Chapter 8

Performance Measurement Framework for Reverse Supply Chain (Maintenance Management)

The previous Chapter demonstrates integration of Analytic Hierarchy Process (AHP) with modified BSC to facilitate effective Green SCPMS. This Chapter demonstrates use of DEA for Maintenance Performance Measurement to facilitate measurement of relative efficiencies, define targets and benchmarking of similar Maintenance Units.

8.0 INTRODUCTION

Reverse logistics or reverse SC has become a field of importance for enterprises due to increasing environmental concerns, legislation, extended producer responsibility and stakeholder demands (Agrawal, Singh, & Murtaza, 2015). Reverse SC involves activities related to collection, repair, reuse, recycle and disposal of product from the customers. Repair activities and maintenance management is an important component in reverse SCs. The customer satisfaction as well as customer retention largely depends on the performance of 'After Sales Maintenance and Service' component of the SC. Effective Performance Measurement System (PMS) serve as an indicator of how well the system is functioning. Measuring maintenance performance can facilitate a greater understanding of the system, monitor and improve its overall performance (Charan et al., 2008).

The present Chapter examines the performance measurement factors relating maintenance units in SC and proposing a method for bench marking of maintenance aspects in SC with DEA. Examination of matrices to carry out maintenance performance measurement has been done in the present study. This study selected the automobile industry and maintenance aspects thus considered are more specific to an automobile servicing and maintenance unit though the principles can be applied to similar SCs with minor adaptations. This Chapter is organised into the following sections: i. Reverse SC; ii. .Measurement of Maintenance Performance; iii. Demonstration of using DEA for benchmarking Maintenance Performance in SC.

8.1 Reverse SC

The idea and practice of reverse SC dates to the origin of SC management. Different perspectives of reverse logistics are seen in the literature. Bansia, Varkey, & Agrawal (2014) identifies the key processes of reverse SC as product acquisition, collection, inspection/sorting and disposition. Product acquisition involves collection or receipt of used or repairable products from customers and this is a very uncertain activity since the enterprise no more have control over the product once it is delivered to the end user. Products after acquisition are then inspected and sorted for appropriate disposal. Product returns may be commercial returns, service returns, distribution returns or end of life returns. In general, a separate inspection of each item is required for sorting the products. After the products are inspected, appropriate disposal decision is taken for further processing. The disposition alternatives could be product reuse through repair and reclamation, remanufacturing or recycle (Bansia et al., 2014). There are many models of reverse logistics such as third party outsourced model, collection by retailor model, rent/replacement model etc. A basic flow diagram for a reverse SC is given at Figure 8.1.

