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A Decision-Making Framework for the Optimal Selection of Suppliers

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Abstract

As supply chains continue to globalize, the need for robust supplier qualification and supplier selection and evaluation programs becomes increasingly critical. In this context, this paper aims to present a methodological approach for the optimization of the procurement processes in today's globalized supply chains. More specifically, we first provide a categorization of the relevant past research efforts, and then propose a generic methodological framework for the supplier selection and supplier evaluation problem. This framework is constituted by a five phased conceptual decision-making methodology that outlines the whole life cycle of the supplier selection and evaluation processes. In addition, we provide a new analytical goal-programming model for the initial selection and the periodic re-evaluation of suppliers in today's globalized environment. This mathematical programming model is based on newly developed and integrated real world supplier quality indices.

Keywords: *supplier selection and (re-)evaluation processes, methodological framework, optimization, goal-programming.*

1. Introduction

An effective purchasing and supply management policy entails purchase of the right product, at the right price, in the right quality and quantity, at the right time and on a continuing base. Today, there are constant pressures to suppliers to keep on decreasing the length of time between placing an order and its due date, underscoring the need for systemic and efficient satisfaction of the customer orders. Customers often expect same day service and even when they are willing to wait they expect to be quoted with accurate delivery lead times. In addition, the number of product offerings has increased, while at the same time the life cycle of the products is constantly decreasing. On the other hand, customers often recognize that their procurement policies are inefficient, exhibiting long cycle times, large lot sizes, low yield and long and unpredictable lead times.

Further, taking into consideration the ever increasing globalization of logistics networks, the need for collaboration with reliable and quality certified suppliers and the use of sophisticated supplier selection and evaluation management systems become continuously more critical.

In this context, this paper aims to present a holistic methodological approach for the optimization of the procurement processes in today's globalized supply chains. Specifically, we first provide a categorization of the relevant past research efforts in order to present the managerial insights that result from the existing literature, and to highlight the contribution of this work by considering the current state of knowledge. Secondly, we propose a generic methodological framework for the supplier selection and evaluation problem. This framework is constituted by a five-phased conceptual decision-

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making methodology that outlines the whole life cycle of the supplier selection and evaluation processes.

Next, we provide a new generalized goal-programming model for the initial selection and the periodic re-evaluation of suppliers. The number of suppliers to be used may be predefined or not, while the proposed optimization model may also consider the cases of nearshore and offshore suppliers, as well as emergent ones. Furthermore, this quantitative model is based on newly-developed real-world supplier quality indices.

The rest of the paper is organized as follows. In Section 2 we present a literature review and a categorization of the past modeling approaches dealing with the supplier selection problem. Section 3 accommodates the proposed methodological framework, while in Section 4 we present the proposed optimization model, for supporting the relevant decision-making processes. Finally, we provide conclusions and directions for future research.

2. Related Work

The critical role of the supplier selection process in the development of an organization and the effects on its profitability and viability has been detected and recognized since early 1940s (Lewis, 1943). Then Dickson (1966) conducted a survey among purchasing agents and managers in the U.S.A. and Canada that revealed the existence of 23 criteria that mainly affect the supplier selection decision-making process. Moreover, Hakansson and Wootz (1975) and Dempsey (1978) added some new complementary factors/criteria to those that had already been proposed by Dickson (1966), further enhancing the perception that the quality of products and their delivery are two critical factors for the supplier selection process.

The relevant literature regarding the supplier selection problem, during the last sixty years, is spread over the following two basic directions: the identification and selection of the criteria that a purchasing officer should take into account, and the methods that should be employed in order to compare, evaluate and rank suppliers or to detect the optimal one.

Four review papers have been already published for the supplier selection and evaluation

problem. To this effect, the first effort was that of Webber et al. (1991) who reviewed and classified the different methods/approaches that had been employed to address the vendor selection problem across different business environments. Later on, Degraeve et al. (2000) presented a new taxonomy of the relevant research works based on a single/multiple item and with/without inventory management considerations categorization, and compared the relative efficiency of the vendor selection models using the concept of total cost of ownership (i.e. an approach of quantifying all the costs associated with the purchase process throughout the entire value chain of an organization). De Boer et al. (2000) extended these works by considering the diversity of the procurement situations (in terms of complexity and importance), while they have taken into account all the phases in the supplier selection process. In the most recent literature review, Ho et al. (2010) presented a categorization of the multi-criteria decision-making approaches for the supplier evaluation and selection processes, and provided also evidence that the multi-criteria decision-making models are better than the traditional cost-based ones.

