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A Review of DEA-based Resource and Cost Allocation models: Implications for services

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Abstract: Data envelopment analysis (DEA), by its design, was not intended for resource allocation but for measuring relative efficiency of decision-making units. Despite this, many researchers have successfully applied this modelling technique to a variety of resource and cost allocation decisions in order to improve operational efficiencies. This paper is a comprehensive review and classification of such articles. The papers were classified by industry and by DEA model-orientation. The findings of this paper show that existing models predominately apply DEA to mass service industries (e.g., banking), thus, revealing the opportunity for researchers to further develop DEA-based resource allocation modelling toward improving the operational efficiencies of other service industries (e.g., professional services). To guide researchers to this end, we offer a discussion of the use of DEA modelling when the service provider and the customer are both resources needing to be allocated, in other words, using DEA to model professional or co-created services.

Keywords: data envelopment analysis; DEA; fixed cost allocation; resource allocation; services; service co-creation.

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1 Introduction

Data envelopment analysis (DEA) is a well-established operations management field with hundreds of papers published on the topic. DEA originated in the late 1970s in order to evaluate efficiency in decision-making units (DMUs). The original methodology of DEA was presented by Charnes et al. (1978) in the seminal paper 'Measuring efficiency of decision making units'. The initial DEA model built on the previous work of Farrell (1957).

The purpose of DEA is to analyse the performance (i.e., efficiency) of a sample of units within an organisation. Each unit, in the sample, has a measure of performance that is a ratio of its weighted outputs to weighted inputs. The weights are a measure of the decrease in efficiency with each unit reduction of output and a measure of the increase in efficiency with each unit reduction of input (Fitzsimmons et al., 2013). The solution to a DEA analysis will determine the most favourable weights for each unit. Multiple inputs and outputs are aggregated to achieve an overall performance rating. This overall performance rating reflects which DMUs are efficient and which units should be able to improve their inefficiency. The measurements can be used in performance evaluation and benchmarking (Cooper et al., 2004).

DEA, by its design, was not intended for resource allocation but for measuring relative efficiency of DMUs. Golany et al. (1993) was one of the first who attempt to use DEA for resource allocation. The paper explores effectiveness and efficiency for varying managerial situations. Effectiveness is defined as an organisation's ability to meet organisational goals. Efficiency is defined as how well DMUs achieve set goals. The paper uses DEA to allocate a budget in a way that is conducive to meeting the overall organisational goals. Since this paper was published, other researchers have written papers using DEA-based resource and fixed cost allocation models. These models have all been applied to a variety of service organisations.

There are several other survey papers on the study of DEA and its applications. Emrouznejad et al. (2008) performed a DEA survey in which they classified published articles by year, journal, author, number of pages, and keywords. Cook et al. (2010) performed a review of two-stage network DEA models. The authors classified papers into four categories: standard DEA, efficiency decomposition, network DEA, and game-theoretic DEA. Paradi and Zhu (2013) surveyed 80 published papers focused on

the use of DEA for bank branch efficiency and performance improvement. Liu et al. (2013) used a citation-based approach to survey the DEA filed in its entirety spanning form 1978–2010. Despite the above survey papers, this paper is the first survey paper solely focused on using DEA for resource allocation as the primary decision model goal.

The nature of service systems is changing due to the involvement of the customer in the service process. Customers are increasingly being valued as resources. Thus, resource allocation, while combined with customer co-creation of services, becomes even more impactful in the research in service industry. Verma et al. (2013) discuss how service firms can improve their resource planning by developing a model of co-creation. Trinh and Kachitvichyanukul (2013) have developed a framework for the design of service systems while considering the customer as a co-producer. They show the trade-off between the service provider and the service recipient. Komulainen and Tapio (2013) suggest that customer perceived value of B2B services can be enhanced by co-creation processes with customers. Beyond resource allocation, customer participation can also improve perceived service productivity and customer loyalty finds (Uzkurt, 2010). These papers served as a strong motivation to us to conduct a structured survey on the literature with emphasis on resource allocation and customer co-creation in services.

This paper seeks to provide researchers with a comprehensive source of information on DEA-based resource and fixed cost allocation models and to show how DEA could be used for resource allocation in a variety of service industries. This paper contributes to existing literature by:

- synthesising published articles focused on the use of DEA for resource and cost allocation
- providing a classification scheme which focuses on model formation and the effects of those formations on DEA results
- providing readers ideas on using DEA-based resource allocation modelling for a variety of service organisations in an effort to capture the co-creation of the service.

