Internship Project on Remanufacturing

Term Report

By:- SRIJIT SARKAR

JADAVPUR UNIVERSITY

REMANUFACTURING -Introduction

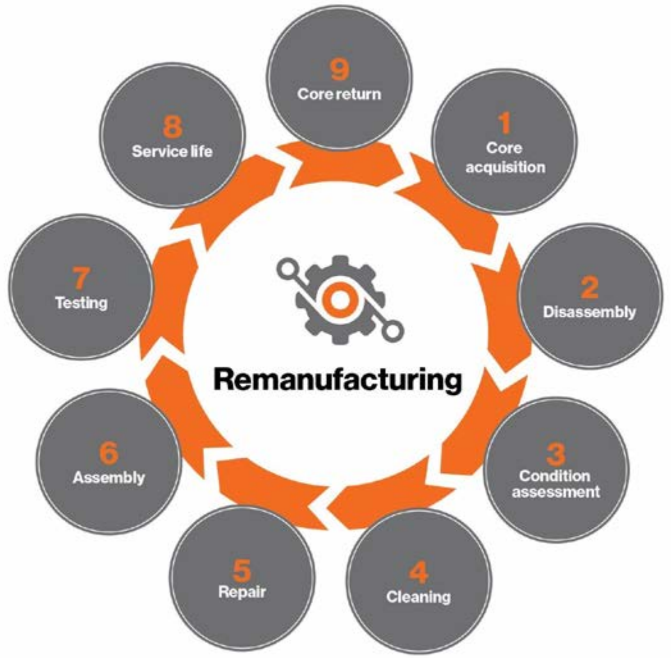
- Remanufacturing is an industrial process by which a previously sold, worn, or non-functional product can be rebuilt and recovered.
- Through the disassembly, cleaning, repair and replacement of worn out and obsolete components, the piece can be returned to a ‘like-new’ or ‘better-than-new’ condition and will be just as reliable as the original product.
- Remanufacturing plays an important role in the concept of a circular economy.

Our Problem is focused on remanufacturing of car Engines

Buyback Strategy and Buyback Contract

- **Buyback strategy** is strategy where used engines are collected before the end of their useful life so that some revenue can be generated by remanufacturing or reusing them.

- **Buyback Contrack** between manufacturer and retailer/customer at the time of selling the new engine customer/ retailer should return used engine after a fixed residence time i.e. buyback time and manufacturer also pays buyback price to the customer or retailer at the time of returning used engine.



Remanufacturing as a Closed Loop Supply Chain

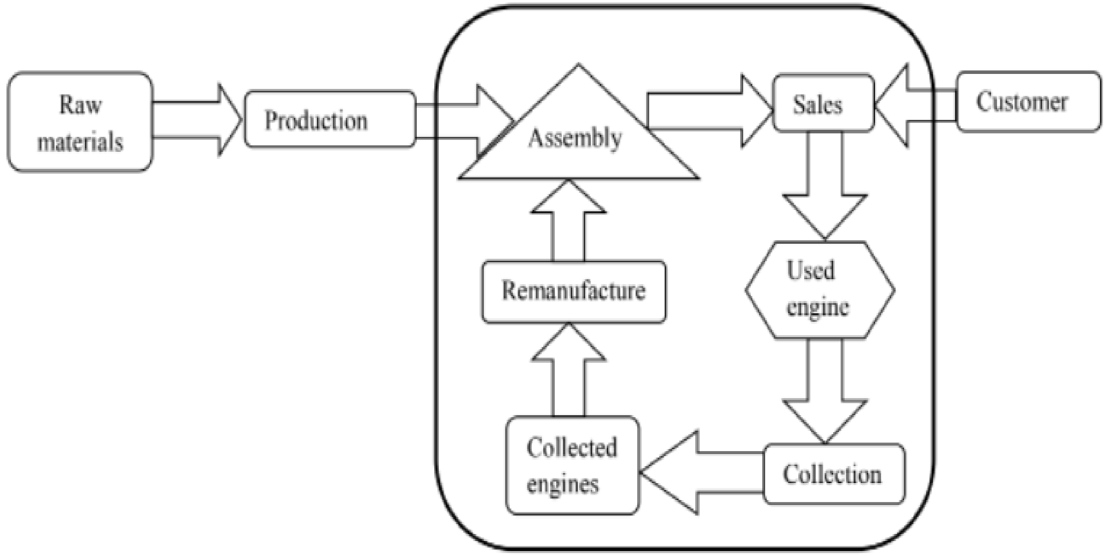


Figure 1: Remanufacturing as a Closed Loop Supply Chain

If each company are responsible for their own products which means that if each company can collect their own product from the end user after a fixed usage time; the companies will get better control of their own remanufacturing businesses. This process is called closed-loop supply chain.

This project concerns with the remanufacturing of car engine as a closed loop supply chain system which is shown in Figure 1

The Problem Description

Main objective of this study is to develop a life cycle optimization model for remanufacturing of car engine and to solve using metaheuristics methods

Car engine has many parts having unequal service life. When engine parts fail the replacement of these parts by new one is very costly.

Therefore, remanufacturing of car engine is most preferable. Remanufacturing produces as good as like new car engine

Car engine has three types of parts.:

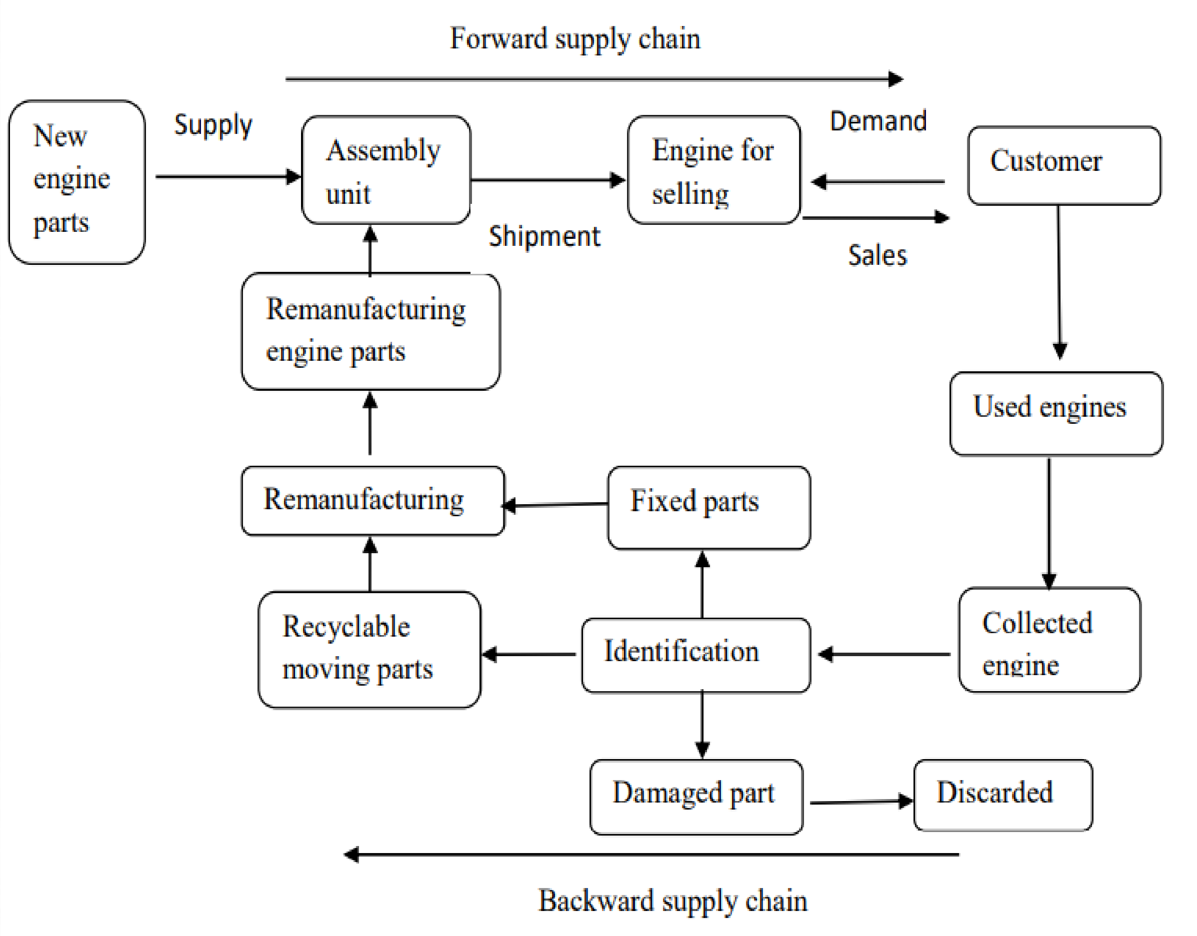
a) Fixed parts having long service life. -> cylinder head, bearing block, bearing caps, damper etc.
b) Moving parts which deliver the torque having shorter service life ->piston, connecting rod, crankshaft, camshaft, valves etc.
c) Some other parts of engine having very short life and these parts are damaged soon -> gaskets set, piston ring, valve cover, stoker kit etc.

