**Annexure 1**

Proposed B-INLP Model of MP Problem with BO for an OEM

***Objective Function***

}-{ ….. (1)

***Product Demand Constraint***

..... (2)

***Product Ending Inventory Constraints***

….. (3A)

….. (3B)

***Product Backordering Constraints***

….. (4A)

….. (4B)

***Product Assembly Capacity Constraint***

….. (5)

***Product Assembly Flow Balance Constraint***

….. (6)

***Component Ending Inventory Constraint***

….. (7)

***Component Manufacturing Capacity Constraint***

….. (8)

***Component Manufacturing Flow Balance Constraint***

….. (9)

***Raw Materials Ending Inventory Constraint***

….. (10)

***Component and Raw Material Procurement Restriction Constraints***

….. (11A)

….. (11B)

….. (11C)

….. (11D)

***Integer and Non-Negativity Constraints***

….. (12)

**Annexure 2**

Developed LINGO Set Code for INLP Model of the MP-CR problem with BO&PS for an OEM

SETS:

m/1..j/ :;

n/1..i/ : CMC, AMC, CPC, ARMC, CDRC ,IHCC, LLLEIC0, ULQPC, LLQPC;

q/1..p/ : AAP, CAP, CDIsRP, ADisRP, IHCP, CBP, LLEIP0, QPB0, SP;

c/1..3/ : ;

s/1..r/ : CPRawM, IHCRawM, LEIRawM0, ULQRawMP, LLQRawMP;

sn(s,n) : NRawM;

sm(s,m) : LEIRawM, QRawMP;

qm(q,m): D, QTOPA, LEIP, QPB, QTTPA;

qq(q,q) : CSP;

qqm(q,q,m): QSP;

nq(n,q) : NUC;

nm(n,m): LLEIC, QCM, QCP, LIRMC;

nc(n,c) : CRMC, RDRC;

qc(q,c) : APRP, RORRP, IHCRP, LEIRP0;

ncm(n,c,m): QCRM, QRCD;

xcm(q,c,m): QRPD, LEIRP, QRP;

ENDSETS

**! Objective Function /Objective 1/;**

Max = @SUM(qm(b,a)|a#GT#1:SP(b) \*(D(b,a) + QPB(b,a-1) - QPB(b,a))) +

@SUM(qm(b,a)|a#EQ#1:SP(b) \*(D(b,a) + QPB0(b) - QPB(b,a))) -

(@SUM(qm(b,a):CAP(b)\*(QTTPA(b,a) + QTOPA(b,a))) + @SUM(qm(b,a): CBP(b)\*QPB(b,a)) + @SUM(qm(b,a):IHCP(b)\*LEIP(b,a)) + @SUM(qqm(b,v,a): QSP(b,v,a)\*CSP(b,v)) +

@SUM(nm(v,a):CMC(v)\*QCM(v,a)) + @SUM(nm(v,a):CPC(v)\*QCP(v,a)) +

@SUM(ncm(v,x,a): CRMC(v,x)\*QCRM(v,x,a)) + @SUM(nm(v,a):IHCC(v)\*LLEIC(v,a)) +

@SUM(sm(z,a):IHCRawM(z)\*LEIRawM(z,a)) + @SUM(sm(z,a):CPRawM(z)\*QRawMP(z,a)) + @SUM(xcm(b,v,a):IHCRP(b,v)\*LEIRP(b,v,a)) +@SUM(xcm(b,v,a): APRP(b,v)\*QRP(b,v,a)) + @SUM(ncm(v,x,a):CDRC(v)\*QRCD(v,x,a))+@SUM(xcm(b,v,a): CDIsRP(b)\*QRPD(b,v,a)));

**! Product Demand Constraint / Constraint 2/;**

@FOR(m(a)|a#EQ#1: @FOR(q(b): D(b,a) + QPB0(b) + @SUM(q(w)|w#GT#b: QSP(w,b,a)) <= QTOPA(b,a) + QTTPA(b,a) + QPB(b,a) + LLEIP0(b) + @SUM(q(v)|v#LT#b: QSP(b,v,a))));

@FOR(m(a)|a#GT#1: @FOR(q(b): D(b,a) + QPB(b,a-1) + @SUM(q(w)|w#GT#b: QSP(w,b,a)) <= QTOPA(b,a) + QTTPA(b,a) + QPB(b,a) + LEIP(b,a-1) + @SUM(q(v)|v#LT#b: QSP(b,v,a))));

