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EVALUATING CONSTRUCTION PROJECT SUCCESS WITH USE OF THE M-TOPSIS METHOD

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Abstract. A problematic of construction project success evaluation is discussed in this paper. It is established that the success of a construction project depends on success in achieving goals in different success criteria which may or may not be co-dependent; hence, the calculation of construction project success is a multi-dimensional evaluation problem. Therefore, it is necessary to discuss the overall success of a construction project as a multi-criterion problem that can be solved using a multi-criteria decision method. A new approach to overall construction project success calculation is presented, based on the multi-criteria decision method M-TOPSIS. M-TOPSIS ranks results from ideal solution to negative ideal solution which suitable fits with a presented new approach to generalized project success evaluation method. For an ideal solution, the best values from all considered projects, including pre-production plan parameters, are used, and for negative ideal solution, minimal parameters for each criterion are defined. Because, in civil engineering, projects can be done even better than planned, results from M-TOPSIS are then transposed, so that results are presented on a scale from minimal solution (0) to planned solution (1) and above. Several project successes can be compared with each other and ranked according to their performance with this method. Since results from this method are very sensitive to incorrectly input data, the basic M-TOPSIS method theory is closely, presented and a simple practical example for using the suggested method is also shown.

Keywords: construction management, construction project, project evaluation, success factors, MCDM, multi-criteria methods, TOPSIS, M-TOPSIS.

1. Introduction

The management of construction projects always generates a specific need for decision making, which results in unforeseeable conditions in the project's future. The systematic character of projects requires an analysis of every decision concerning project goals, an analysis of interactions between decisions concerning project goals and possibly a modification of decision-making criteria. The goals can be characterised by criteria that can affect an entire project at different levels. For example, the finish date of a certain activity can influence the starting date of another activity or the finish date of the entire project. Naturally, the duration of the activity is also related to the activity's costs, which means that criteria are also interrelated. Therefore, since the project is a multi-dimensional problem, multi-criteria decision methods (MCDM) are being increasingly used, to deal with decision-making issues in projects.

As it turned out in practice, the project's correlation cost at the implementation stage is usually significantly higher than the cost of an additional risk analysis at the planning stage; therefore, emphasis should be placed on the complexity and thoroughness of procedures and analyses at the planning stage (Błaszczyk, Nowak 2009). Since, in general, the meaning of success of the concluded project is the project's deviation from the planned parameters, we must first determine the measurement criteria for measuring this deviation, thereafter the parameters of success, and we finally must choose the evaluation method. Many authors indicate more or less complicated approaches towards successful evaluation of the project's success, determination of individual factors in project success or determination of the values of evaluation parameters (Šaparauskas, Turskis 2006; Doloi, Lim 2007; Šarka *et al.* 2008; Vukomanović, Radujković 2008; Park 2009; Antuchevičienė *et al.* 2010); however, no method has yet been presented that would take into account different success criteria and establish a general mark for the success of a completed construction project. Based on the findings of other authors and on the scientific work by the authors of this paper, we hereby suggest a new approach to construction project success evaluation.

2. Success and measuring success

Project success is the most important goal of project management, but it presents a challenge to be defined. Ilbeigi and Heravi (2009) found that for a long time in the past, there was no standardised definition of project success and that there was also little consideration of success criteria. Project success in the past was usually measured in terms of total costs and time required for the project's conclusion. If more than one success criterion was considered, often no distinction was made between the success of the project's product and the success of the project management. However, in modern project management, project success stands for successfully achieved goals related to cost, time, quality and other given criteria, which means that the goals must first be determined and thereafter compared with the achieved results.

Because of the lack of exact mathematical and quantitative measurement models for project success, a measurement model must first be determined. The model initially requires success criteria and success parameters. These criteria basically originate from the basic project management success criteria; cost, time and quality (Pšunder *et al.* 2009). To determine target values (success parameters) for these criteria, it is crucial to use the same procedure to determine these values as for obtaining results from the measured construction project, since, if we want to compare the success of several projects, it is important that all of the input data be determined in the same way. The criteria's parameters can be determined numerically (real numbers) or by way of assessment (linguistically), and they can depend on the decision makers in the project. Therefore, for a general evaluation model, we must choose only those criteria are that relevant to all projects. Different criteria have different units of measurement. In order to compare different criteria with each other, the criteria must be made uniform (normalized) so that criteria values can be obtained without units of measurement. From the point of view of decision makers, different criteria have different levels of importance; hence criteria must be weighted. Weighting determines the importance ratio of each criterion compared to other criteria and therefore normalizes all the criteria in the given relation. The sum of those normalized and weighted criteria yields performance values for each of the finished projects on a scale from non-success to planned success. Thus, each alternative (measured project) is marked with a unique value, its non-dimensional performance mark.

