Chapter 18
Measurement of Flexibility and Its Benchmarking Using Data Envelopment Analysis in Supply Chains

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18.1 Introduction

Managing Supply Chain (SC) operations is critical to any organization's ability to compete effectively in today's global and dynamic environment. Good Supply Chain Management (SCM) practices results in a variety of advantages such as increased customer value, increased profitability, reduced cycle times, less inventory levels (William et al. 2007) and increased flexibility (Hoek et al. 2001). Flexibility is increasingly mentioned as one of the major challenges to the business world, given volatile markets and increasingly varying performance requirements (Li et al. 2009). Companies are becoming increasingly aware that for competing in continuously changing environment, it is necessary to monitor, understand and control their flexibility capabilities.

Nomenclature

SC = Supply chain
SCM = Supply chain canagement
PMS = Performance measurement system
SCPM = Supply chain performance measurement
SCPMS = Supply chain performance measurement systems
DEA = Data envelopment analysis
DMU = Decision making unit
HCU = Hypothetical composite unit
E = Relative efficiency score

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Literature survey indicates that interest on performance measurement of SCs has notably increased in the last two decades (Taticchi et al. 2010). Various performance metrics are in place for measuring effectiveness of SC. Different perspectives of Supply Chain Performance Measurements (SCPM) are available in literature. Flexibility and agility in SC have been considered as one of the performance parameters in many studies; however detailed study focusing on measurement of flexibility in SC is limited (Li et al. 2009). The measurement of flexibility in large, complex systems, such as supply chain systems, has rarely been addressed. The reason for this is that unlike other performance measures which demonstrate it in ongoing operations, flexibility need not be a demonstrated measure but a potential capability to meet a future need. There have been attempts to create a framework for agile supply chain and its measurement (Hoek et al 2001) and development of an instrument to measure supply chain agility (Li et al. 2009). Beamon (1999) has proposed a framework for measurement of flexibility in SC and identified performance measures for flexibility in SC.

The present research is examining the Performance Measurement aspects of flexibility in SC and suggesting a methodology for bench marking of Flexibility capabilities in SC using Data Envelopment Analysis (DEA). DEA is a performance measurement technique developed by Charnes et al. (1978) and is used for determining the relative efficiency of a set of comparable businesses and it can also be used for benchmarking. DEA results provide decision makers with improvement potentials, targets, and peer organizations as bench marking units. The paper also demonstrates the methodology of using DEA to measure flexibility and its bench marking of similar SCs.

This paper is organized into the following sections: (1) Performance Measurement in SC; (2) Measurement of Flexibility in SC; (3) DEA for Performance Measurement and Benchmarking; (4) Demonstration of using DEA for benchmarking flexibility in SC.

18.2 Performance Measurement in SC

Supply Chains (SC) are increasingly depending on Performance Measurement Systems (PMS) as a means to align their processes and resources with strategy and to achieve their organization objectives (Neely 2005). Literature review indicates that a number of frameworks and models for performance measurement have been developed since 1980s. Tangen (2004) suggests that a major objective of such PMSs is to encourage proactive rather than reactive management. Gunasekaran et al. (2001) adds that performance measures can facilitate a greater understanding of the Supply Chain (SC) and improve its overall performance therefore achieving organisational objectives.

Much progress has been made since last two decades in establishing PMSs which include a portfolio of measures aimed to balance the more traditional, single focus view on profitability (Taticchi et al. 2010). Neely (2005) defined PMS as a balanced and dynamic system that enables support of decision-making processes by gathering, elaborating and analyzing information. Bititci et al. (1997) defines SCPM as the reporting process that gives feedback to employees on the outcome of actions. Tangen (2004) proposed that performance should be defined as the efficiency and effectiveness of action.

Effective SCPM has been associated with a variety of advantages including increased customer value, increased profitability, reduced cycle times and average inventory levels and even better product design (William et al. 2007). The objective of SCPM therefore has to facilitate and enhance the efficiency and effectiveness of SCM. The main goal of SCPM models and frameworks is to support management by helping them to measure business performance, analyze and improve business operational efficiency through better decision-making processes (Tangen 2005). An effective, integrated and balanced SCPM can engage the organisation's performance measurement system as a vehicle for organisational change. It also provides insight to reveal the effectiveness of strategies and to identify potential opportunities. It makes an indispensable contribution to decision making in SCM, particularly in re-designing business goals and strategies, and re-engineering processes (Charan et al. 2008).

