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Integration management of strategic supply chain based on genetic algorithm

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Abstract. Strategic supply chain research needs to take into account the three major stages of supply chain, namely, procurement, production, distribution, and their interactions. In order to study the limitations of the existing supply chain design model and establish a strategic supply chain integrated management system which is suitable for different customer needs, facilities matching relationship and supplier priority, a hybrid integer nonlinear programming (MINLP) model was established. Two-step method was used to solve the constraint problem in the model, and the adaptive genetic algorithm (AGA) was used to solve the model. Finally, the experimental results show that the proposed mixed integer nonlinear programming model can effectively solve the problem of supply chain coordination in strategic supply chain design, and can get a better supply chain design.

Key words. Strategic supply chain design model, mixed integer nonlinear programming, adaptive genetic algorithm.

1. Introduction

As China's bicycle export market scale increases every year, China has become the world's largest bicycle manufacturer. According to statistics, China produced 80.26 million bicycles and 32.57 million automatic bicycles in 2015. Large bike manufacturers and parts suppliers form a strategic logistics partnership while producing the bicycles. The expansion of the bicycle manufacturer examines its ability to generate energy, but also puts pressure on the supplier's ability to supply. As the environment changes, if bicycle manufacturers continue their relatively inflexible supply mechanism, this will greatly reduce customer confidence and loyalty. Nowadays, the key for the success or failure of an enterprise is the ability to coordinate the

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complex network relationships between supply chain facilities and the integration of integrated management. Therefore, it is very important for the bicycle company to establish a reliable and effective supply chain cooperation alliance and continuously optimize it. The theoretical significance of this paper lies in optimizing the comprehensive configuration of the strategic and operational levels of the supply chain, namely, considering the product parts procurement, product design, production and transportation and other aspects of the products, so as to provide a new research perspective for bicycle manufacturers and improve the competitiveness of the supply chain.

2. State of the art

Supply chain design model has important significance, and it has been more concerned by domestic and foreign scholars. For example, in the design of low-carbon supply chain network, the least sum model is built among logistics costs, distribution centers, fixed costs, and carbon emissions costs through concave functions, the Lagrangian relaxation method is used to decompose the model into vest pack problems and a single supplier location problem and analyze supply chain network design and operating costs, so that the number of distribution centers based on the cost of carbon emissions can be obtained, and the distribution center utilization can be improved [1]. Closed-loop supply chain network design uses non-linear cost and continuous variable. Functional activity arcs and variational inequalities are used to design cost functions and build models to analyze the impact of recycling rates on sales, operations and recovery costs, design costs, profits, and demand for market demand, recovery and value [2]. Based on the general closed-loop supply chain, a multi-objective mixed integer linear programming model can be proposed to optimize the supply chain network. The model not only determines the number of products and nodes in the closed-loop supply chain network, but also selects the best suppliers and manufacturers [3]. The utility software system (GAMS) is used to solve and obtain the corresponding optimization scheme. But the GAMS can only solve small-scale data problems. In order to ensure the stable performance of the supply chain when the design parameters are perturbed, a robust optimization supply chain design model is established from the upstream selection supplier to the downstream location and distribution requirements, and the method of determining the value of the regret value is proposed, and the tabu search algorithm of supply chain node configuration is designed. Robust optimization can effectively avoid investment risk [4]. Supply chain involves a number of equipment such as raw materials and parts suppliers, the final product producers, distribution centers. According to the requirements of the customers, the supply chain members are designed and integrated, the strategic supply chain design integration model is proposed to enable collaborative scheduling of production and product offerings to ultimately achieve optimal supply chain performance [5]. Aiming at the existence of multiple nodes in the recycling and remanufacturing supply chain network, the equilibrium variational inequality model with both positive and reverse logistics is established. The advantage of this model is that it qualitatively and quantitatively analyzes the competition behaviors among several manufacturers and among retailers, the supply chain competitiveness is determined by the overall efficiency of the members in the chain [6].

