Evaluating Contractor Performance*: Application to the Dubai Construction Industry*

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Predicting the performance of the contractor is very important for both the contractor and the owner especially in highly competitive markets. The research presented in this paper offers a new model for contractor performance prediction. The model developed here utilizes qualitative as well as previously unconsidered quantitative measures about the contractors' performance. The model makes use of performance measures such total weighted tardiness, average number of late jobs, average lateness, average cost overrun etc… to evaluate the contractors in addition to qualitative measures relating to safety, environment, and personnel. The Analytical Hierarchy Process (AHP) was employed to assign scores to each contractor based on a pair-wise comparison between the identified qualitative measures. The model was tested for the case of the United Arab Emirates. Twenty contractors were selected, and construction managers/owners were asked to evaluate the contractors based on a questionnaire as well as historical project records. Discriminant analysis was conducted and the contractors were divided into three groups: High Performance Contractors, Medium Performance Contractors and Low Performance Contractors.

Keywords: Contractor Performance, Competency, Project Management, Building Construction

INTRODUCTION

Contractor performance can be defined by the level and quality of projects delivered to clients. It has been a common practice however to select the least cost bidder among competing contractors to perform the job. Conversely this may not ensure quality which is an indispensable measure in project delivery. Predicting the performance of the contractor is highly important for both the contractor and the owner. During the last few decades the United Arab Emirates witnessed a huge construction boom that has attracted to the construction market a large number of competing contractors. Predicting the performance of construction firms in such a situation is indispensable in order to ensure quality and guarantee international standards. With the onslaught of contractors working in the construction industry the need for a contractor's performance model that deals with that market has also increased.

This paper presents a novel contractor competence model, which investigates the relationship between the contractors' qualitative performance measures as well the quantitative measures while evaluating uncertainty in these measures. Cost and schedule records from previously accomplished projects by contractors were used to extract quantitative performance measures. Previous records of the contractors in question were used to evaluate some important parameters such as the cost overrun, the cumulative cost overrun, average delay, tardiness as well as several other schedule and cost performance measures. Contractors and owners were interviewed and a questionnaire was designed and distributed to determine the most important and relevant qualitative measures. Then the Analytical Hierarchy Process (AHP) was employed to assign scores to each contractor based on a pair-wise comparison between the identified qualitative measures. The qualitative analysis conducted through the AHP and the results obtained from the quantitative analysis are compared and a discriminant analysis was conducted. The results were used to group contractors into categories based on a prediction of the contractors' performances**.**

To demonstrate the applicability of the model, it was tested for the case of the United Arab Emirates. Twenty contractors from the country were selected and construction managers/owners have been asked to evaluate them based on specific criteria. The remainder of this paper is organized as follows; firstly, a review of the literature is provided that highlights the major research efforts conducted on the topic. Secondly the model is presented in detail and is broken down into individual steps. Thirdly, the application of the model to the case of the UAE is discussed and results obtained are presented. Finally, conclusions are drawn and limitations of the model are examined.

LITERATURE REVIEW

Literature review into contractor evaluation methods show that several research efforts have dealt with the issue. For instance, Shen et al (2003) investigated the Contractor Key Competitiveness Indicators. The researchers used the AHP approach to determine the key competitiveness indicators of contractors in the Chinese Construction Market. Wong (2004) developed a contractor performance prediction Model for the United Kingdom construction contractors. The researchers used the Logistic Regression approach to predict contractor effectiveness in the U.K market. Another research in this domain is the Contractor Selection for Design/Build Projects (Palaneeswaran and Kumaraswamy, 2000). The research focused on developing a model for contractor prequalification and bid evaluation in design/build projects. It presents a comparative overview of some international practices in the design/build contractor selection process. Also (Singh and Tiong, 2006) studied the contractor selection criteria for the Singapore construction industry. They conducted a local study that aimed to develop a computer-interactive multi-criteria decision system for contractor selection involving identification of contractor selection criteria for inclusion in a contractor performance assessment system. (Singh and Tiong, 2005) also developed a fuzzy decision framework for contractor selection. Furthermore, (Alarco´n and Mourgues, 2002) proposed a contractor selection system that incorporates the contractor's performance prediction. In this research, a modeling framework developed in previous researches was used to develop a conceptual model of a project that depicts a causal structure of the variables, risks, and interactions that affect a contractor's performance for a specific project from the owner's point of view. F.Waara and J. Bröchner (2006) investigate Price and Nonprice Criteria for Contractor Selection. The purpose of their research was to describe and explain how public owners use multiple criteria for the award of construction contracts. They showed that it is likely that the non price criteria support the alignment of owner and contractor interests, and that bidder behavior should be affected by the likelihood of repeated contracts, and by the transparency of owners' evaluation procedures. In addition, several earlier studies have also tackled the topic (Hatush and Skitmore 1997, Holt and Olomolaiye 1994, Invancevich et al 1997).