The most widely cited Supply Chain Performance Measurement Systems (SCPMS) are the SMART (1988), the performance measurement matrix (1989), the Balanced Scorecard (1992), the integrated dynamic PMS (1997) and the Performance Prism (PP) (2001). In the Indian context, there have been many attempts to measure the performance at the organizational level, but very few attempts have been made to measure the performance at inter-organizational level and measure flexibility at SC level.

18.3 Measurement of Flexibility in SC

Review of related literature on flexibility indicates that majority of research in flexibility measurement has been done in the field of Manufacturing Flexibility Sethi and Sethi 1990; Schmenner and Tatikonda 2005. Measures for flexible manufacturing systems (FMS) on the machine and plant levels exist and have been well-studied. There has also been work done in the area of Strategic Flexibility at organizational level, however, literature on flexibility at SC level are comparatively less. The reasons for limited work on SC flexibility performance measurement are attributed to the multiple dimensions of flexibility in SC and the fact that flexibility is not a demonstrated measure in SCs, but a potential attribute (Beamon 1999). SC flexibility should incorporate both within the firm and between-firms flexibility. Literature indicates several advantages of flexible SCs (Beamon 1999; Hoek et al. 2001; Li et al. 2009). Significant of them are enumerated as under:

1. Reductions in the number of backorders.
2. Reductions in the number of lost sales.

3. Reductions in the number of late orders.
4. Increased customer satisfaction.
5. Ability to respond to and accommodate demand variations, such as seasonality.
6. Ability to respond to and accommodate periods of poor manufacturing performance.
7. Ability to respond to and accommodate periods of poor supplier performance.
8. Ability to respond to and accommodate periods of poor delivery performance.
9. Ability to respond to and accommodate new products, new markets, or new competitors.

In an uncertain environment, SCs must be able to respond to change. Flexibility measures the ability of the SC to adapt to volume and schedule variations from other partners of the SC. Beamon (1999) discussed two types of flexibility: (1) Range flexibility and (2) Response flexibility. Range flexibility measures the extent the operation can be varied. Response flexibility measures the ease (in terms of cost, time, or both) with which the operation can be varied. The SC need to adapt adequately to the uncertain environment by incorporating range flexibility and response flexibility in its design.

Hoek et al. (2001) conducted an audit of agility in the SC and introduced agility as an emerging management concept centered on responsiveness to dynamic, turbulent markets and customer demand. Based on this audit it was established that customer sensitivity is the key element in SC agility. The other factors of SC agility constructs are Virtual integration, Process integration and Network integration. Li et al. (2009) developed an instrument for measuring supply chain agility. They developed a 12-item instrument with six dimensions per item. The instrument has been validated through research. The proposed methodology can be used to examine the links between SC agility-related variables, SC agility, and outcomes of agility.

The key elements in SC performance measurement, according to Beamon (1999), are measurement of: (1) *Resources,* (2) *Output* and (3) *Flexibility. Resource measures* concentrate on efficiencies, are related to costs and targets effective utilization of resources. *Output measures* emphasize on customer responsiveness and aims at providing high level of customer service. *Flexibility* measures how well the system reacts to uncertainty and its ability to respond to a changing environment. *Resources measures* and *Output measures* have been widely used in existing SCPMS models. However *Flexibility* has been limited in its application to SCPMS.

Flexibility measures are different from resource and output measures in many aspects. Slack (1983) indicates that flexibility measures potential behavior, whereas other operational objectives are actually demonstrated by the system's operating behavior (performance). Therefore, flexibility does not have to be demonstrated by the system in order to exist. This aspect of the absence of performance demonstration of flexibility in ongoing operational situations makes its measurement challenging and necessitates different approach. Beamon (1999) identified four types of SC flexibility; they are:

1. **Volume flexibility (Fv)**. It is the ability to change the output level of products produced. The volume flexibility measure, Fv, measures the proportion of

demand that can be met by the supply chain system within range of volumes that are profitable.

2. **Delivery flexibility (Fd)**. It is the ability to change planned delivery dates. Delivery flexibility is measured as the percentage of slack time by which the delivery time can be reduced.
3. **Mix flexibility (Fm)**. It is the ability to change the variety of products produced. Mix flexibility measures either the range of different product types that may be produced during a particular time period, or the response time between product mix changes.
4. **New product flexibility (Fp)**. It is the ability to introduce and produce new products which also includes the modification of existing products. It is measured as either the time or cost required to add new products to existing production operations.