3. Methodology

A set of products is designed and manufactured via a supplier, a manufacturer, a distribution center (DC), and ultimately a customer base, as shown in Fig. 1, which form a supply chain. The manufacturer is responsible for the overall design and production of the product and the supplier provides the required parts or the design and production of the intermediate part according to the needs of the manufacturer [7]. Each production manufacturer completes product design, production and sales according to customer requirements. However, due to the manufacturer's own production conditions, it is impossible for a single manufacturer to produce enough products to meet market demand, so different manufacturers are required to produce the same product together [8]. The current global manufacturing practice is that a number of manufacturers of a product belong to the same enterprise, while suppliers and distribution centers (DC) do not belong to the same enterprise. In addition, the decisions made by the enterprise on suppliers, manufacturing manufacturers and distribution centers are within the scope of the supply chain. It can be seen from the above that the supply chain is the best choice when dealing with international companies [9].

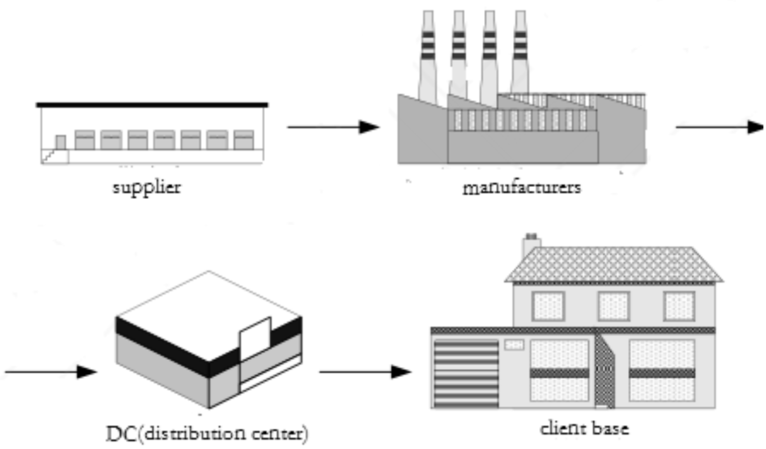

Fig. 1. Schematic diagram of product path

The model is based on the following assumptions: each manufacturer can produce any product; the product within the manufacturer is divided into a limited set of sub-tasks, that is, each product is supplied by one or more suppliers; if a supplier assumes the task of designing a component, it is responsible for the production of the part; each manufacturer procures parts from multiple suppliers, each of which serves a number of manufacturers; each distribution center is open to any product; the distribution center transports all the products received to the customer; according to the location, the customer is divided into different regions to form a customer base; the design and production capacity of the supplier and the manufacturer is known; the capacity of the distribution center is known; and the transportation costs between the facilities are known [10].

The objective function Q is the minimum value of the total cost of the whole supply chain period (yuan/period), as shown in equations (1)–(4):

$$\mathrm{Min} C = f_1 + f_2 + f_3 \,, \tag{1}$$

$$f_1 = \sum_{rj} U_{rj} \frac{\eta_{rj}}{\delta_{rj}} + \sum_{rj} U_{rj} f_{rj}^{\mathrm{S}} + \sum_{rj} U_{rj} p_{rj}^{\mathrm{S}} Z_{rj} + \sum_{rjk} U_{rj} c_{rjk}^{\mathrm{SP}} R_{rjk} \,, \tag{2}$$

$$f_2 = \sum_{ik} V_{ik} \frac{\eta_{ik}}{\delta_{ik}} + \sum_{ik} V_{ik} f_{ik}^{\mathrm{P}} + \sum_{ik} U_{ik} p_{ik}^{\mathrm{P}} X_{ik} + \sum_{ikl} V_{ik} c_{ikl}^{\mathrm{PD}} Q_{ikl} \,, \tag{3}$$

$$f_3 = \sum_{il} W_{il} f_{il}^{\mathrm{D}} + \sum_{il} W_{il} p_{il}^{\mathrm{D}} Y_{il} + \sum_{ilm} W_{il} c_{ilm}^{\mathrm{DZ}} P_{ilm} \,. \tag{4}$$