The above mentioned researches are part of large efforts in the contractor selection methods. The research presented in this paper is different from previous research efforts in many ways; Firstly, the model developed here utilizes qualitative as well as previously unconsidered quantitative measures about the contractors' performance to investigate their performance. Secondly, the analysis performed in the proposed model correlates the quantitative data and qualitative data using discriminant analysis, which has revealed interesting conclusions about the contractors' competency prediction. Finally, the model is tested using data from the UAE and is shown to be applicable to the construction industry in that country (though the model could also be appropriate for the construction industry in general). No such research efforts have been conducted for the purpose of contractor selection in the UAE construction arena.

Table 1: Qualitative Measures Used

Staff & Equipment Quality	Safety & Environmental Protection	Other Criteria
Staff Training Program : describes whether the firm has initiatives to improve the staff quality through training programs	**Health Record:** Workers health record for previous projects	**Time Control**: Time management to deliver projects on time
Project manager Performance: describes how competent is the project and manager and the decision maker of the firm	**Risk Management** : How the company deals with work related accidents	**Cost Control**: How the project cost stays within the estimated cost
Availability of Key Personnel : gives an impression of the key personnel available in the firm	**Environment Protection** : Efforts toward environment protection	**Reputation**: What degree of fame the firm has

Equipment Condition: New, old, sophisticated etc...	**Environment Protection Records**: previous projects' environmental impact	**Technology**: How much the firm take advantage of the technology advance
Equipment Suitability : How much the quality and quantity of the equipment used suits the size of the tasks to be performed		

THE PROPOSED MODEL

A schematic of the contractor performance model suggested in this paper study is shown in Figure 1. The model is broken down into a number of steps; first the important qualitative measures for comparing and assessing the contractors' performance have to be identified. A ranking of the contractors based on the AHP analysis of the qualitative measures follows this. Simultaneously, the quantitative measures are calculated from the records of the contractor at hand. Finally, discriminant analysis is conducted to aggregate the contractors into the various performance categories. Each of those steps is discussed next.