18.4 DEA for Performance Measurement

DEA is a non parametric performance measurement technique developed by Charnes et al. (1978) and is used for determining the relative efficiency of a set of comparable business called Decision Making Units (DMU). It has been applied to a wide range of problems in the fields of management, economics and business operations. In DEA, efficiency is defined as:

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

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 favorable 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 % 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 inputs and outputs.

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

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

S.t.

$$\left(\frac{\sum_{k=1}^{s} v_k\, y_{ki}}{\sum_{j=1}^{m} u_j x_{ji}}\right) \leq 1 \quad \forall i$$

$$v_k, u_j \geq 0 \quad \forall j, k \tag{18.1}$$

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. 18.1 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 (Talluri 2000):

$$\begin{aligned} & Max \left(\sum_{k=1}^{s} v_k\, y_{kp}\right) \\ & s.t. \quad \sum_{j=1}^{m} u_j\, x_{jp} = 1 \\ & \quad \left(\sum_{k=1}^{s} v_k\, y_{ki} - \sum_{j=1}^{m} u_j\, x_{ji}\right) \leq 0 \quad \forall i \\ & \quad v_k, u_j \geq 0 \quad \forall j, k \end{aligned} \tag{18.2}$$

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 maximize its efficiency score. So the v_k and u_k values gives output and input weight ages corresponding to max relative efficiency possible for the DMU considered.

18.4.1 Benchmarking in DEA

For every inefficient DMU, DEA identifies a set of corresponding efficient units that can be utilized as benchmarks for improvement. The benchmarks can be obtained from the dual of the DEA LPP formulation given above at Eq.18.2.

Min E

Subjected to:

$$\sum_{i=1}^{n} \lambda_i y_{ki} \geq y_{kp} \quad \forall j$$
$$\sum_{i=1}^{n} \lambda_i x_{ki} \leq E.x_{kp} \quad \forall k$$
$$\lambda \geq 0 \quad \forall i \tag{18.3}$$

Where:

$E =$ Efficiency score
$\lambda_{\mathrm{i}} =$ 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. The former, also known as input-oriented model emphasizes 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.

DEA is receiving increasing importance as a tool for evaluating and improving the performance of manufacturing and service operations. It has been extensively applied in performance evaluation and benchmarking. DEA approach has the following benefits which make it suitable for its application in flexibility performance measurement and bench marking in SC:

1. DEA deals with individual cases (Madu and Kuei 1998).
2. It can produce a single measure for each company (Madu and Kuei 1998).
3. It places no restriction on the functional form of the input-output relationship.
4. Able to handle disproportionate multiple inputs and outputs (George and Rangaraj 2008)
5. Does not requiring the decision maker any priory arbitrary weights (George and Rangaraj 2008).
6. It focuses on revealed best-practice frontiers rather than on central tendency properties of empirical data (Madu and Kuei 1998).
7. It can provide an indication of the levels of improvement needed before an inefficient company could be considered efficient (Talluri 2000).

18.5 Demonstration of Using DEA for Benchmarking Flexibility

18.5.1 SC Model

A simplified and generic approach to SCPMS has been adopted to demonstrate using of DEA for bench marking Flexibility. The supply chain model considered is shown in Fig. 18.1 which contains four echelons. The four echelons; supply,

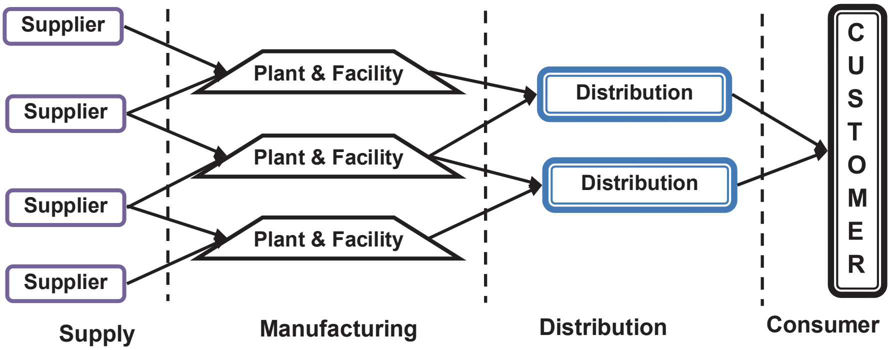

Fig. 18.1 Supply chain

manufacturing, distribution, and consumers comprise of numerous facilities. DEA methodology considers relationship between multiple inputs with multiple outputs.