In the above equations, i is the set of products provided to the customer, j is the candidate supplier set, k is the set of potential manufacturers, l is the distribution center set, m is the customer group set and r is the set of parts provided to the supplier. Symbol f_{rj}^{S} is the production preparation cost of supplier j on production parts r, f_{ik}^{P} is the production preparation cost of supplier k on production parts i, f_{il}^{D} is the setup cost at which the distribution center l delivers the product i. Symbol δ_{ik} is the capacity of the manufacturer k to design the product i, δ_{rj} is the capacity of the supplier j to design the component r, c_{rjk}^{SP} is the unit transportation cost (yuan/unit) from supplier j to manufacturer k to transport part r, c_{ikl}^{PD} is the unit transportation cost (yuan/unit) from the manufacturer k to the distribution center l to transport product i, c_{ilm}^{DZ} is the unit transportation cost (yuan/unit) from the distribution center l to the customer base m to transport products i, p_{rj}^{S} is the unit purchase cost (yuan/unit) of part r from the supplier j, p_{ik}^{P} is the unit production cost (yuan/unit) of manufacturer k to produce product i, p_{il}^{D} is the unit cost of the capacity of the product i at the distribution center l (i.e. the cost of processing and inventory) (yuan/unit). Symbol η_{rj} is the cost coefficient of the supplier j to design component r, η_{ik} is the cost coefficient of the supplier k to design component i, D_{im} is the average demand (unit/period) of product i in customer group m, X_{ik} is the quantity (unit/period) of product i manufactured by manufacturer k, Y_{il} is the quantity (unit/period) of the product i received by the distribution center l, Z_{rj} is the quantity (unit/period) of the component r provided by the supplier j, Q_{ikl} is the quantity (unit/period) of the product i being transported from the manufacturer k to the distribution center l, R_{rjk} is the quantity (unit/period) of the part r being transported from the supplier j to the manufacturer$k$. Symbol P_{ilm} is the quantity (unit/period) of the product i being transported from the distribution center l to the customer base m, U_{rj}: if the supplier j provides components with the r value, it is equal to 1, otherwise it is 0, V_{ik}: if the manufacturer k produces the product i, its value is 1, otherwise 0, W_{il}: if the distribution center l accepts the product i, its value is 1, otherwise it is 0.

The total cost in the objective function includes fixed and variable. It contains the three stages costs of the supply chain: procurement, production and transportation phase. In the procurement phase, the cost includes parts design, production preparation, parts procurement and transportation costs [11]. Among them, the design cost comes from the ability of the supplier to design a specific component. At the production stage, the cost includes product design, production preparation, production up costs, and transportation costs from the manufacturer to the distribution center. During the transportation phase, the cost includes the cost of the equipment, the inventory costs of the distribution center, and the transportation costs from the distribution center to the customer base [12].

Constraint processing is a very important problem in model solving, and a two-step approach is proposed to deal with constraints. In the first step, constraints are divided into two types: ability-related constraints and priority-related constraints. Competence-related constraints are the constraints of the entity in terms of production capacity, set-up costs, and distribution center capacity. Priority related constraints are thinking about solutions from a holistic perspective, so there are bill of materials constraints in the model, supplier preference and facility pairing. In other words, the ability-related constraints have an effect on the entity itself, and the priority-related constraints affect the structure of the supply chain [13]. In the second step, the constraint processing module has a screening function in the process of solving the solution. Initially, the constraints are stored in a collection. Whenever a new solution is generated, the constraint processing module checks the constraints in the collection from the aspects of valid a priori constraints. In the process of solving, it is necessary to include viable and unfeasible solutions in the interactive search process, so as to promote diversified development [14]. In this study, different penalty factors are assigned to varying degrees of competency-related constraints and prior correlation constraints. As shown in Fig. 2, there is a pair relationship between supply chain facilities.

The solution corresponding to a supply chain can be divided into several segments. Each fragment represents a supply chain stage, such as supply, production and distribution, which is mainly composed of two attributes: location and value. The location represents the corresponding index in the different fragments, which can describe the state or priority. As shown in Fig. 3, among the suppliers, suppliers 2 and 4 are selected; among the manufacturers, 1, 2 are selected; and in the transit center, 2, 3 are selected. There are three segments in the second paragraph, each of them represents a stage. The three segments correspond to the product from the supplier to the manufacturer, the manufacturer to the transit center, and the transit center to the customer base.

The combination of roulette and "elite" strategies is used to select the operator, the top 20 % of the individual is retained, so that they do not cross and mutate.

