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# Cost-Estimating Model for Low-Volume Roads

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ABSTRACT

The Forest Service, U.S. Department of Agriculture, is required to perform accurate and comprehensive road cost estimates to carry out the legislative intent of Congress in the programming, allocation, and use of funds. This study utilizes multiple regression analysis to develop unit-price equations and total project cost equations for cost estimation. A sample consisting of 26 projects from the western United States is used for preliminary model development. The equations developed are applied to a second sample with six projects located in the same area. The results indicate that the model has potential for determining reliable preliminary road cost estimates. Because of its simplicity, this model could reduce the resources spent on this task and lead to the reduction of transportation cost.

One of the major concerns of the Forest Service, U.S. Department of Agriculture, is the accuracy of road cost estimates. Estimates are used to carry out the legislative intent of Congress in the programming, allocation, and use of funds. Two types of preliminary estimates used for this purpose are the office estimate and the field-verified estimate. The former is based on office information such as land use plans, aerial photographs, topographic maps, and other resource information. It is used to support activities such as land use planning, resource management planning, area transportation planning, and long-range (over 5 years) fiscal programming. The second type of estimate is based on all the information available for an office estimate plus more extensive field verification, including some rough field measurements and more detailed resource information gathering. This estimate is used in resource and transportation project planning, short-range (2 to 5 years) fiscal programming, and budgeting.

The accuracy of both preliminary estimates varies in accordance with the reliability of the data base. Deviations can range from 35 to 50 percent for the office estimate and from 20 to 30 percent for the field-verified estimate (1). Two main sources of these deviations are unit-quantity and unit-price predictions. The major concern of this study is unit-price prediction.

Conventionally, road costs are estimated by either constructed costs or historical bids or a combination of both. The constructed-cost method utilizes production rates, labor and equipment costs, profit and risk, taxes, and material costs to estimate the unit price. On the other hand, the unit price derived from the historical-bid approach is estimated by the weighted average of bids submitted by contractors over some period of time. These unit prices are adjusted by a cost trend factor to reflect the cost at the time when the project will most likely be constructed.

The objective of this study is to use regression analysis to develop unit-price estimating models based on historical-bid data. Several other studies have been made along these lines to improve cost estimation (2,3). The results of these studies indicated that by using regression analysis, it is possible to estimate highway construction costs with a higher degree of reliability than can be obtained by simple unit-cost weighted averages. In the present study, a sample of 26 new construction projects was utilized for model development. This model was verified by six projects, including new construction and reconstruction. However, it should be noted that this paper does not suggest weakness or deficiency in current Forest Service policies or practices but is intended to illustrate the potential usefulness

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of the application of regression analysis to cost estimation.

## DATA SOURCE

A sample of 26 projects was collected from the western United States. The sample included road projects constructed in the study area during 1980-1982. The information on quantities, bid cost, and average bid unit-cost estimates was provided by an automated bid tabulation system. Other road characteristics such as side slope, clearing, and so on, were collected by questionnaire.

The six components investigated were engineering, earthwork, bases, pavement, bridges, and other incidental items (4). A review of past projects in the study area indicated that although the relative proportion of total cost attributable to each of the components varies from job to job, earthwork cost generally constitutes the largest portion of the total (nearly 50 percent). The average percentage composition of the total construction cost for the selected 26 roads was roughly as follows:

| Item | Portion of Total Construction Cost (%) |
|---|---|
| Engineering | 2.7 |
| Earthwork | 46.9 |
| Bases | 26.4 |
| Pavement | 4.1 |
| Bridges | 0.7 |
| Incidental | 19.2 |

These six components are used as the explanatory variables that make up the total project cost. Fourteen major cost items that contributed the bulk of the costs attributable to the six components were chosen for estimating unit prices.

## METHODOLOGY

The system assumes that the bid price is a function of the project characteristics that directly influence the required effort to complete the project and the scale of economy. These characteristics may affect the bidding behavior and bid cost. For this study they were identified as follows:

1. Side slope (percent),
2. Soil condition:
   a. Common (percent),
   b. Solid rock (percent),
   c. Riprap (percent),
3. Clearing:
   a. Light (percent),
   b. Medium (percent),
   c. Heavy (percent),
4. Remoteness (travel distance from center of local community to project by miles),
5. Length of road (miles),
6. Net gradient of the project (percent),
7. Complexity of project (in terms of number of items), and
8. Quantity of project (by item or overall).

