New Product Development Creativity: A Data Envelopment Analysis Approach

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Innovation is critical for firm competitiveness and survival. A crucial part of innovation is team brainstorming and idea generation. Using a sample of one hundred and twenty-eight new product development managers in the United States, we examine communication factors that support the highest levels of efficiency for generating novel, useful, and manufacturable ideas during the initiation stage of the new product development process. The efficiency of new product development managers in achieving desirable creativity levels when examining these factors is assessed using Data Envelopment Analysis (DEA). The study results provide practical recommendations to enhance team creative output by adjusting input values based on the performance of the most efficient units.

Keywords: new product development, data envelopment analysis, creativity, team communication

INTRODUCTION

Team creativity and innovation are critical for firm competitiveness and survival. Given the role that organizational creativity plays in firm profitability (Adams, Jeanrenaud, Bessant, Denyer, & Overy, 2016) and the high failure rates of innovation efforts (Stevens & Burley, 2004), companies look for ways to enhance and optimize their new product development efforts. Relevant aspects of team creativity include the safety of a team's communication environment (Gibson & Gibbs, 2006), the amount of internal and external team communication (Keller, 2001), and the richness of the most utilized communication channels (Oke & Idiagbon-Oke, 2010). These elements support a team's knowledge exchange processes, which scholars have linked with team effectiveness (Hajro, Gibson, & Pudelko, 2017).

A psychologically safe communication environment, characterized by open and supportive communication, voicing opinions, and taking risks (Gibson & Gibbs, 2006; Gibson, Huang, Kirkman, & Shapiro, 2014), for example, is considered a key differentiator in teams' knowledge exchange processes (Hajro et al., 2017). Research suggests psychologically safe communication climates can help mitigate in-group/out-group distinctions that may form along subgroup boundaries (Gibson et al., 2014). This type of climate may also help reduce the adverse effects of virtual team elements on innovation, such as geographic dispersion, electronic dependence, dynamic structures, and national diversity (Gibson & Gibbs, 2006). A psychologically safe climate supports innovation by promoting sharing ideas, discussing differences, spontaneous and informal communications, providing unsolicited information, resolving differences by suspending judgments, supporting openness to ideas and perspectives, and active listening (Gibson & Gibbs, 2006).

Team creativity requires combining and integrating information from multiple members (Leenders, Engelen, & Kratzer, 2003). New knowledge and insights are created through the exchange of information, which builds on the knowledge of various team members, a process facilitated through effective communication (Leenders et al., 2003). Communication supports the creation and dissemination of ideas to produce a novel insight and is thus essential in promptly making the required information available to various members (Leenders et al., 2003). Given the relevance of communication in a team's knowledge exchange processes, the literature suggests that communication frequency strongly influences team performance regardless of the type of team or performance considered (Leenders et al., 2003).

Communication processes can be better understood by examining the frequency of communication and the media used (Oke & Idiagbon-Oke, 2010). Media richness considers a communication channel's capacity to convey information effectively (Oke & Idiagbon-Oke, 2010). Channels with high media richness include face-to-face, video conferencing, and telephone, while those with low media richness consider emails, blogs, wikis, bulletins, documents, and memos (Daft, Lengel, & Trevino, 1987; Oke & Idiagbon-Oke, 2010). Research suggests that team performance depends on the match between the type of communication channels used in a task and its characteristics (Oke & Idiagbon-Oke, 2010).

The new product development literature supports the relationship between team creative performance and higher levels of communication safety (Gibson & Gibbs, 2006), adequate channel richness (Oke & Idiagbon-Oke, 2010), and proper communication frequency (Leenders et al., 2003). However, firms facing resource constraints need to find strategies to optimize the use of resources that support creative efforts. For example, in certain circumstances, it may be time-consuming or expensive to create a safer communication environment or to communicate with richer channels, such as face-to-face meetings or videoconferences. In addition, there may be circumstances in which new product development teams can produce the same quality and number of outputs with fewer resources. In either circumstance, companies may benefit from identifying pathways to optimize the use of their resources.

This study exemplifies the use of Data Envelopment Analysis to identify new product development teams that use inputs most efficiently to generate creative outputs and provide recommendations that lacking teams can implement to become more efficient.

DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is a method originally developed by Charnes et al. in their 1978 paper (Charnes, Cooper, & Rhodes, 1978), in which they applied linear programming to estimate production frontiers. DEA is a non-parametric method that incorporates available data to compare feasible inputs and outputs of existing operations - generally manufacturing or service operations. Since its publication, this method has been extensively used in various industries to determine the most efficiently operating units (typically referred to as Decision Making Units (DMUs)). In addition, DEA is used to create pathways for less efficiently operating units to improve their efficiency levels to that of their best-performing peers. The method's name comes from the phenomenon the virtual "frontier" creates when the most efficient units "envelope" all non-efficient units.

DEA is relatively easy to understand, interpret and act upon, and as a result, is a prevalent method in practical economics and operations research. For example, if one can identify a set of Decision Making Units with common inputs and outputs (without an upper limit on the number of inputs and outputs used), the method will be able to produce (among other things) the following: a.) Identify which DMUs are the most efficient and which need improvement, b.) Identify a set of benchmark DMUs for all units, c.)

Determine target values for each DMU's level of inputs or outputs to achieve the best efficiency among all DMUs.

The are several versions and variations of the basic methodology, the most important of which, from the standpoint of this publication, are discussed shortly:

1. Scaling assumptions. When employing the method, one must decide on two basic scaling assumptions: Constant versus Variable returns to scale (CRS vs. VRS). CRS assumes that at any given DMU, the outputs change *in constant proportion* with the changes in input, while VRS works with the assumption that the change in output is not linear but either increases or decreases with the size of the input.
2. Input our Output orientation. Input orientation focuses on how to change the inputs of DMUs to achieve the desired efficiency, while Output orientation focuses on the opposite, namely: What output should be reached with the given inputs to achieve top efficiency.

LITERATURE REVIEW

Data Envelopment Analysis has been used extensively since its development in the late 1970s. It would be impossible to list all the relevant publications and use cases since its inception. Thus, this review will only aim to demonstrate a peek into the wide variety of applications and explain how this paper adds value to the literature by applying the method to a new area.

Maintaining efficient food production may be a challenge in the future, yet some recent applications of DEA look to address this problem. For example, a comparison of rice production facilities and several companies was conducted in the northern territory of Iran by Mardani (Mardani, Sabouni, Azadi, & Taki, 2022). DEA was also used in Japan (Masuda, 2018) to demonstrate that an increase in the scale of farming increases the energy efficiency of highly mechanized rice production. Mardani (Mardani & Salarpour, 2015) also applied DEA in Iran for companies in potato production to measure and analyze their efficiency. Dairy farms researched by Sefeedpari (Sefeedpari, Shokoohi, & Pishgar-Komleh, 2020) indicated substantial room for improvement in the industry in Iran. The same industry was examined by Stokes et al. (Stokes, Tozer, & Hyde, 2007) in Pennsylvania (United States) and found that more than 70% of the farms could improve their efficiency and laid down guidelines to achieve it. Lastly, a similar study was conducted in Greece by Theodoridis (Theodoridis & Ragkos, 2015), where the proportion of efficient farms was under 20%.

The success of DEA at production facilities prompted the use of the method in other business settings, such as department efficiencies and branch comparisons. For example, Moreno and Tadepalli (Moreno & Tadepalli, 2002) used DEA to create a single measure efficiency metric for academic departments at a public university in the United States and identify pathways for improvement for inefficient ones. Sîrbu et al. (Sîrbu, Cimpoieş, & Racul, 2016) used a similar approach amongst the departments of a Moldovan university to identify weaknesses and create a ranking order. The studies done at publicly funded institutions can be of great value when limited funds are available.

For-profit institutions also find value in the application of the method. Bank performance is a classical area: Kimiaroodi and Otadi compared the performance of Persian banks in their study (Kimiaroodi & Otadi, 2015) to try to introduce an easily measured metric into a somewhat fuzzy area. Palečková (Iveta, 2015) applied the method to Slovakian commercial banks and found that the largest banks seemed to be less efficient than small and middle-sized ones.

A NEW AREA OF APPLICATION

As we can see from our venture into the wide use of Data Envelopment Analysis, it is almost exclusively used in areas where inputs and outputs are relatively easily measurable. Our current study aims to use this method and apply it in an area that is difficult to measure: Creativity.

Creativity by nature is objective, and measuring it in a business context could be of great importance. It would allow companies to quantify inputs leading to creativity and be able to influence it. This paper creates a framework with the help of Data Envelopment Analysis for new product development, where the outputs include a relatively easily measurable component: manufacturability and one which is difficult to grasp: Creativity.