**! Product Inventory Constraints / Constraints 3A and 3B/;**

@FOR(m(a)|a#EQ#1: @FOR(q(b): LEIP(b,a) = @IF(QTOPA(b,a) + LLEIP0(b) + QTTPA(b,a) + @SUM(q(v)|v#LT#b: QSP(b,v,a)) #GT# D(b,a) + QPB0(b) + @SUM(q(w)|w#GT#b: QSP(w,b,a)),

QTOPA(b,a) + LLEIP0(b) + QTTPA(b,a) + @SUM(q(v)|v#LT#b: QSP(b,v,a)) - D(b,a) - QPB0(b) - @SUM(q(w)|w#GT#b: QSP(w,b,a)), 0)));

@FOR(m(a)|a#GT#1: @FOR(q(b): LEIP(b,a) = @IF(QTOPA(b,a) + LEIP(b,a-1) + QTTPA(b,a) + @SUM(q(v)|v#LT#b: QSP(b,v,a)) #GT# D(b,a) + QPB(b,a-1) + @SUM(q(w)|w#GT#b: QSP(w,b,a)), QTOPA(b,a) + LEIP(b,a-1) + QTTPA(b,a) + @SUM(q(v)|v#LT#b: QSP(b,v,a)) - D(b,a) - QPB(b,a-1) - @SUM(q(w)|w#GT#b: QSP(w,b,a)), 0)));

**! Backordering Constraints /Constraints 4A and 4B/;**

@FOR(m(a)|a#EQ#1: @FOR(q(b): QPB(b,a) = @IF(QTOPA(b,a) + QTTPA(b,a) + LLEIP0(b) + @SUM(q(v)|v#LT#b: QSP(b,v,a)) #GE# D(b,a) + QPB0(b) + @SUM(q(w)|w#GT#b: QSP(w,b,a)),

0, D(b,a) + QPB0(b) + @SUM(q(w)|w#GT#b: QSP(w,b,a)) - QTOPA(b,a) - QTTPA(b,a) - LLEIP0(b) - @SUM(q(v)|v#LT#b: QSP(b,v,a)))));

@FOR(m(a)|a#GT#1: @FOR(q(b): QPB(b,a) = @IF(QTOPA(b,a) + LEIP(b,a-1) + QTTPA(b,a) + @SUM(q(v)|v#LT#b: QSP(b,v,a)) #GE# D(b,a) + QPB(b,a-1) + @SUM(q(w)|w#GT#b: QSP(w,b,a)), 0, D(b,a) + QPB(b,a-1) + @SUM(q(w)|w#GT#b: QSP(w,b,a)) - QTOPA(b,a) -QTTPA(b,a) - LEIP(b,a-1) - @SUM(q(v)|v#LT#b: QSP(b,v,a)))));

**! Product Substitution Constraints/ Constraints 5A and 5B/;**

@FOR(m(a)|a#GT#1: @FOR(q(v): @SUM(q(b)|b#GT#v: QSP(b,v,a)) <= @IF( QTOPA(v,a) + QTTPA(v,a) + LEIP(v,a-1) + @SUM(q(w)|w#LT#v:QSP(v,w,a)) #GE# D(v,a) + QPB(v,a-1),QTOPA(v,a) + QTTPA(v,a) + LEIP(v,a-1) + @SUM(q(w)|w#LT#v: QSP(v,w,a)) - D(v,a) - QPB(v,a-1), 0)));

@FOR(m(a)|a#EQ#1: @FOR(q(v): @SUM(q(b)|b#GT#v: QSP(b,v,a)) <= @IF( QTOPA(v,a) + QTTPA(v,a) + LLEIP0(v) + @SUM(q(w)|w#LT#v:QSP(v,w,a)) #GE# D(v,a) + QPB0(v),

QTOPA(v,a) + QTTPA(v,a) + LLEIP0(v) + @SUM(q(w)|w#LT#v: QSP(v,w,a)) - D(v,a) - QPB0(v), 0)));

**! Downward Substitution Constraint/ Constraint 5C/;**

@FOR(m(a): @FOR(q(b): @SUM(q(v)|v#LT#b: QSP(v,b,a))= 0));