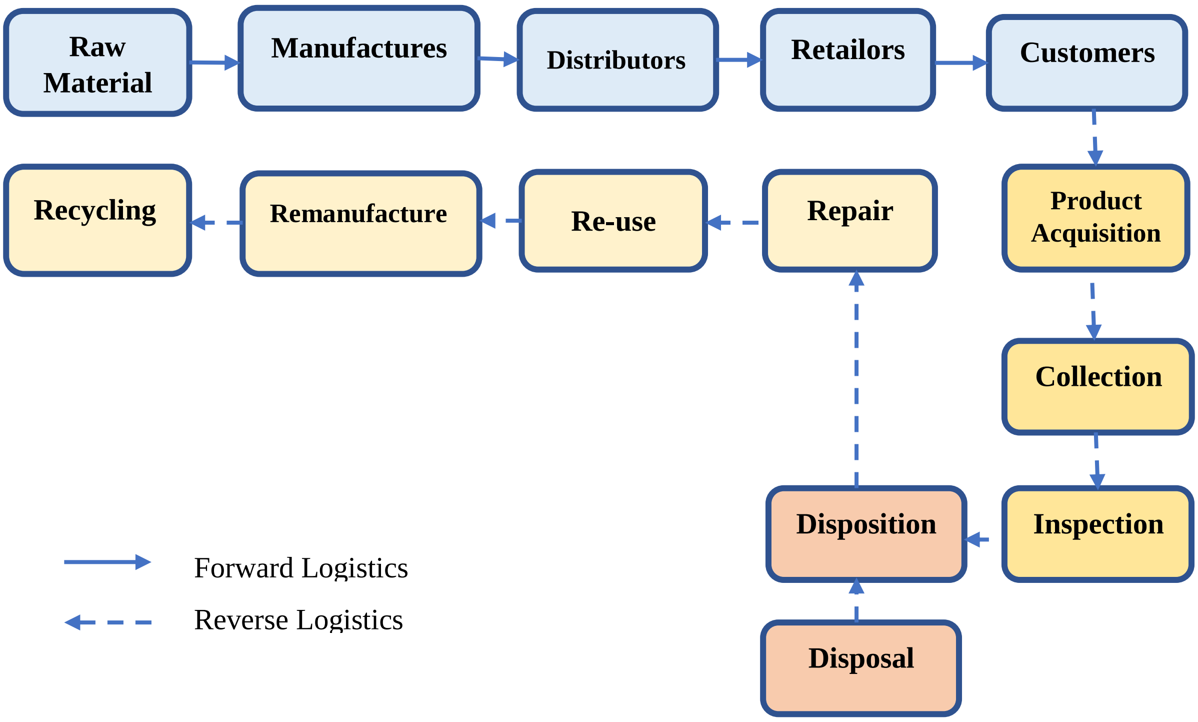

Figure 8.1 Reverse Supply Chain Flow Diagram (Agrawal et al., 2015)

8.2 Measurement of Maintenance Performance

Like other SC functions, performance measurement is important in managing the maintenance function. Many approaches for measuring maintenance performance are seen in literature since 1990s. The different categories of measures show different areas of interest in maintenance performance in both literature and practice.

Many of the literature studied proposes lists of Key Performance Indicators (KPI) but lacks a methodological approach of selecting or deriving them. As a result, users are left to decide the relevant KPI's for their situation. Further, an operational level-based maintenance measurement model that links maintenance objectives to maintenance process and results is also lacking (Muchiri, Pintelon, Gelders, & Martin, 2010). A summary of Maintenance Performance Measures observed from literature is given at Table. 8.1.

Table 8.1 Summary of Maintenance Performance Systems (Muchiri et al., 2010)

Maintenance Performance Systems	Proposed By
"Audit approach and value-based measurement"	Dwight (1999)
"Aggregated measures like maintenance productivity index"	Löfsten (2000)
"Strategic approach of managing maintenance performance"	Tsang (1998)
"Key Performance Indicator (KPI) for managing the maintenance function"	Weber & Thomas (2006) as cited by Muchiri et al. (2010)
"Measuring the impact of maintenance on business's objectives"	Al-Najjar (2007)

8.3 Performance Measures for After – Sales Service and Maintenance Unit

The Maintenance Unit under study is a typical authorised service station cum workshop of the OEM (say an automobile manufacturer). The services provided by the Unit includes preparation and inspection of the equipment (say vehicle) before sales, provide free scheduled preventive maintenance, warranty repairs, paid preventive maintenance, breakdown repairs, inspections to assess damage and estimate cost of restoration, onsite repairs by mobile repair team and defect analysis for future design improvements. The procedure for undertaking work involves the following sequence of actions:

1. In- inspection to assess defects and estimate costs
2. Preparation of job card
3. Allocation of resources (mechanic, ancillary facility, garage space, spare parts, lubricant, test equipment etc)
4. Cleaning /washing of the equipment
5. Repair/ Replace parts/ Adjust/ Calibrate/ Test
6. Servicing/ lubricating
7. Final inspection and testing
8. Cleaning
9. Delivery to customer

Various resources are necessary to provide effective maintenance support. These resources are considered as the inputs to the system. The inputs or the resources utilised for providing the maintenance services are:

1. Trained Manpower
2. Spare Parts
3. Tools
4. Test equipment
5. Technical literature (workshop manual, circuit diagram etc)
6. Ancillary Facilities (welding, painting, upholstery etc)
7. Infrastructure (garage space, water supply, power, air conditioning etc)
8. Administrative support

Literature indicate many attributes as indicators of maintenance performance measure (Manzini, 2010; Muchiri et al., 2010; Parida & Kumar, 2006; Simões, Gomes, & Yasin, 2011). The performance measures considered for this study are listed below:

1. Mean Time Between Failures (MTBF)
2. Mean Time to Repair (MTTR)
3. Equipment Availability
4. Jobs done per day

5. Percentage of income from return customers

MTBF is the calculated elapsed time between natural failures of a system during employment (Misra, 2008). MTBF can be calculated as the arithmetic mean (average) time between failures of a system. The MTBF is typically part of a model that assumes the failed system is immediately repaired as a part of a renewal process. MTBF provides a measure of quality of maintenance and reliability.