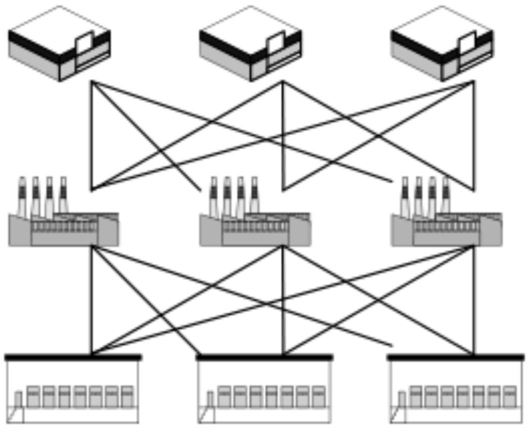

Fig. 2. Pairwise relationships between supply chain facilities

Supplier				Plant			DC			Stage 1			Stage 2			Stage 3			
1	0	1	0	1	1	0	0	1	1	2	3	1	3	2	1	1	3	4	2

Fig. 3. Chromosome coding

The fitness function of this paper is shown in the equation

$$\text{Fitness} = \begin{cases} \frac{1}{1+\exp((f-f_{\text{avg}})/c)}, g \geq 20\,\% n, \\ \frac{1}{1+\exp(f-f_{\text{avg}})}, g < 20\,\% n. \end{cases} \tag{5}$$

Here, f is the original fitness: this fitness function is for solving the minimum value of the objective function. If the problem itself is solved as the minimization problem, f directly represents the objective function.

The crossover probability p_{c} and the mutation probability p_{m} are the key parts of the genetic algorithm. Compared with the traditional genetic algorithm, the adaptive genetic algorithm (AGA) can adaptively change the crossover and mutation probability in the optimization process according to the number of iterations and its own fitness function, which avoids the problem that the standard genetic algorithm (GA) falls into the local solution or premature convergence in the solution (Wang et al. 2015) [15].

The crossover probability p_{c} and the mutation probability p_{m} are given as

$$p_c = \begin{cases} 0.6 - \frac{0.6-0.8}{1+\exp(10(2-\frac{3(f_{\max}-f)}{f_{\max}-f_{\text{avg}}+1}))}, & f' \geq f_{\text{avg}} \\ \\ 0.8 - \frac{0.8-0.9}{1+\exp(10(1-\frac{3(f_{\text{avg}}-f)}{f_{\text{avg}}-f_{\min}+1}))}, & f' < f_{\text{avg}} \end{cases} \tag{6}$$

$$p_m = \begin{cases} 0.005 - \frac{0.005-0.01}{1+\exp(10(\frac{3(f_{\max}-f)}{f_{\max}-f_{\text{avg}}+1}-2))}, & f \geq f_{\text{avg}}, \\ 0.001 - \frac{0.001-0.005}{1+\exp(10(\frac{3(f_{\text{avg}}-f)}{f_{\text{avg}}-f_{\min}+1}-1))}, & f < f_{avg}. \end{cases} \tag{7}$$

4. Results analysis and discussion

In this paper, the feasibility and potential of mixed integer nonlinear programming supply chain model and adaptive genetic algorithm were explained by bicycle. In general, the bicycle has three direct subassemblies, including the front and rear wheels (Wl), the main frame (Mf) and the foot (also including the chain) (Pa), among them, the main frame (Mf) further comprises a seat (Sa) and a frame (Fr). (Note: here the wheels (Wl) represented the front wheels and rear wheels; each bicycle needed a unit of wheels, and the number of each unit component was 1.) Table 1 shows the four program characteristics, Table 2 shows the manufacturer's design/production capacity under the program 1, as well as the manufacturer and distribution center setup costs and customer requirements. Table 3 shows the transportation costs between the two facilities in scenario 1.

According to the AGA parameters and the solving steps set up above, the model was solved by AGA. The convergence is shown in Figs. 4–7. When the program was different, the workload of suppliers, manufacturers and distribution centers was obtained as shown in Tables 4–6.