**! Restricted Substitution Constraint / Constraint 5D/;**

@FOR(m(a): @FOR(q(b): @SUM(q(w)|w#GT#b: QSP(w,b,a)) <= QTTPA(b,a)));

**! Product Assembly Capacity Constraint / Constraint 6/;**

@FOR(m(a):@FOR(q(b): QTOPA(b,a) + QTTPA(b,a) <= AAP(b)));

**! Assembly Flow Balance Constraints / Constraints 7A, 7B and 7C/;**

@FOR(m(a)|a#GT#1: @FOR(n(x): QCM(x,a) + QCP(x,a) + LIRMC(x,a) + LLEIC(x,a-1) >= @IF(@SUM(c(v):RDRC(x,v)) #EQ# 3,

@SUM(q(b): (QTOPA(b,a)+QTTPA(b,a))\*NUC(x,b)), @SUM(q(b): QTOPA(b,a)\*NUC(x,b)))));

@FOR(m(a)|a#EQ#1: @FOR(n(x): QCM(x,a) + QCP(x,a) + LIRMC(x,a) + LLLEIC0(x) >= @IF(@SUM(c(v):RDRC(x,v)) #EQ# 3,

@SUM(q(b): (QTOPA(b,a)+QTTPA(b,a))\*NUC(x,b)), @SUM(q(b): QTOPA(b,a)\*NUC(x,b)))));

@FOR(m(a): @FOR(n(v): @SUM(c(x): QCRM(v,x,a)) >= @IF(@SUM(c(x): RDRC(v,x)) #EQ# 3, 0, @SUM(q(b): QTTPA(b,a)\*NUC(v,b)))));

**! Component Ending Inventory Constraints / Constraints 8A, 8B and 8C/;**

@FOR(m(a)|a#GT#1: @FOR(n(v): LLEIC(v,a) = (@IF(@SUM(c(x): RDRC(v,x)) #EQ# 3,

QCM(v,a) + QCP(v,a) + LIRMC(v,a) + LLEIC(v,a-1) - @SUM(q(b): NUC(v,b)\*(QTOPA(b,a) + QTTPA(b,a))), QCM(v,a) + QCP(v,a) + LIRMC(v,a) + LLEIC(v,a-1) - @SUM(q(b): NUC(v,b)\* QTOPA(b,a))))));

@FOR(m(a)|a#EQ#1: @FOR(n(v): LLEIC(v,a) = (@IF(@SUM(c(x): RDRC(v,x)) #EQ# 3,

QCM(v,a) + QCP(v,a) + LIRMC(v,a) + LLLEIC0(v) - @SUM(q(b): NUC(v,b)\*(QTOPA(b,a) + QTTPA(b,a))),

QCM(v,a) + QCP(v,a) + LIRMC(v,a) + LLLEIC0(v) - @SUM(q(b): NUC(v,b)\* QTOPA(b,a))))));

@FOR(m(a): @FOR(n(v): LIRMC(v,a) = @IF(@SUM(c(x): RDRC(v,x)) #EQ# 3, 0, @SUM(c(x):QCRM(v,x,a)) - @SUM(q(b): NUC(v,b)\*QTTPA(b,a)))));

**! Component Manufacturing Capacity Constraint / Constraint 9/;**

@FOR(m(a): @FOR(n(b): QCM(b,a)<= AMC(b)));

**! Manufacturing Flow Balance Constraint / Constraint 10/;**

@FOR(m(a)|a#GT#1: @FOR(s(z): @SUM(n(v):QCM(v,a)\*NRawM(z,v)) <= QRawMP(z,a) + LEIRawM(z,a-1)));

@FOR(m(a)|a#EQ#1: @FOR(s(z): @SUM(n(v):QCM(v,a)\*NRawM(z,v)) <= QRawMP(z,a) + LEIRawM0(z)));

**! Raw Material Inventory Level Constraint / Constraint 11/;**

@FOR(m(a)|a#GT#1: @FOR(s(z): LEIRawM(z,a) = QRawMP(z,a) - @SUM(n(v): NRawM(z,v)\*QCM(v,a)) + LEIRawM(z,a-1)));

@FOR(m(a)|a#EQ#1: @FOR(s(z): LEIRawM(z,a) = QRawMP(z,a) - @SUM(n(v): NRawM(z,v)\*QCM(v,a)) + LEIRawM0(z)));