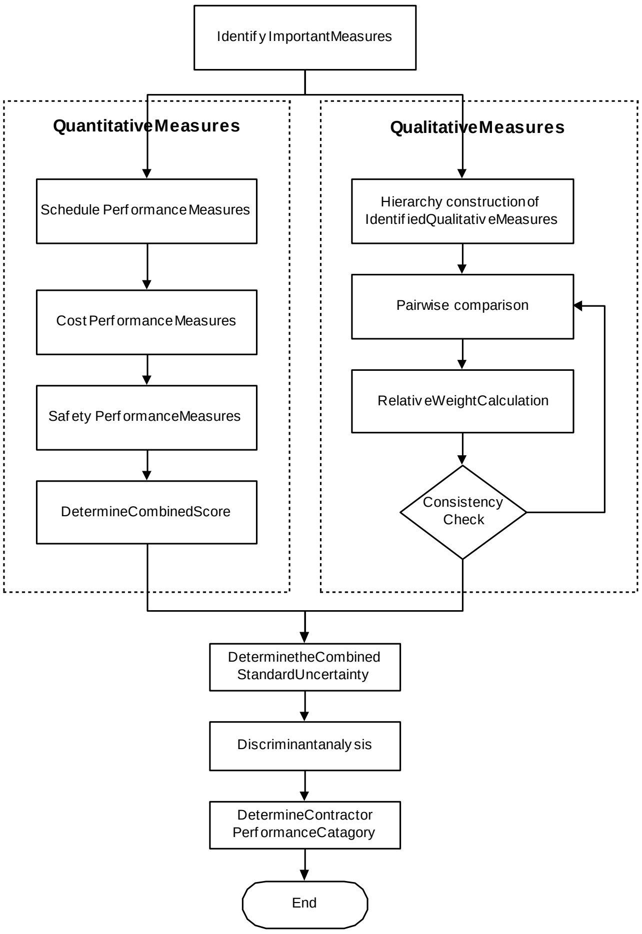

Figure 1: A schematic of the Proposed Model

Constructing a list of contractor performance measures

Contractor performance depends on a large number of factors. These factors can be broken down to qualitative measures that can be subjectively/objectively assessed and ones that can be quantitatively calculated from the contractors' records. The wide array of measures that can be utilized have been considered in previous research efforts described above. A master list of all these measures was constructed. This research focused on the most important ones for the UAE construction market. A final list of qualitative measures was constructed after extensive interviews and a questionnaire sent to the contractors, construction managers and owners. Data from questionnaires in addition to selection factors from projects were collected. The measures considered in this study are grouped into three categories as table 1 shows. Similar lists can be constructed for different situations. It is important to note that the time and cost control measures refer to the management and control procedures that the contractor has in place. These measures are intended to assess the quality of these processes and procedures rather than the actual cost and time performance. The actual cost and time performance will be assessed using quantitative measures as will be described. The same is true for health records, where the qualitative measure assesses the availability and quality of health and safety record keeping processes.

Evaluating the contractors' qualitative performance measures

This paper uses the AHP to evaluate the relative weight of the each of the above-mentioned measures in order to determine the score assigned to each contractor in the survey. The Analytical Hierarchy Process (AHP) was first introduced by Saaty (1980) as a new approach to deal with complex economic, technological and socio-political problems, which often involve a great deal of uncertainty. The details of the AHP can be found in (Saaty,1980) and therefore here we will only specify how the AHP was applied to the problem. First the problem of contractor performance prediction is decomposed into the main decision factors. Table 1 shows the main factors and sub factors for each. These factors represent the performance criteria on the basis of which contractors are evaluated through the score assigned to them by the construction managers/owner. Then a pairwise comparison is conducted. Here, the qualitative measures identified above are compared to each other (e.g. " What is more important in contractor performance: Safety or Equipment Condition? and, what is the degree of that importance?). In this way a decision matrix whose elements a_{ij} between the measures considered, C_i can be constructed. Next the relative weights of the qualitative measures are calculated. The eigenvector of the decision matrix established in the previous stage (the outcome of the pair wise comparison) is the priority vector of the qualitative measures compared which represents their relative weights

Constructing a quantitative model for contractor performance evaluation. The next step is to determine quantitative measures to be used for contractor evaluation. These measures can be calculated from the actual performance of the contractor on jobs using historical records. It is important to note that not all the proposed quantitative measures need to be used to evaluate the contractors in all situations. In fact, one of the points this paper is trying to present is the fact that owners can evaluate the contractors based on a set of certain performance measure that lend themselves to the project at hand and the characteristics of the specific contractual environment. The quantitative measures can be broken down into 3 main categories; schedule, cost and safety. The most common measure of schedule performance by contractors and one that is most prevalent is the lateness of a particular job or the average lateness of all the jobs on record for a certain contractor. In the industrial scheduling domain however several other measures of schedule performance are usually considered. Some of these measures may be adapted for use in the construction domain. For example the average degree of lateness of all the projects on record for the contractor can be calculated from,

$$\frac{\sum_{j=1}^{N} L_j}{N} = \frac{\sum_{j=1}^{N} \frac{C_j - d_j}{d_j}}{N} \qquad (1)$$

Another two important measures are average tardiness and average earliness on projects completed. Contractors can have a mixed performance when it comes to the average L_j (i.e. some projects are completed substantially behind schedule and vice versa. One can consider the maximum lateness $L_{\max} = \max(L_1,...,L_n)$ to identify this, but this is susceptible to outliers. The average tardiness and lateness can therefore expose such mixed performance and can be calculated using,

$$\frac{\sum_{j=1}^{N} T_j}{N} = \frac{\sum_{j=1}^{N} \max(L_j,0)}{N}, \qquad (2) \text{ and, } \qquad \frac{\sum_{j=1}^{N} E_j}{N} = \frac{\sum_{j=1}^{N} \max(-L_j,0)}{N} \qquad (3)$$

In equations 4 and 5, the Lj in the equation refers to the lateness of the job, and consequently Max (0, Lj) refers to the absolute value of the lateness and not the maximum (since max of a negative Lj and 0 is zero). This is also true for the tardiness equation. Therefore, equations 4 and 5 consider the average absolute lateness or tardiness versus the maximum lateness or tardiness.

