OPTIMAL ANALYSIS OF FARM AGRICULTURAL MACHINERY EQUIPMENT BASED ON MATHEMATICAL MODELLING

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基于数学模型的农业机械设备优化分析

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ABSTRACT

With the development of science and technology, the degree of agricultural mechanization is getting higher and higher. Agricultural machinery is an important support for the development of agricultural modernization. Optimizing the allocation of agricultural machinery is conducive to improving agricultural production efficiency and economic benefits. In this paper, mathematical modelling method is mainly used in the analysis and optimization of agricultural machinery configuration. By determining the objective function and constraint equation, combined with the actual situation of Xinjiang Production and Construction Corps, the linear programming model and workload model of agricultural machinery and equipment optimization are established. Finally, the actual number of agricultural machinery and equipment and the number of optimal allocations of Xinjiang Production and Construction Corps farm were compared. The effectiveness of the optimization model is verified by comparing the optimized agricultural machinery equipment with the actual equipment. The results show that the optimized equipment model has good optimization effect. On the basis of reducing the number of agricultural machinery and equipment, the matching rate of agricultural machinery is improved, and the operation cost of agricultural machinery is effectively reduced. It is hoped that this study can provide certain reference and reference for the optimization analysis of agricultural machinery and equipment based on mathematical modelling.

摘要

随着科学技术的发展，农业机械化程度越来越高，是农业现代化发展的重要支撑。优化农机配置，有利于提高农业生产效率和经济效益。本文在分析和优化农机具配置时，主要采用数学建模方法。通过确定目标函数和约束方程，结合新疆生产建设兵团的实际情况，建立了农机设备优化的线性规划模型和工作量模型，最后对新疆某生产建设兵团农场的实际农机设备数量与优化配置数量进行了比较。并将优化后的农机设备与实际设备的对比结果，验证了农机设备优化模型的有效性。研究结果表明，优化后的设备模型具有良好的优化效果，在减少农机设备数量的基础上提高了农机具的匹配率，有效降低了农机作业成本。希望本研究能为基于数学建模的农机设备优化分析提供一定的参考和参考。

INTRODUCTION

Agriculture is the basis for human survival, an important guarantee for human food and clothing, and it plays an important role in economic prosperity and social stability. With the development of science and technology, the degree of agricultural mechanization is getting higher and higher, which is an important support for the development of agricultural modernization. Agricultural mechanization is conducive to ensuring long-lasting, efficient and high-quality agricultural operations. It can also resist natural disasters to a certain extent, liberate rural farm labour productivity, and further increase farmers' income *(Rangkuti A.R., Saleh A., 2011).* The reasons for the unreasonable farm machinery and equipment deployment include two aspects. On the one hand, there is a lack of a scientific plan for farm machinery and equipment. On the other hand, it is the pursuit of the quantity and performance of agricultural machinery, regardless of whether the equipment is reasonable *(Li Y.B., Li H. and Guo X., 2020)*. In this case, the existing agricultural machinery and equipment supporting production in Xinjiang Production and Construction Corps are more complex, and the types of machinery and equipment are also more complex, resulting in the waste of agricultural funds and labour *(Wang B., He J., Zhang S. and Li L.L., 2020)*. In a certain way, the problem is transformed into a model, and the relationship between the problems is found. Therefore, this study uses mathematical modelling to analyse the optimal allocation of farm machinery and tools in order to achieve the purpose of rationally optimizing the allocation of agricultural machinery and tools.

Gorucu et al analysed the proficiency of farm youths in using tractors, trucks and cars through questionnaires when they studied the farm youth's mastery of the technology used in agricultural equipment. This research provided a certain degree for young people working on the farm *(Gorucu S. and Murphy D., 2018).* When studying the situation of safety accidents on the farm, *Gorucu S. and others* mainly investigated the incidents or character characteristics of collisions with agricultural equipment, carriages, etc. recorded by the transportation department. The results show that the root cause of the farm accidents is the improper operation of equipment by farm personnel *(Gorucu S., Kassab D.M.C., 2016). Ceylan H. et al* conducted a series of tests when studying the impact of heavy farm implements on rigid pavement structures, including the response of rigid pavement to agricultural vehicles, and compared the response with the response of a standard semi-trailer *(Ceylan H., Wang S. and Kim S., 2015).* When studying agricultural activities in Nagaran, *Paneque R.P.* and others analysed the agricultural mechanization strategy of improved tools. This strategy mainly maximizes the economic benefits of agriculture through the improvement of agricultural equipment, indicating that agricultural mechanization is very beneficial to agricultural production *(Paneque R P., Morejon M.Y. and Fernandes H.C., 2019). Mehlhorn S.A. and others* analysed the impact of a special plan on road drivers' understanding of agricultural tools when studying the problems of agricultural equipment on public roads. The program made the drivers realize the necessity of sharing public roads with farm equipment drivers through special presentations *(Mehlhorn S.A., Darroch B. and Jackson S.W., 2017)*.