In addition to the aforementioned factors, socioeconomic conditions including per-capita personal income, unemployment rate, the number of construction workers, and the number of bidders were also used to examine the bidding behavior. However, it has been found that these factors have no significant relationships to the bid cost.

Two types of models will be developed. One is for estimating the unit prices of major items and the other is to estimate the total cost of a project. They are discussed in the following paragraphs.

### Unit Price

Unit price (U) as a function of road characteristics ($y_r$) and quantities ($q_k$) is

$$U = a + \sum_{k=1}^{d} b_k q_k + \sum_{r=1}^{e} b_r y_r \qquad (1)$$

where a and b are constants. Fourteen major items were selected for the unit-price estimate. They are classified as follows:

| | | |
|---|---|---|
| 201 | (01) | Clearing and grubbing |
| 201 | (03) | Clearing and grubbing |
| 203 | (01) | Excavation, Method 1 |
| 203 | (02) | Excavation, Method 2 |
| 203 | (03) | Excavation, Method 3 |
| 304 | (01) | Crushed aggregate |
| 306 | (01) | Reconditioning of roadbed |
| 408 | (01) | Liquid asphalt |
| 601 | (01) | Mobilization |
| 603 | (01) | Corrugated metal pipe |
| 611 | (01) | Pit development |
| 619 | (01) | Hand-placed riprap |
| 621 | (01) | Spillway inlet assemblies |
| 625 | (03) | Seeding, hydraulic method with mulch |

### Total Cost

Total cost (T) as a function of the sum of the estimated low-bid prices by items ($c_i$) is

$$T = a + b \sum_{i=1}^{n} c_i \qquad 1 = 1, 2, 3, \ldots, n \qquad (2)$$

where n is the number of items and a and b are constants to be estimated. Note that the low bidder differs in his prices from item to item and is not necessarily the bidder who was awarded the contract.

Total cost (T) as a function of the costs of the major components ($c_j$) is

$$T = a + \sum_{j=1}^{m} b_j c_j \qquad j = 1, 2, 3, \ldots, m \qquad (3)$$

where m is the number of major components and other terms are as defined previously.

Total cost (T) as a function of the sum of the relative importance scores in terms of cost ($s_i$) is

$$T = a + b \sum_{i=1}^{n} s_i \qquad i = 1, 2, 3, \ldots, n \qquad (4)$$

where the relative importance scores may be developed as follows:

1. Compute the average cost by item,
2. Select the item with the least deviation as the basic item,
3. Compute the weight of each item by dividing the cost of each item with the cost of the basic item, and
4. Multiply the quantity of each item by its weight and obtain the relative importance scores.

Total cost (T) as a function of relative importance scores of the major components ($s_j$) is

$$T = a + \sum_{j=1}^{m} b_j s_j \qquad (5)$$

Total cost (T) as a function of preliminary quantity estimate ($q_k$) and road characteristics ($y_r$) is

$$T = a + \sum_{k=1}^{d} b_k q_k + \sum_{r=1}^{e} b_r y_r \quad \begin{array}{l} k = 1, 2, 3, \ldots, d \\ r = 1, 2, 3, \ldots, e \end{array} \qquad (6)$$

where d and e are the number of items and other terms are as defined previously.

The regression analysis will be used for the model calibration. The stepwise precedure, that is, entering a variable at a time, of the Statistical Package for the Social Sciences was used for computation.

## MODEL CALIBRATION

### Unit-Price Models

As shown in Table 1, unit-price models were developed for 14 major cost items. The data indicate that the unit price of clearing and grubbing, in terms of dollars per acre, is related to the percentage of clearing in the light category, side slope, road length, and time of the year when the bid took place. The first two variables represent the effort required and the third variable represents the project size. The signs for these three variables are as expected. The variable for the time of the year is a dummy variable that equals 1 for the time period of April to September and 0 otherwise. This means that when the bid takes place during the construction season, the unit price for clearing and grubbing is $213/acre lower than that of the off-construction season bid. The coefficient of determination ($R^2$) for the equation is 0.2194.

