. I tried several scenarios for Q, T_1 and T_2 to find the best scenario. Table 5 summarizes some of these scenarios.

Table 5: Scenarios for Q, T_1 and T_2

	Description	Q (units)	T1 (days)	T2 (days)	Total Cost	Note
1	Continuous production in full capacity (5000 units in a year) without downtime	20	25	0	$180,853	Very high total cost since we produce much more than demand, but results also in less stock-outs (zero)
2	Full capacity with downtime	50	10	15	$160,473	High total cost, but the labor cost is reduced
3	Partial capacity with downtime	50	7	18	$54,730	Fairly low total cost, but we can try better
4	Partial capacity with downtime	46	7	18	$36,010	Low total cost, but we can try better
5	Partial capacity with downtime	50	65	185	$35,621	Best scenario in terms of total cast

Fig.11 shows the production cycles and the inventory level of one year for the winning scenario, produce 50 units every day in uptime which is 65 days, and stop producing for 185 days. Fig.12 shows the inventory level for the whole period of simulation, which is 80 years. We notice that the inventory level keeps growing, which means very high (infinite) inventory for infinite horizon. However, we can accept this scenario since the simulation is run for 80 years which is long period, and the companies usually change their objectives and regulations in shorter periods, i.e. 10 to 15 years, or even shorter.

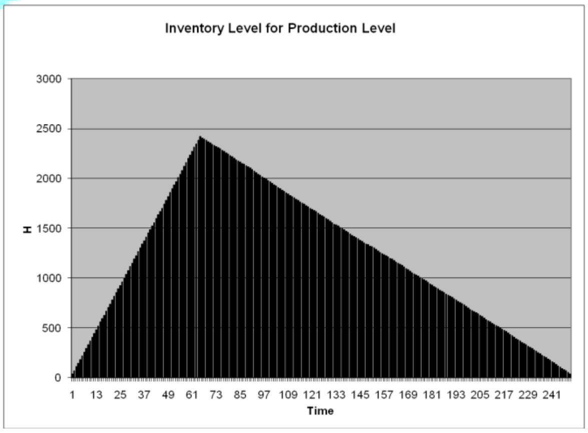


Fig.11: Production cycles and the inventory level of one year

By comparing the two choices: "make" and "buy", we found that the "Buy" policy results in total annual cost of $42,886, while the "make" policy results in total annual cost of $35,621. So, according to "cost" factor in evaluating the "make" and "buy" options, "make" policy is better since it results in lower cost. However, the third option is to “Make Some and Buy Some”. We will discuss this in the following section.

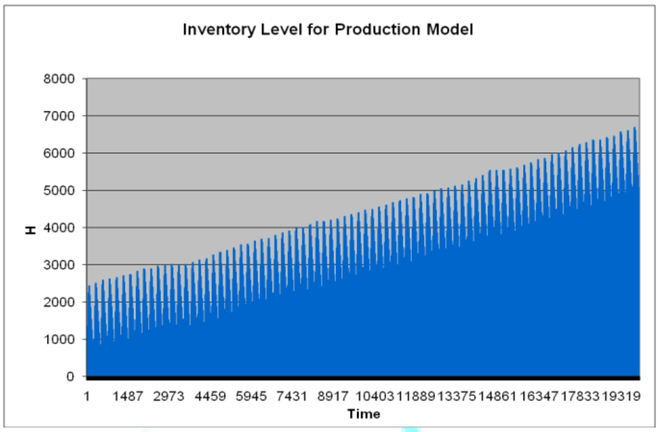


Fig.12: Inventory level for the whole period of simulation

5.3. Study of “Make Some and Buy Some” Option

We have discussed two options: to “buy” 100% of the quantity required to satisfy the demand, or to “make” 100% of the quantity in-house. However, the optimal cost may exist between the two options. That is, we will examine the option in which we “make” some of the quantity required and “buy” the rest. Table 6 summarizes several Scenarios of this policy.

Table 6: Scenarios for “make some and buy some” policy.

Percentage of buy	Percentage of make	Buy cost	Make cost	Total Cost
0%	100%	0	35621	35621
10%	90%	4563	30327	34890
20%	80%	8879	24371	33250
30%	70%	13154	22930	36084
40%	60%	17416	21038	38454
50%	50%	21661	16264	37925
60%	40%	25903	14426	40329
70%	30%	30133	11141	41274
80%	20%	34363	6994	41357
90%	10%	38584	3629	42213
100%	0%	42886	0	42886

It is found from Fig.13 that the minimum cost exists when 20% of the quantity is bought and 80% is made in-house. So, this policy is the best in terms of cost.