EMPIRICAL ILLUSTRATION

The Data Envelopment Analysis approach was used to examine the efficiency of new product development teams in the United States. Creativity and manufacturability of ideas were considered *outputs*, and several dimensions of team communication were considered *inputs*. These included the extent of each team's psychologically safe communication climate, communication channel richness, amount of internal communication, and the amount of external communication outside the project group but within the business unit, outside the business unit but within the company, and outside the company. Please find the summary of inputs and outputs in Table 1.

TABLE 1
SUMMARY OF INPUTS AND OUTPUTS USED FOR THE MODEL

	Name	Code
Input 1	Communication channel richness	ChanRich
Input 2	Amount of internal communication	Int Com
Input 3	Amount of external communication (outside the project group, within the business unit)	ExtCom1
Input 4	Amount of external communication (outside the project group and within the business unit, within the company)	ExtCom2
Input 5	Amount of external communication (outside the company)	ExtCom3
Input 6	Psychologically safe communication climate	ComSafe
Output 1	Level of creativity	Creativity
Output 2	Level of manufacturability	Manufacturable

The sample size of inputs and output performance measures must be large enough to obtain meaningful efficiency values. A popular rule of thumb suggests considering $3*(s+m)$ (Banker, Charnes, & Cooper, 1984; Provision, 1997), where s is the number of outputs, and m is the number of inputs. The size dataset for this study is more than adequate based on these standards, as it considers 128 teams versus the suggested 24. The data was gathered via a Qualtrics survey panel of new product development managers. Table 2 shows a subsection of the full range of data used for analysis:

TABLE 2
DATA USED FOR ANALYSIS

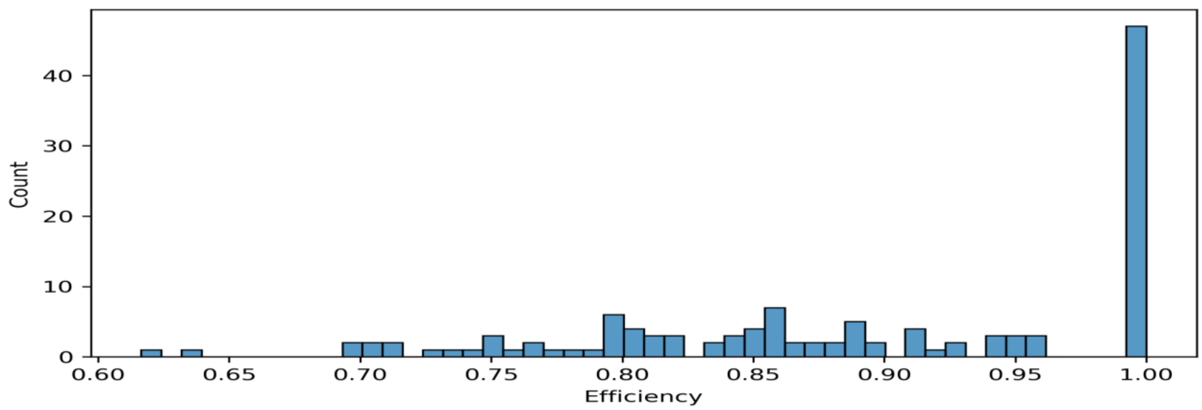
DMUS	Inputs						Outputs	
	ChanRich	Int Com	ExtCom1	ExtCom2	ExtCom3	ComSafe	Creativity	Manufacturable
C3	186	7	7	7	6	7.0	6.0	5
C4	105	6	5	5	3	6.3	5.8	6
C6	165	7	7	7	7	7.0	7.0	7
C7	109	6	6	6	4	6.0	6.0	6
C10	160	6	6	3	5	4.7	4.0	6
C11	119	6	5	4	4	6.3	5.8	6
C12	149	6	6	3	6	6.0	6.4	7
…	…	…	…	…	…	…	…	…
C246	142	4	4	5	5	4.3	5.0	4
C248	126	7	7	5	1	5.3	5.2	7
C249	1167	7	6	6	5	6.7	5.4	7

The nature of the operations means that the inputs do not yield constant returns to scale (since doubling the amount of communication would not necessarily double the outputs), and thus VRS is used. Furthermore, since the managers of the DMUs mostly have control over the inputs, the input-oriented approach was used. Therefore, the results will suggest how to adjust the input values to reach peak efficiency.

DEA RESULTS

The DEA model was run, and the following results - shown in Tables 1 through 3 - were obtained. First, the relatively most efficient DMUs were identified. 47 of the 128 decision-making units were identified to have the highest efficiency of 1.0. The lowest efficiency score was 0.62. (See Figure 1 for the distribution of efficiencies).