Following from the previous paragraph, to calculate the success mark of the finished project we need the following:

1) success criteria;
2) a method for obtaining success parameters for criteria and project performance indicators from measured projects;
3) a method for evaluating parameters for assessment;
4) a method for normalizing criteria;
5) a method for weighting criteria;
6) a method for calculating a final mark for project success.

For the performance of these procedures, use of the multi-criteria decision method TOPSIS has proven to be the most suitable.

Multi-criteria decision methods are primarily intended to serve as an aid to decision-making processes in the construction industry, mostly for selecting technical solutions for construction problems. However, their use has recently begun to spread to other construction fields and to project management in general. Šubrt (2004), for example, suggests that the multi-criteria method can be used for solving problems associated with optimisation of critical paths in resource oriented path problems; Barin *et al.* (2009) use MCDM to analyse the influence of criteria on decision-making in renewable energy source management; Zavadskas *et al.* (2010) show how a multi-criteria method can be used to compare risk assessment of construction projects; Mahdavi *et al.* (2008) suggest that SWOT analyses can be evaluated by the multi-criteria method; while Šaparauskas and Turskis (2006) suggest the use of the multi-criteria method for evaluating the construction sustainability level. Certain multi-criteria methods provide, in addition to their ranking, the non-dimensional evaluation of alternatives, which concurs with the basic approach to project success evaluation described in the previous paragraph. The most suitable for this is undoubtedly the TOPSIS method. By using such methods, the success of project implementation may be evaluated from a new perspective, as proposed in this paper.

Project success implies successfully achieved goals in the field of different project goals. The basic success criteria are the cost, time and quality of implementation. Since the meaning of these criteria is too wide to be precisely evaluated, many authors indicate more detailed success criteria. For instance, Alarcon and Serpell (1996) suggest the following parameters to be used as project success evaluation criteria:

- change of costs = actual cost/budgeted cost;
- change of duration = actual duration/planned duration;
- reclamations = % of sample rejections;
- change of goals = change orders/budgeted cost.

For example, Takim and Akintoye (2002) suggest the following success indicators for the concluded project:

- meets pre-stated objectives;
- meets time;
- meets budget;
- technical specifications;
- acceptable quality;
- meets corporate priorities;
- harmony;
- absence of any claims and proceedings;
- reduction of work conflicts/disputes;
- transfer of experience;
- investment opportunities;
- value for money.

On the other hand, Salminen's (2005) research shows that, even if the evaluation of project success depends on different viewpoints and expectations, authors usually propose similar criteria. According to him, the most common success parameters are the following:

- keeping to budget, profitability;
- schedule adherence;

- quality/technical specifications/low number of defects;
- product functionality;
- client satisfaction with the product and service;
- cost and time predictability/minimization of client surprise;
- contractor satisfaction;
- project manager/team satisfaction;
- environmental sustainability;
- safe performance/low accident rates.

For each selected criterion, a benchmarking parameters calculation method must also be determined. This is very important, since for example, there is no point in comparing absolute profit from a EUR 1,000,000 budgeted project with a EUR 10,000 budgeted project. These parameters (benchmarking criteria values) must be obtained from the available project results; therefore, the selection of the calculation method mostly depends on the type of data. For example, if we want to evaluate a project's financial success, we can take an accounting rate of the return method if we can obtain all the required data from all the projects to perform such a calculation; otherwise we must choose another suitable method (Medanić *et al.* 2005). If we cannot obtain all the required data from all the projects, such a criterion is not suitable for project success evaluation. For a general construction project success evaluation method, as proposed in this paper, we must therefore use those criteria that can be calculated for almost all completed construction projects, so they have to be basic and simple.

