HARVESTING SCHEDULING OPERATIONS FOR THE MACHINERY OWNERS UNDER MULTI-FARMLAND, MULTI-TYPE SITUATION WITH TIME WINDOW --AN EMPIRICAL STUDY ARISING IN AGRICULTURAL CONTEXTS IN CHINA
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基于时间窗的多农机点、多农田作业点、 多机型的混合农机资源调度问题研究

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Abstract: *Harvesting scheduling operations and allocations are very important for the agricultural machinery owners and the farmers regarding to finish the harvesting work. Most of the machinery owners schedule their farm machinery by experience, which is a big waste of the agriculture resources. This paper is an attempt to schedule the agricultural machinery for the machinery resource centers under multi-farmland, multi-type machinery situation with time window constrain in order to maximize efficiency of resource utilization. A novel modelling method with improved genetic algorithm is presented. An empirical study of an agricultural machinery association in Hebei province in China is illustrated and the results show that the models and the scheduling algorithm proposed in this study can improve agricultural utilization of the farm machinery resource centers and reduce the costs of agricultural machinery usage.*

Keywords: *scheduling operations, agricultural machinery, time window，multi-type machinery*

INTRODUCTION

China, as one of the biggest agricultural countries in the world, has achieved rapid development, with high rates of agricultural mechanization and the continuous progress of agricultural modernization. As a result, there are more and more agricultural machinery cooperation organizations or agricultural machinery associations in China. However, Most of the machinery owners schedule their farm machinery by experience, which is a big waste of the agriculture resources, so harvesting scheduling operations and allocations are very important for the agricultural machinery owners and the farmers in order to finish the task of agricultural harvesting on time, as well as improve the utilization efficiency of agricultural machinery and reduce agricultural resource waste.

The paper is organized as follows. The next section is the literature review regarding the schedule operations. Following is the introduction of model for the agricultural machinery scheduling and routing problem for the machinery owners under multi-farmland, multi-type machinery situation with time window constrain. Section 4 illustrates an empirical study of an agricultural machinery association in Hebei province in China. Finally, the analysis results and the conclusions are discussed along with the related managerial implications.

The main concerns about the harvesting scheduling operations are the schedule for the agriculture machinery and the farmland. There have been increasing researches focused on the scheduling of the operations that are carried out when the crops are harvested.

摘要: *合理的农机资源调配方案，对顺利完成农田作业起着非常重要的作用。而在中国，绝大多数的农机主和农场主是按照经验进行农机资源的调度和安排，这无疑对有限的农机资源是一种浪费。本文在实地调研的基础之上，提出一种实际作业中经常会碰到的复杂问题，问题中同时考虑多农机点、多农田作业点、多机型及时间窗约束等因素。本文建立了考虑多农机点、多农田作业点、多机型及时间窗约束的混合农机资源调度数学规划模型，并提出一种改进的模糊遗传算法求解混合农机资源调度模型。本文所提出的模型具有较好的可解性，且算法具有较好的计算结果和计算效率。结合河北省某农机协会，展开初步的应用试验，实证研究的结果表明模型和算法能够实现农机的快速、最低成本调度，大幅提高了某农机组织的农机利用率，并降低农机利用成本。*

关键词: *混合资源调度安排，农业机械资源，时间窗，多种农机车型*

引言

中国作为世界农业大国之一，近年来随着中国农业机械化和农业现代化进程的持续推进，出现了越来越多的农机合作组织、农机专业服务组织、农机行业协会等组织形式。由于农业生产具有较强的时效性和连贯性，对于大范围的农业生产作业，需要对农机资源进行合理配置和有效调度。在中国，依然是农机主凭借经验对农机资源进行调度，这就造成了农机资源的极大浪费，尤其是在对农机资源需求较大的农产品收割时段。因此十分有必要针对中国的实际情况，对农机资源进行合理配置和有效调度，以按时完成农业生产任务，提高农机利用率，避免农作物损失和农机资源浪费。

本文的主要研究思路和论文结构如下：第一章介绍了本文的研究意义和研究背景，下一章对有关农机资源调度的相关文献进行了总结和分析，第三章主要进行了考虑多农机点、多农田作业点、多机型及时间窗约束等因素的混合农机资源调度的模型研究。第四章对河北省某农机协会进行了实证研究，最后，对本文所建立的模型及实证结果进行了分析，并探讨了该模型对农机协会的管理意义。

农机调度的本质是农业机械与农田的资源调度问题，农机调度问题对于农作物收获季农业资源的利用率十分重要。现在越来越多的文献关注了农机调度问题，在可查阅到的相关文献内，虽然不同国家的不同学者都对此问题进

Although this area of scheduling has been the focus of some research, solution techniques reported in the open literature appear to be applicable to different situations from that considered in the present paper [4-12，14,15].