In this manuscript, the most relevant, to our work, research papers found in the literature are classified into two main categories (Table 1), namely:
- Qualitative approaches.
- Quantitative approaches: Non-optimization and optimization models.

2.1 Qualitative Approaches

In general, qualitative papers address the following aspects of the supplier selection problem: identification of suppliers, evaluation of suppliers, negotiations with suppliers, strategic partnerships, etc.

Spekman (1988) intended to help managers understand the nature of strategic partnerships and to better appreciate the decision criteria that will lead to the selection of good partners. Masella and Rangone (2000) compared four different vendor selection systems, which depend on the time-frame (short-term versus long term) and on the content (logistics versus strategic) of the co-operative customer/supplier relationships, by considering various sets of measures. Then Pidduck (2006) presented a partner negotiation model for the

Table 1. Taxonomy of the past research papers

Methodology	Papers
Analytic hierarchy process	Celebi & Bayraktar (2008); Chen & Huang (2007); Ghoudsypour & O'Brien (1998); Morlacchi et al. (1997); Nydick & Hill (1992)
Case-based reasoning	Cook (1997)
Chance constrained-programming	Wu & Olson (2008)
Cluster analysis	Hinkle et al. (1969)
Conceptual framework	Beil (2010); Masella & Rangone (2000); Pidduck (2006); Spekman (1988)
Conjoint Analysis	Mummalaneni et al. (1996)
Data envelopment analysis	Liu et al. (2000); Weber & Desai (1996); Wu & Olson (2008)
Discriminant Analysis	Temur et al. (2009)
Expert systems	Jalao & Martinez (2009); Vokurka et al. (1996)
Fuzzy set theory	Morlacchi et al. (1997); Kumar et al. (2004)
Goal-programming	Karpak et al. (1999); Kumar et al. (2004)
Intelligent Software Agent	Khoo et al. (1998)
Linear-programming	Ghoudsypour & O'Brien (1998)
Market research	Goffin et al. (1997)
Mixed integer-programming	Chaudhry et al. (1993); Rosenthal et al. (1995)
Multi-objective programming	Amid et al. (2006); Weber & Current (1993); Wu & Olson (2008)
Multiple regression analysis	Chapman & Carter (1990)
Neural network	Celebi & Bayraktar (2008); Temur et al. (2009)
Principal Component Analysis	Petroni & Braglia (2000)
Simulation	Ding et al. (2006)
Total cost of ownership	Degraeve et al. (2000); Ellram (1995)

identification of the most significant issues for the partner negotiation and selection processes. Based on UK industry, Goffin et al. (2007) produced empirical evidence for the today's move towards a reduction of the supplier base. More recently, Beil (2010) described the typical steps of a supplier selection process: identifying suppliers, soliciting information from suppliers, setting contract terms, negotiating with suppliers, and evaluating suppliers. Moreover, Beil highlighted also why each of these steps is important, how the steps are interrelated, and how the resulting complexity provides fertile ground for operations research and management science research.

2.2 Quantitative Approaches

2.2.1 Non-Optimization Models

Non-optimization models provide usually a ranking of the candidate suppliers based on a set of predefined selection criteria that address the necessary information for a buyer to make a decision. Non-optimization techniques include among others statistical and financial models, multi-criteria techniques, and computer-based models.

One of the first approaches was that of Hinkle et al. (1969), who addressed the vendor evaluation problem using Cluster Analysis by considering the criteria of quality, delivery, net price, and technical capability, in a general industrial purchasing environment. Later on, Chapman and Carter (1990) addressed the supplier selection problem employing Multiple Regression Analysis, with an emphasis on manufacturing strategies such as just-in-time. Mummalaneni et al. (1996) presented the concept of Conjoint Analysis as a proper method for measuring preferences when six specific criteria (on-time delivery, quality, price/cost targets, professionalism, responsiveness to customer needs, and long-term relationships with the purchasing company) are used jointly in an overall evaluation. Petroni and Braglia (2000) presented an alternative multi-criteria decision-support model for evaluating the relative performance of suppliers based on the statistical multivariate Principal Component Analysis.

