Modified, Stakeholders Perspective based DEA Approach in IT and R&D Project Ranking

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Abstract: The state of art of Data Envelopment Analysis applied to IT and R&D projects evaluation and ranking is presented. Then the role and importance of project stakeholders is discussed. It is shown that this role is not taken into account in the original DEA method applied to project evaluation and ranking. Thus a modification of the DEA method is proposed, in which the stakeholders perspective plays a crucial role. An example illustrates the modified method itself and its advantages.

1 INTRODUCTION

The Data Envelopment Analysis (DEA) has been used for years in the evaluation and comparison of production units, where outputs (produced goods) are generated from inputs (raw resources and labour) (Charnes et al., 1978). The term of production units used in the DEA method has been generalised, so that bank divisions and hospital units can be evaluated, ranked and compared too. The inputs in such cases are labour hours and budgets, the outputs - the services rendered, the number of patients or clients served etc. However, in recent years the method has been used among others to evaluate, compare and rank projects, where inputs and outputs may be of a different nature than in case of production units, even in the generalized sense. In case of projects, especially R&D or IT projects, the inputs and above all outputs may be of a qualitative nature - for example, an important output of a project may be the customer satisfaction. Still, even in such a case the DEA method has turned out to useful in project evaluation and ranking - the relevant literature will be discussed in Section 2.

However, in the DEA method applied to projects there is an inherent mistake. The DEA in its original form (see Section 2) maximises the ratio "weighted outputs sum/weighted inputs sum" for each project in turn, while the decision variables are the weights of inputs and outputs. The idea is that each project has the right to "decide" which weights to use with respect to the inputs and outputs in order to show itself in the most positive light. Thus, the weights may take any nonnegative value, the only condition is that the ratio "weighted output/weighted input" is maximal. However, it has been overlooked that projects are seen differently by different stakeholders (see Section 3). Thus, if the idea is to give to each project the possibility to show itself in a positive light, it should also be possible for each project to choose the best perspective among those of different stakeholders – and in the eyes of individual stakeholders certain sets of inputs and outputs do not count. As it will be shown in Section 4, the possibility to consider various views of various decision makers is not present in the original DEA method. We will introduce it in Section 4. In Section 5 it will be illustrated by means of a computational example.

2 DEA METHOD APPLIED TO PROJECT RANKING

As mentioned above, the DEA method has been recently used to evaluate and compare various units, which may be production units, banks, hospital units, and, last but not least, projects. The basis for the comparison are inputs used and outputs generated by

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the units in question. If there are $K+1$ units, each of them is evaluated by a separated fractional programming model (which may be reduced to a linear one), where the unit being evaluated is numbered as the 0-th unit. The model is formulated as follows (Charnes et al., 1978).

$$\frac{\sum_{j=1}^{J} v_j^0 y_j^0}{\sum_{i=1}^{I} u_i^0 x_i^0} \to max \quad (1)$$

$$\frac{\sum_{j=1}^{J} v_j^0 y_j^k}{\sum_{i=1}^{I} u_i^0 x_i^k} \leq 1, k = 1, \dots, K \quad (2)$$

$$u_i^0 \geq 0, v_j^0 > 0 \quad (3)$$

where x_i^k $(i = 1, \dots, I)$ are inputs of the *k*-th object, $k = 0, \dots, K$ and y_j^k $(j = 1, \dots, J)$ are its outputs, $u_i^0 (i = 1, \dots, I)$ and v_j^0 $(j = 1, \dots, J)$ are decision variables and at the same time weights of the, respectively, inputs and outputs, chosen from the point of view of the 0-the unit - in order to maximise its performance, defined in (1).

Each unit becomes in turn the 0-th unit. The value of the objective function of the fractional programming problem (1)-(3) formulated when the *k*-th unit becomes the 0-th unit will be denoted as p_k and will be considered to be the performance of the *k*-th unit. The units are than ranked in the decreasing order of p_k $(k = 0, \dots, K)$.