**! Components and Raw Materials Procurement Restrictions Constraints / Constraints 12A, 12B, 12C, 12D/;**

@FOR(m(a): @FOR(n(b): QCP(b,a) >= @IF(QCP(b,a) #GT# 0, LLQPC(b), 0)));

@FOR(m(a): @FOR(s(b): QRawMP(b,a) <= @IF(QRawMP(b,a) #GT# 0, LLQRawMP(b), 0)));

@FOR(m(a): @FOR(n(b): QCP(b,a) <= ULQPC(b)));

@FOR(m(a): @FOR(s(b): QRawMP(b,a) >= ULQRawMP(b)));

**! Return Rate Constraints / Constraint 13/;**

@FOR(m(a): @FOR(q(b): @FOR(c(x): QRP(b,x,a) = RORRP(b,x)\*D(b,a))));

**! Returns Ending Inventory Level Constraint / Constraint 14/;**

@FOR(m(a)|a#GT#1: @FOR(q(b): @FOR(c(x): LEIRP(b,x,a) = QRP(b,x,a) - QRPD(b,x,a) + LEIRP(b,x,a-1))));

@FOR(m(a)|a#EQ#1: @FOR(q(b): @FOR(c(x): LEIRP(b,x,a) = QRP(b,x,a) - QRPD(b,x,a) + LEIRP0(b,x))));

**! Dismantling Capacity Constraint / Constraint 15/;**

@FOR(m(a): @FOR(q(b): @SUM(c(x): QRPD(b,x,a)) <= ADisRP(b)));

**! Return Flow Balance Constraint / Constraint 16/;**

@FOR(m(a)|a#GT#1: @FOR(q(b): @FOR(c(x): LEIRP(b,x,a-1) + QRP(b,x,a) >= QRPD(b,x,a))));

@FOR(m(a)|a#EQ#1: @FOR(q(b): @FOR(c(x): LEIRP0(b,x)+ QRP(b,x,a) >= QRPD(b,x,a))));

**! Component Disposal Requirement Constraint / Constraint 17/;**

@FOR(m(a): @FOR(n(v): @FOR(c(x)|x#EQ#1: QRCD(v,x,a) >= @SUM(q(b):NUC(v,b)\*QRPD(b,x,a))\*RDRC(v,x))));

@FOR(m(a): @FOR(n(v): @FOR(c(x)|x#EQ#2: QRCD(v,x,a) >= @SUM(q(b):NUC(v,b)\*QRPD(b,x,a))\*RDRC(v,x))));

@FOR(m(a): @FOR(n(v): @FOR(c(x)|x#EQ#3: QRCD(v,x,a) >= @SUM(q(b):NUC(v,b)\*QRPD(b,x,a))\*RDRC(v,x))));

**! Remanufacturing Capacity Constraint / Constraint 18/;**

@FOR(m(a): @FOR(n(v): ARMC(v) >= @SUM(c(x):QCRM(v,x,a))));

**! Remanufacturing Flow Balance Constraint / Constraint 19/;**

@FOR(m(a): @FOR(n(v): @FOR(c(x): QCRM(v,x,a) = @SUM(q(b): QRPD(b,x,a)\*NUC(v,b)) - QRCD(v,x,a))));

**! Integer and Non-Negativity Constraints /Constraint 20/;**

@FOR(qm(z,a):@GIN(QTOPA(z,a)));

@FOR(qm(z,a):@GIN(QTTPA(z,a)));

@FOR(qm(z,a):@GIN(QPB(z,a)));

@FOR(qm(z,a):@GIN(LEIP(z,a)));

@FOR(nm(v,a):@GIN(LLEIC(v,a)));

@FOR(nm(v,a):@GIN(LIRMC(v,a)));

@FOR(nm(v,a):@GIN(QCM(v,a)));

@FOR(nm(v,a):@GIN(QCP(v,a)));

@FOR(sm(v,a):@GIN(LEIRawM(v,a)));

@FOR(sm(v,a):@GIN(QRawMP(v,a)));

@FOR(xcm(b,x,a):@GIN(QRP(b,x,a)));

@FOR(ncm(v,x,a):@GIN(QRCD(v,x,a)));

@FOR(ncm(v,x,a):@GIN(QCRM(v,x,a)));

@FOR(qqm(b,v,a):@GIN(QSP(b,v,a)));