This paper is not a survey of overall DEA literature. This survey is specific to applications of DEA in the area of resource and cost allocation, which is gaining relevance increasingly in operations management. We find that limited literature exists currently in this area, and therefore, offers a research niche in operations management.

By nature, customer interaction and labour intensity are high in most service encounters, making human resource the most important resource. This makes it challenging to plan for appropriate resource allocation. This is particularly relevant when we design co-created services. A tool such as DEA could be very useful in evaluating resource utilisation in such service settings, and in subsequent efficient resource allocation.

In the broader context of service management, this paper caters to the following components of services: the service encounter; customer involvement and co-creation; new service development and service design; tools for service evaluation.

The remainder of the paper is organised as follows: Section 2 describes the research methodology used; Section 3 describes the classification strategy used and presents the classification of articles; Section 4 offers a discussion of the implications of DEA-based resource allocation models for co-created services; and Section 5 concludes the paper with ideas for future research.

2 Research methodology

We reviewed and analysed published or in press articles. We did not consider conference proceedings, dissertations, or works in progress.

We searched using keywords:

1 data envelopment analysis

2 DEA

3 cost allocation and fixed cost allocation

4 resource allocation.

We queried the following databases:

1 Science Direct

2 Business Source Premier

3 SCOPUS

4 JSTOR

5 ABI/INFORM.

Our major issue was to determine what constituted a DEA-based resource allocation model paper. First, we defined our interpretation of the difference between resource allocation and fixed allocation. We determined that resource allocation is the distribution or redistribution of any number of limited resources deemed necessary for output productivity of individual DMUs. Fixed allocation is the distribution or redistribution of a set amount of a single input. In most of the articles we found, the fixed input was overhead costs that needed to be paid by/removed from individual DMUs. Next, we searched the aforementioned databases using the predetermined keywords. As a result, 30 articles matching our criterion were found. These articles are shown in Table 1. We did find a few published papers that used DEA for production planning which obviously would include some form of resource allocation. All production planning articles were excluded. We also cross-referenced each article found by checking the literature review section and references of each article in an effort to find new articles not previously identified.

3 Classification strategy

We classified the DEA-based resource and fixed cost allocation models based on industry application and model orientation. This classification scheme was chosen because one of the first decisions to be made when applying DEA is whether the input or the output orientation will be used. The model orientation may also affect the optimal solution to the model. We observed the industry to which the model was applied in order to assign each paper to the appropriate quadrant of (Schmenner, 1986) Service Process Matrix.

Table 1 Articles meeting search criterion

ID	*Authors*	*Title*	*Journal*	*Pub year*
1	Amirteimoori, A. and Tabar, M.M.	Resource allocation and target setting in data envelopment analysis	*Expert Systems with Applications*	2010
2	Asmild, M., Paradi, J.C. and Pastor, J.T.	Centralized resource allocation BCC models	*Omega*	2009
3	Athanassopoulos, A.D.	Service quality and operating efficiency synergies for management control in the provision of financial services: evidence from Greek bank branches	*European Journal of Operational Research*	1997
4	Athanassopoulos, A.D.	Goal programming & data envelopment analysis (GoDEA) for target-based multi-level planning: allocating central grants to the Greek local authorities	*European Journal of Operational Research*	1995
5	Beasley, J.E.	Allocating fixed costs and resources via data envelopment analysis	*European Journal of Operational Research*	2003
6	Bi, G., Ding, J., Luo, Y. and Liang, L.	Resource allocation and target setting for parallel production system based on DEA	*Applied Mathematical Modelling*	2011
7	Chen, C-M. and Zhu, J.	Efficient resource allocation via efficiency bootstraps: an application to R&D project budgeting	*Operations research*	2011
8	Cook, W.D. and Kress, M.	Characterizing an equitable allocation of shared costs: a DEA approach	*European Journal of Operational Research*	1999
9	Cook, W.D. and Zhu, J.	Allocation of shared costs among decision making units: a DEA approach	*Computers & Operations Research*	2005
10	Drake, L. and Howcroft, B.	Relative efficiency in the branch network of a UK bank: an empirical study	*Omega*	1994
11	Fare, R., Grabowski, R., Grosskopf, S. and Kraft, S.	Efficiency of a fixed but allocatable input: a non-parametric approach	*Economics Letters*	1997
12	Giokas, D.	Bank branch operating efficiency: a comparative application of DEA and the loglinear model	*Omega*	1991