$$MTBF = \frac{\sum (Start\ of\ Down\,time - Start\ of\ Up\,time)}{Number\ of\ Failures} \tag{8.1}$$

MTTR gives a measure of efficiency of the repair procedures and related to customer waiting time. MTTR is calculated as mean of the active time required for repair of a system/ equipment (Misra, 2008). It does not include waiting time.

$$MTTR = \frac{Total\ Ma\mathrm{int}\,tnence\,Time}{Number\ of\ \mathrm{Re}\ pairs} \tag{8.2}$$

“Availability is the probability that an item, under the combined influence of its reliability, maintainability and maintenance support will be able to fulfil its required function over a stated period of time” (Barabady & Kumar, 2007)(Srivastava, 2010). Availability can be calculated as a function of MTTR and MTBF as under:

$$Availability = \frac{MTBF}{(MTTR + MTBF)} \tag{8.3}$$

Jobs done per day gives mean normative output of the equipment repaired per day. Percentage of income from return customers is a measure of customer satisfaction and quality of maintenance done. The summary of the performance parameters discussed is given at Figure. 8.2.

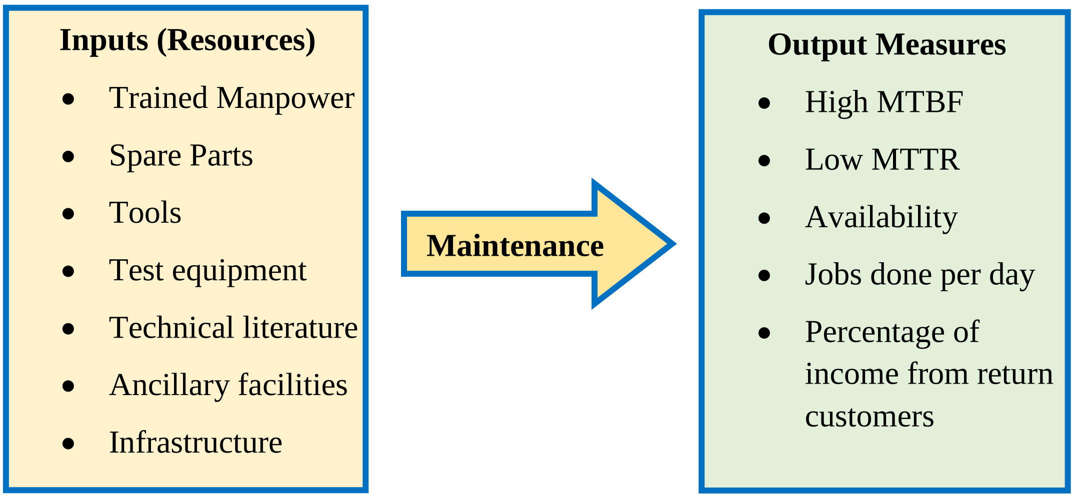

Figure 8.2 Maintenance Performance Parameters

8.4 DEA For Maintenance Performance Measurement

DEA is a nonparametric method used for the estimation of efficiency frontiers. It has been extensively applied in performance evaluation and benchmarking (K.-H. Lee & Saen, 2012; Madu & Kuei, 1998; Shetty & Pakkala, 2010; Talluri, 2000; Wong & Wong, 2007). A brief discourse on DEA is presented at Chapter 5 (Sections 5.3 and 5.4).

In DEA, efficiency is defined as:

$$Efficiency = \frac{Weighted\ sum\ of\ outputs}{Weighted\ sum\ of\ inputs} \tag{8.4}$$

The weights attached to each input and output is not specified a priori. Instead they are computed to show each unit under comparison in its most favourable light. The envelope, or frontier, becomes the surface linking all units whose relative efficiency cannot be exceeded. By definition, units on that surface are then assigned 100 percent efficiency. The best possible efficiency for other units in the sample then brings them as close as possible to the envelope. The efficiency score computed by DEA is a numerical value that describes a system's relative efficiency in terms of its inputs and outputs (Cook & Seiford, 2008; Talluri, 2000).