On the other hand, it may be wise to assess the average number of late jobs, which can be important for certain critical projects.

$$\frac{\sum_{j=1}^{N} U_j}{N}, \ where \ U_j = \begin{cases} 1, if C_j > d_j \\ 0, otherwise \end{cases} \qquad (4)$$

The idea here is that although the average tardiness or lateness is a good indicator of how the contractor is performing in terms of delay, it does not cover the entire picture of contractor performance. Consider for example an owner wanting to choose a contractor for a project that has to completed on time or else severely high losses (financial or reputation, etc…) will be incurred by the owner. This would be considered a critical project, i.e. one where the exact delivery day is crucial. Two contractors are being assessed; Contractor A has relatively low average lateness of 2 days, while contractor B has a high average lateness of 10, which would tend to favour contractor A. However, if we look at the percent of late jobs we see that contractor A has a higher chance of turning a job late (90%), while contractor B has a much lower late percentage of 11%. If the project at hand is critical, i.e. the cost per each late day is high, expected value theory would favour contractor B, and therefore the measure of equation 6 is important.

Table 2: Example showing use of measures

	Contractor A	Contractor B
Number of Jobs Considered	20	18
Average Lateness	2	10
Number of late jobs	18	3
Percent of late jobs	90%	11%

In order to account for the size of the jobs on record, the above measures can be cost weighted. The total weighted tardiness and the total weighted number of tardy jobs become,

$$\frac{\sum_{j=1}^{N} w_j \times T_j}{N} \ (5) \text{ and } \frac{\sum_{j=1}^{N} w_j \times U_j}{N} \qquad (6)$$

Total weighted flow time (the difference between the release time r_j, and the completion time C_j is called the flow time) may sometimes be an important measure when one wants to consider the effect of late starts on the various projects, e.g. the actual project duration was not longer than was planned for but the project may have been delayed because of late starts. This measure for example can be compared to equation (3) in order to reveal such information,

$$\frac{\sum_{j=1}^{N} w_j \times (C_j - r_j)}{N} \qquad (7)$$

This measure account for the fact that a late start may not be the result of a contractor all the time, but it is the experience in the UAE that often contractors are delayed because they did not start after a notice to proceed is issued. Therefore, this measure addresses the issue. In terms of cost, measures similar to those of the schedule could be calculated. The most important of the cost performance measures may be the average cost overrun and the average percent cost overrun, calculated by,

$$ACO = \frac{\sum_{j=1}^{N} \left| A_j - (E_j + Co_j) \right|}{N} \qquad (8)$$

$$APCO = \frac{\sum_{j=1}^{N} \frac{Max(0, A_j - (E_j + Co_j))}{E_i}}{N} \qquad (9)$$

There are several others measures that can also be considered depending on the situation at hand. For example, the amount of liquidated damages can also be a valid cost performance measure. For safety, we consider the 3 main measures, Disabling-Injury Frequency Rate (DIFR), Disabling Injury Severity Rate and the Average Days

Charged (ADC). The DIFR is the number of injuries including illness per million hours of employee work. These include things like fractures, ankle twists, Thumb amputations, dermatitis, etc…

$$\sum_{j=1}^{N} DIFR_j = \frac{\frac{Nd_j}{Ne_j}\times 10^6}{N}$$, where $Ne_j = 2000\times Ft_j + Pt_j \times 1000$ (10) and $$\sum_{j=1}^{N} DISR_j = \frac{\frac{Td_j}{Ne_j}\times 10^6}{N}$$ (11)

Where, Nd_j = Number of disabling injuries on project j, Ne_j = Number of Employee hours worked on project j, Ft_j = Number of full time employees on project j, Pt_j = Number of half time employees on project j and, Td_j = Total days charged to project j. The 2000 figure in equation 11 is the annual work hours of exposure and is a commonly taken to equal 2000 hours per year. The DISR is the number of days lost or charged per million employee hours worked. Days lost include all scheduled charges for all deaths, permanent total and permanent partial disabilities, plus the total days of disability from temporary total injuries which occur during the period covered. Consequently, the ADC can be then be computed to indicate the average length of disability per disabling injury.

$$\sum_{j=1}^{N} ADC_j = \frac{Td_j}{Nd_j}\times 10^6 = \frac{DISR_j}{DIFR_j} \quad (12)$$

All these quantitative measures can also be assessed individually or using a weighted sum product.