Therefore, the selected criteria conditions the data required for the calculation of project success and the available data conditions the selection of the calculation method. However, since there is often no method for determining criteria values, many criteria are linguistically assessed, on account of which we must also consider the correlation factors of assessment precision and apply "fuzzy" methods. Since fuzzy methods can cause result deviations if they are not carefully used, their use should be determined precisely. Since this is a matter for further research, it will not be further addressed in this paper.

3. The TOPSIS and the M-TOPSIS methods

The name of the TOPSIS method is an abbreviation for the Technique for Order Preference by Similarity to Ideal Solution. The TOPSIS method was presented by Hwang and Yoon in 1981 (Hwang, Yoon 1981) and quickly began to be used in the construction industry. The method is one of the classic methods for multi-criteria decision making, based on the distribution of individual alternatives according to the given criteria and parameters. Unlike some other methods (e.g. ELECTRE), the TOPSIS method performs an evaluation of a given set of alternative data without direct comparison between alternatives, with the result expressed as a mark on a scale between the values of the ideal and the negative ideal solution. The alternative closest to the ideal solution and farthest from the negative ideal solution is the best one. Many modifications and improvements of TOPSIS have been introduced (Ren *et al.* 2007; Antuchevičienė *et al.* 2010; Marković 2010; Chamodrakas *et al.* 2011, etc.) and of those, M-TOPSIS (Ren *et al.* 2007) is the most suitable method for our purpose.

The basic algorithm of the TOPSIS method evaluates the decision matrix, which shows 'm' alternatives evaluated by 'n' criteria. Since different criteria have different dimensions, the values in the decision matrix are first transformed into normalized, non-dimensional values, under the following equation (Antuchevičienė *et al.* 2010):

$$a_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}, \tag{1}$$

where: a_{ij} stands for the normalized value; $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$.

The weighted normalized matrix is calculated in such a way that each value within the individual criterion in the normalized matrix is multiplied by the weight of this criterion:

$$v_{ij} = w_i \cdot a_{ij}, \tag{2}$$

where: w_i stands for the weight of the individual criterion i; $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$.

The ideal solution is a group of weighted normalized criteria values, which indicates the ideal criteria values:

$$A^+ = \left\{ v_{1^+}, v_{2^+}, \ldots v_{n^+} \right\}, \tag{3}$$

and the negative ideal solution is a group of weighted normalized criteria values, which indicates the negative ideal criteria values:

$$A^- = \left\{ v_{1^-}, v_{2^-}, \ldots v_{n^-} \right\}, \tag{4}$$

where:

$$v_{j^+} = \left\{ \max_i (v_{ij}),\ j \in J^+; \min_i (v_{ij}),\ j \in J^- \right\}, \tag{5}$$

and

$$v_{j^-} = \left\{ \min_i (v_{ij}),\ j \in J^+; \max_i (v_{ij}),\ j \in J^- \right\}, \tag{6}$$

where: $J^+ = \{i = 1, 2, \ldots, m\}$ and i is related to benefit criteria; $J^- = \{i = 1, 2, \ldots, m\}$ and i is related to cost criteria; $j = 1, 2, \ldots, n$.

Thereafter, using the Euclidean distance, the distances to the ideal solution S_{i^+} and to the negative ideal solution S_{i^-} are calculated for each alternative:

$$S_{i^+} = \sqrt{\sum_{j=1}^{n} (v_{j^+} - v_{ij})^2}, \text{ for } i=1, 2, \ldots, m, \tag{7}$$

and

$$S_{i^-} = \sqrt{\sum_{j=1}^{n} (v_{j^-} - v_{ij})^2}, \text{ for } i=1, 2, \ldots, m, \tag{8}$$

where: $v_{j^+} = \max_i v_{ij}$ and $v_{j^-} = \min_i v_{ij}$.

Thereafter, an M-TOPSIS modification is introduced. Since S_{i^+} and S_{i^-} represent each alternative on an S^+S^- plane, distances from those two points to the relative proximity to the ideal solution are calculated according to the classic TOPSIS method (Antuchevičienė *et al.* 2010):

$$C_i = \frac{S_{i^-}}{(S_{i^+} + S_{i^-})}, \qquad (9)$$

where: $1 \geq C_i \geq 0$ and $i = 1, 2, \ldots, m$.