If there are 'n' DMUs, each with 'm' inputs and 's' outputs, the relative efficiency score of a test DMU is obtained by solving the following model (Talluri, 2000).

$$Max\left(\frac{\sum_{k=1}^{s} v_k \; y_{kp}}{\sum_{j=1}^{m} u_j x_{jp}}\right) \tag{8.5}$$

Subjected to,

$$\begin{aligned}&\left(\frac{\sum_{k=1}^{s} v_k \; y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}}\right) \leq 1 \quad \forall i \\ &v_k, u_j \geq 0 \quad \forall j, k\end{aligned} \tag{8.6}$$

Where:

k = 1 to s; j= 1 to m; I = 1 to n

y_{ki} = Amount of output 'k' produced by DMU 'i'

x_{ji} = Amount of input 'j' used by DMU 'i'

v_k = Weight given to output 'k'

u_j = Weight given to input 'j'

The fractional program shown as above at Eq. 8.6 can be converted to a linear program for ease of solving as an LPP. The linear formulation of the DEA problem is given as follows:

$$\begin{aligned}&Max\left(\sum_{k=1}^{s} v_k \; y_{kp}\right) \\ &s.t. \;\; \sum_{j=1}^{m} u_j \; x_{jp} = 1 \\ &\qquad \left(\sum_{k=1}^{s} v_k \; y_{ki} - \sum_{j=1}^{m} u_j \; x_{ji}\right) \leq 0 \quad \forall i \\ &\qquad v_k, u_j \geq 0 \quad \forall j, k\end{aligned} \tag{8.7}$$

The above problem is run 'n' times (one run per DMU) to calculate the relative efficiency scores of the DMUs. A DMU is considered to be efficient if it obtains a score of 1 and a score of less than 1 implies that it is inefficient. Each DMU selects input and output weights that maximise its efficiency score. So, the ‘v_k’ and ‘u_k’ values gives output and input weightages corresponding to max relative efficiency possible for the DMU considered.

8.4.1 Benchmarking in DEA

For every inefficient DMU, DEA identifies a set of corresponding efficient units that can be utilised as benchmarks for improvement. The benchmarks can be obtained from the dual of the DEA LPP formulation given above. Formulation of the dual on the LPP given at Eq. 8.7 is as under:

Min E

Subjected to:

$$\sum_{i=1}^{n} \lambda_i y_{ki} \geq y_{kp} \quad \forall j$$
$$\sum_{i=1}^{n} \lambda_i x_{ki} \leq E.x_{kp} \quad \forall k$$
$$\lambda \geq 0 \quad \forall i \tag{8.8}$$

Where:

E = Efficiency score, and λ_i = Dual variable

These dual variables (λ_i) can be used to construct an Efficient Hypothetical Composite Unit (HCU). HCU can be used to measure excess use of inputs and potential increase in outputs.

There are two basic DEA orientation models; viz. input reduction and output augmentation (Cooper, Seiford, & Tone, 2015). The former, also known as input-oriented model emphasises how to use minimum input resources to achieve a given level of output. The latter, known as output-oriented model, focuses on using a given level of input to achieve the maximum possible output. The DEA formulation and the set of linear programming equations are placed at annexure to this chapter as Annexure 8.1.

8.5 Demonstration of Using DEA for Maintenance Performance Measurement and Benchmarking

A simplified and generic model has been considered for present study of Maintenance Performance Management. The maintenance model is shown at Figure 8.3.