MODELLING:

Remanufacturing of car engine includes three parts.

a) Manufacturing/forward supply chain (supply, production, assembly, sales)
b) Use and return (buyback return and normal return)
c) Remanufacturing/backward supply chain (collection, remanufacturing of recyclable parts (disassemble and upgrade), assemble and disposal of damaged or non-recyclable parts).

The Framework of the mathematical model developed in the present work is shown below in Figure 3:



FORMULATION :

a) Indices

t = Time period, t = {1. . . T}, (T: planning horizon).

b) Decision variables

$\boldsymbol{S_t}$= Sales rate at time period t.

$\boldsymbol{FPPR_t}$ = Fixed part procurement rate at time period t.

$\boldsymbol{RMPPR_t}$ = Recyclable moving part procurement rate at time period t.

$\boldsymbol{NMPPR_t}$ = Non-recyclable moving part procurement rate at time period

period t.

$\boldsymbol{AR_t}$ =Assembly rate at time period t.

$\boldsymbol{INV_t}$ =Average inventory per year at time period t.

$\boldsymbol{SHR_t}$ = Shipment rate at time period t.

$\boldsymbol{NR_t}$ = Normal return rate at time period t.

$\boldsymbol{BBR_t}$ = Buyback return rate at time period t.

$\boldsymbol{FPRR_t}$ = Fixed part remanufacturing rate at time t

$\boldsymbol{RMPRR_t}$ = Recyclable moving part remanufacturing rate at time period t.

$\boldsymbol{NMPDR_t}$ = Non-recyclable moving part disposal rate at time period t.

$\boldsymbol{BBP_t}$ = Buyback return Price per unit at time period t.

FORMULATION :

c) Parameters

P_t= Average price of the engine.

D_t = Demand rate at time period t.

BBT = Buyback time.

BBF_t = Buyback return fraction at time period t.

NF = Normal return fraction.

NT = Normal return time.

RNF_{fp} = Recovery fraction of fixed part from normal return (0.45).

RNF_{mp} = Recovery fraction of moving part from normal return (0.4).

$RBBF_{fp}$ = Recovery fraction of fixed part from buyback return, f (BBT).

$RBBF_{mp}$ = Recovery fraction of moving part from buyback return, f (BBT).

d) Cost parameters

C_{fp} = Fixed part procurement cost per unit.

C_{rmp} = Recyclable moving part procurement Cost per unit.

C_{nmp} = Non-recyclable moving part procurement cost per unit.

C_a = Assembly cost per unit.

C_h = Inventory holding cost per unit.

C_t = Transportation cost per unit.

C_{nr} = Normal collection cost per unit.

C_{fpr} = Fixed part remanufacturing cost per unit.

C_{rmpr} = Recyclable moving part remanufacturing cost per unit.

C_{dp} = Disposal cost per unit.

Objective to Gain

Total Revenue (t): Sales (t)*Price per engine (t) i.e. $\boldsymbol{S_t} * \boldsymbol{P_t}$

Total Cost (t) =

Fixed part procurement cost (t) i.e. $\boldsymbol{FPPR}_t * C_{fp}$ +

Recyclable moving part procurement cost (t) i.e. $\boldsymbol{RMPPR_t} * C_{rmp}$ +

Non recyclable moving part procurement cost (t) i.e. $\boldsymbol{NMPPR_t} * C_{nmp}$ +

Assembly cost (t) i.e. $\boldsymbol{AR_t} * C_a$ + Inventory holding cost (t) i.e. $\boldsymbol{INV_t} * C_h$ +

Shipment cost (t) i.e. $\boldsymbol{SHR_t} * C_t$ + Normal return cost (t) i.e. $\boldsymbol{NR_t} * C_{nr}$ +

Buyback return cost (t) i.e. $\boldsymbol{BBR_t} * BBP_t$ +

Fixed part remanufacturing cost (t) i.e. $\boldsymbol{FPRR_t} * C_{fpr}$ +

Recyclable moving part remanufacturing cost (t) i.e. $\boldsymbol{RMPRR_t} * C_{rmpr}$ +

Non recyclable moving part disposal cost (t) i.e. $\boldsymbol{NMPDR_t} * C_{dp}$

We need to maximize the profit -> Revenue – Cost

$$\sum \boldsymbol{S_t} * \boldsymbol{P_t} - \sum(\boldsymbol{FPPR_t} * C_{fp} + \boldsymbol{RMPPR_t} * C_{rmp} + \boldsymbol{NMPPR_t} * C_{nmp} + \boldsymbol{AR_t} * C_a + \boldsymbol{INV_t} * C_h + \boldsymbol{SHR_t} * C_t + \boldsymbol{NR_t} * C_{nr} + \boldsymbol{BBR_t} * BBP_t + \boldsymbol{FPRR_t} * C_{fpr} + \boldsymbol{RMPRR_t} * C_{rmpr} + \boldsymbol{NMPDR_t} * C_{dp})$$

Constraints

1. Capacity constraints

a) Procurement capacity:

$FPPR_t <= Capacity_{fpprt}$ (t=1,2,3……,T)

$RMPPR_t <= Capacity_{rmpprt}$ (t=1,2,3……,T)

$NMPPR_t <= Capacity_{nmpprt}$ (t=1,2,3……,T)

b) Assemble capacity

$AR_t <= Capacity_{ar}$ (t=1,2,3……,T)

c) Shipment capacity

$SHR_t <= Capacity_{shrt}$ (t=1,2,3……,T)

d) Collection capacity:

$NR_t + BBR_t <= Capacity_{crt}$ (t=1,2,3……,T)

e) Remanufacturing capacity:

$FPRR_t + RMPRR_t <= Capacity_{rmpt}$ (t=1,2,3……,T)

2. Demand fulfil constraints

a) Demand and sales:

$S_t <= D_t$ (t=1,2,3……,T)

b) Supply rate and demand:

$FPPR_t + FPRR_t <= D_t$ (t=1,2,3……,T)

$RMPPR_t + RMPRR_t <= D_t$ (t=1,2,3……,T)

$NMPPR_t <= D_t$ (t=1,2,3……,T)

c) Assembly rate and demand:

$AR_t <= D_t$ (t=1,2,3……,T)

Constraints

3. Material balance constraints :

a) Supply rate and assembly rate:

$AR_t = FPPR_t + FPRR_t$ (t=1,2,3……,T)

$AR_t = RMPPR_t + RMPRR_t$ (t=1,2,3……,T)

$AR_t = NMPPR_t$ (t=1,2,3……,T)

b) Average inventory:

$INV_t = INV_{t-1} + AR_t - S_t$ (t=1,2,3……,T)

c) Return rate and sales:

$NR_t = NF * S_{t-NT}$ (t=1,2,3……,T)

$BBR_t = BBF_t * S_{t-BBT}$ (t=1,2,3……,T)

d) Remanufacturing rate and return rate:

$FPRR_t = RNF_{fp} * NR_t + RBBF_{fp} * BBR_t$ (t=1,2,3……,T)

$NMPRR_t = RNF_{mp} * NR_t + RBBF_{mp} * BBR_t$
(t=1,2,3……,T)

e) Disposal rate and return rate:

$NMPDR_t = (1 - RNF_{fp} - RNF_{mp}) * NR_t +$

$(1 - RBBF_{fp} - RBBF_{mp}) * BBR_t$ (t=1,2,3……,T)

4. Non negativity constraints:

FPPRt ; RMPPRt ; NMPPRt ; ARt ; SHRt ; NRt ; BBRt ;

FPRRt ; RMPRRt ; NMPDRt >= 0;

6<=BBT<=10; BBPt >=0; P >=$250

$D_{t+1} = D_t + 0.4*BBRt$

$BBR_t = BBF_T * (S_{t-BBT} - BBR_{t-BBT})$

UPDATE

Till now we have successfully coded with Genetic Algorithm in R using the predefined GA package in R

The genetic algorithm is a method for solving both constrained and unconstrained optimization problems that is based on natural selection, the process that drives biological evolution. The genetic algorithm repeatedly modifies a population of individual solutions.

In our case the problem is constrained optimization problem with a lots of constraints discussed earlier

Fitness function and selection

As our problem is full of constraints and our objective is to maximize the profit function.

So on the basis of constraints we will be subtract the penalty from the profit and thus it will minimize the profit.