FIGURE 1
EFFICIENCY SCORE OF DMUS



The non-efficient DMUs will have a target value for each of their inputs. Reaching those target values will enable them to be as efficient as their peers. Table 3 shows each of the targets. As an example, an examination of Table 3 shows that the decision-making unit C3 needs to change its level of inputs to the following values: They do not need Communication Safety (ComSafe) to be at such as high level (7.00) and should decrease the number of resources allocated towards it to a lower level (4.89). Likewise, Channel Richness (ChanRich) is also an input that should be reduced, i.e., fewer resources should be allocated towards it (decrease from 186 to 128.67), etc. Note that due to the relative subjectivity of some of these categories, it would be difficult to attain the exact amount. Still, it does provide organizations with a good idea of what should be changed in their operations to attain the efficiency level shown by their most efficient peers. Since the originally reported values are somewhat subjective, the relative change needed is also reported. As an example, C11 now has the information that it needs to decrease internal communication (Int Com) by approximately 20% compared to its previous level.

Ultimately, the applied DEA method gives the following broad suggestions for new product development teams already generating the required creative outputs: it can help managers identify communication areas where they may not need to invest so many resources to continue to produce their current levels of creativity.

TABLE 3
TARGET VALUES FOR EACH INPUT FOR NON-EFFICIENT DMUS

DMU	Category	Original	Target	Relative Change		DMU	Category	Original	Target	Relative Change
C3	ComSafe	7	4.89	-30.1%		C6	ComSafe	7	6.14	-12.0%
Efficiency	ChanRich	186	128.67	-30.8%		Efficiency	ChanRich	165	134.29	-18.6%
69.9%	Int Com	7	4.89	-30.1%		87.8%	Int Com	7	6.14	-12.2%
	ExtCom2	7	4.40	-37.1%			ExtCom2	7	6.14	-12.2%
	ExtCom3	6	4.19	-30.1%			ExtCom3	7	5.29	-24.5%
	ExtCom1	7	4.57	-34.7%			ExtCom1	7	5.29	-24.5%
C7	ComSafe	6	5.04	-16.1%		C11	ComSafe	6.33	5.03	-20.6%
Efficiency	ChanRich	109	91.49	-16.1%		Efficiency	ChanRich	131	104.07	-20.6%
83.9%	Int Com	6	5.04	-16.1%		83.4%	Int Com	7	5.56	-20.6%
	ExtCom2	6	4.37	-27.2%			ExtCom2	4	3.18	-20.6%
	ExtCom3	4	3.36	-16.1%			ExtCom3	5	2.96	-40.8%
	ExtCom1	6	4.06	-32.3%			ExtCom1	6	4.28	-28.7%
C192	ComSafe	5.67	5.44	-4.0%		C249	ComSafe	6.67	5.43	-18.6%
Efficiency	ChanRich	88	84.46	-4.0%		Efficiency	ChanRich	116	94.42	-18.6%
96.0%	Int Com	6	5.76	-4.0%		81.4%	Int Com	7	5.70	-18.6%
	ExtCom2	6	4.56	-24.0%			ExtCom2	6	4.88	-18.6%
	ExtCom3	3	2.88	-4.0%			ExtCom3	5	3.20	-36.1%
	ExtCom1	6	3.98	-33.7%			ExtCom1	6	3.59	-40.2%

The preceding example shows how the DEA approach can be employed to identify a company's most efficient new product development teams. Furthermore, this example shows how DEA can be useful in assessing not only the causes responsible for the new product development teams' inefficiencies but also the set of changes that each team needs to make to reach the highest possible efficiency.

MANAGERIAL IMPLICATIONS AND CONCLUSIONS

An optimal team environment for organizational creativity usually requires high levels of communication safety, internal and external communication, and channel richness. However, there may be situations in which companies have to work with limited resources and cannot invest the time, effort, or money to create safer communication environments, use richer communication channels, or promote higher levels of internal and external communication.

In environments with restricted resources, organizations managing teams involved in new product development creativity can leverage the DEA approach to identify the most efficient teams and related pathways for lacking teams to become efficient, optimizing their use of resources.

In addition, for new product development teams already generating the required creative outputs, the DEA approach can help managers identify communication areas where they may not need to invest so many resources to continue producing their current creativity levels.

Further studies can examine these dynamics across clusters or industry groups to assess how these insights may apply dependent on firm characteristics.

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