Some of the literature referenced above deals with minimum time lags [1，3，12，13]. There is less literature available on the additional requirement of maximum time lags than there is on minimum time lags. The only exact procedure known to the authors was devised by Neumann and Zimmermann (2000), however it is not capable of solving problems of practical size in reasonable time. There also exist polynomial-time heuristics for solving the scheduling problems [2，11-13]. The last technique is based on a neural network model based on heuristic methods [4，10，16].

Few studies take into account both time factor and spatial factors, however, in agricultural operations, time factor and spatial factors are constraints which appear in the bound form of time period (time window) and network topology, causing difficult in building and solving the model of agricultural [15-17]. In this context, considering multi-agriculture machinery resource center, multi-farmland, multi-type and time window constraints, we establish the mathematical planning models and propose a modified fuzzy hybrid genetic algorithm to solve this kind of scheduling model.

MATERIAL AND METHOD

In this context, we study all farm machinery resources centralized deployment problems under an agricultural machinery association. The agriculture machinery resource refers to the different kinds of agriculture harvester. One agriculture harvester can be arranged to the other farmland after the work in one farmland only if the work in the first farmland is totally finished.

Distribution diagram of agriculture machinery scheduling is shown as follows:

行了研究，但是模型假设、模型的求解、资源配置等等存在的不同的解决方案[4-12，14,15]。

有些文献考虑了农机资源配置过程中的时间滞后性[1，3，12，13]。更多的文献假定最短时间滞后性，少量文献研究假设最长时间滞后性。Neumann 和 Zimmermann 的研究是为数不多的阐述了农机资源配置的程序的文献，但是在有限时间内解决实际农机资源调配问题仍存在一定的局限性。有一些文献应用启发式算法对该问题进行求解[2，11-13]。最近研究的较多的是基于神经网络的启发式算法来求解农机资源调度问题[4，10，16]。

但是在已有文献中很少综合考虑了时间因素和空间因素，而在农机作业中，时间因素和空间因素均是约束条件，而且以时间段(时间窗) 和网络拓扑的约束形式出现，这为农机调度模型的建立和求解增加了难度[15-17]。本研究同时考虑多农机点、多农田作业点、多机型及时间窗约束等因素，并建立相应的数学规划模型，提出一种改进的模糊遗传算法求解混合农机资源调度模型，通过改进的模糊逻辑控制器实现交叉概率和变异概率的动态调整，以加快算法的收敛速度，且能够有效的避免陷入局部最优解。

模型与方法

本文研究在一个农机组织下所有农机资源集中调配的问题，这里农机资源是指不同规格农业收割机。本文考虑农机在完成一个任务后，在时间和经济允许的前提下前往下一个任务点继续服务。但必须先完成当前农田作业点的全部任务，即不允许农机在作业过程中提前离开。

农机调配示意图如下：

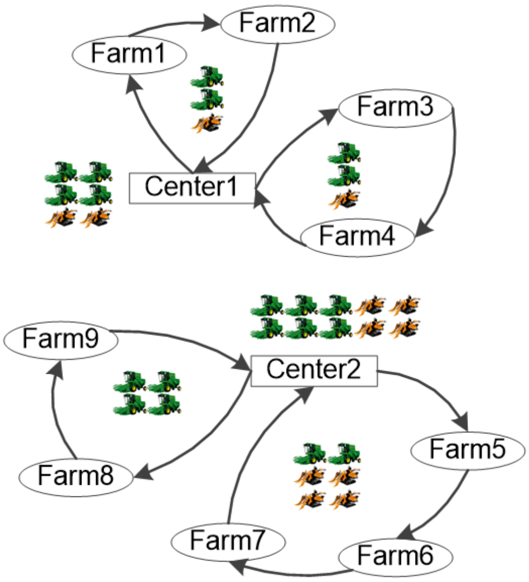

Fig. 1 – Distrubution diagram of agriculture machinery scheduling

The related assumptions are as follows:

(1)There are multiple agricultural machinery resource centers scattering in different position, and the farmland coordinates are known and fixed;

(2)Each agricultural machinery resource center has a

本模型作如下相关假设：

（1）在区域内具有多个分散在不同位置的农机点，且农机点的位置坐标已知且固定；

（2）每个农机点有一定数量的不同型号的农机装备，

certain number of different types of agricultural machinery and equipment, and the number and specifications (speed, fuel consumption, operation ability, etc.)of various types of agricultural machinery equipment are known and fixed;

(3) The farmland are in different positions, and each farmland has a certain number of different types of agricultural machinery equipment;

(4) The location, price, operating time window and the requirements pd agricultural machinery equipment, of each farmland are known and fixed;

(5) All distances between agricultural machinery resource centers and farmland are known, and there is no differences between each of the road;

(6) Take minimizing the farm machinery driving distance as a goal.

且各类型号农机装备的数量和规格（行驶速度、单位油耗、作业能力等）已知且固定；

（3）在区域内具有多个分散在不同位置的农田作业点，且每个农田作业点均需求一定量不同型号的农机装备；

（4）每个农田作业点的位置、作业价格、作业时间窗以及农机装备需求等参数均已知且固定；

（5）所有农机点和农田作业点之间的道路长度已知且固定，假设所有道路通行状况均相等，道路之间不存在任何差异；

（6）以最小化农机行驶总距离为目标。

Table 1

Explanations for the symbols in the modle

No.	Symbols	Explanation of symbols
1	I	The total number of the agriculture machinery resource centers，$i=1, \ldots, I$
2	J	The total number of the farmlands，$j=1, \ldots, J$
3	N	The sum of the number of the agriculture machinery resource centers and the number of the farmlands，$n=1, \ldots, N, N=I+J, i=1, \ldots, I$，$j=1, \ldots, J$
4	P	Types of the agriculture machinery，$p=1, \ldots, P$
5	M_{ip}	The number of *p type of* the agriculture machinery in agriculture machinery resource center i，$k=1, \ldots, M_{ip}$
6	Q_p	The capacity of the agriculture machinery p
7	A_j	The area of the farmland j，$j=1, \ldots, J$
8	C_j	The cost per unit area of farmland j，$j=1, \ldots, J$
9	$[tb_j, te_j]$	The time window for the farmland j，$j=1, \ldots, J$
10	d_{nn*}	The distance from center n to center $n*$，$n=1, \ldots, N, n*=1, \ldots, N$
11	v_p	The average speeds of the agriculture machinery p，$p=1, \ldots, P$
12	c_p	The unit mileage cost of the agriculture machinery p，$p=1, \ldots, P$
13	rd_j	The punishment cost for the late or early arrival for the farmland j，$j=1, \ldots, J$
14	TF_j	The operations time for the farmland j，$j=1, \ldots, J$
15	x_{iknn*}	decision variable，$x_{iknn*}=\begin{cases}1, & \text{the machinery } k \text{ of center } i \text{ from } n \text{ to } n* \\ 0, & others\end{cases}$， n=1, ⋯, N, n*=1, ⋯, N

The Eq.(1) refers to the objective function: transportation costs plus the operations costs plus the delay or early arrival punishment. The Eq.(2) refers to the numbers of the agriculture machinery constrain. The Eq.(3-5) refer to the requirements that all the farmland tasks must be finished on time. The Eq.(3-5) refer to the decision variable value constrain.