M-TOPSIS modifies this calculation in such a way as to firstly set the optimized ideal reference point, $(\min(S_{i^+}), \max(S_{i^-}))$ and then calculate the distance from each alternative to that point with (Ren *et al.* 2007):

$$C_i^M = \sqrt{(S_i^+ - \min(S_i^+))^2 + (S_i^- - \max(S_i^-))^2}, \quad (10)$$

where $i = 1, 2, \ldots, m$.

The best alternative is the one that having the M-TOPSIS coefficient C_i^M nearest to 0.

4. Additional modification of results of the M-TOPSIS method for project success evaluation

As has been established, we can use the TOPSIS method for evaluation of construction project success. Since the TOPSIS method needs ideal and negative ideal solutions, we can use the planned alternative as the ideal solution. However, this alternative may not ultimately represent the ideal solution, since sometimes the project turns out to be more successful than planned. Therefore, the ideal solution must be determined based on the maximum values of individual alternatives under the Eq. (5), as is usual in TOPSIS methods. Based on this, for construction projects the following holds:

$$A^P = \textit{planned solution} = \textit{comparative solution} \neq \textit{ideal solution}. \qquad (11)$$

Because the TOPSIS method works on exactly determined interval, we must also determine the negative ideal solution. Usually, a zero is used in TOPSIS for the negative ideal solution, but for the purpose of evaluating generalised construction project success this would incorrectly affect the results. Because the ratio between alternatives is important, a properly established interval must first be set. The best way involves choosing parameters for the negative ideal solution that could be achieved if the project were implemented in the worst possible way but still completed:

$$A^M = \textit{minimal solution} = \textit{negative ideal solution}. \quad (12)$$

The next step of additional modification is the normalization of the given criteria values. Here is where most mistakes in the application of the TOPSIS method are made. Namely, for correct results, it is recommended that all criteria are benefit criteria, while their values should be expressed according to their mutual interval and not according to the absolute value (Houška, Domeova 2007). Considering that, in the course of project evaluation, the interrelation of values for individual criteria is important, the values of criteria are relativized under the following equation:

$$a'_{ij} = \max(a_{ij}) - a_{ij}, \text{ for cost criteria, or}$$
$$a'_{ij} = a_{ij} - \min(a_{ij}), \text{ for benefit criteria,} \qquad (13)$$

where: a'_{ij} stands for the relativized normalized value; $i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$.

Further on, the values of C_i^M coefficients can be calculated under the Eq. (10). If we want to present results in relation to the planned alternative on the interval from the negative ideal to the planned alternative, we must transpose these results so that the value of the planned solution equals 1 (100%). This is achieved by the following equation:

$$C_i^{M'} = \frac{C_M - C_i}{(C_M - C_P)}, \qquad (14)$$

where: $C_i^{M'}$ – stands for the transposed value C_i^M; C_M – stands for the coefficient of the minimal (negative solution) and C_P – for the coefficient of the planned solution.

After the transposition, the results acquire values in relation to the value of the planned solution. The end results must be such that the following applies:

$$C'_M = 0;\ C'_P = 1 = 100\%. \qquad (15)$$

The values of the remaining alternatives represent the calculated success of individual alternatives in relation to the planned solution in percentages.

5. Case study

The case study of a construction project, presented in the following, is fictional and only serves for a demonstration of this general project success evaluation method. The case involves the building of some construction-engineering structures. For better comparison, we shall presume that the company constructed three identical structures. Internal organisational flaws resulted in the company's failure to construct the first structure in the agreed term; the second structure was built in the agreed term and the third was constructed prior to the agreed time, owing to experience gained.

First we chose criteria for success according to Salminen (2005):

- F_1: cost performance = (target budget – achieved costs)/target budget;
- F_2: time performance = time used/planned time;
- F_3: quality performance = actual costs of elimination of complaints/budgeted cost;
- F_4: safety performance = no. of right observations/ total no. of safety issue observations.

These criteria were then benchmarked by having experts compare the importance of individual criteria. They used following grades:

- 0 – criterion is unimportant in relation to the compared criterion;

1 – criterion is less important than the compared criterion;
2 – criterion is equally important as the compared criterion;
3 – criterion is more important than the compared criterion;
4 – criterion is much more important than the compared criterion.