Ellram (1995) showed the linkage between Total Cost of Ownership (TCO) and supplier selection process, by highlighting the fact that purchasing costs is a crucial element of the total supply chain costs. Degreave et al. (2000) adopted the concept of TCO as a basis for comparing vendor selection models. They proved for a specific case study that, from a TCO perspective, mathematical programming models outperform rating models and multiple item models generate better results than single item one.

Nydick and Hill (1992) showed how Analytic Hierarchy Process (AHP) can be used to structure the supplier selection process and customized for the specific needs of each organization. Chen and Huang (2007) integrated AHP in a software agent technique, so as to take into account both qualitative and quantitative attributes in supplier selection. Morlacchi et al. (1997) used the Fuzzy Set Theory

(FST) in order to develop a model that combines the use of fuzzy theory with AHP and implement it to evaluate small suppliers in the engineering and machine sectors. Weber and Desai (1996) demonstrated the use of Data Envelopment Analysis (DEA) for measuring vendor performance and efficiency, while they provided a methodology for the identification of benchmark values on a group of selected criteria for negotiating with inefficient vendors. Liu et al. (2000) presented a methodology of applying DEA to compare overall supplier performances and demonstrated the applicability of their model through a case study for a manufacturing firm. The objective of this DEA application is to aid decision-making for reducing the number of suppliers and to provide improvement targets for suppliers.

Vokurka et al. (1996) developed a prototype expert system (ES) for the evaluation and selection of potential suppliers that is adaptable to a variety of product considerations and types of business. In parallel, Cook (1997) described Case-Based Reasoning systems in purchasing. Moreover, Khoo et al. (1998) developed an Intelligent Software Agent that highlighted the use of information technologies on the supplier selection decision-making process. This technique includes a client agent from the computer of the sourcing organization, which visits the web sites of prospective vendors to determine if they can supply the desired products according to the procurement specifications. Jalao and Martinez (2009) systematized the supplier selection process for long-term purchasing with the use of a computer-based ES that mimics the purchasing decisions of a purchasing professional. The proposed expert system is called contract ES, and is composed of four functional modules: configuration, supplier evaluation, supplier selection and supplier performance monitoring. Celebi and Bayraktar (2008) presented a novel integration of Neural Network (NN) and DEA techniques for the evaluation of suppliers under incomplete information for the selection criteria. Finally, Temur et al. (2009) presented a study in order to give insights for the supplier assessment process by comparing NN and Discriminant Analysis methods, applied to real world data from 51 long term suppliers of a medium sized company from German Iron and Steel Industry. The criteria that they considered were the following: material quality, distance, discounts on amount and discounts on cash, annual revenue, payment terms, and delivery length.

2.2.2 Optimization Models

Optimization models minimize a cost objective function, as a rule, in order to assist decision-makers in finding the optimal solution for the investigated problem. These techniques include among others mixed integer-programming (MIP), multi-objective programming (MOP), goal-programming (GP), and simulation models.

Chaudhry et al. (1993) employed MIP techniques to address the problem of vendor selection in which a buyer must choose order quantities to place with vendors in a multiple-sourcing network. Furthermore, the authors take into account the price, delivery, and quality of the products, along with the capacity constraints of the vendors, while they assume that suppliers offer price discounts which depend on the size of the order quantities. Similarly, Rosenthal et al. (1995) developed a MIP model that provides the optimal purchasing strategy by minimizing the total purchase cost.

Weber and Current (1993) presented a MOP approach to systematically analyze the inherent tradeoffs involved in multi-criteria vendor selection problems. More recently, Amid et al. (2006) developed a fuzzy MOP model, assigning different weights to various criteria in order to overcome the vagueness of the information that arise in practice, regarding goals, constraints and parameters in the vendor selection problem.

Karpak et al. (1999) used visual interactive GP as a multi-criteria decision analysis tool in order to provide support to decision-makers to identify appropriate vendors and allocate purchase orders among them, while minimizing product acquisition costs and maximizing total product quality and delivery reliability. Kumar et al. (2003) formulate the vendor selection problem as a fuzzy mixed integer GP problem, including three primary goals: minimizing the net cost, minimizing the net rejections, and minimizing the net late deliveries subject to a set of realistic constraints (e.g. buyer's demand, vendors' capacity, vendors' quota flexibility, purchase value of items, budget allocation to individual vendors, etc.).