式(1)为模型的目标函数：农机行驶成本+农机作业成本+延迟或提早到达惩罚；式(2)为农机数量约束；式(3)为实际开始时间的计算公式；式(4)为实际结束时间的计算公式，式(3)和式(4)共同实现了农田作业点任务必须全部完成的约束；式(5)为所有农田作业点必须在规定时间之前完成任务；式(6)为决策变量取值范围约束。

$$\min Z=\sum_{i=1}^{I}\sum_{p=1}^{P}\sum_{k=1}^{M_p}\sum_{n*=1}^{N}\sum_{n=1}^{N}x_{ikpnn*}\cdot d_{nn*}\cdot c_p+\sum_{j=1}^{J}A_j\cdot C_j+\left|tb_j-TFb_j\right|\cdot rd_j \tag{1}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{M_p}\sum_{n*=1}^{N}\sum_{n=1}^{N}x_{ikpnn*}\le M_{ip}, i=1,\ldots,I, \tag{2}$$

$$TFb_j = \sum_{i=1}^{I}\sum_{k=1}^{M_p}\sum_{n=1}^{N} x_{ikpnj} \cdot \left(TFe_n + \frac{d_{nj}}{v_p} \right), j = 1, \ldots, J, \tag{3}$$

$$TFe_j = TFb_j + \frac{A_j}{\sum_{i=1}^{I}\sum_{k=1}^{M_p}\sum_{n^*=1}^{N}\sum_{n=1}^{N} x_{ikpnn^*} \cdot Q_p}, j = 1, \ldots, J, \tag{4}$$

$$TFe_j \le te_j, j = 1, \ldots, J, \tag{5}$$

$$x_{ikpnn^*} \in \{0,1\}. \tag{6}$$

This computation is followed by running Genetic Algorithm (GA) operations. Under the consideration of disadvantages of premature convergence and local optimal solutions of GA, an improved fuzzy genetic algorithm is proposed in this paper, the Selection retains the successful solutions, whereas crossover and mutation are included to try to diversify the remaining candidate solutions for the next generations. In the next step, the parameters of the GA are updated by an adaptive fuzzy logic controller to improve the algorithm’s performance. The newly adjusted parameters are then used in the next generation. This evolutionary process is repeated until a predefined number of generations is reached. The flow chart of fuzzy genetic algorithm is shown in Fig. 2

本文采用遗传算法（Genetic Algorithm, GA）进行求解。遗传算法作为一种快捷、简便、容错性强的算法，在各类优化问题中显出明显的优势。但遗传算法存在早熟收敛、陷入局部最优解等一些固有缺点。为了克服遗传算法的缺点，本文提出一种改进模糊遗传算法求解农机调配模型。选择操作用于更新种群，交叉和变异用于生成新的染色体。在算法迭代过程中，通过模糊逻辑控制器动态调整交叉概率和变异概率，从而避免早熟收敛并提高收敛速度。根据当前种群的最佳适应度、平均适应度和待交叉、待变异个体适应度之间的关系，来控制交叉概率和变异概率。模糊遗传算法的流程图如图 2 所示：

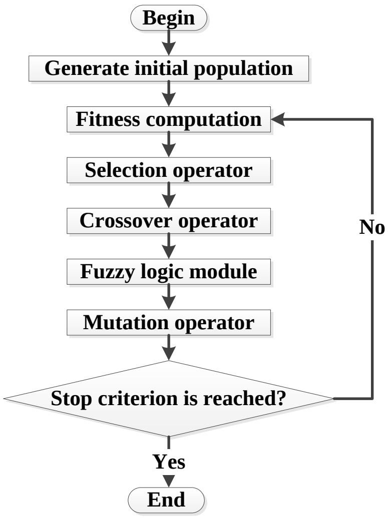

Fig. 2 –The flow chart of fuzzy logic genetic algorithm

(1) Encoding.

Traditionally, a chromosome is a sequence of binary digits, which represents a solution in the problem domain. The bits of the chromosome are referred to as its genes and are mapped to parts of a solution. Binary digit encoding method is used in this paper. There is an example that includes two centers and ten farmlands, and the binary digit encoding of this example is shown in Fig. 3.

（1）编码

传统上，一条染色体是一个二进制数字序列，代表在问题领域的一种解答。染色体的位是它的基因，对应与解决方案的一部分。本文使用了二进制数字编码方法。有一个包括两家农机点和十个农场作业点的例子，这个例子的二进制数字编码如图 3 所示。

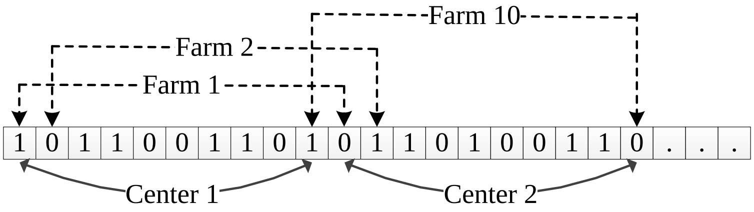

Fig. 3 – Binary digit encoding

(2) Fitness function.