When clearing and grubbing is measured in dollars per mile, its unit price can be explained by its quantity and side slope. As expected, the unit price tends to be reduced when the size of the project is larger. On the other hand, the increase in side slope tends to increase the unit price. The coefficient of determination ($R^2$) of the model is 0.3538.

The size of the project in terms of road length has been found to be a significant variable for explaining the unit price of excavation ranging from Methods 1 to 3. However, the unit price of excavation, Method 1, is also related to the total excavation of a project, whereas the unit price of excavation, Method 2, is also affected by the percentage of solid rock and time of year when the bid took place. The three models for the unit price of excavation are significant, with $R^2$ ranging from 0.6964 to 0.8731.

Two models have been developed for the component of bases. One is for crushed aggregate and the other is for reconditioning of the roadbed. The unit price of crushed aggregate has been found highly related to the quantity of crushed aggregate and road length. The $R^2$ is equal to 0.9309. The unit price for reconditioning of the roadbed can be explained by side slope and time of the year when the bid took place. However, $R^2$ for the model is only 0.2898. The low value of $R^2$ is due to the stability of the unit price for this item.

The unit price of liquid asphalt is highly related to the quantities of liquid asphalt and the total excavation. The model indicates that the liquid as-

**TABLE 1 Unit-Price Models**

| Specification No. | Description of Item | Unit-Price Model | $R^2$ | Mean ($/unit) | Standard Error of Estimate | Durbin-Watson Test |
|---|---|---|---|---|---|---|
| 201 (01) | Clearing and grubbing ($/acre) | $U = 2{,}987.49 - 14.6864X_1 - 1.1805X_2 - 213.5127X_3 + 11.220X_4$ | 0.2194 | 2,742.45 | 1,359.57 | 1,7461 |
| 201 (03) | Clearing and grubbing ($/mi) | $U = 1{,}667.82 - 174.6936X_5 + 48.0763X_4$ | 0.3538 | 1,196.23 | 1,820.34 | 1,7184 |
| 203 (01) | Excavation, Method 1 ($\$/yd^3$) | $U = 2.63 - 0.0140X_6 - 0.00036X_2$ | 0.7628 | 1.96 | 0.38 | 2.1573 |
| 203 (02) | Excavation, Method 2 ($\$/yd^3$) | $U = 2.78 + 0.0715X_7 - 1.2506X_3 - 0.00053X_2$ | 0.8731 | 2.09 | 0.42 | 1.7052 |
| 203 (03) | Excavation, Method 3 ($\$/yd^3$) | $U = 8.02 - 0.7174X_2$ | 0.6964 | 3.94 | 1.56 | 2.1752 |
| 304 (10) | Crushed aggregate ($\$/yd^3$) | $U = 19.54 - 0.00108X_8 - 0.00198X_2$ | 0.9309 | 1.34 | 13.66 | 3.1312 |
| 306 (01) | Reconditioning of road-bed ($/mi) | $U = 286.19 + 14.3063X_4 - 68.1271X_3$ | 0.2898 | 847.67 | 267.03 | 1.7702 |
| 408 (09) | Liquid asphalt ($/ton) | $U = 266.19 - 0.1568X_{10} - 0.7525X_6$ | 0.8865 | 195.00 | 130.51 | 1.9974 |
| 601 (01) | Mobilization ($/job) | $U = 1{,}555.82 + 125.0380X_9 - 8.6642X_2 + 213.4994X_6$ | 0.7539 | 13,324.95 | 9,422.94 | 2.2350 |
| 603 (01) | Corrugated metal pipe ($/ft) | $U = 26.61 + 3.2709X_7 - 0.2364X_4 - 0.0013X_2$ | 0.7955 | 25.73 | 10.22 | 1.1010 |
| 611 (10) | Pit development ($/pit) | $U = 3{,}472.56 + 65.2432X_{11} - 2{,}359.7274X_3 - 0.2272X_{12}$ | 0.9271 | 1,714.29 | 760.02 | 1.8307 |
| 619 (01) | Hand-placed riprap ($\$/yd^3$) | $U = 70.39 - 5.5560X_2$ | 0.3549 | 47.47 | 22.19 | 2.3570 |
| 621 (01) | Spillway inlet assemblies ($/each) | $U = 4.64 + 2.515X_7 + 1.484X_9 + 0.5282X_4 + 0.7984X_{11}$ | 0.7933 | 88.85 | 18.08 | 1.8184 |
| 625 (03) | Seeding, hydraulic method with mulch ($/acre) | $U = 502.11 - 74.9600X_{13} + 20.7764X_4$ | 0.4320 | 902.71 | 501.77 | 1.1744 |