When studying the influence of infrared convection on potato thin layers, *Teshome F.B. et al* used mathematical modelling methods to dry potatoes at thicknesses of 3mm, 5mm, and 7mm, and infrared convection of 500W, 700W, and 900W, respectively. The results show that with the increase of infrared power and potato thickness, the sample water content and drying time are reduced *(Teshome F.B., Degu Y.M., 2019). Mohd T.A.T. and others* established a simulation model of an all-electric vehicle on the MATLAB simulation platform, used mathematical modelling equations to draw and discuss the corresponding simulation results, and used the torque and speed of the electric vehicle involved in the modelling process to determine its energy flow and performance *(Mohd T.A.T., Hassan M.K. and Aziz W.A., 2015)*. When studying the influence of air temperature and speed on potato drying, *Naderinezhad S.* established a corresponding mathematical model of drying, and conducted drying experiments under certain conditions of temperature and wind speed. The results show that drying temperature is an important parameter that affects the drying rate of potatoes *(Naderinezhad S., Etesami N. and Poormalek Najafabady A., 2016).* When studying the activity of dehydrogenase, *Matyja K. et al* established a mathematical model based on the Lagergren's pseudo-first-order equation to describe the short-term change of dehydrogenase activity, and verified the effectiveness of the model through corresponding examples *(Matyja K., Ma A.J.A. and Mazur A.K., 2016).* When studying the evolution of brain heterogeneous modules, *Yamaguti Y and others* used genetic algorithms to construct a mathematical model. The model included two randomly coupled functional areas. The optimization of the functional area parameters verified the effectiveness of the mathematical model *(Yamaguti Y. and Tsuda I., 2015). Bouzid L. et al* established a mathematical model of AISI420 stainless steel based on the surface response method. During the model building process, a statistical simulation of the relationship between cutting parameters, cutting force components and the absolute roughness of the workpiece surface was carried out. The results show that the cutting depth affects the stainless steel, the main factor of surface roughness *(Bouzid L, Yallese M. A and Chaoui K. 2015).*

It can be seen that the research at home and abroad mainly involves the relevant situation of farm agricultural machinery and the application of mathematical models in various aspects. Among them, farm operations mainly include agricultural mechanization, farm tool design, etc.; mathematical models are mainly used in various aspects of industry, biomedicine, production and life *(Yan H., Cui Q. and Liu Z., 2020).* The related researches are less concerned with the application of mathematical models in the analysis of the optimization of agricultural machinery and equipment. Therefore, this study analyses the optimization of the farm agricultural machinery and equipment based on the mathematical model.

MATERIALS AND METHODS

Linear programming analysis and optimization of farm machinery

In the management of agricultural mechanization, the most important and fundamental task is to rationally configure farm machinery and implements to achieve the highest economic benefits at the least cost. The deployment of farm machinery and equipment needs to be based on the actual situation of local agronomy, taking full account of economic and technological development, and following certain principles. The main principles include the principle of existing models, economic principles, reasonable equipment, agronomy and agricultural machinery. Combining the principles and the principle of one machine with multiple purposes, this study mainly used mathematical modelling to conduct research and analysis when studying the problems of farm machinery and equipment deployment, and combined linear programming and workload methods to the farms of the Xinjiang Production and Construction Corps. Among them, the linear programming model mainly includes the objective function and the constraint equation. The constraint equation is mainly composed of agricultural capacity constraints, operating capacity constraints, tractor reserve constraints and variable non-negative constraints. The steps of establishing a linear programming model mainly include the following aspects: first, the objective function is determined. The objective function of the linear programming in this study is the cost of agricultural operations, and that must be minimized. The objective function is constructed as shown in the formula (1).