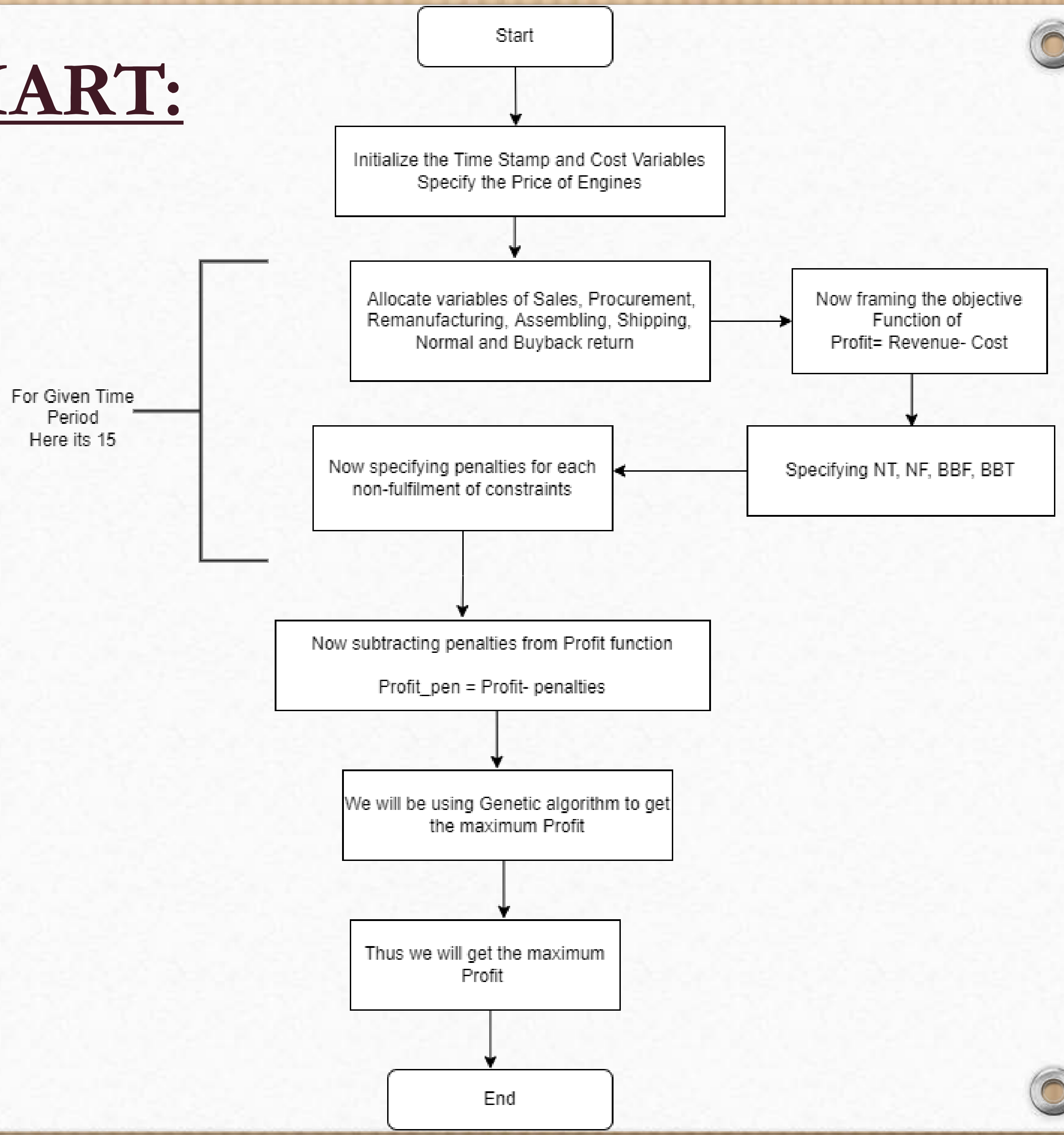
So the best possible solution giving the maximum profit shall get us the best solution which is the above answer of the problem.

This best chromosomes will go to the next iteration.

PROCEDURE & FLOWCHART:

Our steps for solving the problem using Genetic Algorithm

- Allocate the cost variables, procurement, remanufacturing, assembling, shipping
- Form the fitness function which is the Profit function of Revenue - Cost
- We will use the penalty method to adjust the constraints and try to maximize the function
- We coded the GA in R



Various Parameters Assumed

Cost parameters	Assumed value in $
Fixed part procurement cost per unit or C_{fp}	50
Recyclable moving part procurement Cost per unit C_{rmp}	55
Non-recyclable moving part procurement cost per unit or C_{nmp}	45
Assembly cost per unit or C_a	20
Inventory holding cost per unit or C_h	5
Transportation cost per unit or C_t	5
Normal collection cost per unit or C_{nr}	20
Fixed part remanufacturing cost per unit or C_{fpr}	30
Recyclable moving part remanufacturing cost per unit or C_{rmpr}	40
Disposal cost per unit or C_{dp}	8

RNF_{fp} = Recovery fraction of fixed part from normal return	0.45
RNF_{mp} = Recovery fraction of moving part from normal return	0.4
$RBBF_{fp}$ = Recovery fraction of fixed part from buyback return	0.55
$RBBF_{mp}$ = Recovery fraction of moving part from buyback return	0.5
NF = Normal return fraction	10
NT = Normal return time	0.6
Capacity Constraints	100

Genetic Algorithm

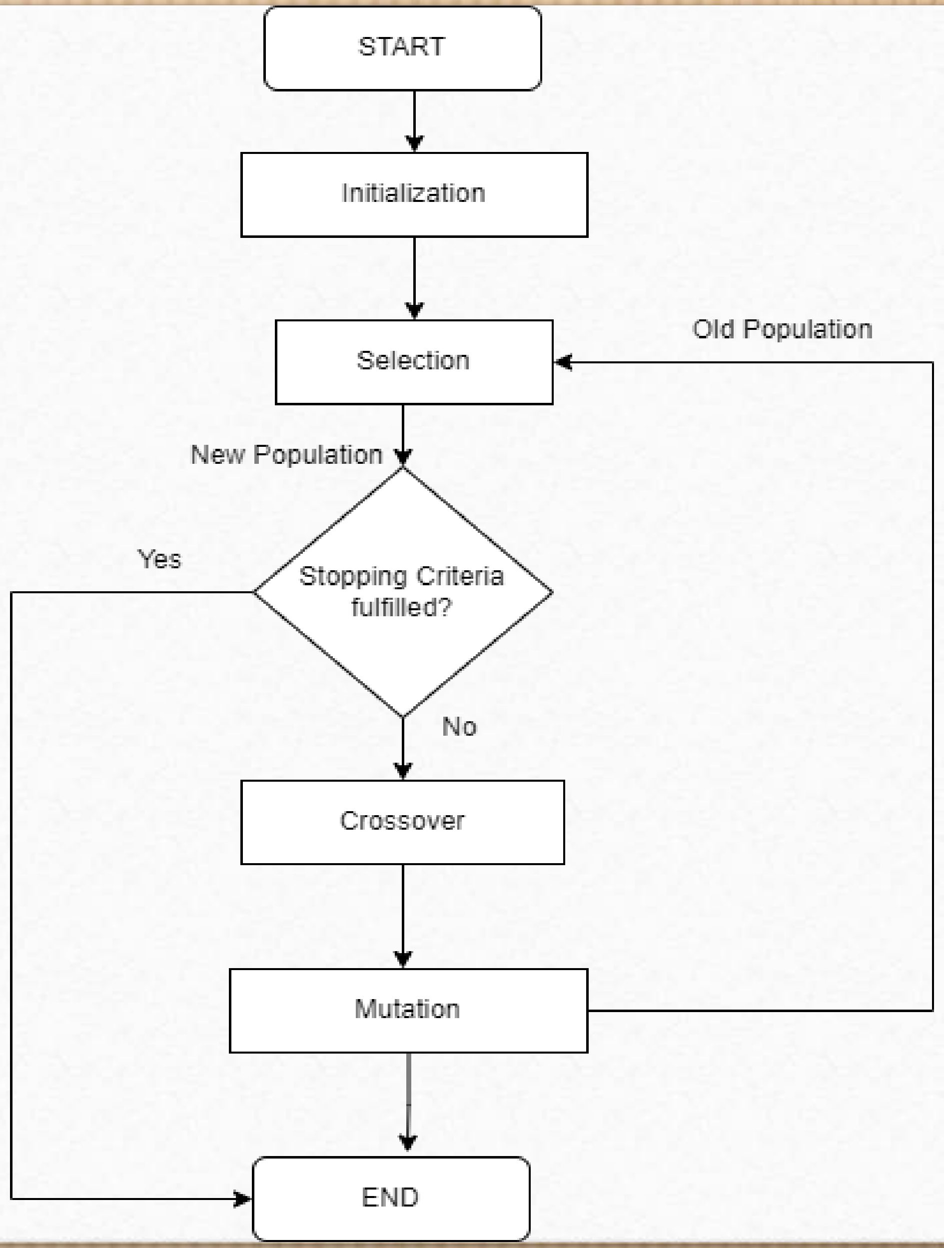
We coded the GA in R

- Generate a random (uniform) population of real values in the certain ranges
- We will be using Tournament selection, Roulette Wheel selection
- Local arithmetic crossover and Uniform random mutation used
- The probability of crossover between pairs of chromosomes = 0.9
- The probability of mutation in a parent chromosomes = 0.01
- Population Size = 50
- Elitism, which is the number of best fitness individuals to survive at each generation - we have chosen the top 5% individuals will survive at each iteration
- The maximum number of iterations to run before the GA search is halted = 1,00,000
- The number of consecutive generations without any improvement in the best fitness value before the GA is stopped = 300
- Genetic Algorithm is ran sequentially