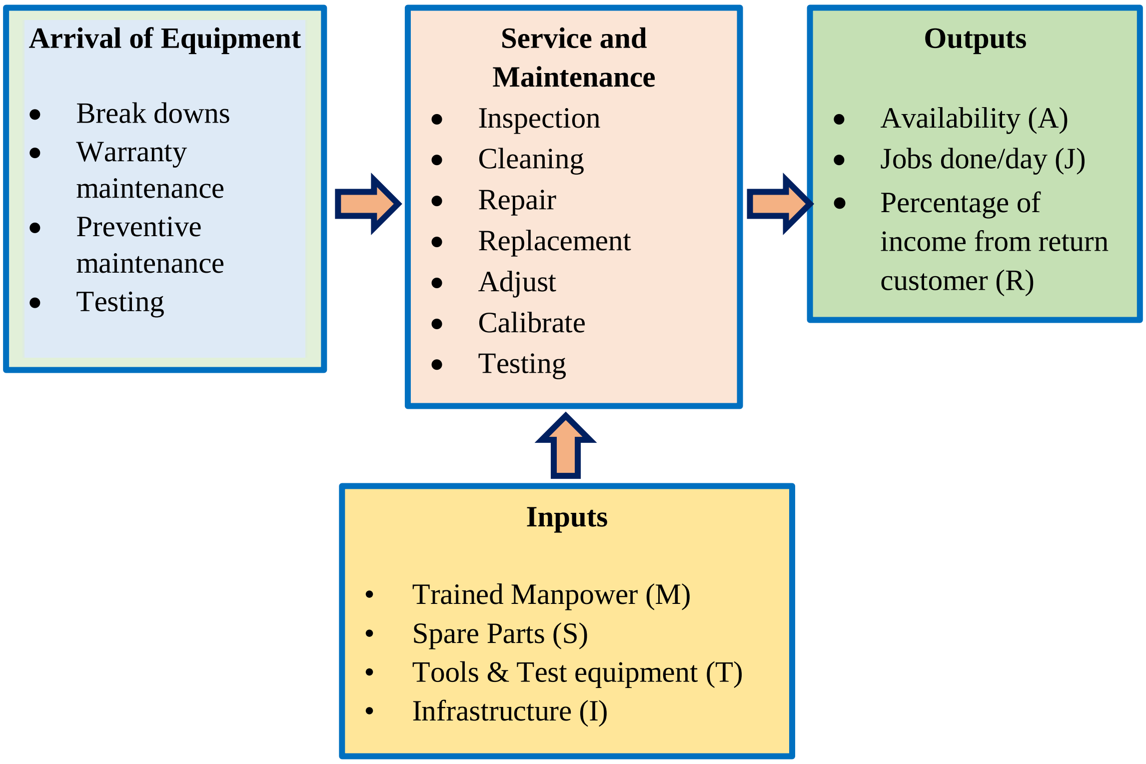

Figure 8.3 Maintenance Model

DEA is effective when organisations operating under similar conditions are compared. SCs with similar processes and features can only be compared to establish benchmarking. In the current case four input parameters (Trained Manpower (M), Spare Parts (S), Tools & Test equipment (T) and Infrastructure (I)) and two output parameters (Availability (A), Jobs done per day (J), and Percentage of income from return customers (R)) are considered. Six similar Service and Maintenance Units (MU1, MU2, … MU6) are considered in the present study.

8.5.1 Data set

The data set for the six different Service and Maintenance Units is given at Table 8.2. The DEA model is solved using the *DEA Fronti*er which is a Microsoft Excel Add-in developed by Joe Zhu (J. Zhu, n.d.). The DEA model is solved as '*Input-Oriented'* and '*Constant Return to Scale (CRS)'*

Table 8.2 Data Set of Input and Output Values of DMUs under consideration

MAINTENANCE UNIT (DMU)	TRAINED MANPOWER (M)	SPARE PARTS (S) (RS IN	TOOLS & TEST EQUIPMENT	INFRASTRUCTURE(I) (RELATIVE	AVAILABILITY (A)	JOBS DONE PER DAY (J) (NOS)	INCOME FROM RETURN CUST (R) %
	Input	Input	Input	Input	Output	Output	Output
MU-1	78	1.75	1.75	1.80	0.93	43	48
MU-2	77	1.75	1.33	0.92	0.77	31	47
MU-3	63	0.85	0.95	0.88	0.91	32	53
MU-4	73	1.12	1.53	0.85	0.95	43	46
MU-5	60	0.75	1.12	1.80	0.90	45	48
MU-6	71	1.85	1.51	0.78	0.79	30	37

8.5.2 Efficiency score

DEA calculates relative efficiencies of Maintenance Units (DMUs) based on the four inputs and three output parameters. The efficiency Score of SCs evaluated is given at Table 8.3. The relative efficiencies indicate that MU-3, MU-4 and MU-5 are relatively efficient whereas there is scope for improvement in case of MU-1, MU-5 and MU-6 with MU-1 as the least efficient.

Table 8.3 Relative Efficiency Score

Maintenance Unit (DMU)	Relative Efficiency (Input oriented CRS Efficiency)
MU-1	0.82339
MU-2	0.86438
MU-3	1.00000
MU-4	1.00000
MU-5	1.00000
MU-6	0.90621

The optimal 'Lamdas' with benchmarks is given at Table 8.4. The result indicates the corresponding efficient units which are related to the inefficient DMUs; MU-1, MU-2 and MU-6. Therefore, it can be noted that for MU-1; the benchmarking Units is MU-3 (being higher Lambda value)

Table 8.4 Optimal Lambda Values

DMU NAME	CRS EFFICIENCY	SUM OF LAMDAS	OPTIMAL LAMDAS WITH BENCH MARKS		
MU-1	0.82339	1.021	0.199 MU-3	0.182 MU-4	0.64 MU-5
MU-2	0.86438	0.910	0.737 MU-3	0.172 MU-4	
MU-3	1.00000	1.000	1.000 MU-3		
MU-4	1.00000	1.000	1.000 MU-4		
MU-5	1.00000	1.000	1.000 MU-5		
MU-6	0.90621	0.832	0.832 MU-4		

8.5.3 Improvements possible

Based on relative efficiencies and the weights improvements possible at each of the input parameters and output parameters are obtained. The results are tabulated at Table 8.5 as target inputs and outputs.

