PERFORMANCE BENCHMARKING OF COMPLEX INFRASTRUCTURE PROJECTS

PARTHA SARATHI BANERJEE

CIVIL ENGINEERING DEPARTMENT
INDIAN INSTITUTE OF TECHNOLOGY DELHI

FEBRUARY 2016

PERFORMANCE BENCHMARKING OF COMPLEX INFRASTRUCTURE PROJECTS

by

PARTHA SARATHI BANERJEE
Civil Engineering Department

Submitted
in fulfillment of the requirements of the degree of Doctor of Philosophy
to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

FEBRUARY 2016

Dedicated

to

My parents, wife and daughters

CERTIFICATE

This is to certify that the thesis titled **"PERFORMANCE BENCHMARKING OF COMPLEX INFRASTRUCTURE PROJECTS"** being submitted by **Mr. Partha Sarathi Banerjee** (Entry No. 2009CEZ8520) to the Indian Institute of Technology, Delhi for the award of degree of Doctor of Philosophy is a bonafide record of the research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the requisite standard, fulfilling the requirements of the said degree. The results contained in the thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

Dr. Anil Sawhney
Associate Dean, Director and Professor
RICS School of Built Environment
Amity University
Noida, Uttar Pradesh – 201 313 (India)

Kciyer 16/2/2016
Dr. K. Chandrashekhar Iyer
Professor
Department of Civil Engineering
Indian Institute of Technology, Delhi
Hauz Khas, New Delhi – 110016 (India)

Date: 16th Feb 2016

ACKNOWLEDGEMENT

Since my young professional days, a cherished goal has been to complete doctoral studies. The journey of my life did not allow an early enrolment and finally when it did, the competing demands from academic, professional and social spheres in my life needed constant balancing. However, this same inflexion point also brought in many professional well-wishers, an overwhelmingly strong social support base, and enhanced level of matured guidance from my academic mentors all of which I may not have got in my younger days.

As I complete my thesis work and pause to look back at the past years, I humbly wish to express my deepest appreciation to all whose help and, most importantly, selfless service have enabled me to reach this important milestone in my career. I am also aware that my words of acknowledgement are grossly inadequate for recognizing all of their efforts. It is difficult to single out contributions, but I would fail myself if I did not mention at least a few of such extraordinary contributions.

First, I am extremely grateful to my supervisor Professor K. Chandrashekhar Iyer for his unwavering support and constant guidance. He reposed faith in my abilities throughout the enrolment period. Without his mentoring, especially during difficult personal times of my medical exigencies, the thesis would not have attained its present status. Professor Iyer's meticulous approach to work, depth of thinking, application of analytical methods for problem-solving, and deriving practical insights from research findings has left an indelible and lasting influence on me. It has been incredible experience learning from him.

I am also equally grateful and obliged to my co-supervisor Professor Anil Sawhney, Associate Dean, Director and Professor of RICS School of Built Environment, for shaping my thinking and approach to work. His guidance has helped me achieve this career milestone.

I wish to express my gratitude to the SRC members Professor K. S. Rao and Dr Uma Maheshwari from Department of Civil Engineering, and Professor Sushil from Department of Management Studies. Their support and review comments at different stages of my work were invaluable. I also gratefully acknowledge the valuable suggestions received from Professor Niladri Chatterjee from Department of Mathematics.

Dr. Arup Roy Choudhury, Chairman and Managing Director NTPC Limited, has been a great source of inspiration for me throughout my doctoral pursuit. His facilitation support for data collection, site visits and large number of personal interviews has helped me to bring out contextual insights which otherwise would not have been possible. I wish to express my deepest gratitude and humble appreciation for his support and affection.

I would like to give special note of thanks to Mr. D. K. Ojha, Director Infrastructure Division, Ministry of Statistics and Programme Implementation, Government of India for providing necessary authorization to approach organizations for conducting the research study. My sincere appreciation to more than 150 officials of NTPC Limited, National Fertilizers Limited, Neyvelli Lignite Corporation, Gas Authority of India Limited, Steel Authority of India Limited and Airport Authority of India who participated in the study and gave their valuable time, inputs and respective organisational data.

I am grateful to my ever-smiling colleague in Deft Advisory and Research, Mr Ajay Rawat, for sharing my professional workload during the period of field studies and analysis. This immense support enabled me take out time for my academic work.

Last but not the least, I wish to express sincere gratitude to my wife Sripurna for her love and understanding throughout the period of this study. Without her support this thesis would have remained as a long cherished dream. Words cannot express my gratefulness to my elder daughter Priyadarshini for her love and inspiration and my younger daughter Madhumanti for her encouragement; both of them have been pillars of support behind my endeavour. My mother, sister and in-laws have given me limitless love and affection, I wish to thank them for that.

Finally, I am eternally indebted to my late father for spiritual love and blessings.

(Partha Sarathi Banerjee)

ABSTRACT

The research commenced with a preliminary analysis of data from 630 projects having an outlay of more than INR 1500 million (approx. USD 25 million) for five years ending 2009, 2010, 2011, 2012 and 2013. This data was made available by Ministry of Statistics and Programme Implementation (MoSPI), Government of India. An initial analysis by MoSPI of the schedule performance of these projects showed delays in execution which could be attributed to managerial inefficiencies during planning and construction. Taking this cue, the objective of this research was set to study managerial efficiency of infrastructure project execution in detail and, as an outcome, develop a method to measure and benchmark the managerial efficiency of project execution. Such a benchmarking exercise when implemented could then set the stage for improving schedule performance of projects. Emanating from the above objective were the following sub-objectives:

i. Develop and test a managerial efficiency benchmarking method that can be applied to improve schedule performance in a wide range of large and complex projects across infrastructure sectors.
ii. Build a Project Complexity Index and measure its impact on performance benchmarking of managerial efficiency in complex infrastructure development projects.