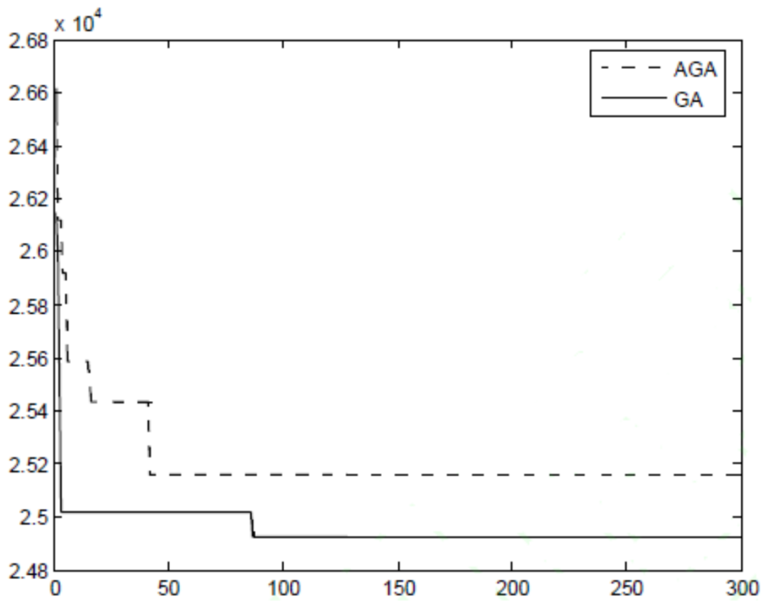

Fig. 4. Convergence graph of adaptive genetic algorithm for scheme 1

Table 1. Four scenarios

Scheme	Supplier quantity	Manufacturer quantity	Number of distribution centers	Customer base quantity
1	4	3	3	4
2	8	5	6	8
3	10	8	10	9
4	15	10	12	10

Table 2. Scenario 1 design/production capacity, establishment cost and demand

Supply chain facilities#	#1	#2	#3	#4
Client needs	580	430	460	350
Supplier design capability	W1/0.9	Sa/0.6; Fr/0.85	Sa/0.8; Fr/0.9	Pa/0.75
Supplier capacity	1820	1900, 1900	2000, 2000	2100
Manufacturer's design capability	Mf/0.88; Bc/0.95	Mf/0.95; Bc/0.85	Mf/0.90; Bc/1	
Manufacturer's production capacity	900	1150	1380	
Distribution center maximum throughput	1250	1080	1050	
Manufacturers build costs	2500	2200	2800	
Establishment cost of distribution center	1200	1800	1000	

Table 3. Transport costs for facilities in scenario 1

Supplier/ manufacturer	1	2	3	Manufacturer/ distribution center	1	2	3	Distribution center/ customer area	1	2	3	4
1	18	15	20	1	8	6	9	1	25	22	18	20
2	12	14	16	2	9	12	10	2	17	21	24	22
3	11	17	15	3	7	10	13	3	15	19	23	20
4	8	13	11									

Table 4. Quantity of components shipped by supplier to manufacturer

Supplier/Plant	1	2	3
1	-	805	1015
2	-	805	0
3	-	0	1015
4	-	805	1015

Table 5. The number of parts shipped by the manufacturer to the distribution center

Plant/DC	1	2	3
1	-	-	-
2	434	371	-
3	435	580	-

Table 6. The number of components shipped by customer base to distribution center

DC/CZ	1	2	3	4
1	580	234	50	5
2	0	196	410	345
3	-	-	-	-

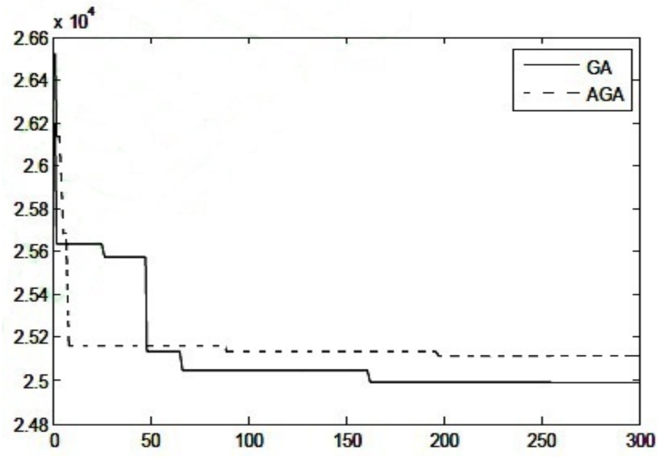

Fig. 5. Convergence graph of adaptive genetic algorithm for scheme 2

It can be seen from the above graph that a mixed integer nonlinear programming (MINLP) model was proposed based on considering the interaction between the strategic and operational layers and the associated constraints. The lowest overall cost of the supply chain was used as the optimization objective. The AGA which can deal with the constraint was used to optimize the model, so that the corresponding optimization scheme was obtained. The experimental results show that the proposed mixed integer nonlinear programming model can effectively solve the problem of supply chain collaborative optimization in strategic supply chain design, and can get a better supply chain design.

