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Efficiency Measurement using Dea

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Abstract: The technique of Data Envelopment Analysis originated with the publication of a seminal paper Measurement of efficiency of decision making units (Charnes et al, 1978). Since then several models and methods are devised over the years and the technique has been used in varied fields and different applications both in the private and the public sectors. This paper surveys the various literature published in the field in the areas of a) various models and methods and b) various application procedures in applying the technique in various fields.The paper demonstrates the use of the method with a practical example of service delivery of Veterinary Districts of Odisha using CCR Output oriented model. The results produced include average efficiencies and projections for achieving efficiency.

Keywords: Efficiency, Data Envelopment Analysis (DEA), Returns to Scale, Most Productive Scale Size, Technical Efficiency, Scale Efficiency.

I. INTRODUCTION

Efficiency is concerned with the best possible utilization of limited resources. It is the capability of a specific application of effort to produce a specific outcome with a minimum amount or quantity of waste, expense, or unnecessary effort. It is usually defined in three different ways as – 1) to produce a given quantity of output with the use of minimum possible inputs, 2) to produce maximum possible output from given quantity of input and 3) to produce maximum possible output from the minimum possible input. Measurement of efficiency has been of great interest to engineers, economists and mathematicians for over many decades (Farell, 1957). Data Envelopment Analysis is one of the methods of measuring efficiency.

Data Envelopment Analysis is a method based on application of linear programming. It is a linear programming-based technique for measuring the performance efficiency of organizational units called Decision Making Units (DMUs). This technique aims to measure how efficiently a DMU uses the resources available to generate a set of outputs. DMUs can include manufacturing units, schools, bank branches, hospitals or even practicing individuals like doctors or lawyers. Most of these DMUs are non-profit organisations where the measurement of performance is difficult as a lot of inputs used by such organisations and a lot of outputs produced by them cannot be measured using a common denominator like money. Efficiencies of DMUs estimated using DEA are relative with respect to the best performing DMU. DEA is a non parametric technique and does not require the assumption of the nature of a distribution (Charnes et al, 1978; Ramanathan, 2003).

The technique of DEA has evolved over the years very rapidly and has found various applications in different fields in the public and the private sectors. This paper looks at various models and methods and application procedures. The second part of the paper looks at the various models and methods while the third part looks at the specific aspects of procedures to be followed while applying the technique in different applications. The methodology is described in the fourth part and results analysis if done in the fifth part. The paper concludes thereafter with some observations followed by references.

II. EFFICIENCY AND ITS MEASUREMENT USING DATA ENVELOPMENT ANALYSIS: THE METHODS AND MODELS

Farell (1957) emphasizes the importance of measuring productive efficiency of an industry both to the economic theorist and the economic policy maker. The paper discusses the various attempts of measuring efficiency, either through some measure of labour productivity or the use of an index number and talks about the shortcomings of both attempts.

Talking further about efficiency and its measurement, the paper goes on to define two types of efficiency, technical efficiency and price efficiency and shows that the overall efficiency of a firm is equal to the product of technical and price efficiencies. Technical efficiency is defined as the success of a firm in producing maximum output from a given set of inputs and price efficiency is defined as a firm's success in choosing an optimal set of inputs.

Considering two types of measuring efficiency, one a theoretical function as could be specified by engineers and the other an empirical one which is the best among observed results, the paper argues that the theoretical function would be very difficult to define in complex practical situations and would be wildly optimistic. And if used to compare real firms and industries it could give a very disappointing picture of those firms and hence, the paper uses empirical values as measures of efficiency. This seminal paper is considered as the beginning for efficiency measurement and precursor for the idea of Data Envelopment Analysis (DEA).

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The actual measurement of efficiencies with the use of linear programming techniques and using empirical results was first proposed by Charnes et al (1978). They propose a method for measuring efficiency for evaluating various programmes of public or not-for-profit organizations. The program consists of a set of Decision making Units (DMUs) who are supposed to be producing multiple outputs by utilizing a given set of inputs and the ‘decision making efficiencies’ are being measured for each of such DMUs. The paper allows for usage of both inputs and outputs to be non-monetary and hence may not be readily weighted using market prices or costs. The proposed method obtains the efficiency measure using linear programming by maximizing the ratio of weighted outputs to weighted inputs of a given DMU, subject to the constraint that no other DMU will get an efficiency score of more than one using the same set of weights for its outputs and inputs. With this paper, the technique of DEA for efficiency measurement was born. The method developed in this paper became known as the CCR model and is one of the most widely used model of DEA for measuring technical efficiency under the assumption of constant returns to scale (CRS). CCR refers to the first letters of the names of the three authors, Charnes, Cooper and Rhodes.