$$S_{\min} = C_f + C_v \tag{1}$$

In the formula (1), S_{min} is the minimum value of the function S of the cost of the farm operations; C_f is the fixed cost of farm machinery operations throughout the year; C_v is the variable cost of farm machinery operations throughout the year. The fixed fee can be expressed as follows:

$$C_f = \sum\left(a_i X_i + b_j X_j\right) \tag{2}$$

where i represents the serial number of the tractor in the farm; j represents the serial number of the farm tool; the tractors and farm tools in the farm are numbered to facilitate the later research work; a_i represents the fixed cost of the i type tractor operation for the whole year, Yuan/unit; b_j is the i type agricultural tool operation the fixed cost required for the whole year; X_i is the number of tractors equipped throughout the year. The variable costs of farm machinery operations throughout the year can be expressed as equation (3).

$$C_v = \sum C_{mn} W_{mn} X_{mn} \tag{3}$$

where m represents the serial number of agricultural machinery operations; n represents the number of units that complete the first operation of the farm, C_{mn} represents the variable cost of the n type farm operation tools when carrying out the farm operation m, Yuan/mu (1 mu = 666.66 square meters, 1 RMB = 0.1530 USD); W_{mn} represents the productivity of the n type farm operation tool when performing the m item farm operation, mu/unit shift; X_{mn} represents the n type farm operation tool when performing the m item farm operation number of machine shifts. Then, after the objective function is determined, the constraint equation is determined, and the workload constraint can be expressed as follows:

$$\sum W_{mn} X_{mn} \geq A_m \tag{4}$$

where: A_m represents the area of operation required to complete the m operation in farm operations, acres.

The constraint conditions of the equipped amount of the tractor can be expressed as follows.

$$\sum X_{im} \leq T_m M_{im} X_i \tag{5}$$

where: X_{im} represents the number of i class tractor shifts required to complete the m operation, T_m represents the probability of the tractor's available ground time in the m farm operation stage; M_{im} represents the m operation completed. X_i is the number of the i type tractor equipped. The constraint amount of farm implements can be expressed as follows:

$$\sum X_{jm} \leq T_m M_m X_j \tag{6}$$

where T_m represents the probability of the agricultural machinery being able to land on the m farm operation stage; X_{jm} is the number of the j farm implement shifts required to complete the m farm operation, and X_j represents the number of farm agricultural equipment equipped, M_m is the largest farm operation shift to complete the m operation.

The corresponding workload model can be established as follows.

$$n_{rm} = \frac{U_{rm}}{D_m \alpha_m W_{rm}} \tag{7}$$

where the agricultural machinery serial number is indicated by r; n_{rm} is the number of r type agricultural machinery required to complete the m farm operation; U_{rm} is the area of the r farm operation required to complete the m agricultural machinery, and D_m is the phase m farm operation; α_m is the operable shift per day when the m operation is performed, and W_{rm} is the productivity of each shift of the r-type agricultural machinery when the m farm operation is completed.

Optimal equipment of farm machinery in Xinjiang Production and Construction Corps farm

Aiming at the problem of optimal allocation of agricultural machinery and equipment, the optimization of agricultural machinery and equipment of Xinjiang production and Construction Corps was studied as an example. Xinjiang production and Construction Corps has some differences in climate conditions, natural environment, crop planting conditions, agricultural machinery and equipment conditions. In this study, the status of agricultural planting and agricultural machinery and equipment of Xinjiang production and Construction Corps is taken as the research object. The main food crops of Xinjiang production and Construction Corps are corn, wheat, cotton, tomato and pepper. At the same time, it has a high degree of agricultural mechanization and agricultural machinery equipment. The deployment of Xinjiang production and Construction Corps is also at the forefront.

According to the existing tractor types of Xinjiang production and Construction Corps, combined with the safety, efficiency, reliability and agronomic adaptability of agricultural machinery operation, two models were selected, namely High-power Tractor Dongfanghong lx2204 and medium horsepower tractor John Deere Jd5-750, taking cotton, corn and tomato as the main research objects, established the corresponding optimization model of agricultural machinery and equipment. The planting process of Xinjiang production and construction corps farm is shown in Table 1. It can be seen from the table that the business items include whole tomato field, cotton field and corn field, tomato planting, cotton planting, corn planting and weeding. The operation area of tomato field is 10000 mu, cotton field is 64340 mu, and corn field is 20000 mu.