Usually, the reciprocal of objective function is chose as fitness function. But the fitness value will be small and can't be adjust. And the difference of fitness value in different problems is greatly.

(3) Selection operator

Binary tournament selection: In this selection process, two individuals are selected at random from the population and the fittest one is selected for reproduction.

(4) Crossover operator

Order crossover operator (OX): The order crossover operator is designed for order-based permutation problems. Two crossover points are randomly selected and the segment between them is copied to the offspring from the first parent. Starting from the second crossover point in the second parent, copy the elements to the offspring in the order they appear in the second parent, avoiding repetition. The second offspring is created in the same way, reversing the roles of the parents. The steps are shown in Fig. 4 and 5.

（2）适应度函数

通常情况下，目标函数的倒数会作为适应度函数被选择。并且适应度值比较低，且不能调整。不同问题中的适应度值差别非常大。

（3）选择方案

二进制比赛选择：在这个选择过程中，从总量中随机选择两个个体，最合适的那个被选出来用于再交叉。

（4）交叉算子

顺序交叉算子（牛）：顺序交叉算子是用来解决订单排序问题的。两个跨界点是随机选择的，并且它们之间的部分是从第一批复制到后代的。从第二父母的第二个交叉点开始，按照在第二父母中出现的顺序复制到后代中，避免了重复。以相同的方式创建了第二个后代，扭转了父母的角色。步骤如图 4 和 5 所示。

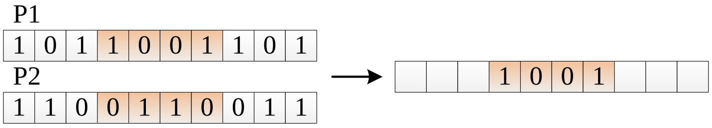

Fig. 4 – Crossover operator

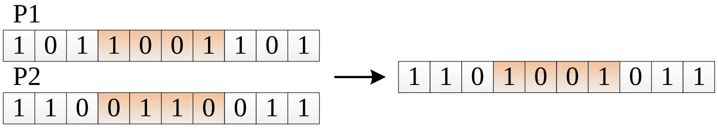

Fig. 5 – Crossover operator

(5) Mutation operator

Invert mutation: This operator works by randomly selecting two positions in the string and reversing the order in which the values appear between those positions (Fig. 6).

（5）变异算子

反转突变： 此运算符的工作原理是随机选择两个字符串中的位置并扭转这些位置之间的值的显示的顺序（图 6）。

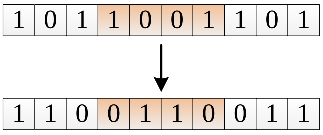

Fig. 6 – Mutation operator

In this context, we propose a fuzzy logic rule according to the chromosome fitness value and the population average fitness value variation. F is the fitness value of current chromosome. $\overline{F_r}$ is the average fitness value of chromosomes of generation r's population. $F_{\max}$ is the fitness value of the best chromosome in current population. $F_{\min}$ is the fitness value of the worst chromosome in current population. The output parameter is the mutation probability, and the input parameters are shown in table 2.

本文提出一种根据染色体适应度值及种群平均适应度值调节变异（mutation）概率的模糊逻辑规则。F 是当前染色体的适应度值。$\overline{F_r}$ 是在当前人口的染色体适应度的平均值。$F_{\max}$ 是当前人口中最好染色体的适应度值。$F_{\min}$ 是当前人口中最坏染色体的适应度值。输出的参数是变异的概率，输入的参数如表 2 所示。

Table 2

Input parameters of fuzzy logic module

Input parameter	**Parameter explanation**
$\Delta\overline{F}$	$\Delta\overline{F}=\frac{\left(\overline{F_r}-\overline{F_{r-1}}\right)}{\overline{F_{r-1}}}$, $\Delta\overline{F}\in[0,1]$, $r>1$

Input parameter	Parameter explanation
α	$\alpha = \frac{(F_{\max} - F)}{(F_{\max} - F_{\min})}$, $\alpha \in [0,1]$

There are nine sematic values in the fuzzy logic module, which ES means extremely small, VS means very small, S means small, RS means relatively small, M means medium, RL means relatively lager, L means lager, VL means very lager and EL means extremely lager. The triangle membership function is used in this paper. According to the sematic value and triangle membership function, we can get the graphic of membership function as shown in Fig. 7.