Banker et al (1984) discuss about two types of efficiencies, technical efficiency and scale efficiency as parts of the technical efficiency as measured under the CCR model. Based on the efficiency measurement of the ratio form derived by the CCR model, which could be measured using observed data and without any assumptions about the weights of individual inputs and outputs or of any functional form for the production function, the paper developed methods to accomplish the separation of technical and scale efficiencies without altering the above stated conditions and using observed data. The model so developed became known as BCC model with the letters representing the first letters of the names of the authors, Banker, Charnes and Cooper. This is another widely used model of DEA.

The concept of estimation of most productive scale size (MPSS) was first proposed by Banker (1984). The paper ‘developed a relationship between the most productive scale size for particular input output mixes and returns to scale for multiple-inputs and multiple-outputs situations.’ The same is employed using the CCR model to estimate the MPSS for convex production possibility sets.

Banker and Morey (1986) developed the mathematical formulations for evaluating technical and scale efficiencies when one or more of the inputs or outputs are exogenously determined and beyond the discretionary control of DMU managers. Ray (1988) developed a method for investigating the source of differences in efficiency across different units using an econometric formulation. Using DEA for measuring the efficiency of firms, he shows that the observed differences in efficiency can be explained in terms of differences in nondiscretionary inputs across firms.

Tone (1996) presented a simple method for deciding the local returns to scale characterization of individual DMUs using BCC model first for the efficient units and then for the inefficient units through the observation of RTS of their peers. The paper then expands the method to include both output oriented and additive models of DEA.

Banker (1996) developed test statistics T_{EX}, T_{HN} and T_{SM} (with the assumption that efficiency scores follow the exponential distribution or half normal distribution or with the non-parametric assumption) to test hypotheses using Chi-square distribution and F distribution about the characteristics of the production frontier like returns to scale, input substitutability, model specification and also about variations in efficiencies in relation to the production frontier.

Banker et al (2004) discussed returns to scale (RTS) in DEA for each of the available models. In specific, the BCC and CCR in their input orientation and the multiplicative model in output oriented form, no such distinction is necessary in the additive model which simultaneously maximizes outputs and minimizes inputs in a vector optimization form.

Cook and Seiford (2009) review the various research thrusts in DEA over the thirty years from the publication of Charnes et al (1978). The paper focused on various methodological developments during the period in relation to various models to measure efficiency, approaches to restrictions on multipliers, considerations regarding the status of variables and modeling of data variation. The paper reviewed both the Constant returns to scale (CRS) model, the CCR, the variable returns to scale (VRS) model, the BCC, both of radial projection constructs of either input or output orientations. The paper discussed the Pareto-Koopmans (PK) or additive model introduced by Charnes et al (1985) which uses sum of slacks in its formulation and combines both orientations to an extent. Tone (2001) introduced the slacks based measure (SBM) which is unit invariant and hence overcomes the units problem of the additive model. The paper also talked about the least distance projections as against the greatest distance projection of the additive model, developed by Frei and Harker (1999), and many others including Charnes et al (1992, 1996). The paper discussed about invariance to data alterations which was a subject of importance in DEA literature like those of Ali and Seiford (1990), Thrall (1996), Pastor (1996) and Cooper et al (2006). The paper talked about two types of data transformation, Scaling using a common multiplier (x’ = ax) and translation using a common additive (x’ = b+x). It also describes the property of units invariance and translation invariance of a model if scaling and translation respectively do not result in a change of outcomes of the model from those of using original data itself. The paper also discussed about multilevel models like network DEA, Supply chain DEA models, multi-component / parallel models and hierarchical/nested models.

Forsund (2018) examines two apparently different definitions of efficiency and showed that they were identical when both were based on solving linear programming problems. The paper attempts to give the basic idea of efficiency analysis using DEA for researchers who are not so familiar with the technique and tried to explain the concept of shadow prices.

Emrouznejad and Yang (2018) state that there has been an exponential growth in the number of publications of DEA, both in theory and in its applications. Immediately after the publications of CCR in 1978, it had been recognized as a modern tool for performance measurement.

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The paper presents some summary statistics of publications growth in the field, the most utilized journals, authorship analysis and keywords analysis in a survey of 40 years of DEA from 1978 to 2016.