Table 1

Xinjiang production and construction corps farm annual agricultural machinery operation process

Farm project	Operating area (mu)	Production unit shift productivity (mu/shift)	
		LX2204	JD5-750
Turn the tomato field	10000	400	400
Turn the cotton field	64340	210	260
Turn the cornfield	20000	130	130
Tomato sowing	10000	400	400
Cotton sowing	64340	210	260
Corn sowing	20000	130	130
Tomato field weeding	10000	400	400
Cotton field weeding	64340	210	260
Cornfield weeding	20000	130	130

The amount of farm machinery equipment includes the following variables, X_1 is the number of LX2204 tractors; X_2 is the number of JD5-750 tractors; X_3 is the number of sprayers; X_4 is the number of combined soil preparation machines; X_5 is the number of cotton seeders; X_6 is the number of tomato planters; X_7 is the number of tillage and fertilization machines; X_8 is the number of ploughs; X_9 is the cotton stalk returning machine. The number of shifts of the John Deere JD5-750 tractor group includes the following variables: X_{10} is the number of shifts for removing weeds in tomato fields; X_{11} is the number of shifts for removing weeds in cotton fields; X_{12} is the number of shifts for removing weeds in corn fields; X_{13} is the number of shifts for sowing tomatoes; X_{14} is the amount of cotton planted; X_{15} is the number of machine shifts for planting corn; X_{16} is the number of machine shifts for whole tomato fields; X_{17} is the number of machine shifts for whole cotton field; X_{18} is the number of machine shifts for whole corn field. The number of shifts of Dongfanghong LLX2204 tractor group includes the following variables: X_{19} is the number of tractors in the whole tomato field;

X_{20} is the number of tractors in the whole cotton field; X_{21} is the number of tractors in the whole corn field; X_{22} is the number of tractors in the tomato field; X_{23} is the shift number of cotton field tractors; X_{24} is the number of tractor tool benches in the corn field; X_{25} is the number of tractors in the weeding field; X_{26} is the number of tractor tool benches in the weeding field; X_{27} is the number of tractor shifts in the corn field. After the determination of the variables is completed, the constraint equation containing the variables is established. The constraint equation for the whole tomato field is shown in the following formula:

$$400X_{16} + 400X_{19} \geq 10000 \tag{8}$$

The constraint equation of the whole cotton field is expressed as follows.

$$260X_{17} + 210X_{20} \geq 64340 \tag{9}$$

The constraint equation of the whole corn field is expressed as follows.

$$130X_{18} + 130X_{21} \geq 20000 \tag{10}$$

The constraint equation for tomato planting fields is expressed as follows.

$$400X_{13} + 400X_{22} \geq 10000 \tag{11}$$

The constraint equation of cotton planting field is expressed as follows.

$$260X_{23} + 210X_{14} \geq 64340 \tag{12}$$

The constraint equation for sowing corn field is expressed as follows.

$$130X_{15} + 130X_{24} \geq 20000 \tag{13}$$

The constraint equation for weed removal in tomato field is expressed as follows.

$$400X_{10} + 400X_{25} \geq 10000 \tag{14}$$

The constraint equation for weed removal in cotton field is expressed as follows.

$$260X_{26} + 210X_{11} \geq 64340 \tag{15}$$

The constraint equation for weed removal in corn field is expressed as follows.

$$130X_{12} + 130X_{27} \geq 20000 \tag{16}$$

The constraint equations of this model include dynamic constraint equation, implement constraint equation and workload constraint equation. When carrying out the dynamic constraint, it is necessary to consider the different operation items of the same tractor in a certain period of time, that is, the sum of the teams using a certain tractor in a certain stage should not exceed the maximum number of teams provided by the function. The general agricultural tools are not universal and cannot provide multiple operations in the same operation period. Therefore, when the agricultural tools are constrained, the sum of the use teams of agricultural tools should not exceed the total team of agricultural tools. Workload constraint, that is, each team completes the required amount of work within the specified time.