在模糊逻辑模块有 9 个语义值,ES 意味着极其微小,VS 意味着非常小,S 意味着小,RS 手段相对较小,M 意味着中间,RL 意味着相对大,L 意味着大,六世意味着非常大和 EL 意味着极其大。本文采用三角形的隶属函数。根据语义值和三角形隶属函数，我们可以得到如图 7 所示的隶属函数的图形。

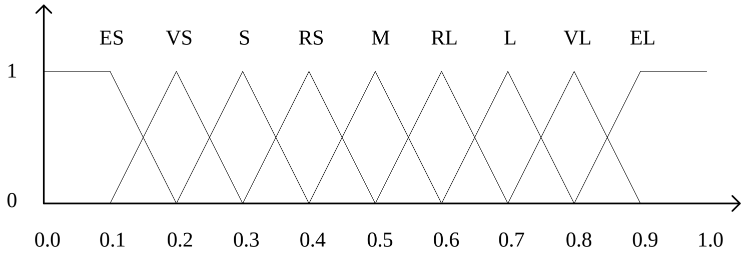

Fig. 7 – The membership function graphic of input and output parameter

According to the fuzzy logic and the membership, we can get the fuzzy logic rules as shown in table 3.

根据模糊逻辑与会员资格，我们可以得到模糊逻辑规则，如表 3 所示。

Table 3

The fuzzy logic rules of mutation probability

γ / $\Delta\overline{F}(t)$	ES	VS	S	RS	M	RL	L	VL	EL
ES	M	RL	RL	L	L	VL	VL	EL	EL
VS	RS	M	RL	RL	L	L	VL	VL	EL
S	RS	RS	M	RL	RL	L	L	VL	VL
RS	S	RS	RS	M	RL	RL	L	L	VL
M	S	S	RS	RS	M	RL	RL	L	L
RL	VS	S	S	RS	RS	M	RL	RL	L
L	VS	VS	S	S	RS	RS	M	RL	RL
VL	ES	VS	VS	S	S	RS	RS	M	RL
EL	ES	ES	VS	VS	S	S	RS	RS	M

RESULTS

An empirical study of an agricultural machinery association in recent five years schedule in Hebei province in China is illustrated. The situations of this asscociation is as follows: there are five agricultural machinery resource centers, and there are 6-10 large-size, medium-size and small-size harvesters in each resource center. There are 9 farmlands (131 thousand mu)in 2010 and 13 farmlands (164 thousand mu)in 2014. The time peirod for harvesting is twelve days. The cost for harvesting is recorded according to the actual values. We compare the actual costs with the optimized costs in recent five years, and the results are shown in Table 4.

结果

结合河北省某大型农机组织近 5 年的收割作业，开展模型的试验和应用。实证分析的基本情况为：该农机组织下设 5 个农机点，每个农机点拥有 6~10 部大、中、小型收割农机；收割作业覆盖的农田作业点有从 2010 年的 9 块增长到 2014 年的 13 块，覆盖面积从 2010 年的 13.1 万亩增长到 2014 年的 16.4 万亩。要求在 12 天之前，将所有农田收割完毕。为了便于对比，每亩单位收割成本等相关费用按当年实际数值计算。将近五年的收割成本与优化后的结果进行对比，对比结果见表 4。

Table 4

The empirical study results

Year	Area (mu)	Costs		Cost reduction（%）
		actual costs	optimized costs	
2010	13.1	1420.5	1253.7	11.74
2011	14.7	1524.4	1337.7	12.25