Table 1 Articles meeting search criterion (continued)

ID	*Authors*	*Title*	*Journal*	*Pub year*
13	Golany, B. and Tamir, E.	Evaluating efficiency-effectiveness-equality trade-offs: a data envelopment analysis approach	*Management Science*	1995
14	Golany	Models for improved effectiveness based on DEA efficiency results	*IIE Transactions*	1993
15	Hadi-Vencheh, A., Foroughi, A.A. and Soleimani-damaneh, M.	A DEA model for resource allocation	*Economic Modelling*	2008
16	Kao, C.	Data envelopment analysis in resource allocation: an application to forest management	*International Journal of Systems Science*	2000
17	Korhonen, P. and Syrjänen, M.	Resource allocation based on efficiency analysis	*Management Science*	2004
18	Li, Y., Yang, F., Liang, L. and Hua, Z.	Allocating the fixed cost as a complement of other cost inputs: a DEA approach	*European Journal of Operational Research*	2009
19	Li, Y., Yang, M., Chen, Y., Dai, Q. and Liang, L.	Allocating a fixed cost based on data envelopment analysis and satisfaction degree	*Omega*	Article in press
20	Lozano, S. and Villa, G.	Centralized DEA models with the possibility of downsizing	*The Journal of the Operational Research Society*	2005
21	Marinescu, M.V., Sowlati, T. and Maness, T.C.	The development of a timber allocation model using data envelopment analysis	*Canadian Journal of Forest Research*	2005
22	Oral, M. and Yolalan, R.	An empirical study on measuring operating efficiency and profitability of bank branches	*European Journal of Operational Research*	1990
23	Pachkova, E.V.	Restricted reallocation of resources	*European Journal of Operational Research*	2009
24	Schaffnit, C., Rosen, D. and Paradi, J.C.	Best practice analysis of bank branches: an application of DEA in a large Canadian bank	*European Journal of Operational Research*	1997
25	Sherman, H.D. and Gold, F.	Bank branch operating efficiency: evaluation with data envelopment analysis	*Journal of Banking & Finance*	1985
26	Sherman, H.D. and Ladino, G.	Managing bank productivity using data envelopment analysis (DEA)	*Interfaces*	1995

Table 1 Articles meeting search criterion (continued)

ID	*Authors*	*Title*	*Journal*	*Pub year*
27	Thanassoulis, E.	A data envelopment analysis approach to clustering operating units for resource allocation purposes	*Omega*	1996
28	Wu, H., Du, S., Liang, L. and Zhou, Y.	A DEA-based approach for fair reduction and reallocation of emission permits	*Mathematical and Computer Modeling*	Article in press
29	Wu, J. and An, Q.	New Approaches for resource allocation via DEA model	*International Journal of Information Technology*	2012
30	Yan, H., Wei, Q. and Hao, G.	DEA models for resource reallocation and production input/output estimation	*European Journal of Operational Research*	2002

Table 2 Articles classified by industry

ID	*Authors*	*Industry*
1	Amirteimoori, A. and Tabar, M.M.	Gas company
2	Asmild, M., Paradi, J.C. and Pastor, J.T.	Public service organization
3	Athanassopoulos, A.D.	Bank branches
4	Athanassopoulos, A.D.	Allocating central grants/funds to local authorities
5	Beasley, J.E.	Telecommunications
6	Bi, G., Ding, J., Luo, Y. and Liang, L.	Working circles and districts
7	Chen, C-M. and Zhu, J.	Allocating funds across R&D projects
8	Cook, W.D. and Kress, M.	Highway maintenance crews
9	Cook, W.D. and Zhu, J.	Numerical example
10	Drake, L. and Howcroft, B.	Bank branches
11	Fare, R., Grabowski, R., Grosskopf, S. and Kraft, S.	Farming
12	Giokas, D.	Bank branches
13	Golany, B. and Tamir, E.	Numerical example
14	Golany	Not stated
15	Hadi-Vencheh, A., Foroughi, A.A. and Soleimani-damaneh, M.	University
16	Kao, C.	Forestry
17	Korhonen, P. and Syrjänen, M.	Supermarket
18	Li, Y., Yang, F., Liang, L. and Hua, Z.	Automobile manufacturer
19	Li, Y., Yang, M., Chen, Y., Dai, Q. and Liang, L.	Telecommunications
20	Lozano, S. and Villa, G.	Numerical example

Table 2 Articles classified by industry (continued)