Note: Variables are defined as follows:
U = unit price ($1,000 per unit),
$X1$ = percent of clearing in light category (%),
$X_2$ = length of road (mi),
$X_3$ = time of year (1 for April to September period and 0 otherwise),
$X_4$ = side slope (%),
$X_5$ = clearing and grubbing (acres) – 201 (03),
$X_6$ = total excavation (1,000 $yd^3$),
$X_7$ = percent of solid rock (%),
$X_8$ = crushed aggregate ($yd^3$) – 304 (01),
$X_9$ = remoteness (mi from local community to project),
$X_{10}$ = liquid asphalt (ton),
$X_{11}$ = percent of riprap (%),
$X_{12}$ = pit-run aggregate ($yd^3$) – 304 (01),
$X_{13}$ = seeding, hydraulic method with mulch (acre) – 625 (03), and

$R^2$ = coefficient of determination (ranges from 0 to 1 for the quality of model from poor to perfect).

Standard error of estimate = $[(u - \bar{u}^2)/(n - 2)]^{1/2}$, where $\bar{u}$ is the mean, u is the estimated value, and n is the number of observations.

phalt unit price tends to be low when the amounts of asphalt and excavation are large. For paved roads, excavation accounts for more than half of the new construction cost and may represent the size of the project. The trade-off between the liquid asphalt unit price and excavation quantity is expected. However, this trade-off is ignored by the conventional cost-estimate approach. The model has an $R^2$ as high as 0.8865.

The last six models of Table 1 were developed for the six major items of incidental construction. As expected, the cost of mobilization is highly related to the remoteness or distance from the local community to the site of the project and the length of the road. Because the remoteness reflects the transportation cost, and the road length represents the size of the project, the bidder considers distance as the major factor for determining mobilization cost and is willing to trade off this cost with the cost of other items. The model has a significant coefficient of determination, $R^2 = 0.7539$.

The unit price of corrugated metal pipe can be explained by the percentage of solid rock, side slope, and road length. Solid rock requires extra effort for excavation and thus tends to increase unit price. On the other hand, steep ground requires less effort for pipe installation and tends to reduce unit price. The equation also indicates that the bidder is willing to trade off the unit price of corrugated metal pipe with the size of the project in terms of road length in miles. The unit price of pit development is a function of the percentage of riprap, the quantity of aggregate, and time of the year when the bid took place. As expected, riprap increases difficulty in pit development and enhances unit price. However, the cost would be reduced if the quantity of aggregate to be produced is large or the bid takes place in the construction season. These two models are highly significant, with $R^2$ equal to 0.7955 and 0.9271, respectively.

The unit price of hand-placed riprap has been found to be related to road length. In this case, the road length represents the size of the project or the quantity of hand-placed riprap, or both. Therefore, the longer the road segment is, the lower the unit price of hand-placed riprap. Four important explanatory variables included in the model for the unit price of spillway inlet assemblies are percentage of solid rock, remoteness, side slope, and percentage of riprap. All of these four factors tend to increase the unit price of spillway inlet assemblies because of the difficulty in installation or high transport cost. The unit price of seeding by the hydraulic method with mulch can be explained by the quantity of such seeding and the side slope. The coefficients of determination for these three models are 0.3549, 0.7933, and 0.4320, respectively.

The foregoing discussion indicates that the unit price is determined by the level of effort required for accomplishing a job such as a side slope, category of clearing, type of soil, and the size of the project in terms of road length or quantities of specific items. The more the required effort is, the higher the unit price. On the other hand, the larger the project is, the lower the unit price.

### Total-Cost Models

Five models for estimating total cost of a project are given in Table 2. The first two models require estimating unit price and quantities for all items, and the third and fourth models require estimating unit price and quantities for major items. The last equation requires only an estimate for asphalt and gravel in terms of thickness (inches) as well as the work on excavation (cubic yards).