Year	Area (mu)	Costs		Cost reduction（%）
		actual costs	optimized costs	
2012	15.6	1588.1	1405.6	11.49
2013	15.9	1578.8	1386.5	12.18
2014	16.4	1676.8	1451.4	13.44
Average	15.14	1557.7	1366.9	12.22

CONCLUSIONS

This paper is an attempt to schedule the agricultural machinery for the machinery resource centers under multi-farmland, multi-type machinery situation with time window in order to maximize efficiency of resource utilization. A fuzzy logic genetic algorithm is presented to solve this model. An empirical study of an agricultural machinery association in Hebei province in China is illustrated and the results show that the models and the scheduling algorithm proposed in this study can improve agricultural utilization of the farm machinery organizations and reduce the cost of agricultural machinery cost as high as 1980 thousand RMB per year, which accounts for 12.22 percents.

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REFERENCES

[1]. Bartusch, M., Moehring, R., Radermacher, F. (1988) – *Scheduling project networks with resource constraints and time windows.* Annals of Operations Research, Volume 16, p.: 201–240;

[2]. Brinkmann, K., Neumann, K. (1996) – *Heuristics procedures for resource-constrained project scheduling with minimum and maximum time lags: the minimum project-duration and resource levelling problems.* Journal of Decision Systems, Volume 5, p.:129–155;

[3]. Brucker, P., Drexl, A., Moehring, R., Neumann, K., Pesch, E.(1999) – *Resource-constrained project scheduling: notation, classification, models, and methods.* European Journal of Operational Research, Volume 112, p.:3–41;

[4]. Harris, R. (1990) – Packing method for resource levelling. Journal of Construction and Engineering and Management, Volume 116, p.:331–350;

[5]. Hu, Z. (2014) – *A green reaping farm machine scheduling model.* ACTA Agriculturae Shanghai, Volume 30, Issue 6, p.:133-135;

[6]. Kirkby, M. W., Wong, P., Hager, W. A., Huddleston, M. E. (1980) – *A guide to the integrated resources planning model.* Berkeley, CA: ASDA Forest Service;

[7]. Manley, B. R., Threadgill, J. A., Wakelin, S. J., (1991) – *Application of FOLPI: a linear programming-based forest estate model.* Bulletin 164, Rotorua, New Zealand: Forest Research Institute;

[8]. McNaughton, A.J., (1995) – *Forest harvesting with catchment constraints.* In Proceedings of the 31st Annual Conference, Operational Research Society of New Zealand, Victoria University of Wellington, Wellington, New Zealand;

[9]. McNaughton, A. J., Ronnqvist, M., Ryan, D. M., (1998) – *The scheduling of forest harvesting with*

结论

本文建立了考虑多农机点、多农田作业点、多机型及时间窗约束的混合农机资源调度数学规划模型，并提出一种改进的模糊遗传算法求解混合农机资源调度模型。并对河北省某农机协会进行了实证研究，从实证分析结果能够看出，本文所提出的模型具有较好的可解性，且算法具有较好的计算结果和计算效率。本文设计的农机调度模型，平均每年能够为该农机组织节约资金额度达 190.8 万元，节约资金比例达 12.22%。因此，本文的模型和方法具有非常高的应用推广价值。

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参考文献

[1]. Bartusch, M., Moehring, R., Radermacher, F. (1988) – *基于资源约束和时间窗口约束的调度方案网络模型*，运营管理年刊，第 16 卷，201–240；

[2]. Brinkmann, K., Neumann, K. (1996) – *对于资源受限型项目在最大和最小时间迟滞平衡方面的创新性设计：最小项目工期和资源均衡问题研究*，决策系统研究，第 5 卷，129 –155；

[3]. Brucker, P., Drexl, A., Moehring, R., Neumann, K., Pesch, E. (1999) – *资源受限项目优化：定义，分类，模型，和方法*，欧洲运筹学，第 112 卷， 3–41；

[4]. Harris, R. (1990) – *基于定量装箱法的优化资源分配*，工程建设与管理，第 116 卷， 331–350；

[5]. 胡志文. (2014) – *绿色收割农机调度模型*，上海农业学报，第 30 卷，第 6 期，133-135；

[6].Kirkby, M. W., Wong, P., Hager, W. A.,Huddleston, M. E. (1980) – *一种集成资源模型设计*，CA: ASDA 林业局；

