Evaluating Team Performance Using Slack Based Data Envelopment Analysis

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Abstract— **The main objective of this paper is to devise a Data Envelopment Analysis (DEA) model to assess team performance. The DEA model in this study uses slack based measure (SBM), a method which deals directly with the input excesses and output shortfall. An explanatory example has been given to demonstrate the applicability of the model to evaluate team performance. From this study, it is found that DEA is suitable to measure team performance. The model is able to provide improvement targets to the inefficient teams. Lastly, a few directions for future research have been identified.**

Keywords— **Team performance evaluation, Data Envelopment Analysis (DEA), Slack Based Measure (SBM)**

I. INTRODUCTION

Traditionally, employees have been evaluated and rewarded as individuals. This type of evaluation is still practiced in organizations where most work is still independently completed by different individuals. However, today's business environments have become much complex and dynamic which have been attributed to globalization and competitiveness of the global economy [1]. Complex and dynamic environments require fast and innovative responses [2]. To cope with these challenging environments, increased employee involvement is mandatory because these conditions require rapid decision making, flexible approaches, capital-intensive processes, and knowledge work [1]. Many mechanisms to increase employee involvement involve the creation of formal or informal teams to facilitate integration, coordination, and innovation [1].

In order to cope with increasing demands for faster product introduction and higher quality products and services, teams are formed. A team is a unit formed by two or more individuals who interact with each other dynamically, interdependently, and flexibly [3]. Team members share same valuable goals, objectives, tasks, and operating environments [4]. Teams can both be temporary and permanent. Temporary teams are formed to solve a particular problem and may be disbanded after they have achieved their objectives. Permanent teams are established to achieve long term objectives or solve long term problems.

Since many organizations have formed teams to accomplish complicated tasks more effectively and efficiently, it is important for such organizations to include team performance assessment in their appraisal system. Team performance can be viewed as the actual results of a team in achieving its targets [5].

Team performance evaluation has been extensively researched due to its importance on organizational performance. However, it remains to be a difficult area due to standardized measures are still lacking. Evaluation systems which indicate clearly which measures to consider and show how well the teams are performing are needed.

Performance measures or metrics are an important component of performance evaluation. Experts in the field of performance measurement have proposed an array of possible measures. However, these measures have to be evaluated before adopted for team evaluation. In addition, it is hard, if not impossible, to propose a universal set of measures for all organizations to evaluate their teams due to the differences between the organizations. For instance, a manufacturing firm's and an accounting firm's measurements would be fundamentally different. Therefore, care must be taken in deciding a set of performance measures to be implemented in an organization.

Furthermore, a sound team performance evaluation has to ensure that all the important elements must be measured to get a true picture of a team's performance. However, due to the interdependencies between the measures, it would be very difficult to establish explicit relationships between them.

Another important feature of performance evaluation is providing feedback to the teams so that the teams would not only know their performance levels but also have an idea on which areas they should improve on.

The major objective of this paper is to propose a method to measure team performance based on Data Envelopment Analysis (DEA). In this paper, team performance is evaluated as a process which converts multiple inputs into multiple outputs. A productivity approach is use where the performance is measured by a weighted ratio of the outputs to the inputs. To ensure fairness in the evaluation, DEA is used to devise the team performance evaluation model. DEA is a mathematical model which determines the set of weights for the measures which would optimize the performance score of a decision making unit (DMU) under evaluation while comparing it relatively with the other DMUs.

The rest of the paper is structured as follows. The next section gives a review on the topic of team performance evaluation. Following this, the developed model will be explained. Then, an application of the model on research and development teams is demonstrated using experimental data. Finally, the paper ends by giving conclusions of the study and a few future research directions.

II. A Review on Team Performance Evaluation

A team is composed of individuals, often having heterogeneous knowledge, skills, and attitudes, working interdependently to achieve a shared goal [6]. The term team performance embodies teamwork, which can be understood as the behavioral, cognitive, and affective processes that teams possess in order to coordinate their interactions towards shared goals [7]. To achieve these goals, they have to coordinate, communicate, and cooperate [8]. Thus, team performance evaluation can be defined as the application of standardized evaluation tools to assess the goal achievements of teams in relation to the resources given.

