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SELECTION AND PRIORITIZATION OF PROJECTS – A DATA ENVELOPMENT ANALYSIS (DEA) APPROACH

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Abstract

When an organization has multiple projects to be initiated the challenge it faces is the lack of a methodology that would select and prioritize projects that compete for limited resources. This research applies the Data Envelopment Analysis (DEA) approach to the selection and prioritization of projects. Published research will be used to identify factors used in the selection of projects, classify these factors into inputs and outputs, then develop and solve a DEA model for each project. Results from the solved DEA models will be analyzed to identify highly efficient projects and make recommendations on how to improve inefficient projects.

Keywords: *DEA, DEA inputs, DEA outputs, project selection*

I. INTRODUCTION

Decision making is at the core of all management functions. Managers are constantly called upon to make decisions in order to solve problems and/or to select one course of action from several possible alternative actions in order to obtain the goals and objectives of the organization. Since decisions direct actions, decisions regarding an organization's, resources, strengths, weaknesses, and future growth are all important factors that will have a considerable impact on the performance of a firm and which will determine the success or failure of the firm. For the past two decades, a factor that has had a significant impact on decision making in many firms is globalization. During the 1990's the forces of globalization (i.e., new demands of international competition and dramatic advances in technology) substantially changed the nature and operation of markets and organization of the production function in many industries throughout the world. As a result, today's highly competitive and demand driven market has put increased pressure on management to allocate and utilize resources appropriately in an effort to achieve optimal

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performance efficiently. Since decisions may be related to the allocation of scarce organizational resources, some of which involve substantial resources, may be difficult to reverse and can affect a company's business into the future, it is important that decisions are made that allow a firm to operate as efficiently and effectively as possible with the given resources.

One of the results of globalization is that it has had a huge impact on the way that organizations perform activities. In order for firms to keep pace with the fast changing environment there is a greater emphasis on project management. Project management was primarily driven by firms that realized the benefits not only of organizing work around projects, but also the need to communicate and coordinate tasks across departments and professions. It is an effective way of dealing with international projects. For project managers and their teams the decision making process often involves selecting one alternative project from several alternative projects. The decision making may be complicated since one or more projects selected from competing projects may be evaluated according to different criteria. Some projects require multiple decision makers and difficulties may arise due to different goals involved. For example, an important part of decision making for competing projects is to verify and validate alternatives. This may require input not only from the project manager but also from engineers or analysts. Even if decision makers share the same selection criteria, the importance level that is attached to each criterion is not necessarily the same, due to different budgets, time factors, alternative projects under consideration etc. At times several competing projects may be considered at the same time, with no interest a priori to one or more of the projects. The decision making may be further complicated because of a large number of attributes that must be considered. As a result, in order to arrive at a viable decision, managers at times must cope with an enormous amount of data relating to competing projects. Consequently, selecting the 'best' project from a potentially large number of different projects with varying levels of capability and potential is a complicated and time-consuming task. In summary, at any time a typical organization has multiple projects to be initiated and the challenge organizations face is the lack of a methodology that would help them select and prioritize projects that simultaneously compete for limited organizational resources. This paper presents an example of how Data Envelopment Analysis (DEA) may be used as a tool for selection and prioritization of projects. A review of the last 25 years of research involving applications of DEA methodology is summarized in Table 1. This table is not meant to be a comprehensive review but rather an overview of the different applications, inputs and outputs that have been utilized with DEA.

The next section summarizes the basics of DEA and its application in managerial decision-making. This is followed by a section that summarizes a DEA approach for selection and prioritization of projects. Next, a DEA model for project selection decision is developed and solved. Finally, model results are analyzed and interpreted to identify managerial implications of the DEA approach to project selection.