III. APPLICATION PROCEDURES FOR DATA ENVELOPMENT ANALYSIS

One of the earlier literature on application procedures for DEA is the paper Golany and Roll (1989). The paper begins by arguing that most traditional methods of efficiency measurement fail to be useful in measuring the efficiencies of public programmes and those of not-for-profits due to the fact that such measures are - process measures and have no attention to outcomes, as some of these inputs and outcomes could be qualitative in nature and hence are not readily quantified and the assignment of relative proper weights are difficult for each of such factors, the difficulty in formulating explicit functional relationships between inputs and outputs and averaging performance across many DMUs fail to explain the behavior of individual DMUs. Hence the paper argued that DEA is an appropriate method to overcome such difficulties. The paper dealt with application procedures for definition and selection of DMUs, determination of inputs and outputs that are relevant and to be included in the DEA model, the model to be used for the given application and the analysis of the efficiency outcomes. The paper elaborated these aspects and illustrated the points with an example before concluding. The paper also described some of the most common models and gave a brief on under what conditions each of those may be used.

Boussofiane et al (1991) focused on key issues in practice in applying DEA. The paper recommended the use of any resource used by a unit as an input; outputs may include a range of performance and activity measures and environmental factors which affect the production of outputs in the model. The paper focused on the use of information obtained from the DEA models including peer groups, identifying efficient operating practices, target setting, identifying efficient strategies, monitoring efficiency changes over time and resource allocation. Predominant peers can be indentified with the help of λ values of each peer in the composite DMU formed and can be used as chief comparator for inefficient unit as per the paper.

Dyson et al (2001) notes the various issues in application of DEA as homogeneity of DMUs, the input and output variables used and their measurements and the weights for them in the analysis. The paper highlighted the pitfalls in these aspects and tries to develop protocols to overcome these issues. Some of the pitfalls and their protocols shown in the paper are as follows:

In the case of comparing non-homogenous DMUs, the paper suggested the use of external comparators or clustering uniform units into homogenous sets. In the case of non-homogenous environments, the paper suggested the use of environmental variables in the analysis. The existence of economies or diseconomies of scale can be a problem; hence appropriate Constant Returns to Scale (CRS) or Variable Returns to Scale (VRS) models should be used depending upon where the actual data falls into. In the absence of an indication of VRS or CRS, hypotheses tests for the scale effects may be conducted as proposed in Banker (1996). Another decision to be made is about the number of inputs and outputs to be used in the analysis. The paper states that the assumption on the scales of measurement of inputs and outputs is that they be of the ratio scale or at least of an interval nature and another assumption is of isotonicity of inputs and outputs. The paper warns of the consequences of using percentages and other normalized data along with volume measures and instead suggests the use of surrogate volume measures and use of numerators and denominators on opposite sides (inputs and outputs) instead of using ratios. Similarly the paper also warns against the use of qualitative variables the measures of which not being of interval or ratio scale need to be transformed judgmentally. Another pitfall noted in the paper is the presence of undesirable inputs or outputs which will lead to anti-isotonicity. The paper suggests possible measures like inverting the values, subtracting the value from a large number or using the inputs as outputs and vice versa, albeit noting the shortcomings of each of these measures.

The paper discusses the various pitfalls related to use of freedom to select weights in the DEA model. Some of these are linearity assumptions, zero-value weights relative values and linked input/output weights. The paper suggests various measures to tackle these issues like the introduction of non-linear value function, absolute weight restrictions, relative weight restrictions and linking the weights of inputs / outputs respectively.

The other problem discussed in the paper is related to restricting weights itself and suggested possible solutions for the same. The issues discussed are justifying a weight restriction, non-transferability of weight restrictions, interpretations of efficiency results where weight restrictions are used leading to non-radiality, the distinction between absolute vs. relative efficiency and the use of redundant weight restrictions.

Smith and Street (2005) discuss the context within which efficiency measurement models like data envelopment analysis (DEA) and stochastic frontier analysis (SFA) are deployed, their underlying assumptions and their usefulness for a regulator of public services. In specific, four model building issues of weights attached to public services outputs, specification of the statistical model, the treatment of environmental influences on performance and the treatment of dynamic effects are discussed and recommendations are made.