The ratios p_k $(k = 0, \dots, K)$ correspond to the situation when each unit has the right to choose the inputs and outputs weights is such a way that the ratio "weighted sum of outputs/weighted sum of inputs" as for it as high as possible, and the only constraints are (2) and (3).

Recently the DEA method has been often applied to projects, especially to IT and R&D projects. In the following we will show which inputs and outputs are chosen for projects when they are compared by means of the DEA method.

For IT projects (understood as projects concerning the development, installation and use of computer systems and applications (American Heritage Dictionaries, 2014) the authors use the following inputs:

- cost of the project, duration of the project, number of employees needed - the actual and the planned one (Gusmao and Costa, 2012; Asosheh et al., 2010);
- green dollar cost (expenses paid to entities outside the organisation), brown dollar cost (internal expenses, the cost of personnel used), project actual duration, potential risk (potential loss to the corporation) (Sowlati et al., 2005).
- labour, other expenses, duration (Wray and Mathieu, 2008)

The outputs for IT projects have been grouped by various authors in several categories (Sowlati et al., 2005; Gusmao and Costa, 2012; Wray and Mathieu, 2008):

- financial perspective (cost reduction of the organisation in which the product of the IT project has been implemented, profit increase of the organisation, green dollar benefits (profit to the organisation or reduction of expenses paid outside the organisation), brown dollar benefits (reduction of internal expenses, reduction of the cost of personnel used);
- internal business perspective (a better control of internal processes, their increased security achieved thanks to the product of the project in question);
- customer/stakeholder perspective (increased customer satisfaction, a higher compliance with needs of stakeholders) - the role of various stakeholders is here underlined;
- learning perspective (benefits consisting in the fact that thanks to the project the organisation has achieved new skills);
- uncertainty perspective (here the risks linked to the use of the project product are meant: the higher the risks, the lower the output of the project);
- the complexity of the product of the project;
- intangible benefits (to individual members of the organisation or to organisational units of the organisation or to the whole organisation realising the project);
- software production related outputs: number of function points realised, number of lines of code.

R&D projects (R&D, i.e. Research and Development, comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications (Frascati Manual, 2002)) have also been subject to evaluation and ranking by means of DEA method, The following inputs have been used in the literature (Eilat et al., 2008; Revilla et al., 2003; Yuan and Huang, 2002):

- project cost (budgeted and actual):
- the full time equivalent of highly trained personnel (managers, engineers and scientists, holding PHD, master, bachelor degree) used for the realisation of the project;

- total organisation revenues;
- total organisation R&D Budget, Total number of corporate employees
- total number of organisation employees;

It has to be underlined that the last three inputs listed above refer not to the project being evaluated, but to the whole organisation implementing the project.

As for the outputs, the following ones have been used for R&D projects (Eilat et al., 2008; Revilla et al., 2003; Yuan and Huang, 2002):

- discounted cash flow generated by the project;
- performance improvement achieved thanks to the project;
- customer satisfaction with the product of the project;
- congruence with the strategy of the organisation realising the project;
- synergy with other projects realised by the organisation;
- project team satisfaction;
- the number of team members trained in project management thanks to the project realisation;
- probability of technological and commercial success of the project product;
- technical gap size covered by the project product;
- the newness of the technology used;
- the complexity of market activities needed to commercialize the project product;
- new scientists gained by the organisation thanks to the project;
- total income generated by the project;
- number of patents and copyrights gained thanks to the project;
- number of dissertations worked out thanks to the project;
- number of reports issued thanks to the project;
- number of technology innovations worked out thanks to the project;
- number of seminars organised thanks to the project;
- number of technology transfers resulting from the project.

To sum up the state of the art of the DEA application to IT and R&D projects evaluation and ranking, it has to be said that the inputs and outputs used are often of a qualitative nature and their value has to be given by an expert. Another important thing is that the inputs and outputs used are not of the same importance to each project stakeholder. For example, the team satisfaction, new dissertations and new skills of the project team may be of a high importance to the persons responsible of the scientific development of the organisation members, but it will be of no importance to the financial manager of the organisation. For the latter the project cost and the revenues generated by it will be much more important.