Team performance evaluation can be used for multiple purposes. First, it can be used to guide learning through a systematic, developmental feedback [9]. Second, it provides a snapshot of team development. This allows management to have a clear picture on the current performance of its teams. Third, it can be used to validate the effectiveness of team trainings [9]. Fourth, it provides a guide to reward groups for good performance and encourage the organization to move towards a more team-focused environment [10]. Performance measurement contributes towards team success and it is necessary if members are to be rewarded for team performance [2].

Due to its importance, team performance evaluation has been widely researched and there are a number of team performance measurement models. Reference [11] reviewed about 130 models and frameworks of team performance. Among these different models and frameworks, the dominant framework is the input-process-output (IPO) framework, which originates from the general system theory and its many derivatives [11]. IPO models emphasize the importance of throughputs as mediators or moderators of the relations between input and output measures and they have advanced the collective understanding of the factors that constitute team performance [11].

Multiple measures have to be employed for performance evaluation [12]. Financial measures alone are not sufficient as they fail to capture critical aspects of performance and are not timely enough [13]. Scott and Tiessen found that teams that use comprehensive performance measurement, with both financial and non-financial measures, and encourage team members to participate in developing performance targets, perform better than those that do not [2]. Therefore, the measures should include not only the financial components, but also the other components such as quality, operational and cognitive elements. In addition, the measures used should be able to capture both the inputs and outputs of the teams. As mentioned earlier, a universal set of measures that can fit all organizations is not available. For a list of most commonly used measures, readers can refer to Scott and Tiessen [2]. An organization should increase the participation of its team members in developing a set of measures that is suitable for the organization based on its business nature.

Taking the approach of the IPO framework, this study developed a team performance evaluation model based on DEA. This will be explained in the following section.

III. DEA Model for Team Performance Evaluation

Taking the approach of the IPO framework, this study developed a team performance evaluation model based on DEA. This section will firstly present the conceptual model and the performance measures involved. Then, the developed DEA model will be described.

A. Conceptual Model for Team Performance Evaluation

In this study, a team is viewed as a DMU or process which converts multiple inputs into multiple outputs. In other words, this is an adaptation of the IPO framework. Figure 1 shows the conceptual model for this IPO concept.

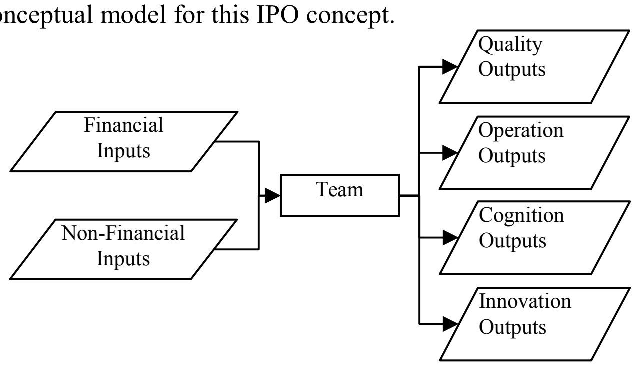

Figure 1. Team as DMU

The inputs or enablers are categorized into financial and non-financial inputs; while the outputs or results are categorized into quality, operation, cognition, and innovation outputs.

Tables 1 and 2 show the input and output measures proposed in this study. An explanation on the measures is given next. It has to be noted that this list is by no means to be an exclusive or universal list for evaluation of teams in any organization because as mentioned earlier, an organization has to develop a set of measures based on its business nature.