A more recent paper related to application procedures is by Cook et al (2014). The paper stresses the importance of understanding the “process” being evaluated and which would help in the choice of inputs and outputs to be used. The paper makes the point that the ‘efficient DMUs as defined by DEA may not necessarily form a “production frontier” but a best-practice frontier”. The paper discusses the difficulty in classifying factors as inputs or outputs.

Referring to the problem of number of inputs and outputs to be used – as this is an important decision in DEA as it is known that as the number of inputs and outputs are increased, the discrimination power of DEA is decreased and hence, there is a need to use more DMUs in the analysis if number of factors is more – the paper mentions some of the thumb rules set by other authors like number of DMUs to be at least double the number of factors or three times the number of factors, the paper argues that there is no statistical basis for such rules despite accepting the fact that larger number of factors will lead to lower discrimination power.

As for the orientation, the paper states that if one is interested in input minimization then one should use input-oriented model and if output miximisation is of interest then an output oriented model need to be used. If on the other hand both input reduction and output increase are the goals, the paper suggests the use of a slacks based measure model. Regarding the use of both a ratio/percentage factors and some raw data factors, the paper argues that such use is permissible in DEA applications and that there are no justification for generalizing that use of both types of variables should not be done simultaneously.

IV. METHODOLOGY

The output oriented model of CCR is used in this study. The efficiency may be measured as the ratio of outputs to inputs in any production process. If the number of inputs and/or outputs are multiple then a weighted output/weighted inputs ratio can be an option. However, the weights to be assigned to individual outputs and inputs becomes a problem. In DEA, the problem is tackled by using linear programming to find weights for inputs and outputs. The method uses the data of various outputs and inputs to assign weights to each of these variables. The output oriented CCR model in matrix form is as follows: (Cooper et al, 2006)

$$\max \quad \eta$$

Subject to the constraints

$$x_o - X\mu >= 0$$

$$\eta y_o - Y\mu <= 0$$

$$\mu >= 0$$

Where η is a scalar which needs to be measured and is the measure of efficiency of a particular decision making unit (DMU). x_o is the input vector of a particular DMU_o (where we have 'n' DMUs), X is the input matrix of all DMUs, y_o is the output vector of DMU_o and Y is the output matrix of all DMUs and μ is a non negative vector. The method tries to maximize η, such that a combination of different DMUs produce maximum possible outputs (at least as high as y_o) utilizing least inputs (at most as much as x_o).

V. RESULTS ANALYSIS

The above model is illustrated with the data of inputs used and outputs produced by 30 Veterinary Districts of Odisha which was available online (GoO, 2016). Table 1 gives the descriptive statistics of data.

Table 1: Descriptive Statistics of Inputs and Outputs

Statistics	Max	Min	Average	SD
Number of VDs	42	4	18	8
Number of LAC	330	30	149	75
Total AI	95031	5056	32742	20740
Infert camps	715	2	106	175
Infert treat	17189	36	2084	3388
De-worming	146299	98	24131	32065
Treatment	599600	45900	176780	120703
Castration	93800	1300	17337	17155
Vaccination	2640500	487600	1007137	487021

The Veterinary districts had 18 veterinary dispensaries (VD) on an average and 76 Livestock Aid Centers (LAC) on an average as inputs which have conducted around 33000 artificial inseminations (AI), more than 100 infertility camps, more than 2000 infertility treatments, more than 24000 deworming, more than 175000 treatments, more than 17000 castrations and more than 10 lakh vaccinations on an average as outputs. The table also gives the corresponding minimum, maximum and standard deviation values for each of these factors. The correlation between various variables is found to be significant and positive for all pairs of variables, which is a requirement for using DEA for efficiency measurement (not presented here due to lack of space).

DEA was used to find the efficiency of each of the districts, the results of which are presented in table 2. The (I) or (O) given in brackets represent inputs and outputs respectively. The average efficiency scores of all the 30 veterinary districts is 0.84 (84%) with 10 districts having efficiency scores of 1 (100%) representing efficient among the 30 districts with the minimum score being 0.47 (47%). The average reduction required in number of VDs is 17.66 (-2.56%) and number of LACs is 145 (-2.43%) per district for achieving efficiency. Similarly the average increase in outputs required are nearly 40000 (28%) for AI, 194 (1050%) for infertility camps, 4600 (1141%) for infertility treatments, nearly 42000 (376%) for de-worming, 2.16 lakhs (28%) for treatments, nearly 23000 (59%) for castration and nearly 12.3 lakhs (24%) for vaccinations per veterinary district.