Determining the Performance Level of the contractors. Now that the qualitative and quantitative measures have been determined we need to divide the contractors into various performance levels. Discriminant analysis can be used for this task. This analysis is a statistical technique that uses information from a set of independent variables to predict the value of a discrete or categorical dependent variable. The goal is to develop a rule for predicting which of two or more predefined groups a new observation belongs to based on the values of the independent variables. The results obtained from the quantitative analysis are compared with those obtained using the AHP. The relationship between the quantitative and the qualitative data is explored. One would expect a strong correlation since a contractor who has a high score in one measure should also have a high score in the other. Even if that is not the case, then discriminant analysis would allow for further evaluation by breaking up the contractors into defined categories of performance. So a contractor who is has a superior performance score in qualitative measure can still rank in high category if the quantitative score is within reasonable limits. This final step of the analysis would take this issue into consideration.

Table 3: Sample relative weights of the qualitative measures

	SEQ 1	SEQ 2	SEQ 3	SEQ 4	SEQ 5
SEQ 1	1	5	10	9	5
SEQ 2	0.20	1.00	4.00	9.00	9.00
SEQ 3	0.10	0.25	1.00	4.00	7.00
SEQ 4	0.11	0.11	0.25	1.00	6.00
SEQ 5	0.20	0.11	0.14	0.17	1.00

APPLICATION TO THE UAE CONSTRUCTION MARKET

The above model was applied to contractors working in the UAE. Data from questionnaires in addition to selection factors from projects were collected. A questionnaire was prepared and sent out to 200 contractors, construction managers and owners. The names of these contractors, construction managers and owners were obtained from a local business directory. The contractors were selected at random from the directory and represented about thirty percent of the listed contractors (there are 700 contractors listed with the UAE contractor's association. This number was only about three hundred and fifty 3 years ago).

A list of applicable measures was developed through extensive interviews and the questionnaire. Twenty contractors were selected for the evaluation. Although accurate statistics are hard to obtain, the survey analysis showed that the majority of the general contractors in the UAE are classified as medium size in terms of the amount of work performed annually. The twenty contractors were therefore selected to be medium sized. Data from previously recorded projects of the contractors were also collected and analyzed. Each of the 20 contractors was evaluated based on at least 20 previously recorded projects and was further assessed based on the results of the questionnaires. All projects were selected to be within the last 3 years, meaning that all had been issued certificates of substantial completion within the last 3 years even though a few of them may have started earlier. Table 3 shows sample of the results of the AHP analysis of the qualitative measures and table 4 shows the ranking based on the summary of the quantitative measures.

Table 4: Sample Contractors' ranking

Qualitative Criteria		Quantitative Criteria	
Contractor	**Score**	**Contractor**	**Score**
15	65.69433	19	3.76%
19	54.97569	17	4.66%
1	50.16448	2	4.98%
9	45.73912	16	5.25%
18	40.37219	11	5.38%
12	39.52805	8	5.45%
3	38.46389	10	6.32%
20	38.0118	13	6.58%
..	..	..	..
..	..	..	..

The relationship between the qualitative and quantitative measures was explored and a significant correlation was found between the two measures. Figure 2 shows the relationship between the two measures and shows a substantially high R^2 of 0.96 for the regression line between the two. Note that the quantitative measures have been formulated so that lower values signify better results.