@FOR(xcm(z,x,a):@GIN(LEIRP(z,x,a)));

@FOR(xcm(z,x,a):@GIN(QRPD(z,x,a)));

**Annexure 3**

Efficient Inventory and Production Decisions for the Sample Data of the I-OEM Used to Validate the Proposed INLP Model

Exhibit 1 – Efficient Costs, Revenue and Period Wise Local Optimal Quantities for the Multiple Engines at the Local Optimal Solution

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row Number** | **Multiple Engine Related Decision** | **Period Wise Local Optimal Quantities for the Engines** | | | | | | | | | | | | **Costs**  **(Rupees Million)** |
| **CNG Engine** | | | | **Diesel Engine** | | | | **Genset** | | | |
| **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| 1 | Quantity of Type-1 Engines to be Assembled | 1905 | 2000 | 1953 | 1884 | 3300 | 4201 | 4000 | 2930 | 3420 | 3280 | 2860 | 3790 | 37.019 |
| 2 | Quantity of Type-2 Engines to be Assembled | 95 | 0 | 47 | 116 | 1500 | 599 | 800 | 1870 | 0 | 0 | 0 | 0 | 5.291 |
| 3 | Ending Inventory Level for Engines | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0.000 |
| 4 | Quantity of Engines to be Backordered | 400 | 200 | 400 | 700 | 200 | 0 | 0 | 0 | 6980 | 7901 | 9041 | 9950 | 26.964 |
| 5 | Quantity of Engines to be Substituted | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 599 | 800 | 301 | 0.6443 |
| 6 | Total Quantity of Assembled Engines (computed) | 2000 | 2000 | 2000 | 2000 | 4800 | 4800 | 4800 | 4800 | 3420 | 3280 | 2860 | 3790 | -- |
| 7 | Total Excess Assembly Capacity (computed) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1380 | 1520 | 1940 | 1010 | -- |
|  | ***Total Cost Related to Engines at the Local Optimal Solution Obtained for the Company in the Planning Horizon*** | | | | | | | | | | | | | ***69.918*** |
|  | ***Total Quantity of Engine Sold in a Period at the Local Optimal Solution Obtained*** | | | | | | | | | | | | | **Total Revenue from Sales**  **(Rupees Million)** |
| 8 | Total units sold at a selling price  (Sales + Substituted sales) | 2000 | 2000 | 2000 | 2000 | 4800 | 4200 | 4000 | 4500 | 3420 | 3879 | 3660 | 4091 | **712.169** |

Exhibit 2 – Efficient Costs and Period Wise Local Optimal Quantities for the Multiple Engine-Returns at the Local Optimal Solution

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Row Number** | **Multiple Engine Return Relayed Decisions** | **Period Wise Local Optimal Quantities for the Engine-Returns** | | | | | | | | | | | | **Cost**  **(Rupees Million)** |
| **CNG Engine Returns** | | | | **Diesel Engine Returns** | | | | **Genset Returns** | | | |
| **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| 1 | Quantity of Commercial Engines Returned (acquired) | 0 | 0 | 0 | 0 | 500 | 400 | 400 | 450 | 1000 | 960 | 960 | 1000 | 45.569 |
| 2 | Quantity of Commercial Engines to be Dismantled | 0 | 0 | 0 | 0 | 500 | 400 | 400 | 450 | 1000 | 960 | 540 | 1420 | 0.576 |
| 3 | Ending Inventory Level for Commercial Engines | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 420 | 0 | 0.032 |
| 4 | Quantity of EOU Engines Returned (acquired) | 205 | 180 | 220 | 230 | 1000 | 800 | 800 | 900 | 1500 | 1440 | 1440 | 1500 | 41.506 |
| 5 | Quantity of EOU Engines to be Dismantled | 193 | 192 | 206 | 233 | 1000 | 714 | 886 | 900 | 1500 | 879 | 1996 | 1505 | 1.046 |
| 6 | Ending Inventory Level for EOU Engines | 12 | 0 | 14 | 11 | 0 | 86 | 0 | 0 | 0 | 561 | 5 | 0 | 0.042 |
| 7 | Quantity of EOL Engines Returned (acquired) | 1025 | 900 | 1100 | 1150 | 1500 | 1200 | 1200 | 1350 | 1000 | 960 | 960 | 1000 | 26.850 |
| 8 | Quantity of EOL Engines to be Dismantled | 716 | 1208 | 1101 | 1150 | 1053 | 1645 | 1201 | 1351 | 847 | 1521 | 824 | 435 | 1.403 |
| 9 | Ending Inventory Level for EOL Engines | 309 | 1 | 0 | 0 | 447 | 2 | 1 | 0 | 573 | 12 | 148 | 713 | 0.102 |
| 10 | Total Quantity of Return Engines Dismantled (computed) | 909 | 1400 | 1307 | 1383 | 2553 | 2759 | 2487 | 2701 | 3347 | 3360 | 3360 | 3360 | -- |
| 11 | Excess Dismantling Capacity Installed | 491 | 0 | 93 | 17 | 807 | 601 | 873 | 659 | 13 | 0 | 0 | 0 | -- |
|  | ***Total Cost Related to Engine-Returns at the Local Optimal Solution Obtained for the Company in the Planning Horizon*** | | | | | | | | | | | | | ***117.126*** |