Table 1
Inputs and Outputs for Different Applications of DEA

Source	*Application*	*Inputs*	*Outputs*
Cheng *et al.* (2007)	Provides banks with a methodology to evaluate concessionaires	• Concession period • Financial risk to borrower	• Toll setting up and adjusting mechanism • Total investment schedule • Attractiveness of main loan • Financial o Analysis o Strength of other participants • Net present value • Internal rate of return
El-Mashaleh *et al.*, (2007)	Firm performance of construction contractors.	• Expenses o Project management o Safety	• Performance o Schedule o Cost o Safety • Customer satisfaction • Profit
Vinter *et al.* (2006)	Evaluating the performance of several projects	• Cost • Work content • Level of o Monitoring o Uncertainty	• Performance o Schedule o Cost • Design • Documentation
McCabe *et al.* (2005)	Pre-qualification of construction contractors	• Safety record • Current capacity • Related work experience	• Sales history • Employee experience
Athanasso-poulos *et al.* (1999)	UK electricity generating	• Capital expenditures • Controllable costs • Fuel (quantity)	• Electricity produced (megawatt-hour) • Plant availability (%) • 1/ Number of accidents incurred • 1/ Generated pollution
Al-Shammari (1999)	Jordanian manufacturing firms	• Number of employees • Paid in capital • Fixed assets	• Market value per share • Net sales • Net income after taxes
Peck *et al.* (1998)	US aircraft maintenance	• Labor expenses o Airframes/total aircraft operating expenses o Aircraft engines/ total aircraft operating expenses	• Percentage of all scheduled flight arrivals not delayed for mechanical reasons

contd. table 1

Source	*Application*	*Inputs*	*Outputs*
		• Expenditures o Airframe repairs/ total aircraft operating expenses o Engine repairs / total aircraft operating expenses • Material expendi-tures o Airframes/total aircraft operating expenses o Engines/total aircraft operating expenses	
Kozmetsky (1998)	Global semiconductor companies	• Cost of goods sold • Selling, general, and administrative expenses • Total assets	• Net sales
Kirjavainen and Loikkanen (1998)	Finnish secondary schools	• Hours per week o Teaching o Non-teaching • Teachers o Experience o Education • Admission level • Education level of students' parents	• Number of students who passed their grade • Number of graduates • Score of students in compulsory subjects in matriculation examination • Score of students in additional subjects in matriculation examination
Goto and Tsutsui (1998)	US and Japanese electric utilities	• Total number of employees • Generation capacity (mega watt) • Quantity of o Fuel used (kilo calories) o Power purchases (giga watt hours)	• Quantity of electricity • Sold to residential customers (giga watt hours) o Sold to non-residential customers (commercial, industrial, others)
Chu and Lim (1998)	Singapore banks	• Shareholders fund • Interest expenses • Operating expenses	• Annual increase in average assets • Total income • Profits

contd. table 1

Source	*Application*	*Inputs*	*Outputs*
Chandra *et al.* (1998)	Canadian textiles companies	• Number of employees • Average annual investment	• Annual sales
Ahuja and Majumdar (1998)	Indian manufacturing enterprises	• Number of employees • Net fixed assets	• Net value added
Rouse *et al.* (1997)	New Zeland highway maintenance	• Total expenditures on reseals, rehabilitation and general maintenance (contractor costs)	• Kilometers of o Highway resealed o Highway rehabilitated • General maintenance as measured by an index of highway surface defects • Level of service as measured by annual vehicle kilometers • Roughness measures combined for urban and rural highways • Categorical variable (an assessment of environmental difficulty faced; geology and climate)
Baker and Talluri (1997)	Technology selection (robots)	• Cost • Repeatability (mm)	• Load capacity (kg) • Velocity (m/s)
Thore *et al.* (1996)	US computer industry	• Costs o Raw material o Labor • R&D expenditures • Capital investment	• Sales revenues • Profits • Market capitalization (number of shares outstanding multiplied by the stock price)
Russel *et al.* (1996)	US oil companies	• Total costs incurred • Quantity o Proved crude oil o Proved gas	• Quantity o Crude oil o Gas
Ozcan and McCue (1996)	US hospitals	• 1 (scalar or dummy variable)	• Return on assets • Operating cash flow per bed • Operating margin • Total asset turnover
Odeck (1996)	Rock blasting in Norway	• Cost o Labor o Capital o Commodity	• Blasted rock volume (m3)