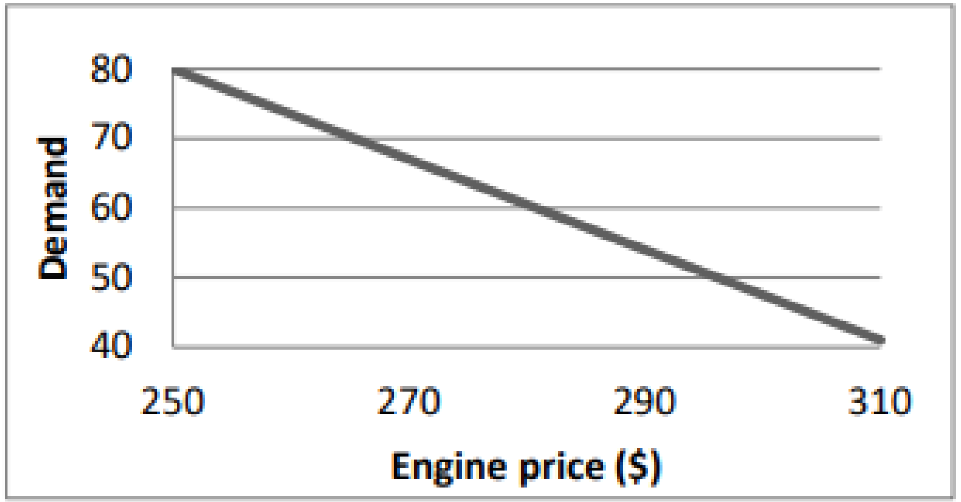
Genetic Algorithm:

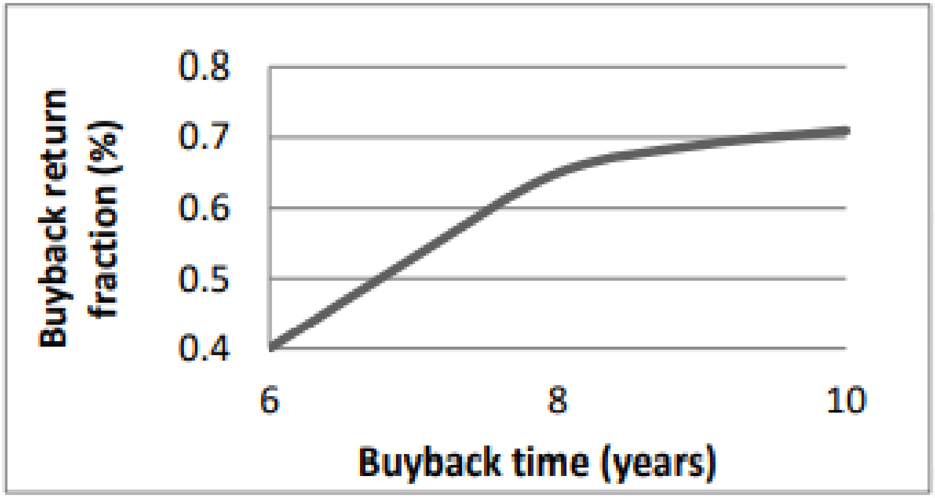
Pseudo Code of Genetic Algorithm:

START
Generate the initial population
Compute fitness
REPEAT
Selection
Crossover
Mutation
Compute fitness
UNTIL population has converged
STOP



Demand-Price and Buyback Fraction-Time Relation





The comparators in latter table are taken from these 2 graphs
With Demand relation with Price and Buyback Fraction relation with Buyback Team

RESULTS TABLE

Price	Buyback Time	Buyback Fraction	Profit- Roulette Wheel	Profit- Tournament
250	**6**	0.4	48577.87	-32180.91
Demand		0.5	45380.97	-39705.86
80		0.65	45731.65	-56308.4
		0.71	40980.95	-69503.51
	7	0.4	45564.88	-14516.5
		0.5	44937.25	-35805.21
		0.65	44172.53	-37300.3
		0.71	42573.97	-40721.09
	8	0.4	46356.31	-41457.85
		0.5	46262.11	51047.76
		0.65	42062.4	-48720.84
		0.71	40935.29	-52191.72
	10	0.4	46489.46	-44951.82
		0.5	44270.22	-56884.04
		0.65	40652.25	-50820.6
		0.71	41690.56	-53171.62

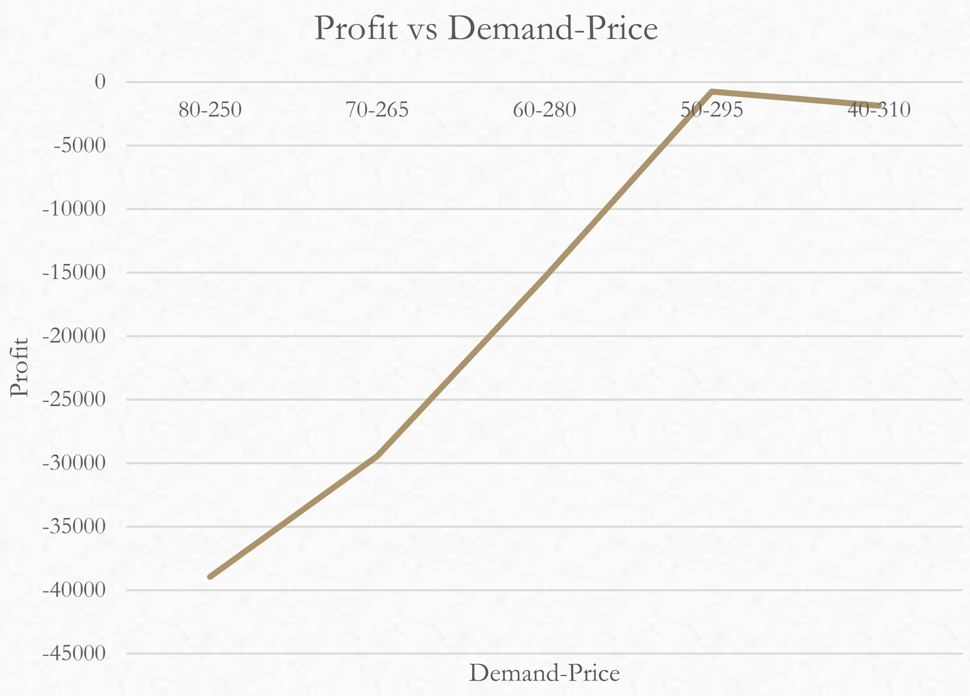
Price	Buyback Time	Buyback Fraction	Profit- Roulette Wheel	Profit- Tournament
265	**6**	0.4	49223.16	-17285.66
Demand		0.5	44487.08	-24132.68
70		0.65	47062.7	-40281.82
		0.71	45181.99	-48814.97
	7	0.4	48510.34	-2693.938
		0.5	24124.14	-26055.63
		0.65	44396.82	-22600.31
		0.71	44487.08	-26403.48
	8	0.4	47033.87	-14617.3
		0.5	47699.74	-35291.93
		0.65	44593.43	-31411.32
		0.71	42895.42	-38390.82
	10	0.4	51459.1	-27775.19
		0.5	47463.83	-42557.39
		0.65	44415.98	-36398.49
		0.71	16883.39	-36337.11

Price	Buyback Time	Buyback Fraction	Profit- Roulette Wheel	Profit- Tournament
280	**6**	0.4	49172.11	-5182.489
Demand		0.5	47145.01	-18616.96
60		0.65	46136.09	49515.03
		0.71	23621.06	-36308.47
	7	0.4	48697.34	8855.374
		0.5	46959.61	-8913.793
		0.65	27550.93	-11555.18
		0.71	44760.08	-14722.29
	8	0.4	47036.89	-2121.9
		0.5	46650.93	-23820.74
		0.65	45707.01	-18616.4
		0.71	42828.88	-40787.17
	10	0.4	29425.27	-15529.3
		0.5	46276.96	-26275.42
		0.65	43110.24	-36888.09
		0.71	43346.98	-45210.62