Table 2: Efficiency Scores, Ranks and input / output Projections of DMUs

Particulars	Statistics	Average	Max	Min	St Dev
Efficiency	Score	0.8422	1	0.4678	0.1572
	Rank	14	30	1	10.5045
Number of VDs (I)	Projection	17.6646	42	4	8.372
	Diff.(%)	-2.5618	0	-28.971	7.1603
Number of LAC (I)	Projection	145.068	330	30	75.2002
	Diff.(%)	-2.4345	0	-24.693	6.864
Total AI (O)	Projection	39855.9	95031	5056	22874.4
	Diff.(%)	28.0428	113.786	0	32.4447
Infertility camps (O)	Projection	193.668	715	2	208.083
	Diff.(%)	1049.91	17577.1	0	3302.47
Infertility treatment (O)	Projection	4611.03	17961.5	44	4695.82
	Diff.(%)	1141.06	25045.1	0	4549.86
De-worming (O)	Projection	41539.8	146299	98	34732.8
	Diff.(%)	375.703	3794.45	0	814.281
Treatment (O)	Projection	215985	599600	45900	132487
	Diff.(%)	28.4056	113.786	0	30.9955
Castration (O)	Projection	22949.6	93800	1300	18218.7
	Diff.(%)	58.8688	384.005	0	97.786
Vaccination (O)	Projection	1227844	2640500	487600	563593
	Diff.(%)	24.0689	113.786	0	27.9616

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VI. CONCLUSIONS

This paper has surveyed various important publications on models and methods of DEA and various applications procedure to be followed while applying the technique in different areas in public and private sectors and the not-for-profit organisations. The technique has evolved rapidly over the years and has devised models and methods and found applications in areas not thought of when the technique was originally devised. However, the applications in the not-for-profits and public sector areas for which the method was originally devised has been very limited and may need to be explored as new research areas. The technique is demonstrated using data of inputs and outputs of veterinary districts of Odisha. The results suggest that the average efficiency is 0.84 (84%). The decrease in inputs and increase in outputs to achieve efficiency of all DMUs is also discussed for individual inputs/outputs.

Notes: This paper is based on the research work done for the Ph.D. thesis of the first author, to be submitted to KIITDU.