Table 8.5 Target Inputs and Outputs

MAINTENANCE UNIT (DMU)	TRAINED MANPOWER (M)	SPARE PARTS (S) (RS IN LAKHS)	TOOLS & TEST EQUIPMENT (T)	INFRASTRUCTURE (I) (RELATIVE VALUE)	AVAILABILITY (A)	JOBS DONE PER DAY (J) (NOS)	INCOME FROM RETURN CUST (R) %
	Target Input				Target Output		
MU-1	64.22	0.85	1.18	1.48	0.93	43.00	49.64
MU-2	59.02	0.82	0.96	0.80	0.83	31.00	47.00
MU-3	63.00	0.85	0.95	0.88	0.91	32.00	53.00
MU-4	73.00	1.12	1.53	0.85	0.95	43.00	46.00
MU-5	60.00	0.75	1.12	1.80	0.90	45.00	48.00
MU-6	60.71	0.93	1.27	0.71	0.79	35.76	38.25

The results indicate, for inefficient Maintenance Units, the ideal combination of inputs and outputs possible. For example, for MU-1 the number of trained manpower can be reduced from 78 to 64; Spare Parts expenditure from 1.75 Lakhs to 0.85 Lakhs; Tools & Test Eqpt expenditure from 1.75 Lakhs to 1.18 Lakh and so on. The output of MU–1 can be increased to: Availability - 0.93; Jobs done per day - 43 and income from return customers - 49.64%. No improvements are possible for the efficient Maintenance Units.

8.6 Results and Discussion

Maintenance Performance Measurement is a significant parameter in SCM in today's dynamic and competitive environment. Measuring Maintenance Performance is necessary to monitor, control and improve overall SC effectiveness and customer satisfaction especially in an after sales service and maintenance unit. An input oriented, constant return to scale DEA model has been formulated to evaluate and benchmark six competing and similar Maintenance Units.

DEA is a suitable tool for evaluating relative efficiencies of similar organisation. An attempt has been made to use DEA for benchmarking Maintenance Performance of after sales Service and Maintenance Units in SCs. The procedure has been demonstrated with a sample case of six similar Maintenance Units. The demonstration shows how DEA can be used for benchmarking and evaluating possible improvements in inefficient SCs. DEA results provide management with improvement potentials, targets, and peer DMUs. Hence, DEA is a detailed steering and controlling tool to specify possible changes in structure and resource allocation.

The limitation of the methodology is that, it can be employed only for SCs with similar processes. DEA is primarily a diagnostic tool and does not prescribe any reengineering strategies to make inefficient units efficient (Talluri, 2000). Such improvement strategies must be studied and implemented by managers by understanding the operations of the efficient units. Also, further study is required to validate that the sufficiency of inputs selected, appropriate for the selected outputs and establish correlations.

Annexure 8.1

DEA FORMULATION FOR MAINTENANANCE PERFORMANCE

E = Efficiency score of DMU under evaluation and

λ_{ij} = Dual variable corresponding to the efficient hypothetical composite unit (HCU).

For Maintenance Unit-1 (1st DMU), the LPP formulation:

Min E

s.t.

$78\lambda_{11} + 77\lambda_{12} + 63\lambda_{13} + 73\lambda_{14} + 60\lambda_{15} + 70\lambda_{16} \geq 78$ (i)

$1.75\lambda_{21} + 1.75\lambda_{22} + .85\lambda_{23} + 1.12\lambda_{24} + .75\lambda_{25} + 1.85\lambda_{26} \geq 1.75$ (ii)

$1.75\lambda_{31} + 1.33\lambda_{32} + .95\lambda_{33} + 1.53\lambda_{34} + 1.12\lambda_{35} + 1.51\lambda_{36} \geq 1.75$ (iii)