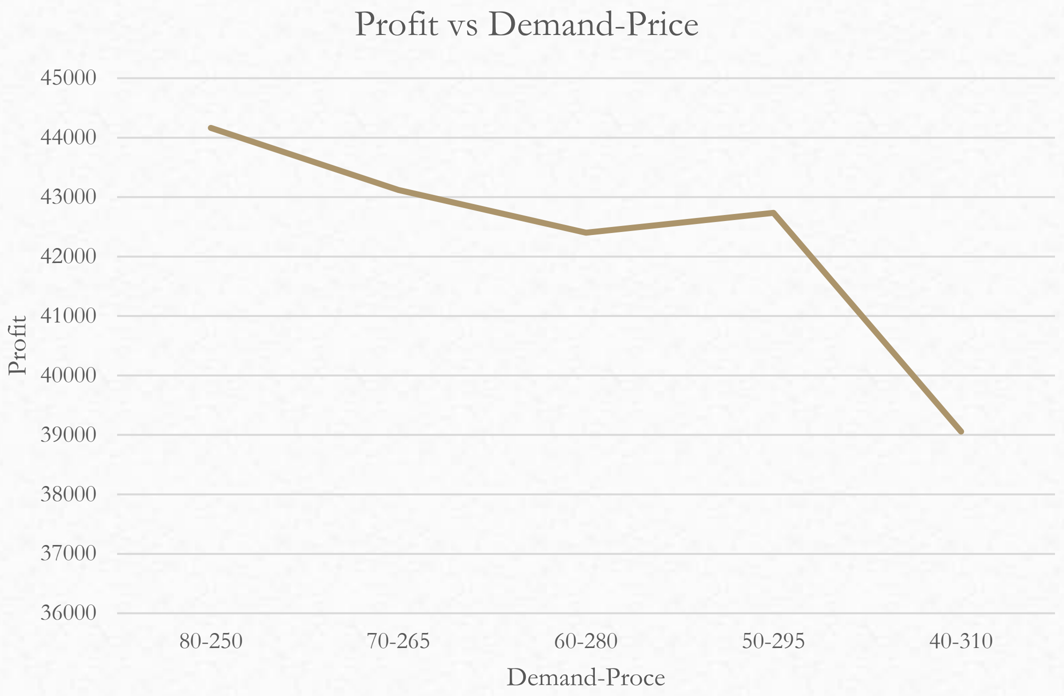
Price	Buyback Time	Buyback Fraction	Profit- Roulette Wheel	Profit- Tournament
295	**6**	0.4	46958.62	3709.358
Demand		0.5	44196.25	-2405.334
50		0.65	44058.23	46484.24
		0.71	28925.8	-36678.79
	7	0.4	45827.15	15719.85
		0.5	43983.13	-124.879
		0.65	42469.89	-1244.836
		0.71	42844.93	-5886.223
	8	0.4	44440.88	4665.284
		0.5	44783.38	47129.63
		0.65	42483.11	-10121.78
		0.71	40182.15	-15538.34
	10	0.4	47181.14	-5711.05
		0.5	43571.02	-17375.47
		0.65	40806.88	-16774.37
		0.71	41061.89	-17649.63

Price	Buyback Time	Buyback Fraction	Profit- Roulette Wheel	Profit- Tournament
310	**6**	0.4	41937.47	9519.531
Demand		0.5	39860.17	3723.806
40		0.65	40076.02	-10181.57
		0.71	36823.38	-18683.21
	7	0.4	39965.06	17537.14
		0.5	39548.06	6345.904
		0.65	38870.12	3562.226
		0.71	38404.94	730.8247
	8	0.4	40699.02	5766.308
		0.5	40499.04	-4608.651
		0.65	37679.07	-4043.103
		0.71	36617.9	-9135.24
	10	0.4	40787.74	2132.1
		0.5	39005.47	-7495.715
		0.65	36786.6	-10468.24
		0.71	37332.49	-14252.68

Profit Vs Demand-Price for Tournament and Roulette Wheel



Tournament Selection



Roulette Wheel Selection

OBSERVATION GENERATED

It can be Observed from the table :

In Tournament

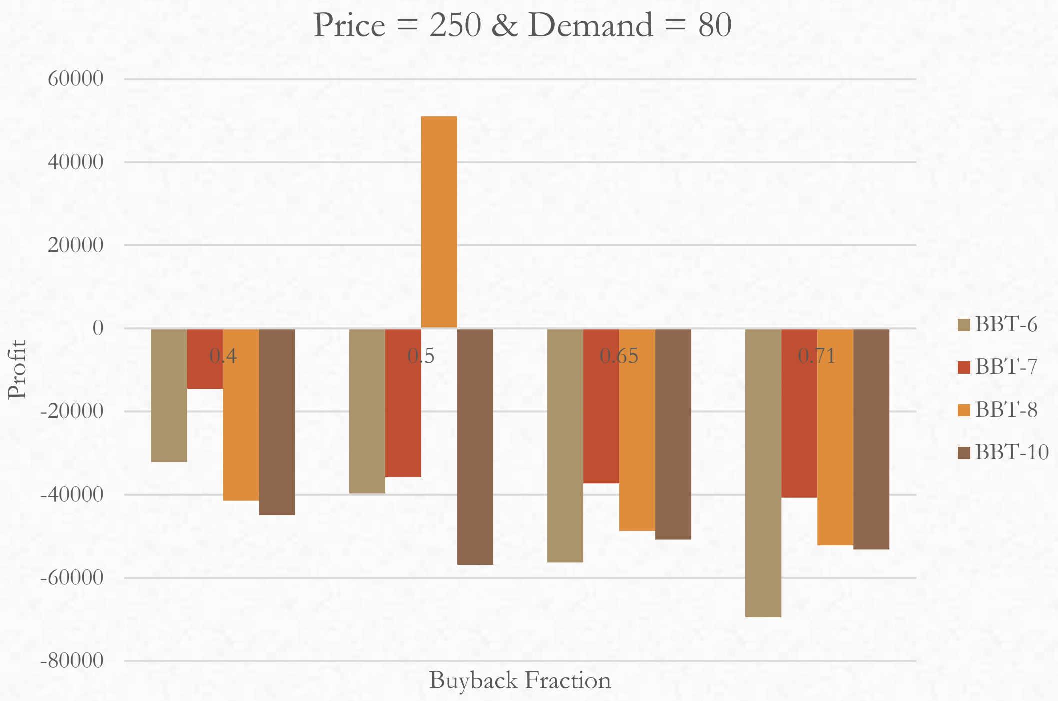
- With increase in Price and decrease in Demand the Profit increases to some extent and then decreases
- With decrease in Buyback Time and Buyback Fraction the Profit increases

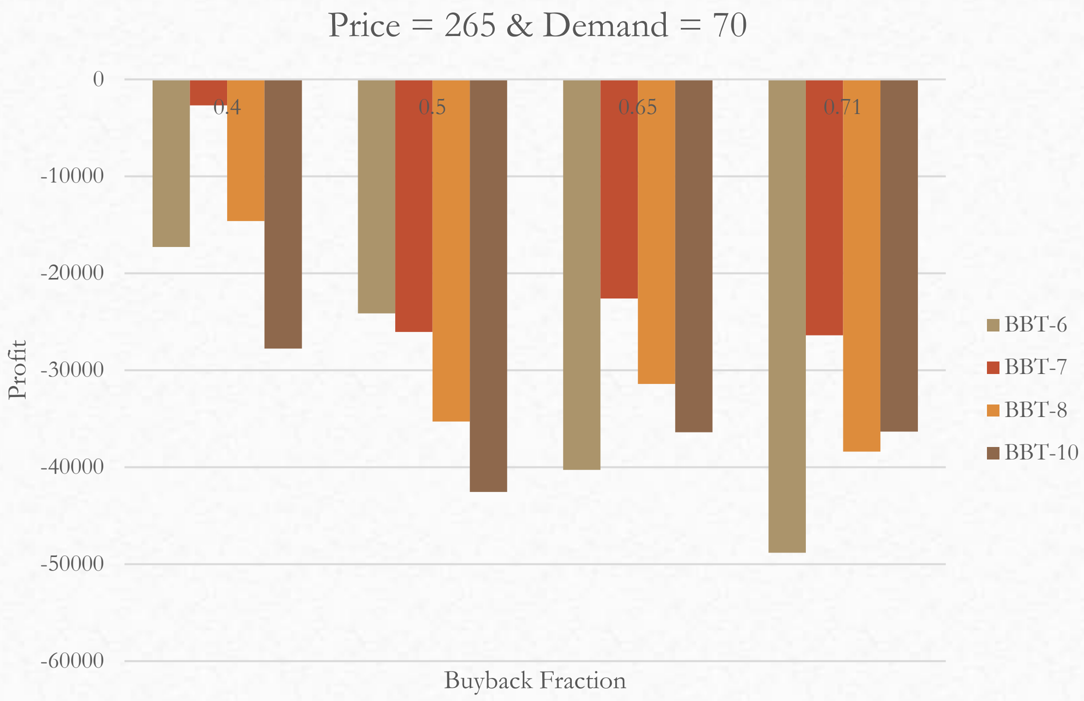
In Roulette Wheel

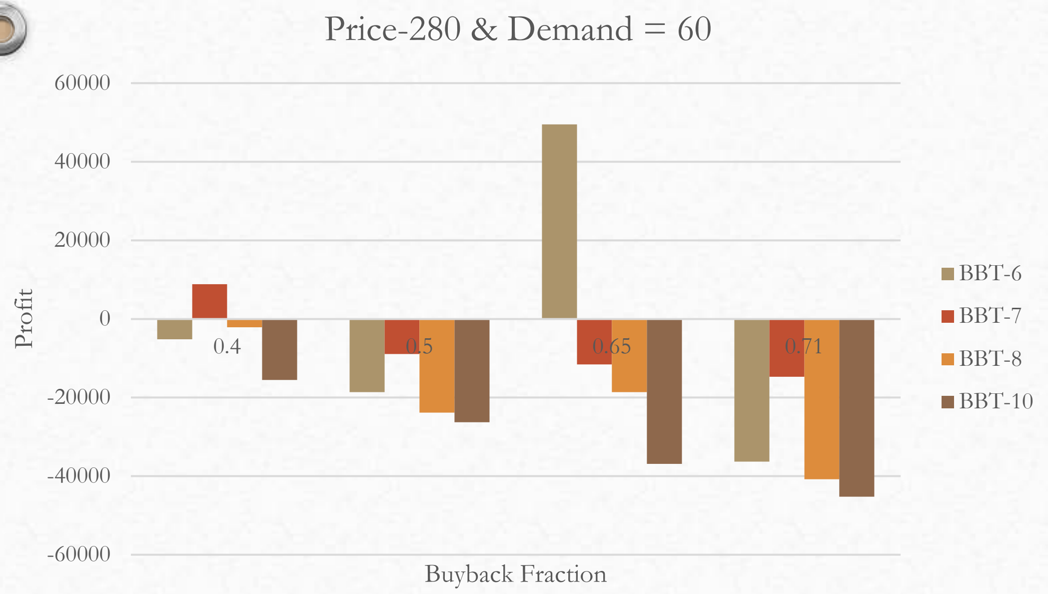
- With increase in Price and decrease in Demand the Profit decreases mostly
- With increase in Buyback time the profit first decreases, then increases and again decreases