[7]. Manley, B. R., Threadgill, J. A., Wakelin, S. J., (1991) – *FOLPI 模型应用：一种基于线性规划的森林地产模型*，164 号公告，Rotorua，新西兰森林研究所；

[8]. McNaughton, A.J. (1995) – *不同流域森林的采伐限制*，*新西兰运筹学会*，第 31 届年度会议期刊，惠灵顿维多利亚大学，惠灵顿，新西兰；

[9]. McNaughton, A. J., Ronnqvist, M., Ryan, D. M., (1998) –

adjacency constraints. In Proceedings of the 33rd Annual Conference. Operational Research Society of New Zealand, The University of Auckland, Auckland, New Zealand;

[10]. Moder, J., Phillips, C., Davis, E. (1983) –*Project management with CPM, PERT and project diagramming.* New York, USA: Van Nostrand Reinhold;

[11]. Neumann, K., Zhan, J. (1995) – *Heuristics for the minimum projectduration problem with minimum and maximum time lags under fixed resource-constraints.* Journal of Intelligent Manufacturing,Volume 6, p.:145–154;

[12]. Neumann, K., Zimmermann, J. (1999a) –*Methods for resourceconstrained project scheduling with regular and nonregular objective functions and schedule-dependent time windows.* In J. Weglarz (Ed.), Project scheduling: Recent models, algorithms, and applications (pg. 261–287). Boston, USA: Kluwer;

[13]. Neumann, K., Zimmermann, J. (1999b) –*Resource levelling for projects with schedule-dependent time windows.* European Journal of Operational Research, Volume117, p.: 591–605;

[14]. Neumann, K., Zimmermann, J. (2000) – *Procedures for resource levelling and net present value problems in project scheduling general temporal and resource constraints.* European Journal of Operational Research, Volume 118, p.:591–605;

[15]. Sessions, J., Sessions, J. B., (1991) –*Tactical harvest planning using SNAP 2.03.* In Proceedings of the Conference of the International Union of Forestry Research;

[16]. Takamoto, M., Yamada, N., Kobayashi, Y., Nonaka, H. (1995) –*Zero-one quadratic programming algorithm for resource levelling of manufacturing process schedules.* Systems and Computers in Japan, Volume 26, p.: 68–76;

[17]. Weintraub, A., Barahona, F., Epstein, R. (1994) –*A column generating algorithmfor solving general forest planning problems with adjacency constraints.* Forest Science, Volume 40, p.:142–161.

相邻森林区块采伐限制的优化调整，第33届年度会议期刊，新西兰运筹学学会，Auckland大学，奥克兰，新西兰；

[10]. Moder, J., Phillips, C., Davis, E. (1983) – *基于CPM，统筹学和项目图解法的项目管理*，纽约，美国：Van Nostrand Reinhold；

[11]. Neumann, K., Zhan, J. (1995) – *采用固定资源约束下的最小和最大时间迟滞法优化最小工期问题的算法*，智能制造，第6卷，145–154；

[12]. Neumann, K., Zimmermann, J. (1999a) –*基于正则和非正则目标函数和时间调度窗口方法的资源受限项目调度方法*，项目调度：最近的模型，算法，和应用，261–287，波士顿，美国：Kluwer；

[13]. Neumann, K., Zimmermann, J. (1999b) –*基于计划依赖性时间窗方法的项目资源平衡研究*，运筹学（欧洲），第117卷， 591–605；

[14]. Neumann, K., Zimmermann, J. (2000) – *在项目总时间和资源约束情况下关于资源平衡和净现值问题的优化设计*，欧洲运筹学，第118卷， 591–605；

[15]. Sessions, J., Sessions, J. B., (1991) – *基于SNAP 2.03设计采伐计划设计*，国际林业研究会会议期刊；

[16]. Takamoto, M., Yamada, N., Kobayashi, Y.,Nonaka, H. (1995) – *基于0-1二次规划算法的资源均衡法制造工艺方案*，系统和计算机（日本），第26卷， 68–76；

[17]. Weintraub, A., Barahona, F., Epstein, R. (1994) – *通过邻接约束法研究列生成算法解决一般的森林规划问题*，森林科学，第40卷， 142–161.