18.5.2 Performance Measures Considered

The present study considers the *'Resources'* consumed in the SC as the input parameters and the *'Flexibility'* measures as the outputs. Resource parameters and Flexibility parameters as proposed by Beamon (1999) are summarized at Table 18.1.

DEA is effective when organizations 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 (Capital, Distribution costs, Manufacturing cost, and Inventory) and two output parameters (Volume flexibility and Delivery flexibility) are considered.

The flexibility parameters Volume flexibility (F_v) and Delivery flexibility (F_D) are calculated based on the procedure suggested by Beamon (1999).

$$F_v = P\left(\frac{O_{\min} - \bar{D}}{S_D} \leq D \leq \frac{O_{\max} - \bar{D}}{S_D}\right) \tag{18.4}$$

$$F_D = \frac{\sum_{j=1}^{J} (L_j - E_j)}{\sum_{j=1}^{J} (L_j - t^*)} \tag{18.5}$$

Where:

O_{min}, O_{max} – Minimum and maximum profitable output volume.

Table 18.1 List of input and output parameters

Input: Resources		Output: Flexibility	
Input parameter	Explanation	Output parameter	Explanation
Capital	Total cost of resources used. Measure of capital	Volume flexibility	The ability to change the output level of products produced
Distribution costs	Total cost of distribution, including transportation and handling costs	Delivery flexibility	The ability to change planned delivery dates
Manufacturing cost	Total cost of manufacturing, including labor, maintenance, and re-work costs	Mix flexibility	The ability to change the variety of products produced
Inventory	Costs associated with held inventory	New product flexibility	The ability to introduce and produce new products (this includes the modification of existing products)

D – Demand volume which is a random variable with an approximate normal distribution with D as the arithmetic mean and S_D as the standard deviation.
P – Indicates probability of meeting the demand between O_{min} and O_{max} based on normal probability distribution.
L_j – Latest time period during which the delivery can be made for job j
E_j – Earliest time period during which the delivery can be made for job j.
j – 1 to j jobs in the system.
T* – Current time period (Modal value of time taken to complete the job).

18.5.3 Data Set

Data set for the six SCs under consideration (DMU) are given at Table 18.2. The six SCs are hypothetical and the data is representative sample.

18.5.4 DEA Formulation

The benchmarking is done by solving the dual of the DEA given at model Eq. 18.3. The dual variables (λ_i) correspond to HCU and E the efficiency measure of the DMU under consideration. HCU can be used to measure possible improvements in terms of reduction in inputs and increase in outputs of the DMU.

The mathematical formulation for the case under study is given at Appendix. The DEA model is solved using the *DEAFronti*er which is a Microsoft Excel Add-In developed by Joe Zhu. The DEA model is solved as *'Input-Oriented'* and *'Constant Return to Scale (CRS)'*.

Table 18.2 Data set

SC (DMU)	Capital (Rs in crores)	Manufacturing cost (Rs in crores)	Distribution costs (Rs in crores)	Inventory (Rs in crores)	Volume flexibility (in percentage)	Delivery flexibility (in percentage)
	Input	Input	Input	Input	Output	Output
SC-1	7.85	4.74	1.25	0.95	71	77
SC-2	6.00	4.35	1.33	0.85	74	85
SC-3	5.75	3.87	1.45	1.12	62	95
SC-4	6.55	4.02	1.33	0.95	55	85
SC-5	7.00	4.34	1.12	0.85	65	97
SC-6	7.25	5.00	1.31	0.97	66	63

Table 18.3 Relative efficiency core

SC (DMU)	Relative efficiency
SC-1	98.43 %
SC-2	100.00 %
SC-3	100.00 %
SC-4	90.74 %
SC-5	100.00 %
SC-6	88.31 %

18.5.5 Efficiency Score

DEA calculates relative efficiencies of SCs based on the multiple input and output parameters. The relative efficiency score (E) of SCs evaluated is given at Table 18.3. The relative efficiencies indicate that SC-2, SC-3, and SC-5 are relatively efficient in terms of flexibility whereas there is scope for improvement in case of SC-1, SC-4, and SC-6.