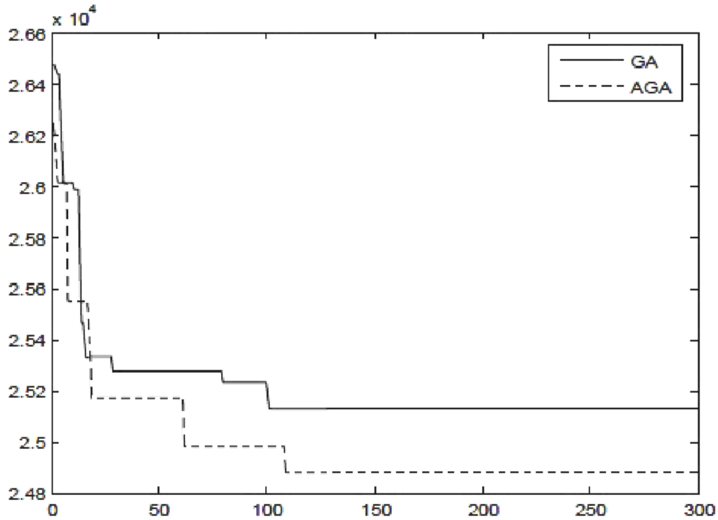

Fig. 6. Convergence graph of adaptive genetic algorithm for scheme 3

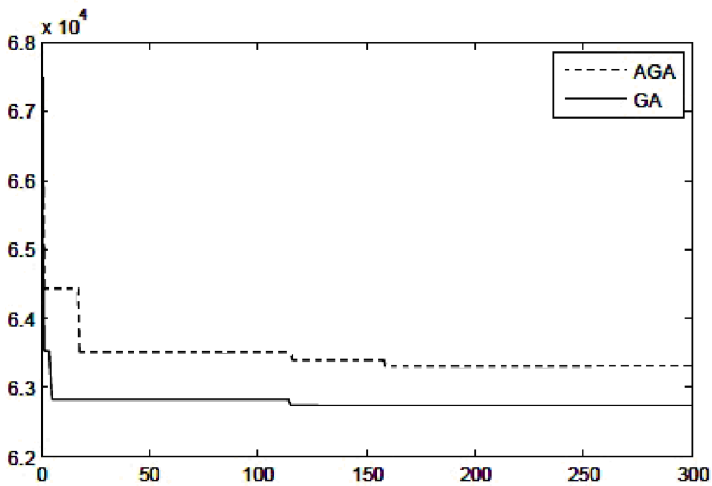

Fig. 7. Convergence graph of adaptive genetic algorithm for scheme 4

5. Conclusion

The purpose of this paper is to optimize the strategic and operational layers of the supply chain. In order to achieve the goal, in this paper, the mixed integer nonlinear programming model and the supply chain designed by the adaptive genetic algorithm (GA) were established on the basis of the consideration from the aspects of the supply chain, and the lowest cost of supply chain was optimized. Based on the adaptive genetic algorithm, the model was solved, and the optimal supply chain design scheme was obtained. Finally, the following conclusions were drawn: the model and the solution method provide the decision support in the supply chain design. The mixed integer nonlinear programming model takes into account the three main stages of the procurement, production and distribution of the supply chain and the interaction among them, and considers the optimal allocation of the supply chain from a holistic perspective, and puts the implementation of paired relations and supplier preferences in the constraints, which helps the actual design of the supply chain. In this paper, the optimal design of the supply chain was implemented, and the optimal supply chain design was obtained through the use of AGA. However, this paper still has some limitations, for example, when the enterprise is pursuing multiple performance indicators at the same time, such as cost, income and so on, this design cannot meet it, it is necessary to comprehensively configure the supply chain in a multi-objective form.

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