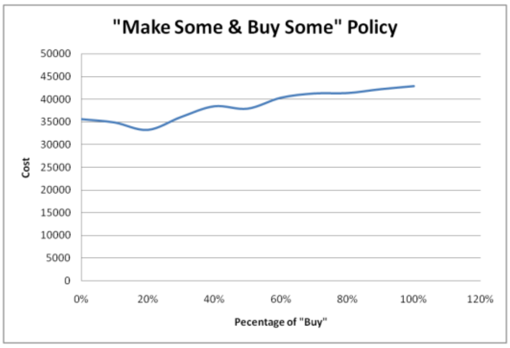


Fig.13: Costs vs. percentage of "buy".

VI. Sensitivity Analysis And Results

We did analysis on SCM, which is a qualitative area. We found that the "make" option got a score of 95 out of 100, and "buy" option got a score of 83 out of 100. For the rest of areas considered in process make-or-buy decision, we assume that the designated team has met and decided the scores of each area.

Table 7: Areas Scores

	Tech. & Manu. Processes	SCM	Support Systems	Social Impact	Overall Score
Weight	24.0693%	32.4778%	35.7263%	7.6266 %	100%
"Make" Score	54	95	83	100	81.13076
"Buy" Score	89	83	64	61	75.89531
Gap	-35	12	19	39	

Table 7 shows the overall scores (81.13 for "make", 75.89 for "buy") showing that "make" is the preferred option. However, not all areas support the "make" option to the same extent, and some area support the "buy" option. It is in this situation where more detailed analysis needs to be undertaken to fully understand and resolve any trade-offs. The first stage of this is a "gap analysis" showing the weighted differences for each of the areas, this shows which areas contribute most to the overall score differences. In this case, "supply chain management", "support systems" and "social impact" are positive. However, "technology & manufacturing processes" is negative, indicating that this is the area of main weakness of internal manufacturing. The gap analysis indicates relationships between changes in certain areas, either by the supplier or in-house, and the effects these will have on the make-or- buy decision. This could be used to identify and put in place improvement activities. Here, for example, if the indicated decision of "make" were adopted, the company should also put in place activities to strengthen the "technology & manufacturing processes".

Although the main indicator for the preferred decision is the overall score, this single figure can be misleading as it could be highly sensitive to particular factors. In order to assess this, sensitivity analyses are performed, and graphs drawn to illustrate cross-over points which might indicate a change of recommendation from make to buy.

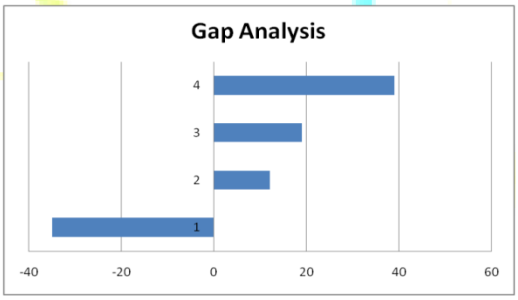


Fig.14: Gap Analysis.

For the sensitivity analysis graph, two points are required. For the first point, a weighting value of zero is given to the area under analysis, which evaluates the effect of not considering that area in the decision. The weightings for the other areas are increased, maintaining their existing proportions, so that they sum to 100. The overall scores are then calculated for both "make" and "buy". For the second point, the individual scores for the area under analysis are used, disregarding all the other areas. This evaluates the other extreme, considering only the one area. The overall scores are calculated again. The points are then joined by straight lines. If the lines do not cross, this means that the decision is not sensitive to changes in weight in that particular area. If the lines do cross, the point where the lines intersect indicates the breakeven point; by increasing/decreasing the weight above/below this point the decision is reversed. If the distance between the original weight and the point where the lines cross is large, the decision is still not sensitive to changes in weight in that particular area. If the distance between them is small, then the decision is sensitive to changes in weight in that area and a review of weightings might be required.

For instance, in Fig.15, the sensitivity graph of "technology and manufacturing processes", the analysis shows that if the weight of "technology and manufacturing processes" increased above the breakeven point, 25%, buying alternative becomes more attractive. Similarly, if the weight of "technology and manufacturing processes" is less than 25%, making alternative becomes more attractive. Since the distance between the original weight, 24% and the point where the lines cross, 25%, is short, the decision is sensitive to changes in weight in area of "technology and manufacturing processes".