The first model assumes that the total cost of a project is a function of the sum of low-bid costs for all items. The second model indicates that the gross construction cost is highly related to the sums of low-bid costs by items for components of earthwork, bases, and incidental construction. The model also reveals that a project requiring construction staking tends to lower the cost. The coefficients of determination for both models are 0.9643 and 0.9807, respectively.

A set of the relative importance scores by item were derived from the average unit price. The product of these scores and the engineering estimated quantities forms the data base for developing the second and third equations of Table 2. The assumptions of these two models are similar to that of the first two equations. The coefficients of determination for both models are 0.9504 and 0.9755, respectively.

The last model of Table 2 is composed of three independent variables including pavement index, aggregate index, and total excavation. Both indices

TABLE 2 Total Cost Models

| Approach of Modeling | Total Project Cost Model | $R^2$ | Mean ($000s) | Standard Error of Estimate | Durbin-Watson Test |
|---|---|---|---|---|---|
| Aggregated low-bid costs | $T = 12.860 + 0.00156X_{23}$ | 0.9643 | 381.39 | 69.01 | 1.9448 |
| Itemized low-bid costs | $T = 12.736 + 0.00182X_{22} + 0.00484X_{24} + 0.00065X_{25} + 0.0027X_{26}$ | 0.9807 | 381.39 | 54.42 | 1.6294 |
| Aggregated scores | $T = 28.667 + 0.00321X_{27}$ | 0.9391 | 381.39 | 88.76 | 1.9406 |
| Itemized scores | $T = 31.602 + 5.0211X_{28} + 0.00157X_{29} + 0.0137X_{30} + 0.0562X_{31} + 0.0542X_{32}$ | 0.9685 | 381.39 | 71.20 | 1.7316 |
| Quantities and road characteristics | $T = 66.79225 + 1.82267X_{33} + 5.61322X_{34} + 1.00170X_{35}$ | 0.8484 | 381.39 | 148.50 | 1.7106 |

Note: Variables are defined as follows:

$T$ = total cost of a project ($000s),
$X_{22}$ = 1 if the component of bridge construction is included in the project,
$X_{23}$ = sum of low-bid costs by items ($),
$X_{24}$ = sum of low-bid costs by items of earthwork,
$X_{25}$ = sum of low-bid costs by items of bases,
$X_{26}$ = sum of low-bid costs by items of incidental construction,
$X_{27}$ = sum of relative importance scores for overall project,
$X_{28}$ = sum of scores for clearing and grubbing (201, 202, 207, 209, 210, 211, 212),
$X_{29}$ = sum of scores for excavation (203, 205, 206),
$X_{30}$ = sum of scores for bases,
$X_{31}$ = sum of scores for bituminous pavements,
$X_{32}$ = sum of scores for incidental construction,
$X_{33}$ = pavement index, which is equal to road length (mi) times thickness of pavement (in.) times asphalt haul distance (mi),
$X_{34}$ = total excavation ($yd^3$ 000s), and
$X_{35}$ = aggregate index, which is equal to road length (mi) times thickness of aggregate (in.) times aggregate haul distance (mi).

TABLE 3 Estimated and Actual Costs of Six Road Projects

| | Project | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | Average[a] |
| Type of construction | New | New | Reconstruction | New and reconstruction | New and reconstruction | Reconstruction | – |
| Date of advertisement | 11/24/81 | 5/1/80 | 8/3/82 | 6/15/82 | 11/16/81 | 9/2/82 | – |
| Low bid ($) | 184,234 | 418,865 | 1,618,584 | 165,060 | 39,030 | 561,915 | – |
| Average-bid unit-price estimate ($) | 225,811 | 302,460 | 2,052,814 | 205,618 | 44,315 | 737,459 | – |
| Percentage difference | +22.6 | –27.8 | +26.8 | +24.6 | +13.5 | +31.2 | 24.4 |
| Aggregated low-bid cost model ($) | 173,550 | 324,600 | 2,023,550 | 181,700 | 41,260 | 415,900 | |
| Percentage difference | –5.8 | –27.5 | +25.0 | –10.1 | +5.7 | –26.0 | 15.8 |
| Itemized low-bid cost model ($) | 181,630 | 409,600 | 1,631,520 | 157,700 | 40,730 | 515,270 | |
| Percentage difference | 1.5 | –2.2 | +0.8 | –2.6 | +4.3 | –9.0 | 3.0 |
| Aggregated score model ($) | 173,410 | 404,160 | 1,830,000 | 158,100 | 44,730 | 593,830 | |
| Percentage difference | –5.9 | –3.5 | +13.1 | –4.2 | +14.6 | +5.7 | 9.9 |
| Itemized score model ($) | 186,260 | 373,590 | 2,149,000 | 176,300 | 63,100 | 531,450 | |
| Percentage difference | +1.1 | –10.8 | +32.8 | +6.8 | +61.7 | –5.4 | 19.8 |