TABLE 1. Input Measures of Team Performance

Symbols	Inputs	Units	Categories
x_1	Number of team members	Number of members	Non-financial
x_2	Monthly number of hours of team meetings	Hour	Non-financial
x_3	Monthly expenditure on team trainings	USD	Financial
x_4	Monthly investment in supportive technologies	USD	Financial

TABLE 2. OUTPUT MEASURES OF TEAM PERFORMANCE

Symbols	Outputs	Units	Categories
y_1	Percentage of quality products	%	Quality
y_2	Percentage of satisfied customers	%	Quality
y_3	Percentage of on-time deliveries	%	Operation
y_4	Estimated monthly number of communications between members	Number of communications	Cognition
y_5	Monthly number of new ideas, knowledge, and solutions generated	Number of ideas, knowledge, and solutions	Innovation
y_6	Monthly number of new products or services generated	Number of products or services	Innovation

1) ***Input measures:*** The first input, x_1, is the number of team members, which is a non-financial measure. Team members are the fundamental building block of a team. They possess different skills and knowledge, collaborate and work together to achieve common goals and objectives. A team with more members is assumed to consume more resources and therefore is expected to produce more outputs.

The second input, x_2, is the monthly number of hours of team meetings, which is also a non-financial measure. Team meetings can have the objectives of information dissemination, idea generation, general discussion, trouble-shooting, etc. The number of hours is chosen instead of the number of monthly meetings because the former represents the consumed resources more accurately.

The third input, x_3, is the monthly expenditure on team trainings. This is a financial or monetary measure. Team trainings can be conducted by internal or external experts. They can be trainings on specific new knowledge or technologies or even team building activities. These trainings are means to transfer up-to-date knowledge to team members and foster a closer relationship between members and thus enhance team performance and teamwork.

The fourth input, x_4, is the monthly investment in supportive technologies, which is also a financial measure. Supportive technologies support team performance in various ways. These technologies include displays and tools to support shared situation awareness, groupware, task tracking and reporting systems, etc.

2) ***Output measures:*** The first output, y_1, is the percentage of quality products. This is grouped under the category of quality output. Quality products are measured by the total number of units produced minus defective, reworked, and scrapped units.

The second output, y_2, which is also in the category of quality output, is the percentage of satisfied customers. It can be a measure of the number of sales or number of customers served minus the number of complaints received.

The third output, y_3, is the percentage of on-time deliveries, which is an operation output measure. On-time delivery is widely used to measure the fulfillment of a customer's demand on the pre-agreed delivery date.

The fourth output, y_4, is set as the estimated monthly number of communications between members. Communications between employees such as emails and phone calls are a way to convey information and share knowledge and it is a cognitive process. It is a central catalyst of information processing and knowledge sharing. Furthermore, more communications also represent better relationships between the members.

The fifth output, y_5, is the monthly number of new ideas, knowledge, and solutions generated, which is categorized as an innovation output. This is a suitable measure to gauge how innovative the members are. The more they interact and synergize their knowledge, the better they will perform in this measurement.

The sixth output, y_6, is the monthly number of new products or services generated, which is also an innovation output. In the fast-paced, challenging, and knowledge-intensive environment, one of the ways that organizations can use to increase their customers is by introducing innovative products or services. Thus, this has been recognized as one of the measures for team performance as well.

B. DEA Modeling for Team Performance Evaluation

For the purpose of consolidating all the measures into a single score which can be easily interpreted by managers and team leaders, DEA is employed. DEA is a mathematical programming technique proposed by Charnes, Cooper, and Rhodes [14]. It compares the measures objectively and relatively between the DMUs (in this case, the teams) under evaluation and determines the optimum set of weights that yields the highest possible performance score for each DMU. DEA is identified to be a suitable tool in evaluating team performance because it can handle multiple inputs and outputs and it does not require prior assumptions on the weights.

A DMU's efficiency is calculated by comparing with all the DMUs under evaluation. The calculation of the performance score in DEA adheres to the traditional productivity performance evaluation approach which obtains the score from the weighted sum of outputs divided by the weighted sum of inputs. However, the set of weights for a DMU is computed in DEA with the objective to give the highest possible relative efficiency score for the DMU, while keeping the efficiency scores of other DMUs in the range of 0 to 1 under the same set of weights [15]. Generally, efficient DMUs obtain a score of 1 while inefficient ones obtain a score of less than 1.