contd. table 1

Source	*Application*	*Inputs*	*Outputs*
Hjalmarsson and Odeck (1996)	Trucks in road construction and maintenance in Norway	• Make and model year • Region of operation • Capacity of the truck in tons • Costs o Wage of driver per year o Fuel per year o Rubber accessories o Maintenance	• Transportation work in kilometers per year • Volume transported in cubic per year • Effective hours in production per year
Thanassoulis (1995)	Police forces in England and Wales	• Number of o Violent crimes o Burglaries o Other crimes o Officers	• Number of o Violent crime clear ups o Burglary crime clear ups o Other crime clear ups
Ray and Kim (1995)	US steel industry	• Labor hours • Cost of material	• Quantity (weighted index of quantities shipped of 80 different steel products)
Lovell *et al.* (1995)	Macroeconomic performance of European countries	• 1 (scalar or dummy variable)	• GPD per capita • 1/ inflation • Employment rate • Trade balance (Exports/Imports) • 1/ (carbon emissions in millions of tons per capita) • 1/ (nitrogen emissions in millions of tons per capita)
El-Maghary and Lahdelma (1995)	Finnish universities	• Total expenditure • Admission (acceptance rate)	• Number of graduates • Number of post graduates • Graduation speed (1/years) • Completion
Athanasso-poulos and Ball (1995)	UK grocery industry	• Capital employed • Fixed assets • Number of employees • Number of outlets • Sales area (m2)	• Total sales

contd. table 1

Source	*Application*	*Inputs*	*Outputs*
McCarty, Yaisawarng (1993)	US school districts	• Number of staff per pupil • Percentage of staff on M.S. Or PHD • Expenditure per pupil	• Percentage of students o Who pass HSPT test o Who pass MPCT test o Who pass RPCT test
Lee and Somwaru (1993)	Share tenancy in US agriculture	• Fertilizers • Pesticides • Seeds • Hired labor • Capital consumption	• Revenues
Eeckaut *et al.* (1993)	Belgian municipalities	• Total operating expenses	• Total population • Length of roads to be maintained • Number of o Senior citizens o Crimes registered in the municipality o Students enrolled in primary schools
Burgess and Wilson (1993)	US veterans hospitals	• Number of o Acute care hospital beds o Long term hospital bids • Clinical labor • Non-clinical labor • Physician hours	• Inpatient days • Number of o Inpatient discharges o Outpatient visits o Ambulatory surgical procedures o Inpatient surgical procedures
Charnes *et al.* (1988)	Chinese cities	• Number of staff and labor • Working fund • Investments in construction and acquisitions of machinery	• Gross industrial output value • Profit and taxes • Retail sales
Grosskopf and Valdmanis (1987)	US hospitals	• Number of physicians • Non-physician labor • Admissions • Net plant asset	• Acute care (inpatient days) • Intensive care (inpatient days) • Surgeries (in-patient and out-patient surgeries) • Ambulatory and emergency care (number of visits)
Bowlin (1987)	US Air Force real-property maintenance	• Supply costs • Available direct labor hrs • Available passenger carrying vehicle (vehicles)	• Completed work orders • Completed job orders • Completed recurring work actions • Delinquent job orders