18.5.6 Improvements Possible

The weights attached to each input and output is not specified in advance (priory). The DEA estimates ideal weights of each input and output parameter to maximize relative efficiency score. Based on relative efficiencies and the weights improvements possible at each of the measurement parameter are obtained. The results are tabulated at Table 18.4. It indicates, for inefficient SCs, the ideal combination of inputs and outputs possible. For example for SC-1, the delivery flexibility can be improved from 77 to 99.2 % with Capital reduced from Rs 7.85 to 7.39 Cr; Manufacturing cost from Rs 4.74 to 4.66 Cr; Distribution costs from 0.95 to 0.91 Cr and Inventory from 0.95 to 0.91 Cr. Similar improvements are possible other inefficient SCs viz. SC-4 and SC-6.

Table 18.4 Improvements possible

SC (DMU)	Capital (Rs in crores)	Manufacturing cost (Rs in crores)	Distribution costs (Rs in Cr)	Inventory (Rs in Cr)	Volume flexibility (in %)	Delivery flexibility (in %)
	Input	Input	Input	Input	Output	Output
SC-1	7.85 to 7.39	4.74 to 4.66	1.25 to 1.23	0.95 to 0.91	71 to 71	77 to 99.2
SC-2	6 to 6	4.35 to 4.35	1.33 to 1.33	0.85 to 0.85	74 to 74	85 to 85
SC-3	5.75 to 5.75	3.87 to 3.87	1.45 to 1.45	1.12 to 1.12	62 to 62	95 to 95
SC-4	6.55 to 5.68	4.02 to 3.64	1.33 to 1.125	0.95 to 0.86	55 to 56.28	85 to 85
SC-5	7 to 7	4.34 to 4.34	1.12 to 1.12	0.85 to 0.85	65 to 65	97 to 97
SC-6	7.25 to 6.40	5 to 4.19	1.31 to 1.15	0.97 to 0.82	66 to 66	63 to 89.38

Table 18.5 Optimal lamda values indicating benchmark units

DMU name	Input oriented CRS efficiency	Sum of lamdas	Return to scale	Optimal lamdas with benchmark DMU	
SC-1	0.98429	1.075	Decreasing	0.127: SC-2	0.948: SC-5
SC-2	1.00000	1.000	Constant	1.000: SC-2	
SC-3	1.00000	1.000	Constant	1.000: SC-3	
SC-4	0.90745	0.885	Increasing	0.408: SC-3	0.477: SC-5
SC-5	1.00000	1.000	Constant	1.000: SC-5	
SC-6	0.88313	0.966	Increasing	0.358: SC-2	0.608: SC-5

18.5.7 Benchmarking

The optimal Lamdas (Dual variable corresponding to HCU) with Benchmarks is given at Table 18.5. The result indicates the corresponding efficient units which are related to the inefficient DMUs; SC-1, SC-4 and MU-6. So it can be seen that for SC-1; the benchmarking Units are SC-2 and SC-5. The significance of SC-5 compared to SC-2 as benchmark Unit for SC-1 will be higher since SC-5 has higher Lamda value. This indicates that adopting processes and systems of SC-5 will be beneficial for SC-2 to achieve increased outputs with reduced inputs.

18.6 Conclusion

Flexibility is a significant parameter in SCM in today's dynamic environment. Measuring flexibility is necessary to monitor, control and improve SC effectiveness. Flexibility measures for SC have been identified through literature as volume flexibility, delivery flexibility, mix flexibility and new product flexibility. Methodology for measurement of these flexibility measures has also been described.

DEA is a suitable tool for evaluating relative efficiencies of similar organizations. An attempt has been made to use DEA for benchmarking flexibility in SCs. The procedure has been demonstrated with a sample case of six similar SCs. 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 as bench marks. Hence, DEA offers 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.

Appendix

DEA Formulation for the Case Under Study

E = Efficiency score of DMU under evaluation and

λ_{ij} = Dual variable corresponding to the efficient Hypothetical Composite Unit (HCU).