There are a number of extensions and variations of DEA models. The DEA model chosen for this study uses the slack based measure (SBM) which was introduced by Tone [16]. SBM is chosen because it is able to deal directly with the input excesses and the output shortfalls of the DMU under evaluation, it is invariant to the units of measurement, and it is monotone decreasing with respect to each input and output slack [15]. The model is described as follows.

Consider there are n DMUs: DMU_1, DMU_2, …, and DMU_n. Each DMU_j, (j = 1, 2, …, n) uses m inputs x_{ij} (i = 1, …, m) and generates s outputs y_{rj} (r = 1, …, s). Let the input slacks (surpluses) be s_i^- (i = 1, …, m) and the output slacks (shortfalls) be s_r^+ (r = 1, …, s). Let the DMU_j to be evaluated on any trial be designated as DMU_0 (0 = 1, 2, …, n). The performance score E_0 of each DMU_0 is found by solving the SBM model shown in Model (1) [15].

$$\min E_0 = \frac{1-\frac{1}{m}\sum_i \frac{s_i^-}{x_{i0}}}{1+\frac{1}{s}\sum_r \frac{s_r^+}{y_{r0}}}$$
$$s.t. \sum_j \lambda_j x_{ij} + s_i^- = x_{i0}$$
$$\sum_j \lambda_j y_{rj} - s_r^+ = y_{r0} \qquad (1)$$
$$\sum_j \lambda_j = 1$$
$$\lambda_j, s_i^-, s_r^+ \geq 0$$

where λ is a nonnegative vector of weights for the inputs and outputs. The highest score a DMU can obtain is 1, which is only achievable when all slacks are equal to zero. Similar to traditional DEA models, a DMU is considered as efficient only if it gets an efficiency score of 1; else it is considered as inefficient. Next, to provide feedback to the inefficient teams on how much improvement they should achieve in their measurements, improvement targets are calculated through an operation called SBM-projection. This is done by subtracting the input excess and augmenting the output shortage as shown in Model (2). For r = 1, 2, and 3, the improvement targets are limited to be within 100 because the unit for y_1, y_2, and y_3 is percentage, thus cannot be more than 100. These improvement targets can be used by teams to devise plans to shift themselves to the efficient frontier.

$$x^*_{i0} = x_{i0} - s_{i0}^-$$
$$y^*_{r0} = \begin{cases} y_{r0} + s_{r0}^+,\ y^*_{r0} \leq 100, \ for \ \ r = 1,\ 2,\ 3 \\ y_{r0} + s_{r0}^+, \ for \ \ r = 4,\ 5,\ 6 \end{cases} \qquad (2)$$

To demonstrate the applicability of the model, an illustrative example will be shown next.

IV. An Illustrative Example

A total of 40 research and development teams or DMUs have been included in this example. Table 3 shows the data set for the 40 DMUs.

A simple program was written using Microsoft Excel to solve Model (1) based on the data set. The results are shown in Table 4. Also included in Table 4 are the slacks (surpluses and shortages) and the ranking of the DMUs according to their performance scores.