The problem of the diversity of views of different project stakeholders and of their importance is treated in the following section.

3 PROJECT STAKEHOLDERS AND THEIR ROLE

Project stakeholders (project stakeholder is an individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a the project (PMI, 2013)) are often very diversified, and often have contradictory expectations with respect to the project.

This statement can be justified by the list of stakeholders of a certain R&D project, financed by an external institution, which was realised be a team at a university with one of the authors of the present paper as project manager. It has to be underlined that the list was not completely identified before the project start. It is only once the project was closed that the complete list of the stakeholders was known. This complete list is as follows:

- the members of the project team;
- the project manager;
- the accounting department;
- the project management department;
- the financial manager of the university;
- the scientific manager of the department.

The members of the project team and the project manager wanted to attain the project goal, which consisted in elaborating a new accounting system, but its achievement depended on the information given by the accounting department. The accounting department did not want a new accounting system, so they did not cooperate, as for them the fulfilment of the project goal meant more work and more challenges. In this situation the financial manager of the university was interested only in one thing: that the project is not found to be a complete failure by the financing institution, so that the university does not have to pay back the project budget. The aim of the project manager was then to find a substitute goal which would be accepted by the financing institution.

The team members were not very motivated to fulfil the substitute goal, but they did it, in order to help the project manager. The scientific manager of the department wanted to have new publications in good journals and he did not care the realisation of which goal these publications will present. The project management department wanted to have all the reports in due times, so that they could register them and send to the financing institution. They did not care much about all the problems which caused that the project was in danger.

Finally the project was accepted with the substitute, much more moderate goal, so that the university did not have to pay any money back and in all official documents the project is qualified as a success, although in the eyes of the project team and the project manager it was a failure, partially due to the wrongful identification of project stakeholders and their views. Above all the role of the accounting department was not identified properly.

The project stakeholders are important. The have been becoming more and more present in the project success perception. In the past it was considered that a project is successful if it meets the specification (scope), cost (budget) and time (deadline). Today most authors expand this definition substantially, introducing other project success measures. The nature of these extensions can be summarised by the following statement: "There have to be two groups of project success measures: objective measures (such as time or cost) and subjective measures (such as the satisfaction of different project stakeholders)" (Chan et al., 2002; Chan et al., 2004). Subjective measures are necessary, because the perception of project success depends strongly on the assessor (Davis, 2014).

That is why project stakeholders management is considered as very important. There are many proposals of methods to identify and manage stakeholders, both for projects in general (Hartono et al., 2014; Missonier and Loufrani-Fedida, 2014) and for IT (Sudevan et al., 2014) and R&D projects (Broom et al., 2013; Geeson et al., 2015).

In the existing DEA approaches to project evaluation and ranking, the stakeholders and their varying views have not been taken into account. All the possible inputs and outputs are allowed in model (1)-(3). Each project tends to maximize its performance by choosing the weights which maximize function (1) and are selected among all non-negative values of the decision variables (3). However, not all the inputs and outputs are important for each stakeholder. In many cases the situation will be as follows: for each stakeholder only a certain subset of inputs and a certain subset of outputs will matter, the other outputs and inputs will have weights equal to zero from the outset. If the philosophy of the DEA approach consists in letting each project present itself in the best light, each project should also have the right to choose the stakeholder for which it has the best performance. And in some cases the decision maker will want to asses and rank projects taking various stakeholders into account. The original DEA method does not make it possible. The proposal formulated in Section 4 covers this gap.