II. DATA ENVELOPMENT ANALYSIS (DEA)

Data Development Analysis (DEA) is an application of the linear programming technique and was developed by Charnes *et al.* (1978) to measure the relative efficiencies of options which involve multiple, incommensurate inputs and outputs. These options are referred to as decision-making units (DMUs). DEA has found a variety of applications in several areas and has been used to measure the performance of physician practices, component suppliers, school districts, banks hospitals, robots, courts etc. Several of these applications were summarized in Table 1 under section I. Lall and Teyarachakul (2006), Thanassoulis *et al.* (1978), Boussofiane et al. (1991) and several other papers addressed the fact that information obtained from DEA assessment can be used to discover which DMUs can be classified as efficient or inefficient, identify possible good operational practices and explore the possibility of setting targets for inefficient units. Banker and Morey (1986) presented the DEA formulation to evaluate the efficiency of DMUs when some of the inputs and outputs are exogenously fixed and beyond the control of the DMUs. Recently, DEA has been integrated with the multiple-objective linear programming (MOLP) as an interactive approach to a resource-allocation problem in organizations with a centralized decision-making environment. Golany (1988) proposed the use of preference information when setting the performance targets in the context of DEA. Sutton and Green (2002) used the DEA notion to evaluate decision choices. They suggested the modified DEA to find weights which show the performance of options and to provide a framework to elicit and use information exogenous to the decision alternatives. The efficiency score of each DMU is determined by the weighted sum of outputs divided by the weighted sum of inputs. Charnes *et al.* (1978) recognized the difficulty in seeking common weights because each DMU may value inputs and output differently; they proposed to use a set of weights that give the highest possible relative efficiency scores.

The fractional form of DEA, which maximize the efficiency h0 of the j0 DMU is defined as follows:

$$\text{Max} \qquad h_0 = \frac{\sum_{r=1}^{t} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}}$$

$$\text{s.t.} \qquad \frac{\sum_{r=1}^{t} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad j = 1\ldots, j_0 \ldots, n$$

$$u_r \geq \varepsilon \quad r = 1\ldots t,$$

$$v_i \geq \varepsilon \quad i = 1\ldots m, \qquad \text{(Model M1)}$$

where

y_{rj} = the amount of the r^{th} output from unit j,

u_r = the weight given to the r^{th} output,

x_{ij} = the amount of the i^{th} input to the unit j,

v_i = the weight given to the i^{th} input, and

ε = a very small positive number

Charnes and Cooper (1962) provide approaches to convert Model M1 into a linear programming model by setting the denominator in the objective function to some arbitrary constant and moving the denominator in the first constraints to the right-hand side of the constraint. For computational convenience, the DEA linear programming model is converted into a dual model as follows:

$$\text{Max} \quad Z_0 - \varepsilon \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{t} s_r^+ \right)$$

$$\text{s.t.} \quad Z_0\, x_{ij_0} - \sum_{j=1}^{n} x_{ij}\lambda_j - \bar{s}_i = 0 \qquad i = 1 \ldots m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{rj_0} \qquad r = 1 \ldots t$$

$$\lambda_j, \bar{s}_i, s_r^+ \geq 0 \qquad \text{(Model M2)}$$

where λ_j, $\bar{s}_i$, s_r^+ are the dual variables.

There are alternatives to measure the efficiency of a DMU. One may use either the input- reducing efficiency or an output-increasing efficiency measure. Both model M1 and M2 measure output-increasing efficiency. In measuring the input-reducing efficiency, the relative efficiency of a DMU (for example DMU j0) is evaluated by finding the best practice DMU's minimum effort required to produce the same amount of outputs as DMU j0 does. In other words, how much effort it takes for the best practice DMU (reference DMU) to produce as much outputs as DMU j0. We consider the application of DEA to project selection; the choices of DMU become project alternatives. For simplicity, we apply model M1 to select the best project candidate.

III. A DEA APPROACH FOR SELECTION AND PRIORITIZATION OF PROJECTS

DEA assesses the relative efficiency of DMUs by obtaining the maximum of a ratio of weighted outputs to weighted inputs. The selection criteria for competing projects will be the inputs and outputs in our study. Several selection criteria have been identified in the literature. Examples of these criteria include: Return on Investment, implementation time, clerical time, training time, net benefit, cost, efficiency, alignment with corporate strategy/goals, to name a few. Note that the units of measure of these criteria varies from $ to hours to percentages to subjective ratings. The DEA approach allows for the simultaneous use of data as it comes regardless of how different the units of measure of the output and input criteria under consideration are.