TABLE 3. Data Set

DMU	x_1	x_2	x_3	x_4	y_1	y_2	y_3	y_4	y_5	y_6
1	27	18	4900	1400	97	96	96	900	7	0
2	11	29	1900	1400	97	87	88	800	5	2
3	23	17	2000	2200	90	86	88	1300	9	2
4	16	30	4500	2200	94	93	90	1500	7	0
5	23	17	1200	1300	95	98	97	1700	9	0
6	12	30	3000	1800	88	93	92	1000	7	2
7	16	28	4400	2000	86	89	88	2600	6	1
8	16	34	2900	1700	98	88	93	900	9	1
9	18	21	3900	1600	99	92	96	4000	9	2
10	24	23	2700	2500	99	97	90	3200	6	2
11	15	22	3200	1500	92	98	91	3100	7	0
12	24	13	3100	2000	86	90	96	2800	9	0
13	27	6	1000	2500	86	86	98	3500	7	0
14	23	32	4000	1800	90	85	97	2000	9	0
15	5	8	2100	1700	91	89	89	3100	8	2
16	15	8	3200	1200	88	86	98	1900	8	1
17	5	26	2500	1200	97	91	98	900	8	1
18	28	12	4000	1900	95	96	89	2800	8	1
19	17	27	3300	1200	92	94	87	2300	8	0
20	19	8	2700	1900	96	88	91	1600	7	0
21	12	28	2300	2100	86	90	85	2700	7	1
22	11	19	3500	1500	93	88	86	1400	9	1
23	15	28	1100	1300	96	96	91	3800	9	1
24	19	20	4700	1400	95	88	99	3100	6	0
25	26	29	4200	2500	93	98	95	1700	6	2
26	5	30	3700	1800	87	85	94	1800	8	1
27	5	29	2400	1400	88	92	96	2600	8	0
28	25	16	3800	1700	85	95	86	1900	5	2
29	26	30	2600	2100	88	85	88	900	9	2
30	25	29	2200	1400	91	97	97	1300	8	0
31	9	26	3300	1700	88	86	96	2700	6	0
32	17	20	1600	1300	97	90	87	1200	9	0
33	19	29	2600	1300	90	86	92	3800	8	0
34	9	32	2000	2400	90	98	99	2600	5	2
35	25	17	2900	1400	98	96	95	3000	10	2
36	24	23	5000	2500	85	93	99	3700	10	2
37	8	25	1700	2000	97	85	97	2900	8	1
38	22	8	1000	1400	85	89	86	3500	10	1
39	8	16	4500	1700	88	97	88	3700	8	2
40	28	35	4200	1200	92	87	96	2600	9	2

From the analysis, there are 19 efficient DMUs and 21 inefficient ones. Slacks in Table 4 represent the input excesses and the output shortfalls respectively. To become efficient, a DMU has to remove the input excesses and augment the output shortfalls. For those inefficient DMUs, Model (2) has been run to obtain the improvement targets for them. The improvement targets are recorded in Table 5.

The improvement targets provide the teams with a direction and focus on which measures they should reduce or increase. Take DMU_1 as an example, to become efficient, it should reduce its number of team members (x_1) from 27 to 17, monthly number of hours of team meetings (x_2) from 18 to 9, monthly expenditure on team trainings (x_3) from 4900 to 3029; increase its percentage of on-time deliveries (y_3) from 96% to 100%, estimated monthly number of communications between members (y_4) from 900 to 2502, monthly number of new ideas, knowledge, and solutions generated (y_5) from 7 to 9, monthly number of new products or services generated (y_6) from 0 to 1; and maintain its monthly investment in supportive technologies (x_4) at 1400, percentage of quality products (y_1) at 97%, and percentage of satisfied customers (y_2) at 96%.