Our proposal will allow to asses and rank projects taking into account for example the following stakeholders and their diversified views:

1) for IT projects:
   a) a customer representative, representing the upper management level, interested in one input: the project price (linked to the project budget), and in three outputs: customer satisfaction, the risk linked to the project product and the product complexity;
   b) the software producer representative, representing the upper management level, interested in one input: the green dollar cost, and in on one output: the green dollar benefits;
   c) another representative of the same software producer, representing a lower management level, interested in one input - the number of employees that were involved in the project, and in three types of output: the skills that the employees gained thanks to the project, other intangible benefits the employees gained thanks to the project, intangible benefits gained through the project team as a whole;
   d) another representative of the same software producer, representing an upper management level, interested in three inputs: the project cost, the project duration, the potential risk linked to the project realisation, and in two outputs: the customer satisfaction and the compliance of the project with customer strategy - which will mean chances for more contracts in the future.
2) For R&D projects:
   a) the financing institution, interested in one output: the budget, and in two types of outputs: the number of publication in high quality journals and the commercialisation chances of the product;
   b) the dean of a university faculty at which the project is realised, interested in two types of

input: the full time equivalent of personnel with various degrees used in the project and the project duration, and in three types of output: the numbers of publications, the number if dissertations worked out and published, the number of high quality personnel members employed thanks to the projects;

c) The financial manager of the institution at which the project is realised, interested in one type of input - the time his/her employees had to spend to help to prepare the project application and in one output: the part of the project budget that will be left at the university disposal.

Of course, the above examples are theoretic, although partially based on the authors' experience. They are not meant to show what the corresponding stakeholders should be interested in, but what they are often interested in, even if it is not correct. The main goal of the above examples is to show that various stakeholders, also those who are important in the organisation which realises the project or for which the project is realised, may have substantially different views about what the significant inputs and outputs of a project are. The modified DEA method will make it possible to take this into account.

4 MODIFIED DEA METHOD

Let $SI = \{i = 1,2, \dots, I\}$ be the set of the indices of all possible inputs that may be considered for the set of projects which are to be evaluated and ranked, and $SJ = \{j = 1,2, \dots, J\}$ the set of the indices of all outputs. There are K+1 projects to be evaluated and ranked. Let $S = \{l = 1,2, \dots, L\}$ be the set of the indices of all the stakeholders that have been identified for the projects in question.

For the l-th stakeholder ($l \in S$) there are given two sets: $SI_l \subset SI$ and $SJ_l \subset SJ$. These sets represent the indices of the inputs and outputs taken by the l-th stakeholder into consideration. It follows that from the point of view of the l-th stakeholder it holds:

$$u_i^{\mathrm{k}} = 0 \text{ and } v_j^{\mathrm{k}} = 0 \quad (4)$$

$$\text{for all } i \in SI \setminus SI_l \text{ and } j \in SJ \setminus SJ_l$$

where u_i^{k} and v_j^{k} are u_i^0 and v_j^0 from (3) when the k-the project becomes the 0-th project for problem (1)-(3), k=0,…K.

We can thus for each project solve L+1 problems: one identical to problem (1)-(3), where the individual stakeholders are not taken into account, one for each stakeholder ($l \in S$). The stakeholders linked problems will be of the following form (for each $l \in S$):

$$\frac{\sum_{j=1}^{J} v_j^0 y_j^0}{\sum_{i=1}^{I} u_i^0 x_i^0} \to max$$

$$\frac{\sum_{j=1}^{J} v_j^0 y_j^k}{\sum_{i=1}^{I} u_i^0 x_i^k} \leq 1, k = 1, \dots, K \quad (5)$$

$$u_i^0 \geq 0, v_j^0 > 0$$

$u_i^{\mathrm{k}} = 0$ and $v_j^{\mathrm{k}} =$ for all $i \in SI \setminus SI_l$ and $j \in SJ \setminus SJ_l$

where each project in turns becomes the 0th project.

For each project k=0,1,…K we would then have L+1 evaluations: p_k, being the value of the objective function of the problem (1)-(3), representing the best possible project evaluation when all inputs and outputs are put in the same box and treated in the same way, and p_k^l, $l \in S$, being the objective function of problem (5), when the k-th becomes the 0th project, and representing the best possible project evaluation when only the inputs and outputs important to the l-th stakeholder are taken into account.

These values can be then interpreted in several ways. We can aggregate them to a final project ranking for example as follows (pf_k, k=0,1,…K stands for the final ranking of the k-th project):

$$pf_k = max\{p_k, p_k^l, l \in S\} \quad (6)$$

or we can define pf_k as a weighted sum of p_k and $p_k^l, l \in S$.