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

Min E

s.t.

$$7.85\,\lambda_{11}+6.00\,\lambda_{12}+5.75\,\lambda_{13}+6.55\,\lambda_{14}+7.00\,\lambda_{15}+7.25\,\lambda_{16}\geq 7.85 \quad \text{(i)}$$
$$4.74\,\lambda_{21}+4.35\,\lambda_{22}+3.87\,\lambda_{23}+4.02\,\lambda_{24}+4.34\,\lambda_{25}+5.00\,\lambda_{26}\geq 4.74 \quad \text{(ii)}$$
$$1.25\,\lambda_{31}+1.33\,\lambda_{32}+1.45\,\lambda_{33}+1.33\,\lambda_{34}+1.12\,\lambda_{35}+1.31\,\lambda_{36}\geq 1.25 \quad \text{(iii)}$$
$$0.95\,\lambda_{41}+0.85\,\lambda_{42}+1.12\,\lambda_{43}+0.95\,\lambda_{44}+0.85\,\lambda_{45}+0.97\,\lambda_{46}\geq 0.95 \quad \text{(iv)}$$
$$71\,\lambda_{51}+74\,\lambda_{52}+62\,\lambda_{53}+55\,\lambda_{54}+65\,\lambda_{55}+66\,\lambda_{56}\leq 71E \quad \text{(v)}$$
$$77\,\lambda_{61}+85\,\lambda_{62}+95\,\lambda_{63}+85\,\lambda_{64}+97\,\lambda_{65}+63\,\lambda_{66}\leq 77E \quad \text{(vi)}$$

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

Min E

s.t.

$$7.85\,\lambda_{11}+6.00\,\lambda_{12}+5.75\,\lambda_{13}+6.55\,\lambda_{14}+7.00\,\lambda_{15}+7.25\,\lambda_{16}\geq 6.00 \quad \text{(vii)}$$
$$4.74\,\lambda_{21}+4.35\,\lambda_{22}+3.87\,\lambda_{23}+4.02\,\lambda_{24}+4.34\,\lambda_{25}+5.00\,\lambda_{26}\geq 4.35 \quad \text{(viii)}$$
$$1.25\,\lambda_{31}+1.33\,\lambda_{32}+1.45\,\lambda_{33}+1.33\,\lambda_{34}+1.12\,\lambda_{35}+1.31\,\lambda_{36}\geq 1.33 \quad \text{(ix)}$$

$0.95\,\lambda_{41}+0.85\,\lambda_{42}+1.12\,\lambda_{43}+0.95\,\lambda_{44}+0.85\,\lambda_{45}+0.97\,\lambda_{46}\geq 0.85$ (x)
$71\,\lambda_{51}+74\,\lambda_{52}+62\,\lambda_{53}+55\,\lambda_{54}+65\,\lambda_{55}+66\,\lambda_{56}\leq 74E$ (xi)
$77\,\lambda_{61}+85\,\lambda_{62}+95\,\lambda_{63}+85\,\lambda_{64}+97\,\lambda_{65}+63\,\lambda_{66}\leq 85E$ (xii)

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

Min E
s.t.
$7.85\,\lambda_{11}+6.00\,\lambda_{12}+5.75\,\lambda_{13}+6.55\,\lambda_{14}+7.00\,\lambda_{15}+7.25\,\lambda_{16}\geq 5.75$ (xiii)
$4.74\,\lambda_{21}+4.35\,\lambda_{22}+3.87\,\lambda_{23}+4.02\,\lambda_{24}+4.34\,\lambda_{25}+5.00\,\lambda_{26}\geq 3.87$ (xiv)
$1.25\,\lambda_{31}+1.33\,\lambda_{32}+1.45\,\lambda_{33}+1.33\,\lambda_{34}+1.12\,\lambda_{35}+1.31\,\lambda_{36}\geq 1.45$ (xv)
$0.95\,\lambda_{41}+0.85\,\lambda_{42}+1.12\,\lambda_{43}+0.95\,\lambda_{44}+0.85\,\lambda_{45}+0.97\,\lambda_{46}\geq 1.12$ (xvi)
$71\,\lambda_{51}+74\,\lambda_{52}+62\,\lambda_{53}+55\,\lambda_{54}+65\,\lambda_{55}+66\,\lambda_{56}\leq 62E$ (xvii)
$77\,\lambda_{61}+85\,\lambda_{62}+95\,\lambda_{63}+85\,\lambda_{64}+97\,\lambda_{65}+63\,\lambda_{66}\leq 95E$ (xviii)