Thirteen projects covering sectors such as power generation, large industrial (steel and fertilizer) units, network utilities (gas compressor stations) and airports construction were taken up for detailed study. The researcher adopted Grounded Theory (GT) approach synthesized with pre-existing knowledge frameworks to collect empirical project case data through open coding and then grouped them through GT selective coding process. The empirical case data thus generated from projects was inductively analyzed using set-theoretic approaches to develop causal factors. These factors were then further configured using appropriate modeling techniques at different stages of study. This approach was used in an initial study of a large and complex airport construction project. After establishing the approach and its findings, the researcher gained confidence on its utility and used it as an inquiry tool in this study.

The sequence of case studies began with the delayed case of fertilizer production unit construction projects. It revealed unique insights and provided cues for further study of Technology Transfer (TT) projects and approach to develop the benchmarking model. In the next stage delayed, sector-wide TT projects of super-critical steam based power generation were studied in their natural settings. Grounded findings of causal factors were validated through an independent survey of equipment manufacturers and thereafter were used to finalize the combinatorial set of causal factors and the propositions which were taken forward for Structural Equation Modeling (SEM). Inferences drawn from the SEM were validated and discussed in two sections: (a) new insight related to earlier TT models and, (b) important findings from this study. The three significant outcome enablers of TT projects were taken forward to subsequent stages of the study.

Benchmarking managerial efficiencies of large projects across infrastructure sectors have been difficult. Most past studies have considered either one or two sectors to illustrate findings. This research attempted to study managerial efficiencies in large projects across multiple infrastructure sectors and to that extent contributed to the taking steps to improve performance of a national portfolio of infrastructure projects which is the need for almost every developing country.

A basket of projects 57 were selected to measure and benchmark the managerial efficiency of project execution. These were configured as Decision Making Units (DMU) in a DEA procedure. This procedure was then integrated with Principal Component Analysis (PCA) to: (i) reduce the dimensionality of data set without losing the main information; (ii) detect structure in the relationships between variables to classify them. Suitable modifications were also made in this DEA-PCA engine and factored in the overall and relative performance of projects to measure and rank their managerial efficiency. The DMUs were then classified based on their inputs and managerial efficiency scores. An appropriate classification method was chosen and clusters of inputs were combined with clusters of managerial efficiencies to evolve a five category benchmarking model. Representative DMUs were discussed to illustrate findings from the benchmarking model.

The managerial efficiency benchmarking model was further improved upon by distinguishing the execution difficulty based on their respective project complexities. A two-tiered Project Complexity measurement framework was developed with four equal-weighted constructs at the top tier and 16 variables in the second tier. Based on this framework, the Project Complexity Index (PCI) was computed for the set of 57 projects identified earlier. The PCI was then applied as an adjusting factor in the modified DEA-PCA benchmarking engine developed in the previous stage of this study. Application of the PCI to adjust the managerial efficiency scores emanating from the DEA-PCA based benchmarking showed it to be a meaningful distinguishing factor. Especially it effectively re-categorized the lesser complex, under-performing DMUs in Civil (versus Mechanical) works and Enabling (versus Core) packages. In addition, the analyses show larger managerial efficiency gains can be achieved in smaller value and less complex (less than INR 5 billion) packages rather than those with higher value.

Though benchmarking as a methodology attempts to achieve significant improvements, the present performances of complex infrastructure projects in India needs a calibrated efficiency improvement approach and dwell in the realms of setting feasible improvement targets. Hence, the selection of benchmarking method kept in view implementation difficulties and recommended that reasonably liberal thresholds be set at the beginning of the implementation process. Going forward, these thresholds can be incrementally tightened as and when the project performances begin to improve.

Keywords: Benchmarking; Project Complexity; Managerial Efficiency; Schedule Performance; Technology Transfer; Data Envelopment Analysis; Qualitative Comparative Analysis; Structural Equation Modeling; Principal Component Analysis; Cluster Analysis.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AAI	Airports Authority of India
AFCP	Ammonia Feedstock Conversion Project
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
EDC	Euclidean Distance Classification
EPC	Engineering, Procurement and Construction
FO	Fuel Oil
GAIL	Gas Authority of India Limited
GHG	Green House Gas
GT	Grounded Theory
JV	Joint Venture
KBR	Kellog Brown and Root
KMC	K-Means Classification
LSTK	Lump-Sum Turn-Key
MOSPI	Ministry of Statistics and Programme Implementation
NFL	National Fertilizer Limited
NG	Natural Gas
NLC	Neyvelli Lignite Corporation
NTPC	National Thermal Power Corporation
PC	Principal Component
PCA	Principal Component Analysis
PCI	Project Complexity Index
PMI	Project Management Institute
QCA	Qualitative Comparative Analysis
SAIL	Steel Authority of India Limited
SEM	Structural Equation Modeling
SOE	State Owned Enterprise
TT	Technology Transfer
UNIDO	United Nations Industrial Development Organization