$1.8\lambda_{41} + .92\lambda_{42} + .88\lambda_{43} + 0.85\lambda_{44} + 1.8\lambda_{45} + 0.78\lambda_{46} \geq 1.80$ (iv)

$0.93\lambda_{51} + .77\lambda_{52} + .91\lambda_{53} + .95\lambda_{54} + .9\lambda_{55} + 0.79\lambda_{56} \leq 0.93E$ (v)

$43\lambda_{61} + 31\lambda_{62} + 32\lambda_{63} + 43\lambda_{64} + 45\lambda_{65} + 30\lambda_{66} \leq 43E$ (vi)

$48\lambda_{71} + 47\lambda_{72} + 53\lambda_{73} + 46\lambda_{74} + 48\lambda_{75} + 37\lambda_{76} \leq 48E$ (vii)

For Maintenance Unit-2 (2nd DMU), the LPP formulation:

Min E

s.t.

$78\lambda_{11} + 77\lambda_{12} + 63\lambda_{13} + 73\lambda_{14} + 60\lambda_{15} + 70\lambda_{16} \geq 77$ (viii)

$1.75\lambda_{21} + 1.75\lambda_{22} + .85\lambda_{23} + 1.12\lambda_{24} + .75\lambda_{25} + 1.85\lambda_{26} \geq 1.75$ (ix)

$1.75\lambda_{31} + 1.33\lambda_{32} + .95\lambda_{33} + 1.53\lambda_{34} + 1.12\lambda_{35} + 1.51\lambda_{36} \geq 1.33$ (x)

$1.8\lambda_{41} + .92\lambda_{42} + .88\lambda_{43} + 0.85\lambda_{44} + 1.8\lambda_{45} + 0.78\lambda_{46} \geq 0.92$ (xi)

$0.93\lambda_{51} + .77\lambda_{52} + .91\lambda_{53} + .95\lambda_{54} + .9\lambda_{55} + 0.79\lambda_{56} \leq 0.77E$ (xii)

$43\lambda_{61} + 31\lambda_{62} + 32\lambda_{63} + 43\lambda_{64} + 45\lambda_{65} + 30\lambda_{66} \leq 31E$ (xiii)

$48\lambda_{71} + 47\lambda_{72} + 53\lambda_{73} + 46\lambda_{74} + 48\lambda_{75} + 37\lambda_{76} \leq 47E$ (xiv)

For Maintenance Unit-3 (3rd DMU), the LPP formulation:

Min E

s.t.

$78\lambda_{11} + 77\lambda_{12} + 63\lambda_{13} + 73\lambda_{14} + 60\lambda_{15} + 70\lambda_{16} \geq 63$ (xv)

$1.75\lambda_{21} + 1.75\lambda_{22} + .85\lambda_{23} + 1.12\lambda_{24} + .75\lambda_{25} + 1.85\lambda_{26} \geq 0.85$ (xvi)

$1.75\lambda_{31} + 1.33\lambda_{32} + .95\lambda_{33} + 1.53\lambda_{34} + 1.12\lambda_{35} + 1.51\lambda_{36} \geq 0.95$ (xvii)

$1.8\lambda_{41} + .92\lambda_{42} + .88\lambda_{43} + 0.85\lambda_{44} + 1.8\lambda_{45} + 0.78\lambda_{46} \geq 0.88$ (xviii)

$0.93\lambda_{51} + .77\lambda_{52} + .91\lambda_{53} + .95\lambda_{54} + .9\lambda_{55} + 0.79\lambda_{56} \leq 0.91E$ (xix)

$43\lambda_{61} + 31\lambda_{62} + 32\lambda_{63} + 43\lambda_{64} + 45\lambda_{65} + 30\lambda_{66} \leq 32E$ (xx)

$48\lambda_{71} + 47\lambda_{72} + 53\lambda_{73} + 46\lambda_{74} + 48\lambda_{75} + 37\lambda_{76} \leq 53E$ (xxi)

For Maintenance Unit-4 (4th DMU), the LPP formulation:

Min E

s.t.