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

Min E
s.t.
$7.85\,\lambda_{11}+6.00\,\lambda_{12}+5.75\,\lambda_{13}+6.55\,\lambda_{14}+7.00\,\lambda_{15}+7.25\,\lambda_{16}\geq 6.55$ (xix)
$4.74\,\lambda_{21}+4.35\,\lambda_{22}+3.87\,\lambda_{23}+4.02\,\lambda_{24}+4.34\,\lambda_{25}+5.00\,\lambda_{26}\geq 4.02$ (xx)
$1.25\,\lambda_{31}+1.33\,\lambda_{32}+1.45\,\lambda_{33}+1.33\,\lambda_{34}+1.12\,\lambda_{35}+1.31\,\lambda_{36}\geq 1.33$ (xxi)
$0.95\,\lambda_{41}+0.85\,\lambda_{42}+1.12\,\lambda_{43}+0.95\,\lambda_{44}+0.85\,\lambda_{45}+0.97\,\lambda_{46}\geq 0.95$ (xxii)
$71\,\lambda_{51}+74\,\lambda_{52}+62\,\lambda_{53}+55\,\lambda_{54}+65\,\lambda_{55}+66\,\lambda_{56}\leq 55E$ (xxiii)
$77\,\lambda_{61}+85\,\lambda_{62}+95\,\lambda_{63}+85\,\lambda_{64}+97\,\lambda_{65}+63\,\lambda_{66}\leq 85E$ (xxiv)

For SC-5 (5th DMU), the LPP formulation:

Min E
s.t.
$7.85\,\lambda_{11}+6.00\,\lambda_{12}+5.75\,\lambda_{13}+6.55\,\lambda_{14}+7.00\,\lambda_{15}+7.25\,\lambda_{16}\geq 7$ (xxv)
$4.74\,\lambda_{21}+4.35\,\lambda_{22}+3.87\,\lambda_{23}+4.02\,\lambda_{24}+4.34\,\lambda_{25}+5.00\,\lambda_{26}\geq 4.34$ (xxvi)
$1.25\,\lambda_{31}+1.33\,\lambda_{32}+1.45\,\lambda_{33}+1.33\,\lambda_{34}+1.12\,\lambda_{35}+1.31\,\lambda_{36}\geq 1.12$ (xxvii)
$0.95\,\lambda_{41}+0.85\,\lambda_{42}+1.12\,\lambda_{43}+0.95\,\lambda_{44}+0.85\,\lambda_{45}+0.97\,\lambda_{46}\geq 0.85$ (xxviii)
$71\,\lambda_{51}+74\,\lambda_{52}+62\,\lambda_{53}+55\,\lambda_{54}+65\,\lambda_{55}+66\,\lambda_{56}\leq 65E$ (xxix)
$77\,\lambda_{61}+85\,\lambda_{62}+95\,\lambda_{63}+85\,\lambda_{64}+97\,\lambda_{65}+63\,\lambda_{66}\leq 97E$ (xxx)

For SC-6 (6th DMU), the LPP formulation:

Min E
s.t.
$7.85\,\lambda_{11}+6.00\,\lambda_{12}+5.75\,\lambda_{13}+6.55\,\lambda_{14}+7.00\,\lambda_{15}+7.25\,\lambda_{16}\geq 7.25$ (xxxi)
$4.74\,\lambda_{21}+4.35\,\lambda_{22}+3.87\,\lambda_{23}+4.02\,\lambda_{24}+4.34\,\lambda_{25}+5.00\,\lambda_{26}\geq 5.00$ (xxxii)
$1.25\,\lambda_{31}+1.33\,\lambda_{32}+1.45\,\lambda_{33}+1.33\,\lambda_{34}+1.12\,\lambda_{35}+1.31\,\lambda_{36}\geq 1.31$ (xxxiii)
$0.95\,\lambda_{41}+0.85\,\lambda_{42}+1.12\,\lambda_{43}+0.95\,\lambda_{44}+0.85\,\lambda_{45}+0.97\,\lambda_{46}\geq 0.97$ (xxxiv)
$71\,\lambda_{51}+74\,\lambda_{52}+62\,\lambda_{53}+55\,\lambda_{54}+65\,\lambda_{55}+66\,\lambda_{56}\leq 66E$ (xxxv)
$77\,\lambda_{61}+85\,\lambda_{62}+95\,\lambda_{63}+85\,\lambda_{64}+97\,\lambda_{65}+63\,\lambda_{66}\leq 63E$ (xxxvi)

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