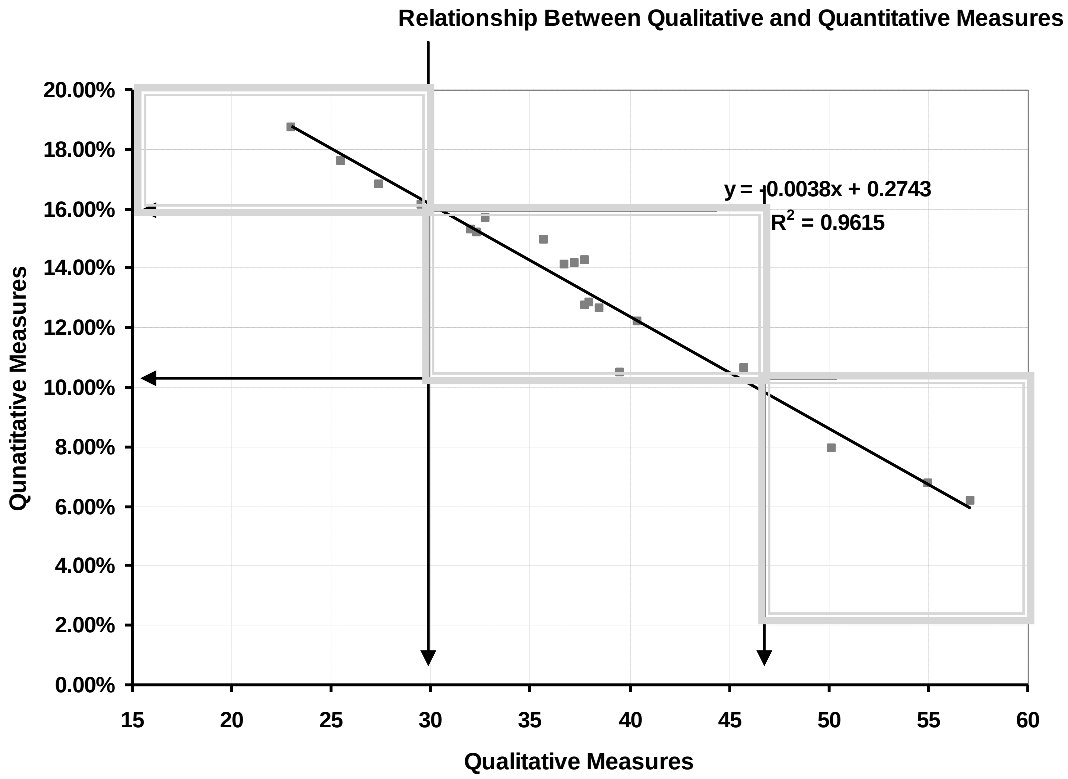

Figure 1, Relationship between AHP score and Quantitative Measures

Table 5: Sample Contractor Classification in 3 groups

Qualitative	Quantitative			
	Average Lateness (days)	ACO	APCO	Group
27.39	36	11876.30	0.17	1
38.01	27	8914.00	0.13	1
37.28	29	9707.00	0.14	2
37.60	27	9113.05	0.13	2
25.50	37	12401.20	0.18	3
29.52	34	11279.70	0.16	3

Discriminant analysis is a statistical technique to classify data into groups based on a set of measurable features. The groups are usually known or predetermined and do not have order (i.e. nominal scale). The classification algorithm gives several categories with a set features measured by the features. Based on the data available a discriminant analysis was conducted and all the contractors were divided into three groups: High Performance Contractors (HPC), Medium Performance Contractors (MPC) and Low Performance Contractors (LPC). For instance, a contractor with high AHP score, low Cost Overrun and Lateness will be qualified as group 1 contractor. Also, a contractor with low AHP score and high Cost Overrun may be qualified as group3 contractor. The breakdown of the 3 groups is shown in figure 2 and the results of the discriminant analysis are shown in Table 5.

CONCLUSION

Predicting contractor performance is of great importance especially in a highly completive market such the case of the UAE construction market. Without a technique to evaluate contractors, clients may risk assigning a project to nonqualified firms. The model described in this paper may serve a tool to predict the performance of the contractors in such markets. The model investigates the relationship between the contractors' qualitative performance measures as well the quantitative measures. Measures such total weighted tardiness, average number of late jobs, average lateness, average cost overrun etc… were utilized to evaluate the contractors in addition to qualitative measures relating to safety, environment, and personnel. Application of the model to the case of the UAE is discussed and results obtained are presented. Cost and schedule records from previously accomplished projects by contractors were used to extract quantitative performance measures. When a comparison between AHP score and combined quantitative measures was performed, contractors with the highest AHP score were also the best performers quantitatively and vice versa, revealing a strong correlation between the two kinds of measures.

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