We adopt here the formula (6), where the basic idea of the DEA method is retained: each project can present itself in the best possible way, by choosing only the weights of the inputs and outputs, but also the stakeholder who would put it in a good position. But any method of aggregating values $p_k, p_k^l, l \in S$ is better than the original approach, in which only values p_k are calculated., because the original method does not allow to take into account the view of even the key stakeholders. Using the original DEA method we may rank lowly some projects which are in fact good, because they would be highly appreciated by the key stakeholders whose opinion is crucial for our organisation. In the next section we will illustrate the proposed approach by an example.

5 COMPUTATIONAL EXAMPLE

Let is consider 10 R&D projects, whose all possible inputs and outputs (for all possible stakeholders) are

given in Table 1. All the inputs names in the Table 1 should be accompanied by words "used in the project" and all the output names by words "generated by the project". The values of the inputs and outputs have been given by experts and it has been made sure that they are commeasurable.

Problem (1)-(3), thus the original DEA method, gives the results shown in Table 2. The original DEA method would thus give us the following ranking of the projects: P5, P7, P8, P4, P6, P1, P2, P9, P3, P10.

Let us now consider two key stakeholders (L=2). We have the following information:

- $SI_1 = \{4,5\}, SJ_1 = SJ = \{1,2,3,4,5\};$
- $SI_2 = SI = \{1,2,3,4,5\}, SJ_2 = \{1,2,3\}.$

This means that the first stakeholder disregards inputs other than the number of assistants and associate professors engaged in the project and the second stakeholder disregards among outputs the number of patents and the number of scientific degrees generated be the project.

Table 1: All possible inputs and outputs for 10 example projects.

Inputs and outputs names			Inputs and outputs values									
			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Inputs	a1	budget [mln. EURO]	0.2	0.3	0.5	0.9	0.1	0.6	0.2	0.8	0.8	0.1
	a2	duration [months]	12	12	24	36	36	12	24	36	24	24
	a3	Nb of full professors	2	2	2	1	3	2	2	3	1	1
	a4	Nb of associate professors	5	5	6	8	2	3	3	6	4	5
	a5	Nb of assistant professors	3	8	2	4	6	9	2	4	2	3
Outputs	b1	Nb of high quality publications	2	1	1	2	5	2	2	3	1	0
	b2	Nb of international conferences presentations	10	12	10	11	13	9	8	8	5	15
	b3	Nb of monographs	1	2	1	1	0	2	2	1	0	1
	b4	Nb of patents	0	0	1	1	0	1	1	2	0	0
	b5	Nb of scientific degrees and titles	2	1	2	3	1	1	2	2	1	3

Table 2: The results of the original DEA for the example projects.

		Input and output weights									
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Inputs	a1	0.606	0.909	0.000	0.000	0.145	0.000	0.545	0.000	0.000	1.173
	a2	0.066	0.029	0.000	0.000	0.000	0.084	0.000	0.026	0.000	0.000
	a3	0.000	0.000	0.000	1.003	0.000	0.000	0.000	0.397	1.356	0.575
	a4	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000
	a5	0.000	0.000	2.030	0.000	0.000	0.000	0.031	0.044	1.162	0.000
Ouputs	b1	0.303	0.000	0.000	0.535	0.014	0.000	0.027	0.000	1.227	0.000
	b2	0.000	0.015	0.406	0.000	0.000	0.050	0.000	0.000	0.323	0.116
	b3	0.000	0.379	0.000	0.000	0.000	0.201	0.210	0.000	0.000	0.000
	b4	0.000	0.000	0.812	0.267	0.000	1.205	0.172	1.499	0.000	0.016
	b5	0.545	0.000	0.000	0.334	0.000	0.000	0.000	0.000	0.000	0.114
Objective function value		1.867	1.512	1.200	2.333	5.000	2.050	3.098	1.308	0.772	3.000

Table 3: The results of problem (5) for *l*=1.