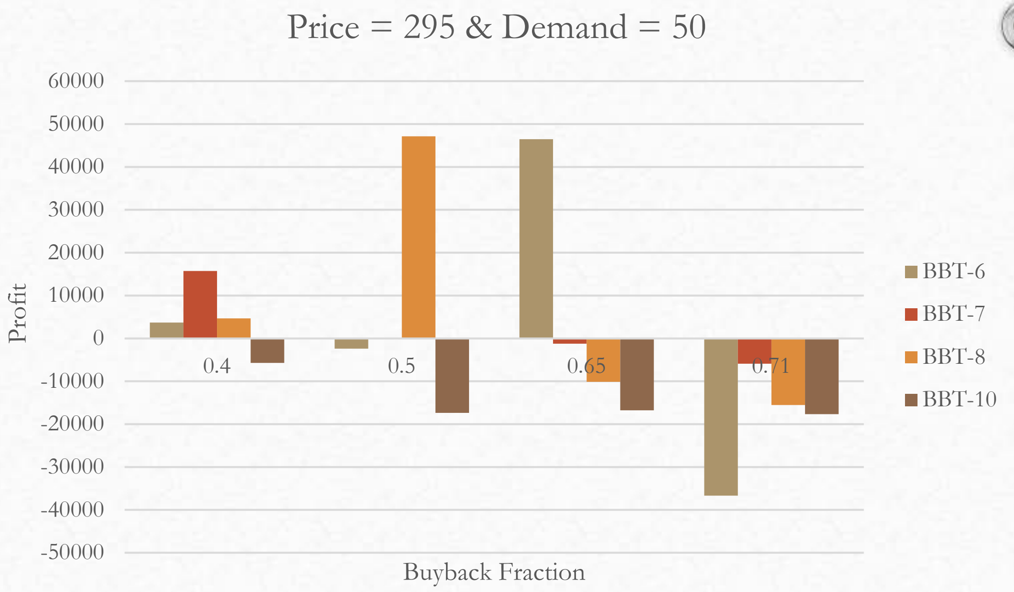
These points seem more realistic when compared to remanufacturing of Car Engines specially the results from Roulette wheel selection which gave all nearly positive profits than Tournament selection

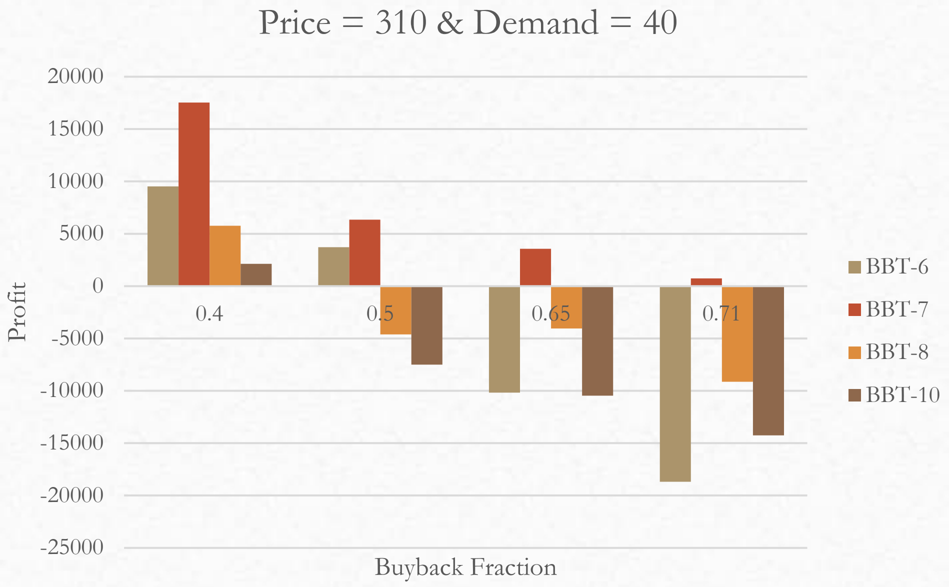
Varying the Buyback Time with Buyback Fractions→ Tournament



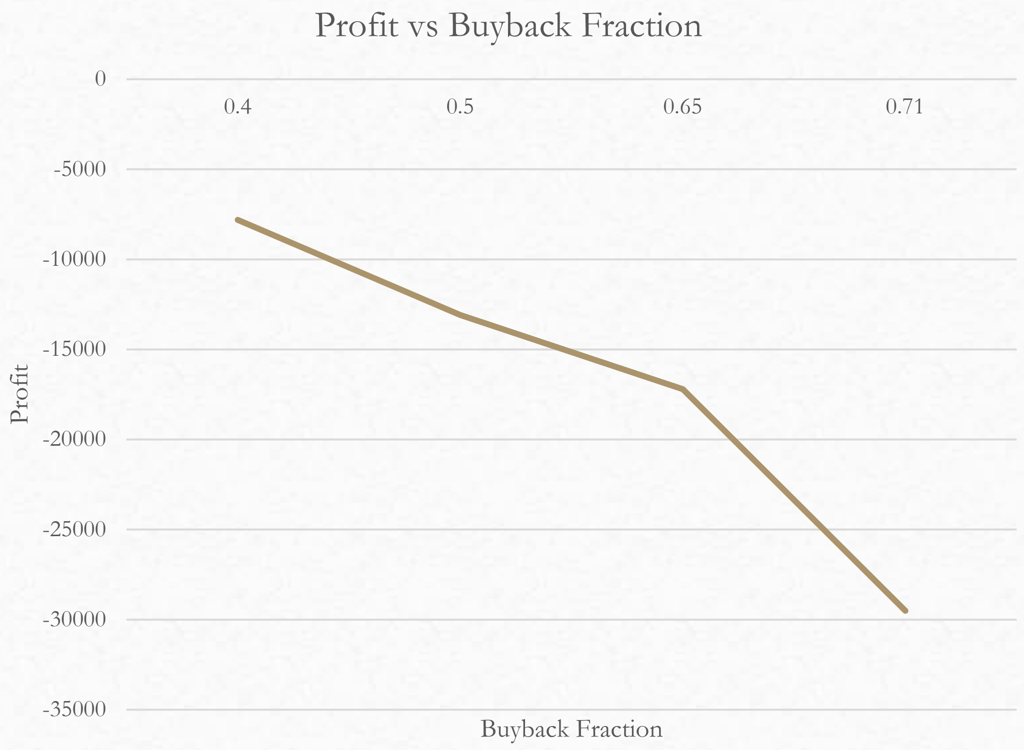


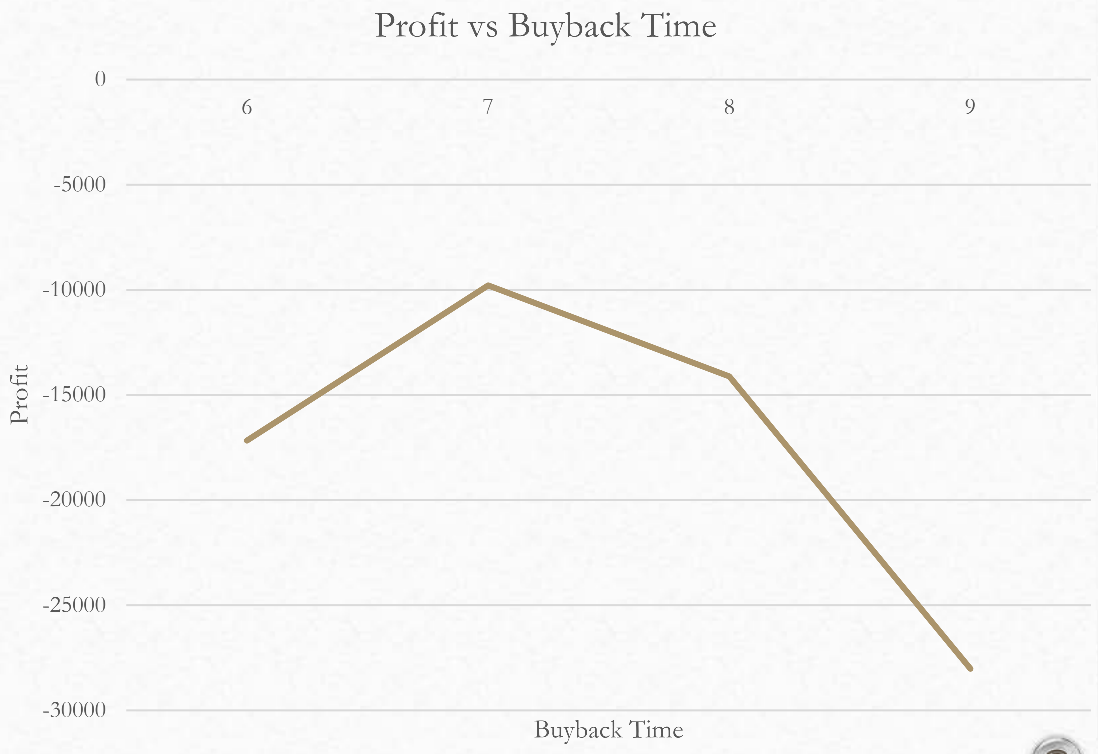

Price-280 & Demand = 60
60000
40000
20000
0
-20000
-40000
-60000
Profit
0.4
0.5
0.65
0.71
Buyback Fraction
BBT-6
BBT-7
BBT-8
BBT-10