Then, establish the objective equation of the farm equipment of the Corps. The operating cost of agricultural machinery mainly includes fixed costs and variable costs, which can be obtained from the expression of the above farm operating costs.

$$S_{\min} = \sum \left(a_i X_i + b_j X_j + C_{mn} W_{mn} X_{mn} \right) \tag{17}$$

The annual fixed cost of farm operations includes the annual fixed cost of power machinery and the annual fixed cost of agricultural tools. Among them, the fixed cost of agricultural machinery and tools consists of depreciation expenses, management fees of agricultural machinery and tools, and fixed capital occupancy interest. The calculation expression is as follows:

$$\text{Annual fixed fee} = \text{Agricultural machinery purchase price} \times \begin{pmatrix} \text{Annual depreciation rate} + \\ \text{Annual management expenses} \\ + \text{Annual capital occupancy rate} \end{pmatrix} \tag{18}$$

$$\text{Annual fixed expenses after apportionment} = \text{Original fixed fee} \times \frac{\text{Annual farmland operations}}{\text{Annual total workload}}$$

In addition, the calculation expression of annual fixed cost is shown in the following formula.

$$\text{Annual fixed cost of agricultural tools} = \frac{\text{Farm tool price} - \text{Residual value}}{\text{Service life}} \tag{19}$$

According to the relevant survey of the Xinjiang Production and Construction Corps, the annual fixed occupancy rate of the Xinjiang Production and Construction Corps is 3.9%, the residual value of agricultural machinery is 10% of the purchase value, and the management fee rate of agricultural machinery is 2.4%. The useful life of most agricultural machinery is about 8 years. The fixed cost of farm machinery of the Xinjiang Production and Construction Corps can be obtained from formula (19) and formula (20) as shown in Table 2. It can be seen from the table that it mainly includes the prices and annual fixed costs of two tractors, sprayers, combined field preparation machines, cotton film planters, tomato planters, and cultivating fertilizer machines. In addition, the variable costs of farm operation units mainly include wages, fuel costs and maintenance costs.

Table 2

Fixed cost of farm machinery

Name of agricultural machinery	Price/yuan	Annual fixed fee/yuan
Dongfanghong LX2204	517000	84382
John Deere JD5-750	126000	20649
Sprayer	42000	4836
Combined soil preparation machine	38000	4386
Cotton film planter	28000	3260
Tomato planter	27000	3048
Cultivator fertilizer applicator	15000	564

RESULTS

According to the established optimization model of agricultural machinery and equipment in Xinjiang Production and Construction Corps, the corresponding optimization results of agricultural machinery and equipment are obtained. In the study of Xinjiang Production and Construction Corps equipment configuration, the main planting plants are tomato, cotton and corn, which account for 76.82% of the farm planting area of Xinjiang production and Construction Corps. Therefore, the number of general agricultural machinery and equipment needs to be divided by 0.7682 to get the number of agricultural machinery and equipment needed by Xinjiang Production and Construction Corps to grow all crops. The actual situation and optimization of agricultural machinery and equipment of Xinjiang Production and Construction Corps are shown in Table 3 and table 4.

Table 3

Comparison of actual equipped quantity and optimized equipped quantity of agricultural machinery

Name of agricultural machinery	Large tractor	Medium tractor	Sprayer	Combined soil preparation machine	Cotton planter	Tomato planter	Cultivator fertilizer applicator
Actual equipped quantity/set	186	528	120	102	148	36	123
Optimize the amount of equipment / Machine	35	51	34	35	37	16	44
Overweight/set	151	477	86	67	111	20	79
Overmatch rate/%	81.18	90.34	72	65.69	75	55.56	64.23

The comparison results of actual agricultural machinery and equipment and optimized equipment in Xinjiang production and construction corps farm are shown in Table 3. It can be seen from the table that the actual number of farm implements in Xinjiang Production and construction corps farm exceeds the number of optimized equipment. Among them, 186 large tractors are actually equipped and 35 are optimized. The actual equipment capacity exceeded the optimized equipment by 151 units, and the overstaffing rate was 81.18%. The actual capacity of medium tractors is 528, and the optimized equipment is 51. The actual equipment capacity exceeded the optimized equipment by 477, and the overstaffing rate was 90.34%. The actual number of sprayer sets is 120, the optimized equipment 34, the actual equipment 86, overshoot rate 71.67%. 65% of the actual number, and the actual number has been optimized. The actual configuration of 148 cotton machines, optimized configuration of 37 cotton machines, the actual configuration of more than 111 cotton machines, overrun rate of 75.0%. There are 36 tomato planters, 16 optimized pieces of equipment and more than 20 optimized pieces of equipment. The overstaffing rate was 55.56%. The actual configuration of the cultivator and fertilizer applicator is 123, the optimized equipment is 44, and the overweight/set is 79.