In order to take into account the uncertainties in the supplier selection problem, Ding et al. (2006) presented a simulation methodology that is composed of three basic modules: a genetic algorithm optimizer, a discrete-event simulator and a supply chain modeling framework.

Hybrid models that combine two or more analytical techniques are also found in the literature. For instance, Ghoudsypour and O' Brien (1998) presented an integrated AHP and linear-programming (LP) capacitated (or not) model to consider both tangible and intangible factors in choosing the best suppliers and placing the optimum order quantities among them such that the total value of purchasing becomes maximum. Furthermore, Wu and Olson (2008) considered three types of vendor selection models: chance constrained-programming, DEA, and MOP, so as to provide alternative tools for the evaluation and improvement of the supplier selection decisions in an uncertain supply chain environment.

2.3 Contribution

The vast majority of the past research efforts focus solely on the selection phase of the overall procurement process. Thus, critical steps of this process such as the identification of the organization's needs, the definition of the procurement strategy, the incorporation of all the relevant in each case selection criteria into an optimization model, the periodic re-evaluation of new potential suppliers for the scope of retaining or changing the selected ones, and the performance monitoring of the existing suppliers are partially considered and analyzed, and not in an integrated manner.

Our research work presents a holistic methodological framework for the optimization of the procurement process, including the development of a conceptual decision-making methodology that address the whole life cycle of the supplier selection and evaluation processes and a novel generic goal-programming model for the initial selection and the periodic re-evaluation of vendors.

3. A Supplier Selection Methodological Framework

In this section a generic methodological framework for the supplier selection evaluation problem is presented (Figure 1). The proposed decision-making methodology is comprised of five main phases: the first three phases of the framework (I, II and III) deal with the initial supplier assessment and selection problem, while Phases IV and V are related to the continuous evaluation of the selected suppliers and the periodic re-evaluation of all the potential suppliers (new and old), for the scope of retaining or changing the selected ones.

In Phase I an organization has to firstly identify its procurement needs/requirements and subsequently the procurement strategy that will be followed. Then, Phase II of the framework deals with the identification of the potential suppliers. The determination of the alternative information sources of suppliers is a key driver of the success or failure of the whole process from a performance perspective. Online searches, companies' web sites, advertisements, trade shows, and professional contacts are the most common tools used today.

After developing a comprehensive list of potential suppliers, the next step is to evaluate each prospective supplier and select the suppliers with whom the organization will initially co-operate (Phase III). First of all, the selection criteria have to be defined, which is generally a case specific process mainly depending on the procurement strategy and the particular needs of each company (Guneri and Kuzu, 2008). Following, specific goals along with their target values that need to be achieved during the procurement process have to be clearly stated. These goals will derive from the selection criteria. Next, companies should collect the required data for each potential supplier, in order to initiate the evaluation process. The next step of Phase III, concerns the optimization of the supplier selection process through an analytical model that should take into account explicitly all the potential suppliers and the goals set by the buyer. The solution of this model will lead to the selection of the best n desired suppliers. One of the n selected vendors will play the role of the key supplier, while the rest secondary ones have to be classified according to their characteristics. To this effect, visits to the n suppliers' facilities can be conducted, so as the buyer can obtain firsthand information about their capabilities.

Following the selection of the vendor partners for the first period of the planning horizon, organizations should proceed to Phase IV of the framework, which concerns the continuous