However, in Fig.16, "Sensitivity analysis for SCM", the graph has negative breakeven point, so, it is not sensitive to weighting. In this case, the gap between the allocated weights and the breakeven points for the sensitive factors was considered large enough for the outcome of the process to be robust. In Fig.17, “Sensitivity analysis for support systems”, the graph has a breakeven point at weight of 35%, while the original weight is 36%. If “support systems” is given a weight greater than 35%, the “buy” policy becomes more attractive, and it is given a weighting less than 35%, the “make” policy becomes more attractive. Since the distance between the original weight and the point where the lines cross is short; the decision is sensitive to changes in weight in area of "support systems".

Since the distance between the original weight and the breakeven point for “social impact” is large, the decision is not sensitive to changes in weight this area.

	Tech. & Manu.	SCM	Support Sys.	Social	Score
weight	0	0.428294	0.471132	0.100574	1
“Make” Score	54	95	83	100	49.16139
“Buy” Score	89	83	64	61	36.28749

	Make	Buy
0	49.16139	36.28749
100	54	89

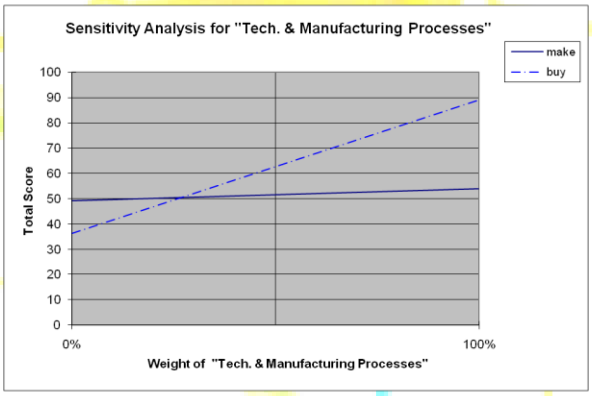


Fig.15: Sensitivity analysis of "technology and manufacturing processes"

	Tech. & Manu.	SCM	Support Sys.	Social	Score
weight	0.356994	0	0.529889	0.113117	1
“Make” Score	54	95	83	100	74.57017
“Buy” Score	89	83	64	61	72.58549

	Make	Buy
0	74.57017	72.58549
100	95	83

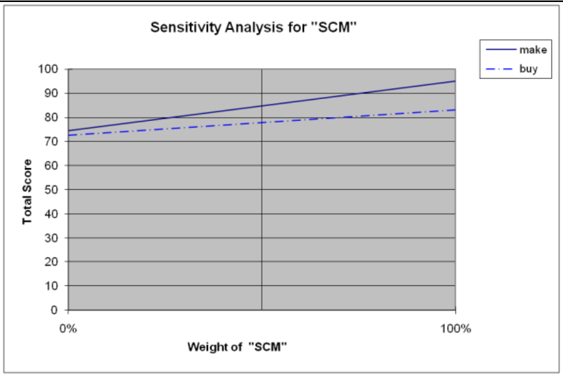


Fig.16: Sensitivity analysis for "SCM"

	Tech. & Manu.	SCM	Support Sys.	Social	Score
weight	0.375065	0.506092	0	0.118843	1
"Make" Score	54	95	83	100	32.13781
"Buy" Score	89	83	64	61	40.6302

	Make	Buy
0	32.13781	40.6302
100	83	64

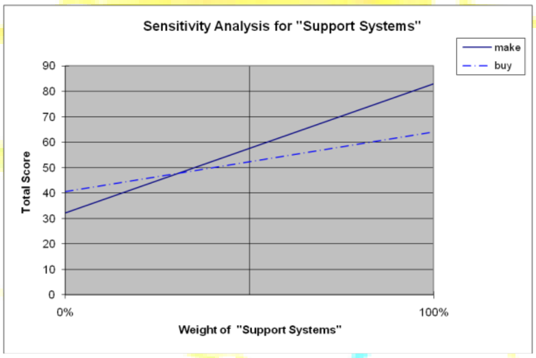


Fig.17: Sensitivity analysis for "support systems"

	Tech. & Manu.	SCM	Support Sys.	Social	Score
weight	0.260848	0.351974	0.387179	0	1
"Make" Score	54	95	83	100	46.22161
"Buy" Score	89	83	64	61	47.99488

	Make	Buy
0	46.22161	47.99488
100	100	61

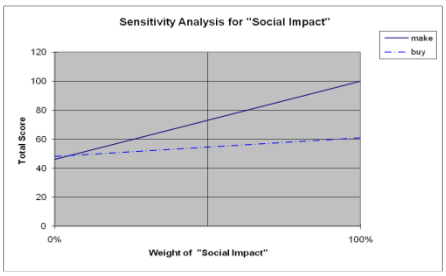


Fig.18: Sensitivity analysis for "social impact"

Which policy to choose?