Exhibit 3 –Efficient Quantities for the Various Components and Corresponding Costs in Each Period at the Local Optimal Solution

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Component Related Decisions** | **Planning Period** | **Local Optimal Quantities for a Components in a Period** | | | | | | | | | | | | | **Cost (Rupees Million)** |
| **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** | **C9** | **C10** | **C11** | **C12** | **C13** |
| Quantity of Components to be Manufactured | 1 | 3464 | 3475 | 7156 | 4205 | 0 | 0 | 4320 | 2320 | 0 | 0 | 0 | 0 | 0 | 10.196 |
| 2 | 4320 | 4320 | 6368 | 3616 | 0 | 0 | 4320 | 1961 | 0 | 0 | 0 | 0 | 340 | 10.738 |
| 3 | 4320 | 4320 | 5947 | 3441 | 0 | 0 | 4320 | 1813 | 0 | 0 | 0 | 0 | 190 | 10.527 |
| 4 | 4320 | 4320 | 7152 | 4110 | 0 | 0 | 4320 | 2529 | 0 | 0 | 418 | 0 | 1057 | 11.270 |
| Quantity of Components to be Purchased | 1 | 1728 | 1728 | 0 | 0 | 13960 | 81760 | 9640 | 0 | 6720 | 6720 | 1344 | 1905 | 1347 | 83.107 |
| 2 | 0 | 0 | 0 | 0 | 13680 | 80640 | 9360 | 0 | 6720 | 6720 | 1344 | 1904 | 0 | 75.366 |
| 3 | 0 | 0 | 0 | 0 | 12853 | 77280 | 8533 | 0 | 6720 | 6720 | 1344 | 1903 | 0 | 71.869 |
| 4 | 0 | 0 | 0 | 0 | 14700 | 84720 | 10380 | 0 | 6720 | 6720 | 1344 | 1884 | 0 | 79.646 |
| Quantity of Components to be Remanufactured from Commercial Returns | 1 | 1350 | 1350 | 3000 | 1500 | 2400 | 0 | 2400 | 1500 | 1500 | 1500 | 0 | 0 | 1000 | 1.193 |
| 2 | 1224 | 1223 | 2720 | 1360 | 2176 | 0 | 2176 | 1360 | 1360 | 1360 | 0 | 0 | 960 | 1.083 |
| 3 | 846 | 840 | 1880 | 940 | 1504 | 0 | 1504 | 940 | 940 | 940 | 0 | 0 | 540 | 0.745 |
| 4 | 1683 | 1683 | 3740 | 1870 | 2992 | 0 | 2992 | 1870 | 1870 | 1870 | 0 | 0 | 1420 | 1.491 |
| Quantity of Components to be Disposed from Commercial Returns | 1 | 150 | 150 | 0 | 0 | 600 | 12000 | 600 | 0 | 0 | 0 | 0 | 0 | 0 | 0.492 |
| 2 | 136 | 137 | 0 | 0 | 544 | 10880 | 544 | 0 | 0 | 0 | 0 | 0 | 0 | 0.446 |
| 3 | 94 | 100 | 0 | 0 | 376 | 7520 | 376 | 0 | 0 | 0 | 0 | 0 | 0 | 0.309 |
| 4 | 187 | 187 | 0 | 0 | 748 | 14960 | 748 | 0 | 0 | 0 | 0 | 0 | 0 | 0.613 |
| Quantity of Components to be Remanufactured from EOU Returns | 1 | 2154 | 2154 | 4673 | 2423 | 2693 | 0 | 2693 | 2500 | 0 | 0 | 0 | 95 | 1693 | 2.161 |
| 2 | 1428 | 1428 | 3040 | 1606 | 1785 | 0 | 1785 | 1593 | 0 | 0 | 0 | 96 | 1071 | 1.425 |
| 3 | 2470 | 2470 | 5373 | 2779 | 3088 | 0 | 3088 | 2882 | 0 | 0 | 47 | 97 | 2202 | 2.491 |
| 4 | 2110 | 2109 | 4538 | 2374 | 2638 | 0 | 2638 | 2405 | 0 | 0 | 233 | 116 | 1738 | 2.133 |
| Quantity of Components to be Disposed from EOU Returns | 1 | 539 | 539 | 520 | 270 | 2693 | 21544 | 2693 | 0 | 2500 | 2500 | 193 | 98 | 0 | 1.560 |
| 2 | 357 | 357 | 338 | 179 | 1785 | 14280 | 1785 | 0 | 1593 | 1593 | 192 | 96 | 0 | 1.031 |
| 3 | 618 | 618 | 597 | 309 | 3088 | 24704 | 3088 | 0 | 2882 | 2882 | 159 | 109 | 0 | 1.788 |
| 4 | 528 | 529 | 505 | 264 | 2638 | 21104 | 2638 | 0 | 2405 | 2405 | 0 | 117 | 0 | 1.514 |