Price = 295 & Demand = 50
60000
50000
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
-50000
Profit
0.4
0.5
0.65
0.71
Buyback Fraction
BBT-6
BBT-7
BBT-8
BBT-10

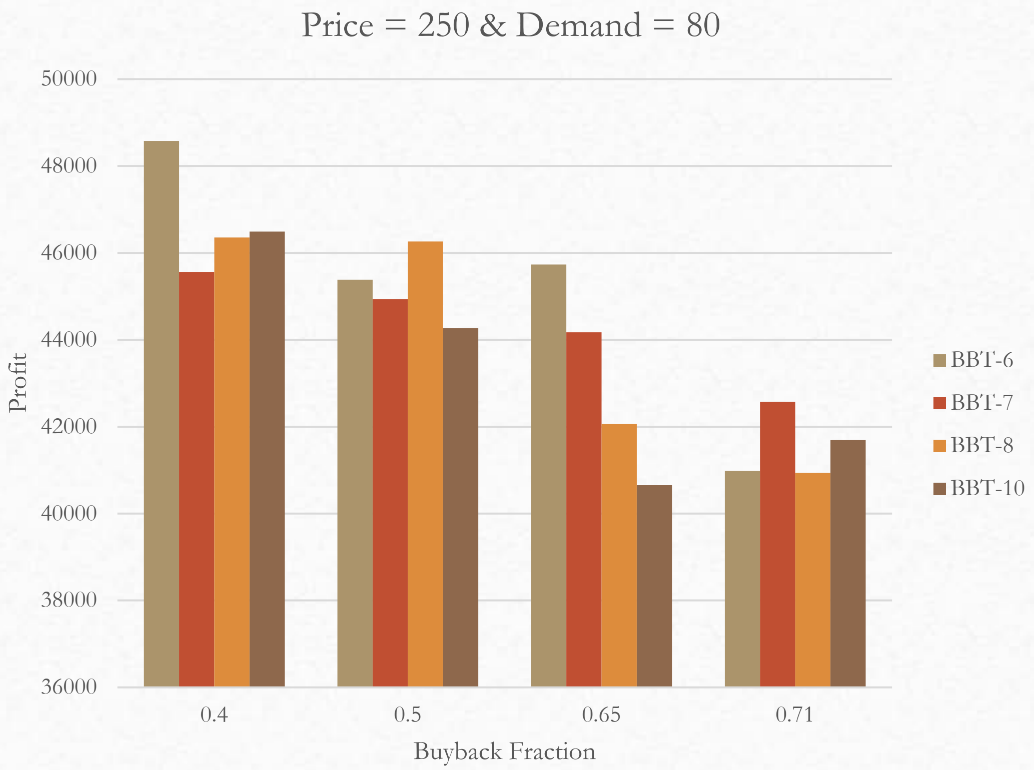

Price = 310 & Demand = 40
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
-25000
Profit
0.4
0.5
0.65
0.71
Buyback Fraction
BBT-6
BBT-7
BBT-8
BBT-10

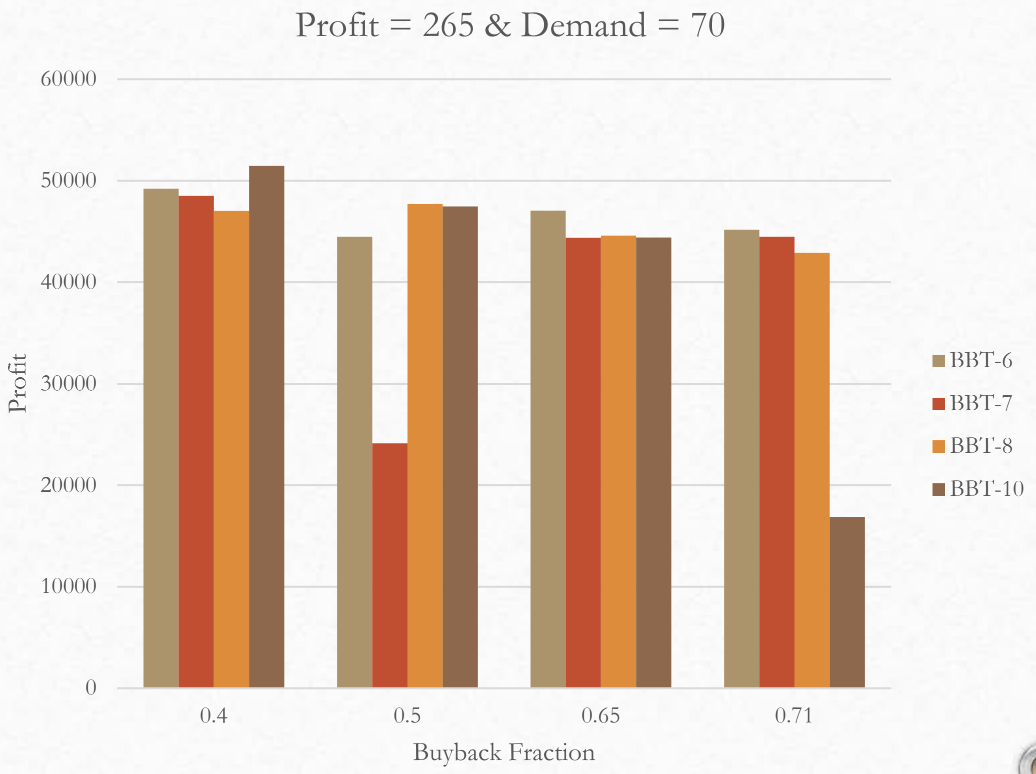
Profit Relation with Demand-Price-Buyback Time → Tournament