IV. DEA RESULTS

Relevant results from a DEA application are dependent upon the ratio of the number of input and output variables to the number of Decision Making Units. A rule of thumb for this ratio is given by Banker *et al*. (1984) as: $s + m < n/3$, where s is the number of inputs, m is the number of outputs and n is the number of DMUs. For illustration purposes and consistent with this rule of thumb, we will be considering 10 DMUs or projects and 4 project features. Return on investment and alignment with corporate strategy will be assumed to be *outputs* and implementation time and project cost will be assumed to be *inputs*. The data set used is included in Table 2. The original data set was obtained from McCain (2011) who applied the prioritization matrix technique to rank three alternative projects. To demonstrate the applicability of DEA to project selection and evaluation, seven additional projects with randomly assigned values of inputs and outputs were added to the original dataset. Alignment with corporate strategy is measured subjectively using a 1-5 score where 5 indicates perfect alignment. Implementation time is given in hours and cost in thousands of dollars.

Table 2
Project Selection Data (Modified from data set in McCain (2011)

Project	*ROI (%)*	*Alignment to Strategy*	*Implementation Time (Hrs)*	*Cost ('000)*
1	20	4	6000	2000
2	15	5	8000	1800
3	30	4	6500	1500
4	20	3	5000	2200
5	25	3	6500	1000
6	10	5	4000	900
7	35	3	7000	3000
8	10	4	6000	1700
9	40	4	10000	3500
10	30	3	5500	1200

Results from applying the DEA model are reported in Table 3. An examination of Table 3 indicates that projects 5, 6 and 10 exhibit a relative efficiency value of 1, meaning that for their individual *return on investment* percentage and *alignment to corporate strategy* score, no better *implementation time* and *cost* features could be offered by any of the competing projects under consideration.

Table 3
Project Efficiency Ratios

Project Number	*Efficiency Ratios*	*Reference Set*
1	0.792	Projects 6,10
2	0.581	Projects 6,10
3	0.929	Projects 6,10
4	0.842	Projects 6,10
5	1.000	—
6	1.000	—
7	0.917	Project 10
8	0.576	Projects 6,10
9	0.733	Project 10
10	1.000	—

The other seven projects under consideration exhibit a relative efficiency value of below 1, indicating that at least one other project in the sample offers better *ROI* and *alignment to corporate strategy* features for comparable levels (hours and $) of *implementation time* and *cost* features. As an illustration consider project 8. The DEA model suggests that project 8 is 42.4% less efficient than its reference set, namely, projects 6 and 10. An examination of the data associated with projects 8 and 6 reveals that a higher alignment score (5,4) and at least as high ROI (10,10) is attained with project 6 than with project 8 even when implementation time and cost features are higher for project 8 (6000, 1700) than for Project 6 (4000, 900). This indicates that one could expect at least as good of a return and better alignment with corporate strategy from project 6 even though it costs less and takes less time to implement than project 8. A consequence of this finding would be that in order for project 8 to be as attractive as project 6, the input variable *cost* would need to change, i.e. the cost of the project will have to be less and/or the implementation time feature will have to improve. As it can be seen then, the DEA results allow for an easier examination of why some projects are in fact better than others and thus provide an opportunity to determine what it would take for a given project to improve its standing relative to others in the sample. In addition, as indicated previously, the DEA approach allows for the use of various units of measure to be included simultaneously and in 'raw' form.

V. CONCLUSIONS, LIMITATIONS AND OPPORTUNITIES

In this paper, a DEA approach is proposed as an alternative procedure to assist decision-makers select the best project from several being considered. An actual data set available in the literature was modified by adding additional projects with corresponding inputs and outputs. This modified data set was used to illustrate how the DEA model works and to compare its features with those of an existing and fairly common procedure (use of informed weights and scores). In the data set used, subjective scores were assigned to the various features offered by the competing projects. Given that the DEA approach allows for the simultaneous consideration of inputs/outputs with different measurement units, a possible area of opportunity would be to replace the scores assigned to various inputs and outputs with actual raw data. For example, the output alignment to strategy could be replaced with another feature that used numerical data and not a rating. Sensitivity analysis may be performed on the results to determine what specific changes must occur in the input and output values of a project showing a relative efficiency of less than 1 in order for the package to attain a relative efficiency of 1.

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