|  |  |
| --- | --- |
| Component Index | C1- Cylinder Block; C2- Cylinder Head; C3- Crankshaft; C4- Camshaft; C5- Pistons; C6- Engine Valves; C7- Connecting rod; C8- Fuel injector pump; C9- Water filter; C10- Oil filter; C11- Distributor; C12- Throttling valve; C13- Compressor |

Exhibit 3 –Efficient Quantities for the Various Components and Corresponding Costs in Each Period at the Local Optimal Solution (Continued)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Component Related Decisions** | **Planning Period** | **Local Optimal Quantities for a Component in a Period** | | | | | | | | | | | | | **Cost (Rupees Million)** |
| **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** | **C8** | **C9** | **C10** | **C11** | **C12** | **C13** |
| Quantity of Components to be Remanufactured from EOL Returns | 1 | 1830 | 1828 | 3611 | 2092 | 1387 | 0 | 1387 | 1900 | 0 | 0 | 713 | 0 | 1563 | 2.178 |
| 2 | 3060 | 3061 | 6032 | 3498 | 2519 | 0 | 2519 | 3166 | 0 | 0 | 1208 | 0 | 2729 | 3.711 |
| 3 | 2188 | 2188 | 4120 | 2500 | 1875 | 0 | 1875 | 2025 | 0 | 0 | 0 | 0 | 1925 | 2.551 |
| 4 | 2055 | 2053 | 3750 | 2236 | 850 | 0 | 850 | 1786 | 0 | 0 | 5 | 0 | 1575 | 2.063 |
| Quantity of Components to be Disposed from EOL Returns | 1 | 786 | 788 | 905 | 524 | 3845 | 20928 | 3845 | 0 | 1900 | 1900 | 3 | 716 | 0 | 1.764 |
| 2 | 1314 | 1313 | 1508 | 876 | 6229 | 34992 | 6229 | 0 | 3166 | 3166 | 0 | 1208 | 0 | 2.915 |
| 3 | 938 | 938 | 1031 | 626 | 4377 | 25008 | 4377 | 0 | 2025 | 2025 | 1101 | 1101 | 0 | 2.106 |
| 4 | 881 | 883 | 972 | 700 | 5022 | 23488 | 5022 | 0 | 1786 | 1786 | 1145 | 1150 | 10 | 2.127 |
| Total Quantity of Components to be Remanufactured (computed) | 1 | 5334 | 5332 | 11284 | 6015 | 6480 | 0 | 6480 | 5900 | 1500 | 1500 | 713 | 95 | 4256 | -- |
| 2 | 5712 | 5712 | 11792 | 6464 | 6480 | 0 | 6480 | 6119 | 1360 | 1360 | 1208 | 96 | 4760 | -- |
| 3 | 5504 | 5498 | 11373 | 6219 | 6467 | 0 | 6467 | 5847 | 940 | 940 | 47 | 97 | 4667 | -- |
| 4 | 5848 | 5845 | 12028 | 6480 | 6480 | 0 | 6480 | 6061 | 1870 | 1870 | 238 | 116 | 4733 | -- |
| Available Remanufacturing Capacity  (for all periods) | | 6480 | 6480 | 12960 | 6480 | 6480 | 0 | 6480 | 7200 | 6480 | 6480 | 5040 | 6480 | 5040 | **--** |
| Inventory of Remanufactured Components | 1 | 3739 | 3737 | 8189 | 4420 | 3290 | 0 | 3290 | 4400 | 0 | 0 | 618 | 0 | 4161 | -- |
| 2 | 5113 | 5113 | 10594 | 5865 | 5282 | 0 | 5282 | 5520 | 761 | 761 | 1208 | 96 | 4760 | -- |
| 3 | 4657 | 4651 | 9726 | 5372 | 4773 | 0 | 4773 | 5047 | 140 | 140 | 0 | 50 | 4620 | -- |
| 4 | 3862 | 3859 | 8172 | 4494 | 2508 | 0 | 2508 | 4191 | 0 | 0 | 122 | 0 | 4617 | -- |
| Ending Inventory Level for Component | 1 | 306 | 315 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 57 | 0 | 183 | 0.075 |
| 2 | 258 | 267 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 609 | 0 | 3 | 0.168 |
| 3 | 422 | 425 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.074 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 |
| ***Total Cost for Component Related Decisions at the Local Optimal Solution Obtained for the Company in the Planning Horizon*** | | | | | | | | | | | | | | | ***392.895*** |