		Input and output weights									
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Inputs	a1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	a2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	a3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	a4	0.070	0.425	0.010	0.010	0.660	1.000	0.029	0.220	0.010	0.082
	a5	0.871	0.010	1.000	0.985	0.010	0.010	0.053	0.169	1.000	0.368
Outputs	b1	0.186	0.000	0.000	0.000	1.000	0.000	0.023	0.000	0.318	0.000
	b2	0.197	0.070	0.203	0.000	0.000	0.158	0.000	0.000	0.174	0.123
	b3	0.000	0.368	0.000	0.000	0.000	0.499	0.257	0.000	0.000	0.000
	b4	0.000	0.000	0.403	0.000	0.000	0.755	0.000	1.000	0.000	0.000
	b5	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
Objective function value		0.792	0.714	1.183	0.746	3.623	1.029	2.909	1.000	0.583	1.216

Table 4: The results of problem (5) for l=2.

		Input and output weights									
		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Inputs	a1	0.000	1.000	0.000	0.000	1.000	0.000	0.168	0.000	0.000	1.000
	a2	0.134	0.032	0.000	0.000	0.000	0.130	0.000	0.000	0.000	0.000
	a3	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.390	1.000	0.343
	a4	0.000	0.000	0.000	0.000	0.012	0.303	0.110	0.000	0.000	0.000
	a5	0.336	0.000	1.000	0.000	0.000	0.000	0.194	0.660	0.849	0.016
Ouputs	b1	0.672	0.010	0.193	0.481	0.068	1.000	0.033	1.000	0.896	0.010
	b2	0.269	0.015	0.199	0.046	0.010	0.010	0.010	0.010	0.236	0.090
	b3	0.201	0.415	0.010	0.313	0.010	0.980	1.000	0.010	0.010	0.010
	b4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	b5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Objective function value		1.615	1.489	1.098	1.779	3.790	1.637	2.854	0.811	0.769	2.781

Table 5: Position of each project in the three rankings.

ranking	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Original DEA	6	7	9	4	1	5	2	3	8	10
Stakeholder 1	7	9	4	8	1	5	2	6	10	3
Stakeholder 2	5	7	8	6	1	4	2	9	10	3

Table 6: Position of each project in the final ranking on the basis of (6).

Ranking	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Value (6)	1,867	1,512	1,200	2,333	5,000	2,050	3,098	1,308	0,772	3,000
Final ranking	6	7	8	4	1	5	2	9	10	3

Table 3 and 4 contain the results of the application of problem (5) for l=1 and 2.

If we considered just the view of the first stakeholder (Table 3), we would have the following ranking of the projects: P5, P7, P10, P3, P6, P8, P1, P4, P2, P9, which is different than the one obtained by means of the original DEA method (especially if we consider e.g. project P10).

The view of the second stakeholder alone would give still another ranking - P5, P7, P10, P4, P6, P1, P2, P3, P8, P9 - which is shown in Table 4.

In Table 5 the positions of each project in the three rankings is shown. This may be a valuable information, for example, we can see that some projects have a very stable position (P5, P7, P6), but in case of some projects the evaluation changes considerably (P10, P8). The influence of the stakeholders may be high.

In Table 6 the aggregated values (6) are shown. This ranking shows the best situation of each project according to the choice of weights and the stakeholders and it might be a useful tool for the project evaluation. The projects at the top of the final ranking are certainly good in the eyes of some stakeholders. For example, if we had used the original DEA method, project P10 would have been rejected. But this project seems to satisfy two key stakeholders. Rejecting it would mean disregarding the key stakeholders of our organisation, which is decisively wrong.

6 CONLUSIONS

In this paper we propose a modification of the DEA method which can be used to evaluate projects. The core of our proposal is the possibility to include in the DEA model the perspectives of various project stakeholders. Project stakeholders, especially the key ones, cannot be neglected in project evaluation and selection. The original DEA method used for project evaluation disregarded them.

The proposal, combined with project stakeholders management methods and with careful project inputs and outputs identification and evaluation, may be useful in project selection problems. But of course real world cases are needed to prove it.

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APPENDIX

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