ID	*Authors*	*Industry*
21	Marinescu, M.V., Sowlati, T. and Maness, T.C.	Forestry
22	Oral, M. and Yolalan, R.	Bank branches
23	Pachkova, E.V.	Numerical example
24	Schaffnit, C., Rosen, D. and Paradi, J.C.	Bank branches
25	Sherman, H.D. and Gold, F.	Bank branches
26	Sherman, H.D. and Ladino, G.	Bank branches
27	Thanassoulis, E.	Hospitals
28	Wu, H., Du, S., Liang, L. and Zhou, Y.	Agriculture
29	Wu, J. and An, Q.	Supermarket
30	Yan, H., Wei, Q. and Hao, G.	Hot appliance company

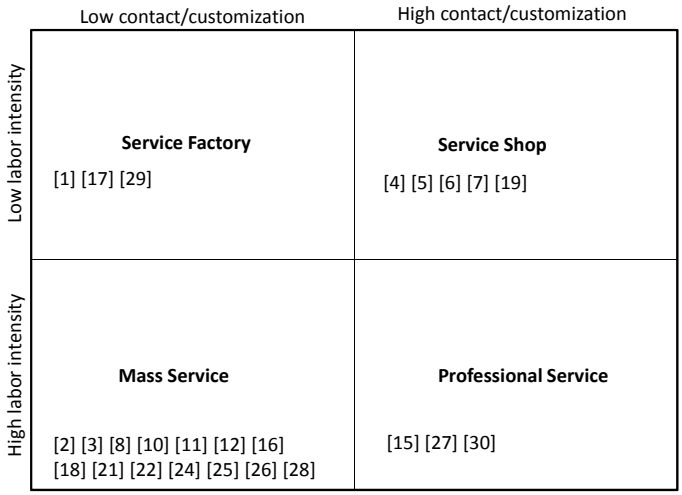
3.1 Classification by industry

For this review, we identified industry application for each paper meeting the search criterion. Table 2 lists the 29 articles with their closest related industry. It is interesting to note that a good number of them are in the financial sector and the rest are across different industry sectors such as hospitals, supermarkets, agriculture, forestry, gasoline, and highway maintenance. We then organised the 29 DEA-based resource allocation papers into a service matrix to identify any possible trends. Schmenner (1986) designed a service matrix to be an initial step towards classification of services. Although this service matrix has drawn criticism over the years, it serves the purpose of defining the scope of this research. Schmenner's Service Process Matrix classifies services based on the degree of client contact/customisation and the degree of labour intensity. The four quadrants of the Service Process Matrix are explained below:

- Service factories are low customer contact and low labour intensive service industries such as the transportation industry.
- Service shops increase in customer contact/customisation. The healthcare industry is an example of service shop.
- Mass services have low degrees of customer contact/customisation and a high degree of labour intensity. The banking and retail industries are examples of industries that produce mass services.
- Professional services have a high degree of customer contact/customisation and high labour intensity. The legal and consulting industries are an example of professional services.

Figure 1 shows how we placed the 30 papers in the four quadrants of Schmenner's Service Process Matrix. We find that 14 of the 30 published papers applied DEA to the mass services quadrant. This is understandable since mass services operate and function much like a manufacturing facility. Only three papers fell in the professional services quadrant, while service shop and service factory had five and three respectively.

Figure 1 Service Process Matrix



3.2 Classification by DEA model orientation

The CCR-Input model determines the optimal values of the decision variables (i.e., weights). The CCR-Input model optimises the best possible weights for the DMU under investigation subject to the constraints. The objective function maximises the weighted sum of the outputs of the DMU under investigation. This is a maximisation problem since, ideally, DMUs would like to maximise outputs for a given set of inputs. Conversely, in the CCR-Output model, the inputs are minimised in the objective function. In the *DEA Handbook*, [Cooper et al., (2004), p.15] states that "in an input orientation one improves efficiency through proportional reduction of inputs, whereas an output orientation requires proportional augmentation of outputs. Moreover, the efficiency of a boundary point can be dependent upon the model orientation." Also, inefficient DMUs can be projected to different points on the efficient frontier depending on model orientation. As a result, the amount of input reduction or output growth may differ based on model orientation. Cooper et al. (2004) provides a correspondence between the two solutions.