|  |  |
| --- | --- |
| Component Index | C1- Cylinder Block; C2- Cylinder Head; C3- Crankshaft; C4- Camshaft; C5- Pistons; C6- Engine Valves; C7- Connecting rod; C8- Fuel injector pump; C9- Water filter; C10- Oil filter; C11- Distributor; C12- Throttling valve; C13- Compressor |

Exhibit 4 –Efficient Quantities for the Omnifarious Raw Materials and the Corresponding Costs in Each Period at the Local Optimal Solution

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Raw Material Related Decisions** | **Planning Period** | **Planning Period Wise Local Optimal Values for Raw Materials** | | | | | | | | | | | | | **Cost**  **(Rupees Million)** |
| **RM1** | **RM2** | **RM3** | **RM4** | **RM5** | **RM6** | **RM7** | **RM8** | **RM9** | **RM10** | **RM11** | **RM12** | **RM13** |
| Quantity of Raw Materials to be Purchased | 1 | 3464 | 3475 | 4320 | 7156 | 4205 | 4281 | 0 | 468 | 0 | 34325 | 45240 | 4281 | 336 | 3.513 |
| 2 | 4320 | 4320 | 4320 | 6368 | 3616 | 0 | 0 | 0 | 2120 | 0 | 45888 | 0 | 358 | 2.985 |
| 3 | 4320 | 4320 | 4320 | 5947 | 3441 | 1813 | 0 | 0 | 0 | 16662 | 44696 | 1813 | 367 | 3.212 |
| 4 | 4320 | 4320 | 4320 | 7152 | 4110 | 2529 | 418 | 1057 | 5482 | 18314 | 48444 | 2529 | 2113 | 3.655 |
| Ending Inventory Level of Raw Material | 1 | 0 | 0 | 0 | 0 | 0 | 1961 | 0 | 530 | 0 | 17360 | 0 | 1961 | 336 | 0.155 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 190 | 760 | 118 | 0 | 0 | 14 | 0.008 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.004 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 |
| ***Total Cost Related to Raw Materials at the Local Optimal Solution Obtained for the Company in the Planning Horizon*** | | | | | | | | | | | | | | | ***13.532*** |

|  |  |
| --- | --- |
| **Raw Materials Index** | RM1- Cylinder block casting; RM2- Cylinder head casting; RM3- Connecting rod casting; RM4- Crankshaft casting;  RM5- Camshaft casting; RM6- Fuel injector pump; RM7- Distributor actuator; RM8- Compressor motor;  RM9- Fasteners; RM10- Cleaning solution; RM11- Coolant; RM12- Fuel injector pump; RM13- Compressor housing |