Figure 1. The proposed five–phased methodological framework
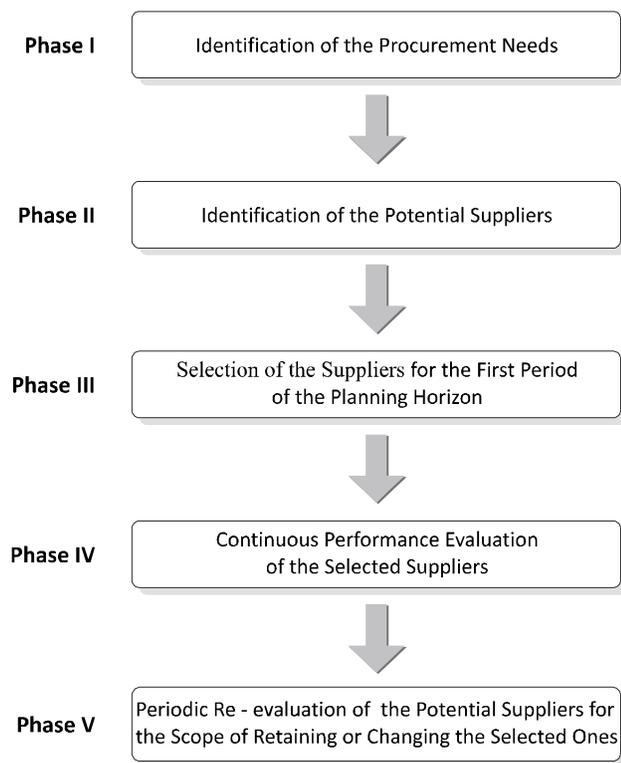
performance monitoring of the selected suppliers. The first step in Phase IV is the development of company-specific supplier measurement indicators, through which the performance of the suppliers will be continuously evaluated. After that the organizations can assess the performance of the selected suppliers through the establishment of proper statistical quality control techniques. In specific cases where an organization confronts poor performance with some of the selected suppliers, it should proceed as soon as possible to the evaluation of the new potential suppliers that will substitute the selected ones.

Finally, Phase V of the methodological framework deals with the re-evaluation of all the potential suppliers for the scope of retaining or changing the selected ones. In order to have a change in the supplier base, the expected performance of the new potential suppliers that compete with the existing ones should be better than that of them. Re-evaluation is a periodic process accomplished in predetermined time intervals. The first step of Phase V is the assessment of the selected suppliers based on the output data of Phase IV. If the performance of the selected suppliers is fully

satisfactory then the organization should continue monitoring them according to Phase IV and not proceed with Phase V, else it has to carry on with the next steps of Phase V that are similar to those described for Phases II and III.

4. Formulation of a Multi-Criteria Supplier Selection Model

The type of evaluation required to optimize supplier selection varies with the nature, criticality, and monetary value of the purchase to be made and thus it is not possible to specifically model a single functional formulation that will address all the problem settings. Consequently, we present a generic formulation of the investigated problem for a single item that is purchased from n vendors. Furthermore, the demand of the item is supposed to be forecasted with a relatively good accuracy, while there is a restriction to the total purchasing budget allocated to this product.

Based on our experience on the procurement management and on the literature review presented in Section 2, we propose an integrated set of selection criteria, which correspond to specific hierarchically categorized goals. Specifically, we have taken into account three priority levels in which all the considered goals are properly allocated. Tables 2, 3, and 4 present the goals of the first, second and third priority level in alphabetical order. We denote with T_j^i the jth goal/target of the ith priority. All the goals can have a ranking range following the Likert scale from 1 (less desired value) to 5 (most desired value).

The next step is to present the proposed generic goal-programming model for the optimization of the supplier selection process, corresponding to Phases

Table 2. First priority goals and selection criteria

Goals
T_1^1 : Financial terms of agreement
T_2^1 : Lead time
T_3^1 : Maximum order quantities
T_4^1 : Purchase price
T_5^1 : Quality of products

Table 3. Second priority goals and selection criteria

Goals
T_1^2 : Customer service
T_2^2 : Geographical proximity
T_3^2 : Logistics performance
T_4^2 : Position in industry
T_5^2 : Reputation
T_6^2 : Risk-management issues
T_7^2 : Long-term relationship

III and V of the proposed decision-making methodological framework. We adopt the minimum maximization formulation for goal-programming in which the maximum deviation from any goal is minimized. The solution of this model will identify the best *n* desired vendors. One of these vendors will be the key supplier from which the buyer will satisfy the largest possible part of his/her needs for the investigating item, while the rest quantity will be met by the secondary suppliers.