Note: + = overestimate, – = underestimate.

[a] Absolute value.

are the product of quantities and haul distance, that is, thickness (inches) times road length (miles) times haul distance (miles). This model does not require an engineering estimate and can be used to predict the costs for projects in the planning stage. The coefficient of determination for the last model is 0.8484.

The foregoing discussion indicates that by using regression analysis, a cost estimating procedure can be developed. All the explanatory variables selected in the modeling analysis are used in actual road construction.

## MODEL VALIDATION

Six projects were selected from the study area for model verification. These projects were not included in the model development and had costs ranging from $44,000 to over $2 million per project.

Because the validation of unit-price models required additional data collection, the equations contained in Table 1 were not verified. However, by assuming a 40 percent clearing in the light category, a 25 percent side slope, a 2-mi road project, and a July bid date, the unit price for 201(01) clearing and grubbing was computed by using the first equation in Table 1, as follows:

$$\begin{aligned}\$2{,}956.14 &= \$2{,}956.14 - (14.686 \times 40.0 = 587.44) \\ &\quad - (1.1805 \times 2.0 = 2.36) - (213.52 \times 1.0 \\ &= 213.52) + (11.220 \times 25.0 = 280.50) \\ &= \$2{,}433.32.\end{aligned}$$

The first four models of Table 2 were applied to the six selected projects. The result is shown in Table 3, in which it is shown that all of the models developed gave better preliminary estimates than simply applying average-bid unit prices without considering the project characteristics. The average difference from the actual low bid was 24.4 percent utilizing the average-bid unit-price estimating procedure and the range was from 3.0 percent for the itemized minimum-cost model estimate to 19.8 percent for the itemized-score model estimate.

Note that in the foregoing applications, the actual unit prices as bid were used in the estimation. Assume that the use of unit-price models will result in a 10 percent of error of the estimate. The ranges of deviations for the four models will be 16.7 to 17.3 percent, 8.3 to 11.7 percent, 9.3 to 13.6 percent, and 20.5 to 24.6 percent, respectively. Therefore, with consideration of unit-price estimate errors, these models can still yield better preliminary estimates than that made by the average-bid unit-price estimate.

## SUMMARY AND CONCLUSIONS

Multiple regression analysis was applied to historical-bid data to develop estimating models to determine preliminary construction costs of low-volume roads. A sample collected from western United States was used to develop 14 unit-price models for major items and five total project cost models for total construction costs. In the modeling, 13 project characteristics were identified and analyzed as the independent variables of unit-price equations. Fifteen component quantities were utilized for developing total project cost equations. The study clearly indicated that extensive data-gathering effort is required to develop models. However, once the model has been developed, it requires no more data than the existing cost-estimate practice. On the basis of a verification check, it was found that by using regression analysis, it is possible to estimate preliminary construction cost for low-volume roads in the western United States with a higher degree of reliability than the average-bid unit-price estimate.

It was found that the bid price is a function of the effort required to complete a job item and the size of the project. The effort is defined by the level of clearing and grubbing, side slope, soil conditions, and remoteness, whereas the project size is described by the quantity of a particular job item. Less effort and large projects tend to lower the unit price, and vice versa. Two total project cost models require both engineering quantities and unit prices; the other three models require only engineering quantities. These models were developed to evaluate the feasibility of using regression analysis for preliminary cost estimating and have not been implemented. Therefore, information on the required time and expense involved in doing a cost estimate by using these models is not available at this time.

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