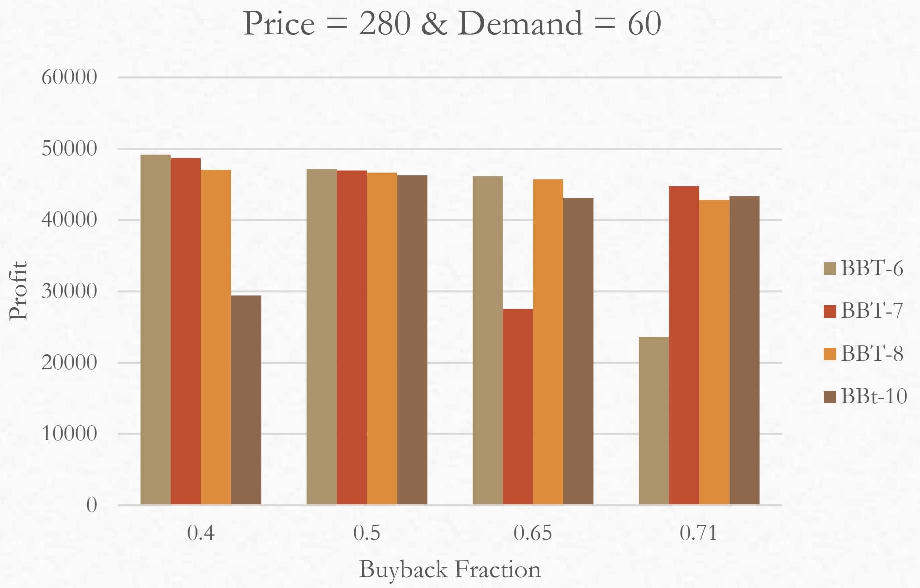


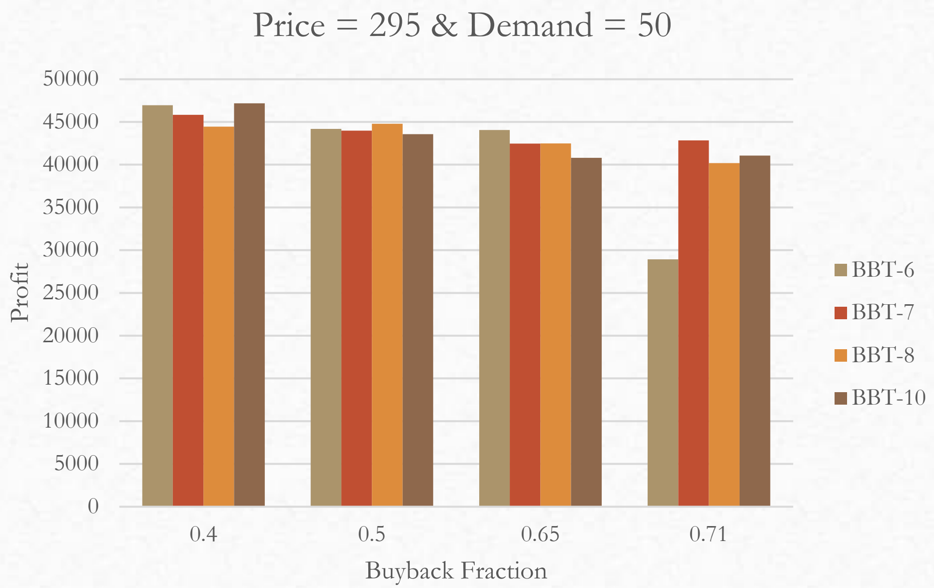


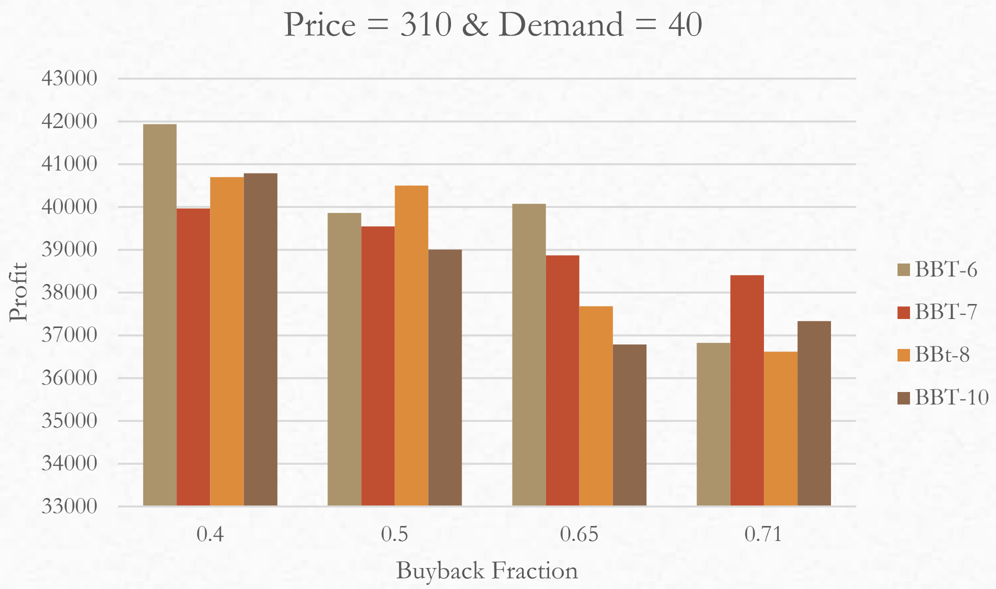
Varying the Buyback Time with Buyback Fractions→ Roulette Wheel



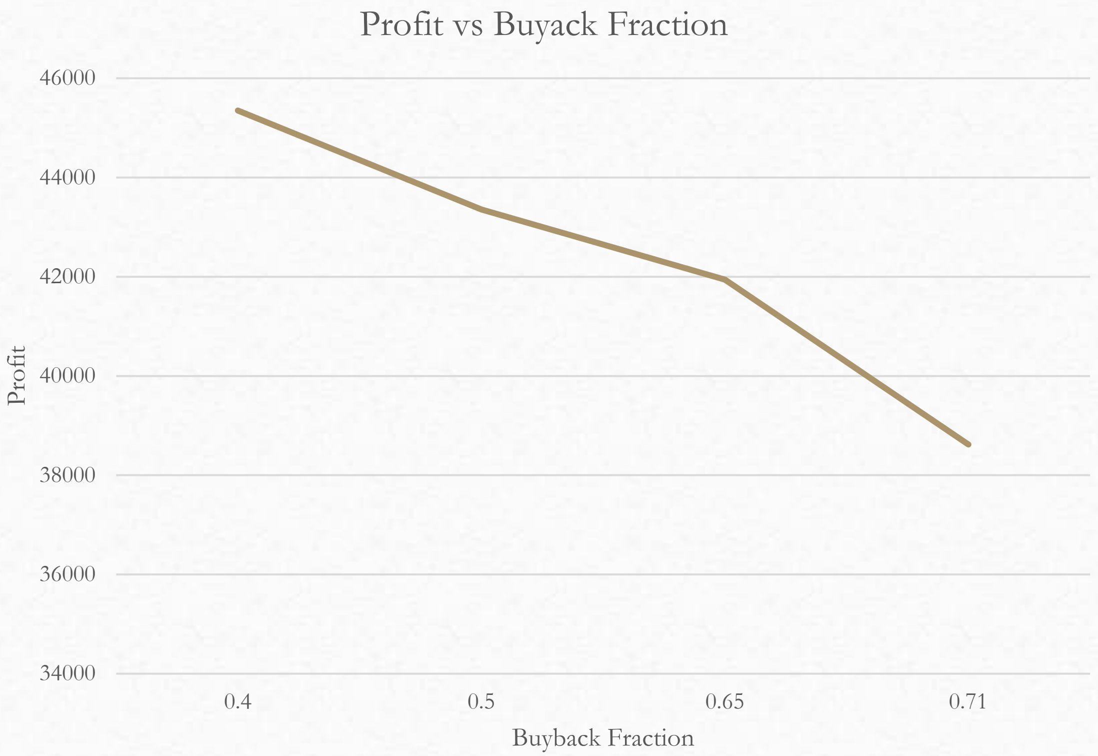


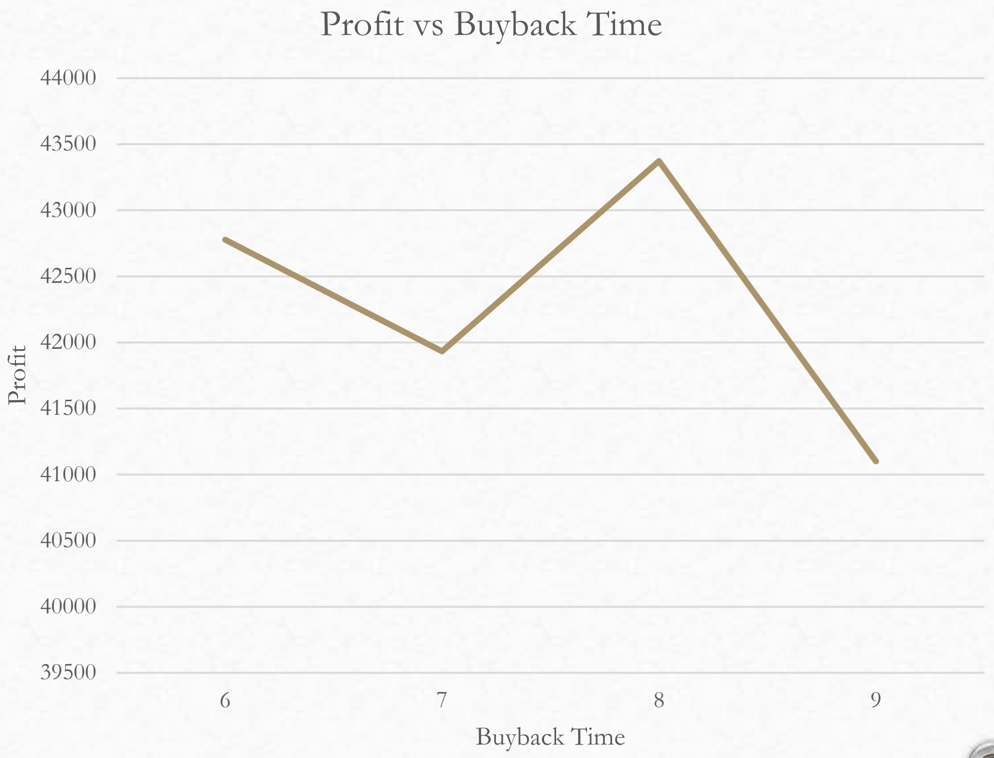

Price = 280 & Demand = 60
60000
50000
40000
30000
20000
10000
0
Profit
0.4
0.5
0.65
0.71
Buyback Fraction
BBT-6
BBT-7
BBT-8
BBt-10


Price = 295 & Demand = 50
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Profit
0.4
0.5
0.65
0.71
Buyback Fraction
BBT-6
BBT-7
BBT-8
BBT-10


Price = 310 & Demand = 40
43000
42000
41000
40000
39000
38000
37000
36000
35000
34000
33000
Profit
0.4
0.5
0.65
0.71
Buyback Fraction
BBT-6
BBT-7
BBt-8
BBT-10

Profit Relation with Demand-Price-Buyback Time → Roulette Wheel





CONCLUSION

Some Similarly Points were found in both Roulette Wheel Selection and Tournament Selection

The following conclusion can be made from the plots

- Profit increases with increase in Engine price to some extent and then profit decreases because of less demand
- As the Buyback Time increases profit increases to a time limit and then sharply decreases, overall Buyback Time increases leads to lower profit
- Profit decreases with increase in Buyback Fraction

The Roulette Wheel Selection gave positive profit and gave better solution than Tournament Selection