From the expert's marks, an mean values of criteria interrelations were taken (Table 1).

Hence, the weights for the criteria are as follows: $w_{F1} = 0.38$; $w_{F2} = 0.22$; $w_{F3} = 0.22$; $w_{F4} = 0.18$.

The same ideal plan for costs and time is applied to all three projects:

- budgeted labour costs: EUR 750,000;
- planned implementation time: 160 days;
- budgeted costs for complaints: EUR 0;
- number of planned safety issues: 0.

During project planning, the worst-case scenario was also considered, which would be evaluated as a total failure:

- labour costs: EUR 975,000;
- implementation time: 250 days;
- cost of complaints: EUR 50,000;
- number of safety issues = 25 out of 40.

Input data for the completed projects is presented in Table 2.

As a comparative solution, we apply the planned solution, and as the negative ideal solution, we apply the worst possible solution or the minimal solution. Therefore, we get the input Table 3.

We must convert the input data from Table 3 to these desired criteria values (Table 4):

F_1: cost performance = (target budget – achieved costs)/target budget;
F_2: time performance = time used/planned time;
F_3: quality performance = actual cost of complaint elimination/budgeted cost;
F_4: safety performance = no. of right observations/ total no. of safety issue observations.

Table 1. Determination of criteria weight

Project	F1 = cost performance	F2 = time performance	F3 = quality performance	F4 = safety performance	Total	%
F1 = cost performance		3	3	3	9	38
F2 = time performance	1		2	2.33	5.33	22
F3 = quality performance	1	2		2.33	5.33	22
F4 = safety performance	1	1.67	1.67		4.33	18
					24	100

Table 2. Project results

Project	Actual implementation costs, EUR	Actual implementation time, days	Cost of complaints, EUR	Number of safety issues
Structure 1	850,000	220	10,000	3
Structure 2	770,000	160	5,000	4
Structure 3	700,000	135	20,000	8

Table 3. Input data

Project	Actual implementation costs, EUR	Actual implementation time, days	Cost of complaints, EUR	Number of safety issues
Planned solution	750,000	160	0	0
Structure 1	850,000	220	10,000	3
Structure 2	770,000	160	5,000	4
Structure 3	700,000	135	20,000	8
Minimal solution	975,000	250	50,000	25

Table 4. Criteria values

Project	F1 = cost performance	F2 = time performance	F3 = quality performance	F4 = safety performance
Planned solution	(750,000 – 750,000)/750,000 = 0.000	160/160 = 1.000	0.000	0.000
Structure 1	(750,000 – 850,000)/750,000 = –0.133	220/160 = 1.375	10,000/750,000 = 0.013	3/40 = 0.075
Structure 2	(750,000 – 770,000)/750,000 = –0.027	160/160 = 1.000	5,000/750,000 = 0.007	4/40 = 0.100
Structure 3	(750,000 – 700,000)/750,000 = 0.067	135/160 = 0.844	20,000/750,000 = 0.027	8/40 = 0.200
Minimal solution	(750,000 – 975,000)/750,000 = –0.300	250/160 = 1.563	50,000/750,000 = 0.067	25/40 = 0.625
$\max(a_{ij})$		1.563	0.067	0.625
$\min(a_{ij})$	–0.300			

By Eq. (13), the cost and benefit criteria are transposed into benefit criteria and are relativized to their mutual interval. In this way, we get Table 5.

By applying Eq. (1), the values are normalized, which produces a matrix of normalized values (Table 6).

The normalized values must then be weighted by the weights selected under Eq. (2), after which we get the weighted normalized matrix of values (Table 7).

From this data, we get the mathematically ideal solution and the mathematically negative ideal solution:

$$A^{+} = \{0.2437; 0.1453; 0.1312; 0.1049\};$$

$$A^{-} = \{0.0000; 0.0000; 0.0000; 0.0000\}.$$

Based on the ideal solution and on the negative ideal solution, the distances from the ideal and from the negative ideal solution are calculated using Eqs (7) and (8) and the relative proximity of the alternative from the ideal solution using the Eq. (10). Results are shown in Table 8.