The over provision rate was 64.23%. From the optimization of the number of agricultural machinery and equipment, compared with the actual agricultural machinery and equipment, the number of optimized agricultural machinery and equipment is greatly reduced, which can effectively reduce the number of farm equipped with agricultural machinery, and then improve the matching rate of agricultural machinery and reduce the operating cost of agricultural machinery.

Table 4

Comparison of actual equipment and optimized equipment

Index	Actual equipment	Optimization Results	Growth rate/%
Power Machinery Equipped	714 units	83 units	-87.68
Agricultural machinery power	43700kW	10390kW	-76.22
Amount of farm tools	1143 units	237 units	-62.74
Annual total cost of mechanical operations	152.595 million	110.1016 million	-27.9
Operating cost per unit area	124.26 yuan/mu	89.59 yuan/mu	-27.9
Matching ratio of agricultural machinery	1:1.6	1:2.7	68.75

The comparison between the optimized agricultural machinery and the actual equipment of Xinjiang Production and Construction Corps is shown in Table 4. It can be seen from the table that the indicators include the number of power machinery, agricultural machinery power, the number of agricultural machinery equipment, the total cost of machinery operation in the whole year, the operating cost per unit area, the matching rate of agricultural machinery, etc. from the number of power machinery, the actual number of equipment is 714, and the optimized number of equipment is 83. The number of optimized equipment is 87.68% less than that of actual equipment, which indicates that the power machinery of Xinjiang Production and Construction Corps, including large and medium tractors, has a serious surplus of equipment, resulting in a serious waste of power. From the actual power of agricultural equipment, 103700kw is optimized. The optimized equipment is 76.22% less than the actual equipment. In terms of the number of agricultural equipment, the actual configuration is 1143, and the optimized configuration is 237. The number of optimized equipment is 62.74% less than that of actual equipment. From the total operating cost of mechanical equipment in the whole year, the actual operating cost is 15.2595 million yuan, and the optimized operating cost is 11.016 million yuan. The optimized equipment cost is 27.99% lower than the actual equipment cost. From the operating cost per unit area, the actual cost of the equipment is 124.26 yuan/mu, and the optimized equipment cost is 89.59 yuan/mu. The operating cost per unit area of the optimized equipment is 27.9% lower than the actual operating cost per unit area. The optimized agricultural machinery equipment increased by 68.75%. On the whole, the optimized proportion of agricultural machinery in the farm is better, and the operation cost of agricultural machinery is reduced on the basis of reducing the number of agricultural machines.

CONCLUSIONS

The most important thing to develop agricultural mechanization is to optimize agricultural machinery and equipment. In this study, the linear programming model and workload model are used to analyse the optimal allocation of agricultural machinery in Xinjiang Production and Construction Corps. By comparing the construction workload and equipment quantity of Xinjiang production and Construction Corps in actual production, the construction workload and equipment quantity of Xinjiang Production and Construction Corps are determined, and the optimized agricultural machinery and equipment are compared with the actual agricultural machinery and equipment. The results show that the model optimizes the power machinery, agricultural machinery equipment and machinery operation cost. Xinjiang Production and Construction Corps has a serious surplus of power machinery and equipment. The overrun rate of large tractors was 81.18%, and that of medium tractors was 90.34%. The allocation of agricultural machinery is unreasonable. After optimization, the matching rate of agricultural machinery increased from 1:1.6 to 1:2.7, and the total operation cost of the equipment yard was 27.9% lower than that of the actual equipment. The optimized equipment model has good optimization effect, improves the matching rate of agricultural machinery on the basis of reducing the number of agricultural machinery equipment, and effectively reduces the cost of agricultural machinery operation. This study verified the effectiveness of the optimized equipment model for the rational allocation of agricultural machinery model, but its wide applicability needs further study.

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