TABLE 4. PERFORMANCE SCORE, RANKING, AND SLACKS OF DMUS

DMU	Score	Rank	s_1^-	s_2^-	s_3^-	s_4^-	s_1^+	s_2^+	s_3^+	s_4^+	s_5^+	s_6^+
1	0.3920	34	10	9	1871	0	0	0	10	1602	2	1
2	1	1	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0
4	0.2462	40	11	22	2306	424	1	0	3	1739	1	2
5	1	1	0	0	0	0	0	0	0	0	0	0
6	0.4257	31	7	22	806	24	7	0	1	2239	1	0
7	0.3803	35	11	20	2300	300	5	0	1	500	2	1
8	0.4002	32	7	21	989	0	0	9	2	2620	0	1
9	1	1	0	0	0	0	0	0	0	0	0	0
10	0.4930	26	19	14	411	647	0	0	7	179	3	0
11	0.5232	23	5	0	1346	0	8	0	6	0	2	1
12	0.3577	37	18	4	738	88	16	10	4	687	0	2
13	1	1	0	0	0	0	0	0	0	0	0	0
14	0.2962	39	15	23	1823	0	8	12	0	1401	0	2
15	1	1	0	0	0	0	0	0	0	0	0	0
16	1	1	0	0	0	0	0	0	0	0	0	0
17	1	1	0	0	0	0	0	0	0	0	0	0
18	0.4859	28	23	3	1735	66	3	0	7	544	1	1
19	1	1	0	0	0	0	0	0	0	0	0	0
20	0.6335	22	1	0	265	0	0	7	14	1335	1	1
21	0.4925	27	7	20	176	381	6	0	5	435	1	1
22	0.6642	21	0	5	1560	0	2	5	8	1233	0	0
23	1	1	0	0	0	0	0	0	0	0	0	0
24	0.5157	24	5	2	2477	0	2	8	0	0	3	1
25	0.3542	38	19	17	1112	0	41	33	36	2859	6	1
26	0.6825	20	0	12	1378	378	7	5	0	78	0	0
27	1	1	0	0	0	0	0	0	0	0	0	0
28	0.5140	25	14	6	1552	0	11	0	8	1385	4	0
29	0.3696	36	20	20	6	0	24	25	22	2929	1	0
30	0.4473	29	9	0	1002	0	11	5	0	2733	2	1
31	0.3924	33	4	14	997	0	10	9	0	144	2	2
32	1	1	0	0	0	0	0	0	0	0	0	0
33	1	1	0	0	0	0	0	0	0	0	0	0
34	1	1	0	0	0	0	0	0	0	0	0	0
35	1	1	0	0	0	0	0	0	0	0	0	0
36	0.4465	30	17	11	1912	0	49	38	32	859	2	1
37	1	1	0	0	0	0	0	0	0	0	0	0
38	1	1	0	0	0	0	0	0	0	0	0	0
39	1	1	0	0	0	0	0	0	0	0	0	0
40	1	1	0	0	0	0	0	0	0	0	0	0

TABLE 5. IMPROVEMENT TARGETS FOR INEFFICIENT DMUS

DMU	x^*_1	x^*_2	x^*_3	x^*_4	y^*_1	y^*_2	y^*_3	y^*_4	y^*_5	y^*_6
1	17	9	3029	1400	97	96	100	2502	9	1
2	5	8	2194	1776	95	93	93	3239	8	2
4	5	8	2194	1776	95	93	93	3239	8	2
9	5	8	2100	1700	91	89	89	3100	8	2
10	9	13	1911	1700	98	97	95	3520	9	2
12	5	9	2289	1853	99	97	97	3379	9	2
13	10	22	1854	1500	100	98	97	3100	9	1
17	6	9	2362	1912	100	100	100	3487	9	2
19	8	9	2177	1800	98	97	97	3401	9	2
21	5	9	2265	1834	98	96	96	3344	9	2
22	18	8	2435	1900	96	95	100	2935	8	1
24	5	8	2124	1719	92	90	90	3135	8	2
26	11	14	1940	1500	95	93	94	2633	9	1
28	14	18	2223	1400	97	96	99	3100	9	1
31	7	12	3088	2500	100	100	100	4559	12	3
33	5	18	2322	1422	94	90	94	1878	8	1
34	11	10	2248	1700	96	95	94	3285	9	2
35	6	10	2594	2100	100	100	100	3829	10	2
36	16	29	1198	1400	100	100	97	4033	10	1
37	5	12	2303	1700	98	95	96	2844	8	2
38	7	12	3088	2500	100	100	100	4559	12	3

V. CONCLUSIONS

As shown in the previous section, the developed model is applicable to evaluate team performance with minimum subjective judgment. It is able to consolidate the 10 performance measures into one performance score. The results could help the teams under evaluation to have an overview on how well they are performing in relation to each other. Furthermore, improvement targets are calculated for those inefficient teams, enabling them to know the specific measures they need to improve or maintain in order to become efficient.

A limitation of this study is all the measures are treated deterministically. However, in real life, measures like the estimated monthly number of communications between members (y_4) are stochastic and hard to be determined accurately. Future work can look at how this issue can be addressed.

Lastly, while team evaluation in this study is not focused specifically on individuals, in future research, evaluation can be done in both team and member levels as to provide individualized feedback for individual members on how they could contribute more to improve their team performance.

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