The achieved results indicate the ranking of individual alternatives on the unset scale. If we want to demonstrate these results relative to the planned solution, we transpose the values using the Eq. (14) and thus get the criteria in relation to the planned solution (Table 9).

Table 5. Relativized input data

Project	F1 = cost performance	F2 = time performance	F3 = quality performance	F4 = safety performance
Planned solution	0.300	0.563	0.067	0.625
Structure 1	0.167	0.188	0.053	0.550
Structure 2	0.273	0.563	0.060	0.525
Structure 3	0.367	0.719	0.040	0.425
Minimal solution	0.000	0.000	0.000	0.000

Table 6. Matrix of normalized values

Project	F1 = cost performance	F2 = time performance	F3 = quality performance	F4 = safety performance
Planned solution	0.5247	0.5168	0.5965	0.5830
Structure 1	0.2915	0.1723	0.4772	0.5130
Structure 2	0.4780	0.5168	0.5369	0.4897
Structure 3	0.6413	0.6604	0.3579	0.3964
Minimal solution	0.0000	0.0000	0.0000	0.0000
Weights	0.38	0.22	0.22	0.18

Table 7. Weighted matrix of normalized values

Project	F1 = cost performance	F2 = time performance	F3 = quality performance	F4 = safety performance
Planned solution	0.1994	0.1137	0.1312	0.1049
Structure 1	0.1108	0.0379	0.1050	0.0923
Structure 2	0.1817	0.1137	0.1181	0.0881
Structure 3	0.2437	0.1453	0.0787	0.0714
Minimal solution	0.0000	0.0000	0.0000	0.0000

Table 8. Calculation of the relative proximity of alternatives from the ideal solution

Project	S_i^+	S_i^-	$C^M{}_i$
Planned solution	0.0544	0.2845	0.0185
Structure 1	0.1733	0.1824	0.1694
Structure 2	0.0728	0.2601	0.0466
Structure 3	0.0623	0.3030	0.0079
Minimal solution	0.3297	0.0000	0.4094

Table 9. Project success

Project	$C^{M\prime}{}_i$	Project success
Planned solution	1.000	100%
Structure 1	0.614	61%
Structure 2	0.928	93%
Structure 3	1.027	103%
Minimal solution	0.000	0%

In comment, we can say that for the first structure project performance was only 61%, since the project met only 61% of set goals; for the second one, the success rate was 94% and for the third one, 103%, meaning that for these structure project goals were over achieved.

This simple case study demonstrates how an exact evaluation of project performance according to the set goals can be done. The final result comprises non-dimensional generalised success marks, which depend only on our criteria assessments and are less dependent on personal marks from project decision makers than results from other methods. The next step in evaluation of this method is to determine standards for result preparation, so that even unrelated projects could be directly compared to each other from the point of view of their success.

6. Conclusions

This paper has presented a systematic analysis of a fundamental approach to a new method of general construction project success evaluation. The method is based on the multi-criteria decision method M-TOPSIS which yields an exact, non-dimensional ranking of project success according to the planned parameters that were set prior to project execution. The purpose of the method is to compare general construction project performance success between different projects. The following conclusions can be reached from this paper:

1) Construction projects are unpredictable and therefore require as much data during decisions as possible.
2) A construction project is a multidimensional problem that can be solved with the use of multi-criteria decision making methods.
3) If we want to compare projects to each other, all the data must be determined in the same way, and criteria must be presented in all compared projects. Therefore, it is important to choose basic criteria with simply obtainable data.
4) Research by other authors showed that, even if the expectations of and viewpoint on a project are very variable, the success criteria are more or less similar and are generally cost, time, quality and safety.
5) For construction projects, we cannot say that a planned performance is equal to the ideal performance, since a project can perform better than planned, and negative ideal performance is not "zero" performance, since we cannot compare projects that are incomplete to completed ones.
6) The M-TOPSIS method allows data that has been relativized and transposed according to the planned parameters, to be directly characterized as a percentage of its general success, which was the main aim of the research.

Further research on this methodology could elaborate the method to a project performance evaluation tool. Such a tool could finally enable the establishment of a statistical database of project performance success which would highly influence future project initiation and planning. Such a database would change the stakeholder's perception of success from the usual economic success to overall project success.

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