We see in Fig.19 that the scores of criteria is proportional to the percentage of "make". That is, as we make more and buy less as the benefits (criteria) scores increase. However, we see in Fig.20 that the minimum cost exist when the benefits score is 82 which is corresponding in Fig.19 to the policy of "make 80% and buy 20%". So, this is the winning policy that satisfies relatively high score of benefits and minimum cost.

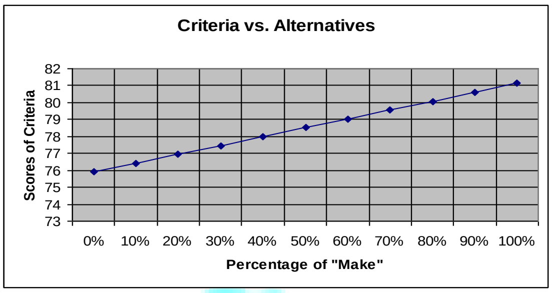


Fig.19: Criteria vs. Alternatives

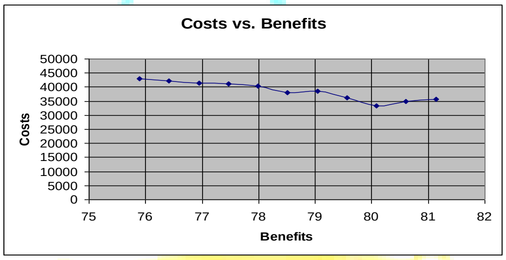


Fig.20: Costs vs. Benefits

VII. CONCLUSION

This project has satisfied the engineering design criteria by introducing a decision making process, in which the basic math and engineering techniques are applied. Further, it has taken into consideration a variety of realistic constraints such as: economic factors, level of technology, SCM and social impact.

In this work, a structured methodology is applied for make-or-buy problem on the case of a hypothetical company. Going through the three phases of the process (a preparation phase; a data collection phase; and an analysis and results phase) and after performing the analytical solution of the costing criteria, sensitivity analysis and simulation were performed using SensIt, RiskSim and Excel spreadsheet. A qualitative analysis was performed for SCM. It is found from the overall scores of making and buying that the company should make the part in-house. It is concluded also from sensitivity analysis that the area of "technology and manufacturing processes" and "support systems" are sensitive for weighting. So, more attention should be paid in evaluating these areas. In spite of that the "make" is the winning policy in terms of the overall score; gap analysis shows weakness in "Technology and Manufacturing Processes". So, the company should also put in place activities to strengthen this area.

In general, it is good idea to support "make" option, especially in the developing countries. By enhancing this policy, the technology is transferred due to building new factories and getting new technical and industrial experience. These benefits cannot be achieved by "buy" policy and treating the imported parts as a "black box" without knowing their functions and internal structures. Another advantage of "make" policy is the social impact. The recent studies has approved that the level of crime is proportional to unemployment. Building new plants and factories offers more jobs for unemployed people, which decreases the level of crime and enhance the prosperity of the society. This is one of the ethical issues in engineering. Even though the "make" option may sometimes appear more costly than "buy" option, it might be less costly in the long term and considering the other factors.

References

[1] D. R. Anderson et al.,*An Introduction to Management Science*(Thomson South-Western, 2008).

[2] J.Padillo and M. Diaby. A multiple-criteria decision methodology for the make-or-buy problem. *International Journal of Production Research*, Volume 37, No. 14, 1999, p. 3203- 3229.

[3] T.s Saaty, *Fundamentals of Decision Making and Priority Theory with the Analytical Hierarchy Process*(RWS Publications, 1994).

[4] S.s J. Moschuris, Organizational participants in the make-or-buy process, *Industrial Marketing Management* 37, 2008, p. 143–153.

[5] K.W. Platts, D.R. Probert, L. Make vs. buy decisions: A process incorporating multi-attribute decision-making. *International Journal of Production Economics*, Volume 77, Issue 3, 11 June 2002, p. 247–257.

[6] M. R. Middleton, *Decision Analysis Using Microsoft Excel*(School of Business and Management, University of San Francisco, 2006).