We did not find any counterintuitive patterns or groupings when we classified the articles by model orientation. The results in Table 3 show the number of authors choosing the input model and the output model − with a slightly greater number of authors using an output-oriented DEA model for resource allocation. We believe more authors choose the output oriented model due to need for growth in the output with the existing input resources. Note that few authors chose both input and output models. Some authors have chosen an efficiency-oriented model in which the objective is to maximise the efficiency score of each DMU (see Table 3 – [5], [14], [16], [25], [26]). Patterns may reveal themselves in the future as more papers are published on this topic.

Table 3 Articles classified by DEA model formulation

ID	*Authors*	*Input*	*Output*	*Efficiency score*
1	Amirteimoori, A. and Tabar, M.M.	x		
2	Asmild, M., Paradi, J.C. and Pastor, J.T.	x		
3	Athanassopoulos, A.D.		x	
4	Athanassopoulos, A.D.		x	
5	Beasley, J.E.			x
6	Bi, G., Ding, J., Luo, Y. and Liang, L.	x		
7	Chen, C-M. and Zhu, J.	x		
8	Cook, W.D. and Kress, M.		x	
9	Cook, W.D. and Zhu, J.	x	x	
10	Drake, L. and Howcroft, B.	x	x	
11	Fare, R., Grabowski, R., Grosskopf, S. and Kraft, S.		x	
12	Giokas, D.		x	
13	Golany, B. and Tamir, E.		x	
14	Golany			x
15	Hadi-Vencheh, A., Foroughi, A.A. and Soleimani-damaneh, M.	x		
16	Kao, C.			x
17	Korhonen, P. and Syrjänen, M.	x	x	
18	Li, Y., Yang, F., Liang, L. and Hua, Z.		x	
19	Li, Y., Yang, M., Chen, Y., Dai, Q. and Liang, L.		x	
20	Lozano, S. and Villa, G.	x		
21	Marinescu, M.V., Sowlati, T. and Maness, T.C.		x	
22	Oral, M. and Yolalan, R.		x	
23	Pachkova, E.V.		x	
24	Schaffnit, C., Rosen, D. and Paradi, J.C.	x		
25	Sherman, H.D. and Gold, F.			x
26	Sherman, H.D. and Ladino, G.			x
27	Thanassoulis, E.	x		
28	Wu, H., Du, S., Liang, L. and Zhou, Y.		x	
29	Wu, J. and An, Q.	x	x	
30	Yan, H., Wei, Q. and Hao, G.	x	x	

For service industries with co-created services, (e.g., professional services) an output-oriented DEA model may be best for allocating resources. Since both the service provider and the client/customer contribute human resource to the delivery of the service there is less control over changes to input resources. The service provider does not have insight into client capacities, capabilities, constraints, and such other factors. Therefore, the resources are nondiscretionary (i.e., cannot be varied at discretion). We would

recommend that a DEA-based resource allocation model for co-created services include nondiscretionary inputs and outputs. By example, Banker and Morey (1986) offer insights into DEA modelling with non-discretionary inputs. The output-oriented model will seek to find an optimal solution by growing the amount of output given a set of inputs.

We provide an example to illustrate our recommendations. An IT consulting firm has a number of projects that need to have a knowledge worker(s) assigned to each. There will also be a need to have a client knowledge worker(s) assigned to each project for testing. Both the service provider and the client knowledge workers may currently be assigned to other projects. The client and the service provider have predetermined human resource availability that most likely will not be fully shared with the other party. Also, neither party knows how much output will be produced by each worker on the project. Therefore, the service provider has no discretion to adjust neither client input nor output and vice versa.

4 Discussion

It is useful to apply a powerful tool such as DEA for resource allocation in co-created services. Inclusion of the customer for co-creation of service offerings has become an important element of new service design. Of the 30 articles we studied, the majority (14) were categorised in the Mass Service quadrant, while only three were categorised in the Professional Service quadrant; thus, revealing an opportunity for future research. There are several challenges to using DEA to model co-created services.

Challenge 1: the production function

For co-created services, the function that maps inputs to outputs is often mis-estimated or mis-specified (White, 2013). When a service provider is unsure of the structure of the production function (mis-specification) or unsure of the parameter values of the function (mis-estimation) the resource allocation plan may be inefficient. The production function is hard to estimate because of the inherent variability in the service process (Dietrich, 2006). Chance constrained DEA may be a way to capture the stochastic nature of service processes. Chance constrained DEA helps modellers determine efficiencies of DMUs in the face of uncertainty. We direct the reader to Charnes and Cooper (1963), Cooper et al. (2002), Land et al. (1993) and Talluri et al. (2006) for examples. Please note these models are not designed for resource allocation.