Table 4. Third priority goals and selection criteria

Goals
T_1^3 : Continuous improvement
T_2^3 : Co-operation with competitors
T_3^3 : E-commerce
T_4^3 : Environmental orientation
T_5^3 : Facilities
T_6^3 : Insurance & warranty policies
T_7^3 : Research & development

The following notations were used for the variables and parameters of the model: $s \in 1...S$ is the set of all the potential suppliers; u_{ij}^- and u_{ij}^+ represent generally the deviational variables from each goal *j* and for each priority level *i*; *D* is the

variable that denotes the maximum deviation from all the considered goals; Y_s is a binary variable that indicate whether supplier *s* will be selected or not; *B* is the budget allocated to the examined item over a fixed planning period; C_s is the capacity of supplier *s* over a fixed planning period; *Q* is the forecasted aggregate demand of the item over a fixed planning period; *sf* is a security factor for the forecasted demand; *n* is the number of vendors competing for selection; v_s is the unit purchase price of the item ordered from supplier *s*; r_{ij}^s is the rating of supplier *s* for the *j*th goal of the *i*th priority level; z_1 and z_2 are coefficients with a domain from 0 to 1 (with $z_1 < z_2$) that reduce the maximum acceptable deviation from all the considered goals of the first and the second priority level, respectively, in relation to the maximum deviation from the goals of the third priority.

The proposed supplier selection optimization model is formulated as follows:

- **Objective function:**
  Minimize D

- **Subject to:**

(1) $\displaystyle\sum_{s=1}^{S} Y_s \leq n$

(2) $\displaystyle Q \cdot \sum_{s=1}^{S} \left(v_s \cdot Y_s \right) - B \cdot \sum_{s=1}^{S} Y_s \leq 0$

(3) $\displaystyle\sum_{s=1}^{S} \left(C_s \cdot Y_s \right) \geq sf \cdot Q$

(4) $\displaystyle\sum_{s=1}^{S} \left(r_{ij}^s \cdot Y_s \right) - T_j^i \cdot \sum_{s=1}^{S} Y_s + u_{ij}^- \geq 0, \ \forall i,$
  j except for i=1 and j=2,4 and 5

(5) $\displaystyle\sum_{s=1}^{S} \left(r_{ij}^s \cdot Y_s \right) - T_j^i \cdot \sum_{s=1}^{S} Y_s - u_{ij}^+ \leq 0,$
  for i=1 and j=2,4 and 5

(6) $u_{ij}^- / T_j^i \leq z_1 D,$ *for i=1 and j=1,3 and 6*

(7) $u_{ij}^+ / T_j^i \leq z_1 D,$ *for i=1 and j=2,4 and 5*

(8) $u_{ij}^- / T_j^i \leq z_2 D,$ *for i=2 and $\forall j$*

(9) $u_{ij}^{-} / T_{j}^{i} \leq D$, *for i=3 and* $\forall j$

(10)   *Y_s are binary variables, while D, u_{ij}^{+} and $u_{ij}^{-} \in \iota$* [+]

The objective function allows us to minimize the maximum deviation from all the goals. On the other hand, appropriate hard and soft constraints are developed. The first three constraints are the hard ones with constraint (1) establishing the maximum number of vendors to be selected. Inequality (2) denotes that the budget allocated to the item over the planning period should not be exceeded. Constraint (3) ensures that the maximum possible quantity that can be ordered for the item from all the selected vendors is at least equal with the forecasted demand over the planning horizon augmented by the case-specific security factor *sf*. Inequalities (4) and (5) are the classical soft constraints with the deviational variables included. Inequalities (6) to (9) indicate that all the percentage deviations from the various goals will not exceed the value of *D*. Constraint sets (10) reflect the binary nature of the vendor selection decision, and the fact that the all the other variables employed are continuous and non-negative.

5. Conclusions and Discussion

In this paper we propose a multi-criteria decision-support methodological framework for the optimization of the supplier selection and evaluation problem, along with a goal-programming model and a set of newly-defined qualitative criteria/goals for capturing a number of real-world issues. The proposed analytical model is quite generic since it is not possible to specifically model a single functional formulation for all the business environments.

The current work can be extended in order to incorporate the allocation of purchase quantities among the selected suppliers and the consideration of the multiple-item problem. A further issue that is worth exploring is that of supplier performance monitoring. Finally, few additional aspects that we intend to take into account in the near future are the ranking of the suppliers through a new optimization model and stochasticity of the quality of the products.

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