REFERENCES

1. Ali A. I. & Seiford L. M. (1990), Translation invariance in data envelopment analysis. Operations research letters, 9(6), 403-405.
2. Banker R. D., Charnes A. & Cooper W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. Management science, 30(9), 1078-1092.
3. Banker R. D. (1984). Estimating most productive scale size using data envelopment analysis. European Journal of Operational Research, 17(1), 35-44.
4. Banker R. D. & Morey, R. C. (1986). Efficiency analysis for exogenously fixed inputs and outputs. Operations research, 34(4), 513-521.
5. Banker R. D. (1996). Hypothesis tests using data envelopment analysis. Journal of productivity analysis, 7(2-3), 139-159.
6. Banker R. D., Cooper W. W., Seiford L. M., Thrall R. M. & Zhu J. (2004). Returns to scale in different DEA models. European Journal of Operational Research, 154(2), 345-362.
7. Boussofiane A., Dyson R. G., & Thanassoulis E. (1991). Applied data envelopment analysis. European Journal of Operational Research, 52(1), 1-15.
8. Charnes A., Cooper W. W. & Rhodes E. (1978). Measuring the efficiency of decision making units. European journal of operational research, 2(6), 429-444.
9. Charnes A., Cooper W. W., Golany B., Seiford L. & Stutz J. (1985). Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions. Journal of econometrics, 30(1-2), 91-107.
10. Charnes A., Haag S., Jaska P. & Semple J. (1992). Sensitivity of efficiency classifications in the additive model of data envelopment analysis. International Journal of Systems Science, 23(5), 789-798.
11. Charnes A., Rousseau J. J. & Semple J. H. (1996). Sensitivity and stability of efficiency classifications in data envelopment analysis. Journal of productivity analysis, 7(1), 5-18.
12. Cook W. D. & Seiford L. M. (2009). Data envelopment analysis (DEA)–Thirty years on. European journal of operational research, 192(1), 1-17.
13. Cook W. D., Tone K. & Zhu J. (2014). Data envelopment analysis: Prior to choosing a model. Omega, 44, 1-4.
14. Cooper W. W., Seiford L. M., & Tone, K. (2006). Introduction to data envelopment analysis and its uses: with DEA-solver software and references. Springer Science & Business Media.
15. Doyle J. & Green R. (1994). Efficiency and cross-efficiency in DEA: Derivations, meanings and uses. Journal of the operational research society, 45(5), 567-578.
16. Dyson R. G., Allen R., Camanho A. S., Podinovski V. V., Sarrico C. S. & Shale E. A. (2001). Pitfalls and protocols in DEA. European Journal of operational research, 132(2), 245-259.
17. Emrouznejad A. & Yang G. L. (2018). A survey and analysis of the first 40 years of scholarly literature in DEA: 1978–2016. Socio-Economic Planning Sciences, 61, 4-8.
18. Färe, R., & Lovell, C. K. (1978). Measuring the technical efficiency of production. Journal of Economic theory, 19(1), 150-162.
19. Farrell, M. J. (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society: Series A (General), 120(3), 253-290.
20. Førsund, F. R. (2018). Economic interpretations of DEA. Socio-Economic Planning Sciences, 61, 9-15.
21. Frei, F. X., & Harker, P. T. (1999). Projections onto efficient frontiers: theoretical and computational extensions to DEA. Journal of Productivity analysis, 11(3), 275-300.
22. GoO (2016), Annual Physical Activity Report 2010-11, Directorate of animal husbandry and veterinary services, FARD, Government of Odisha, accessed on 7/2/2016.
23. Golany B. & Roll Y. (1989). An application procedure for DEA. Omega, 17(3), 237-250.
24. Pastor J.T. (1996). Translation invariance in data envelopment analysis: A generalization. Annals of Operations Research, 66(2), 91-102.
25. Pastor J.T., Ruiz J.L. & Sirvent I. (1999). An enhanced DEA Russell graph efficiency measure. European Journal of Operational Research, 115(3), 596-607.
26. Ray, S. C. (1988). Data envelopment analysis, nondiscretionary inputs and efficiency: an alternative interpretation. Socio-Economic Planning Sciences, 22(4), 167-176.
27. Sexton T. R., Silkman R. H. & Hogan A. J. (1986). Data envelopment analysis: Critique and extensions. New Directions for Program Evaluation, 1986(32), 73-105.
28. Smith, P. C., & Street, A. (2005). Measuring the efficiency of public services: the limits of analysis. Journal of the Royal Statistical Society: Series A (Statistics in Society), 168(2), 401-417.
29. Thrall R. M. (1996). The lack of invariance of optimal dual solutions under translation. Annals of Operations Research, 66(2), 103-108.
30. Tone K. (1996). A simple characterization of returns to scale in DEA. Journal of the Operations Research Society of Japan, 39(4), 604-613.
31. Tone K. (2001). A slacks-based measure of efficiency in data envelopment analysis. European journal of operational research, 130(3), 498-509.

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Prof. L.K. Vaswani was Director, KSRM, KIIT DU and Ph.D. guide to Prof. Ganesha at the time of this research, is currently an adjunct faculty at IRMA and MICA, India. A Ph.D. from Hissar Agriculture University, has more than 42 years of experience as a Faculty and in Industry, has been the director of IRMA. Has published more than 60 research papers, completed more than 50 consulting assignments organisations including World Bank, conducted more than 120 MDPs, and guided 6 scholars for Ph.D and two in the pipeline. His areas of interest are Rural Marketing, CSR and Agriculture Value Chains.

Prof. Rabi N. Subudhi is presently a Senior Professor in the area of Quantitative Methods – Decision Sciences, with over 32 years of teaching experience at University level. He has served earlier at Berhampur University, VIT B-School of VIT University, and KIIT School of Rural Management (KSRM), for their MBA programmes. He has done FDPM from IIM Ahmadabad. He received Senior Research Fellowship (SRF) award of CSIR, Govt. of India, for his doctoral research. He is an active member of many reputed international academic society, like: American Society of Engg. Mgmt (ASEM), ISA-RC (International Sociology Association 'Research Methodology' Sec.), IFORS, ORSI, ICA and ICAS (Int. Conv. of Asian Scholars). He has published/ edited 8 books and authored over 60 research papers. He is an active member of many professional academic bodies and also member of 'Board of Studies' of different Universities. For 6 years he was the editor of management research journal 'Strategy' (of BU), and presently in charge of editing, KIIT Management Research Journal – *Parikalpana*. He has also published many articles in regional language and takes interest in Children's literature. He was the founding editor of a children's fortnightly, 'Suman'.