Challenge 2: the customer

Having the customer as a resource introduces management challenges due to the variable nature of customers. Customer variability exists in the forms of knowledge, abilities, and motivation (Frei, 2006). Co-created services must also be flexible enough to deal with resource requirement changes. In co-created services, there is a high-degree of customer contact and therefore requirement changes are common. These changes can range from the number of resources required, to the desired capability of each resource (Dietrich, 2006). Resource planning models must account for customer variability and must be capable of handling resource requirement changes. Mula et al. (2006) gives a review of

production planning models under uncertainty. The review does not focus on DEA but researchers will find the review useful in model development for co-created services.

Challenge 3: service process design

For the customer co-created services, a spectrum of service delivery systems is possible – from complete self-service to complete dependence on a service provider. An analytical model may identify an optimal level of customer participation, resulting in the highest operational efficiency. The firm can accordingly allocate its resources for this level of optimal performance. Frei and Harker (1999) use DEA to analyse service process design in a retail banking setting.

Another consideration in the design of co-created services is the perceived control between the service provider and the customer. In most professional services such as doctors and lawyers, it is understandable that the service provider has more control. But less professional services offer a significant amount of control to the customer. This balance of power is an important decision in resource planning by the firm. Similarly, the decision on the level of empowerment for the service contact personnel is another important consideration. Tools such as DEA can be useful in this decision-making process.

Challenge 4: measuring productivity

Measuring productivity has long been viewed as a challenge in resource planning for services with a high degree of customer contact. Measuring productivity of service operations is challenging because of the variability in the performance of knowledge workers. This variation makes it difficult to measure production output and often requires decision-makers to measure attributes such as knowledge, skill level, and experience in order to determine potential output production (Nachum, 1999). Furthermore, there is no easy standard method for measuring the skills and capabilities of knowledge workers (Dietrich, 2006). In services with a high degree of customer contact, resources develop solutions to specific customer problems. Therefore, workers need to be creative and think independently. This dynamic environment makes it difficult to determine, at any point in time, the knowledge that each worker truly possesses. Chase and Apte (2007) do not recommend the usage of DEA to measure service productivity because of the linearity of the model formulation and the simplifying assumptions that will need to be made.

5 Conclusions and future research

In this paper, we offered a methodology to evaluate and categorise DEA based articles in the area of resource and cost allocation. We consider our contributions as three-fold. First, it synthesises published articles in our select area – an increasingly relevant area – of resource and cost allocation in the service context. Second, it provides a classification theme that focuses on model formulation and their effects on DEA results. Third, it opens up several ideas on using DEA-based resource allocation models for a variety of service organisations in the effort to capture the co-creation of the service between the customer and the provider.

We felt it was necessary to compile our survey work for the benefit of future researchers in this upcoming area of new service design with customer co-creation. We are in the process of selecting a few of the elements described in this paper and formulating our models using DEA. Our interests lie primarily in the area of converting some of the mass service designs to professional service designs in the effort to bring in more customisation to the design, and yet not lose customer involvement in an efficient operation of the service. A DEA-based model will help keep track of efficiency scores and choose a certain direction of improvement in the design process.

Another angle of our future research will be to look at the co-created service design from the service contact (encounter) perspective. Service contact is the 'critical moment' between customer and service system, and the direct source of service perception (Czepiel et al., 1984; Lovelock, 1988). Chase (1981) defines service contact as "the percent of time that customers have to be in the service production site." Shostack (1984) further extends this definition to "a period of time when customers and service systems interact" and considers every visible element as part of the contact.

Besides theoretical and academic implications, we expect our findings to motivate practicing managers to apply powerful tools such as DEA in business decision making. In today's service business, managers continuously look for ways to allocate resources more efficiently and interact with the customers in the most effective manner. Our structured approach to survey DEA-based articles in this select area would help managers find appropriate tools to this goal.

One possible limitation of our research is that we could find only thirty articles that qualified for our survey in this chosen field. While we consider it sufficient, we hope that more articles will be published in this area in the future. Another concern of ours was that in our classification of the 30 articles in the Service Process Matrix, the majority of the services fell in the Mass Service category. We would like to see more services migrate towards the Professional Service category in the future.

It is often necessary to evaluate service outcomes from customers' perspectives. The key here is to measure customers' perceptions. Customer service perceptions also depend on service processes rather than the service outcomes alone. This may shift the design focus to studying service processes and develop models to capture this. DEA can be a powerful tool in measuring service process efficiency, especially in resource management in co-created services, which is our primary focus.

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