$78\lambda_{11} + 77\lambda_{12} + 63\lambda_{13} + 73\lambda_{14} + 60\lambda_{15} + 70\lambda_{16} \geq 73$ (xxii)

$1.75\lambda_{21} + 1.75\lambda_{22} + .85\lambda_{23} + 1.12\lambda_{24} + .75\lambda_{25} + 1.85\lambda_{26} \geq 1.12$ (xxiii)

$1.75\lambda_{31} + 1.33\lambda_{32} + .95\lambda_{33} + 1.53\lambda_{34} + 1.12\lambda_{35} + 1.51\lambda_{36} \geq 1.53$ (xxiv)

$1.8\lambda_{41} + .92\lambda_{42} + .88\lambda_{43} + 0.85\lambda_{44} + 1.8\lambda_{45} + 0.78\lambda_{46} \geq 0.85$ (xxv)

$0.93\lambda_{51} + .77\lambda_{52} + .91\lambda_{53} + .95\lambda_{54} + .9\lambda_{55} + 0.79\lambda_{56} \leq 0.95E$ (xxvi)

$43\lambda_{61} + 31\lambda_{62} + 32\lambda_{63} + 43\lambda_{64} + 45\lambda_{65} + 30\lambda_{66} \leq 43E$ (xxvii)

$48\lambda_{71} + 47\lambda_{72} + 53\lambda_{73} + 46\lambda_{74} + 48\lambda_{75} + 37\lambda_{76} \leq 46E$ (xxviii)

For Maintenance Unit-5 (5^{th} DMU), the LPP formulation:

Min E

s.t.

$78\ \lambda_{11} + 77\ \lambda_{12} + 63\ \lambda_{13} + 73\ \lambda_{14} + 60\ \lambda_{15} + 70\ \lambda_{16} \geq 60$ (xxix)

$1.75\lambda_{21} + 1.75\lambda_{22} + .85\lambda_{23} + 1.12\lambda_{24} + .75\ \lambda_{25} + 1.85\lambda_{26} \geq 0.75$ (xxx)

$1.75\lambda_{31} + 1.33\ \lambda_{32} + .95\lambda_{33} + 1.53\lambda_{34} + 1.12\lambda_{35} + 1.51\ \lambda_{36} \geq 1.12$ (xxxi)

$1.8\lambda_{41} + .92\lambda_{42} + .88\ \lambda_{43} + 0.85\ \lambda_{44} + 1.8\ \lambda_{45} + 0.78\ \lambda_{46} \geq 1.8$ (xxxii)

$0.93\ \lambda_{51} + .77\ \lambda_{52} + .91\lambda_{53} + .95\lambda_{54} + .9\ \lambda_{55} + 0.79\ \lambda_{56} \leq 0.9E$ (xxxiii)

$43\lambda_{61} + 31\lambda_{62} + 32\lambda_{63} + 43\ \lambda_{64} + 45\ \lambda_{65} + 30\lambda_{66} \leq 45E$ (xxxiv)

$48\lambda_{71} + 47\lambda_{72} + 53\lambda_{73} + 46\ \lambda_{74} + 48\ \lambda_{75} + 37\lambda_{76} \leq 48E$ (xxxv)

For Maintenance Unit-6 (6^{th} DMU), the LPP formulation:

Min E

s.t.

$78\ \lambda_{11} + 77\ \lambda_{12} + 63\ \lambda_{13} + 73\ \lambda_{14} + 60\ \lambda_{15} + 70\ \lambda_{16} \geq 70$ (xxxvi)

$1.75\lambda_{21} + 1.75\lambda_{22} + .85\lambda_{23} + 1.12\lambda_{24} + .75\ \lambda_{25} + 1.85\lambda_{26} \geq 1.85$ (xxxvii)

$1.75\lambda_{31} + 1.33\ \lambda_{32} + .95\lambda_{33} + 1.53\lambda_{34} + 1.12\lambda_{35} + 1.51\ \lambda_{36} \geq 1.51$ (xxxviii)

$1.8\lambda_{41} + .92\lambda_{42} + .88\ \lambda_{43} + 0.85\ \lambda_{44} + 1.8\ \lambda_{45} + 0.78\ \lambda_{46} \geq 0.78$ (xxxix)

$0.93\ \lambda_{51} + .77\ \lambda_{52} + .91\lambda_{53} + .95\lambda_{54} + .9\ \lambda_{55} + 0.79\ \lambda_{56} \leq 0.79E$ (xxxx)

$43\lambda_{61} + 31\lambda_{62} + 32\lambda_{63} + 43\ \lambda_{64} + 45\ \lambda_{65} + 30\lambda_{66} \leq 30E$ (xxxxi)

$48\lambda_{71} + 47\lambda_{72} + 53\lambda_{73} + 46\ \lambda_{74} + 48\ \lambda_{75} + 37\lambda_{76} \leq 37E$ (xxxxii)