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Wheat harvest schedule model for agricultural machinery cooperatives considering fragmental farmlands

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ABSTRACT

For wheat harvesting considering fragmental farmlands, traditional wheat harvest scheduling based on large-scale arable lands is unfavorable in China. Combine-harvesters, owned by agricultural machinery cooperatives, need new harvesting models for fragmental farmlands. This paper provided an operational model to determine the optimal combine-harvesters' scheduling for fragmental farmlands. The objective function is to minimize the wheat harvesting period. The minimal difference of harvesting time among combine-harvesters is considered as constraint. A hybrid tabu search approach is proposed to identify the optimal schedule that achieves the objectives of minimizing the harvesting period and minimizing the differences of harvesting time among combine-harvesters. Real data are collected from Huaguang village, Tangji town, Huaiyuan district, Anhui province, China, which is a typical grain producing region. The model results indicate that the wheat harvesting period can be reduced by approximately 10% and that the efficiency and fairness among different harvester owners can be improved if the model and algorithm proposed in this paper are applied.

1. Introduction

In China, fragmental farmlands are cultivated based on a household contract responsibility system in rural areas. The organizational form of fragmental farmlands is collective ownership. The area per capita of fragmental farmlands is decided by the number of collectives and arable land. The average area per capita of fragmental farmlands is 0.364 acre in Anhui province (Anhui Statistical Yearbook, 2015). The average family size is 3.08 people in Anhui province (China Statistical Yearbook, 2015). Each family contract fragmental farmlands is 1.119 acre. On the other hand, the agricultural income of rural residents is 6274.94 *yuan* in Anhui province (Anhui Statistical Yearbook, 2015). The price of combine-harvester is approximately 80,000 *yuan*, which is hardly afforded by a common household because the contract area for each household is not worth the price. Combine-harvester owners usually organized agricultural machinery cooperatives to harvest the wheat according to the schedule in rural areas in Anhui province.

The scheduling of agricultural machinery was first introduced by van Elderen (1980). Since then, the researchers have focused on improving the harvesting operation procedures. Foulds and Wilson (2005) developed an effective method for combine-harvester's harvesting routing. Ali et al. (2009) studied agricultural machinery routing in a field. Those studies focused on agricultural machinery routing on a piece of large arable land, as in American or Europe. The minimal distance of agricultural machinery is objective. Those studies do not suit wheat harvesting in Anhui province, China. The first reason is that the wheat harvesting period needs to be reduced because the rice yield is significantly influenced by the planting time (Pattar et al., 2001). The paper identified the minimal wheat harvesting period as the objective. The second reason is that the area of each piece of fragmental farmlands is small (the area of each piece of fragmental farmlands is 0.296 acre based on the case study in Huaguang village). Agricultural machinery harvest routing suits only planting regions whose area is large in previous studies. Our study focuses on the wheat harvesting of fragmental farmlands in China.

The agricultural machinery scheduling problem has been widely researched (Bakhtiari et al., 2013; Li and Ye, 2013; Ferrer et al., 2008; Carpente et al., 2010). Bochtis et al. (2013b) proposed a flow-shop problem formulation to solve the biomass collection operations. Biomass was collected by a number of geographically dispersed fields. Bochtis et al. (2014) reviewed agricultural machinery management which job shop scheduling problem (JSSP) and flow shop scheduling problem (FSSP) was contained. Those studies focused on neither minimal combine-harvester' harvesting times nor such case in China and neglected minimizing the differences in harvesting time of different combine-harvesters. The profits of combine-harvester owners are decided by the harvesting time. The gap in different harvesting times is significant because the scheduling scheme is designed by agricultural

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machinery cooperatives based on the previous experience. Unreasonable schemes for combine-harvesters mean that combine-harvester owners produce an improper psychology and influence on the work order. The injustice ultimately leads to increases in the wheat harvesting period.

The maturity date of wheat is fixed in all regions in our study area. The maturity date is generally in early June. Rice is planted after finishing wheat harvesting period. Rice planting times are affected by the length of the wheat harvesting period. Combine-harvesters' task is scheduled by agricultural machinery cooperatives, with all decisions decided by experience. Experience scheduling increases the wheat harvesting period and creates poor team coordination. Rice planting times are delayed and the rice yield decreases (Pattar et al., 2001) due to experience harvest scheduling.

In this paper, we proposed an integer programming combine-harvester scheduling model based on the middle and lower reaches of the Yangtze River. The objective of this model is a minimal harvesting period. Seven constraints are considered. To demonstrate the applicability of the proposed model, here we consider a case study based on the five production teams in Huaguang village, which is located in Huaiyuan district in Anhui province. Fragmental farmlands (442.963 acre) are considered in the model. The optimal schedule for combine-harvesters requires that the wheat harvesting period is minimized, and that the difference in harvesting times among combine-harvesters is minimized.

The remainder of this paper is organized as follows. The literature review of related topics is presented in Section 2. Section 3 proposes the case study location and background. The problem statement and operational model are proposed in Section 4. Section 5 develops the hybrid algorithm for the operational model. In Section 6, a real case is developed and analyzed to demonstrate the validity of the model and the algorithm. In Section 7, conclusions and future research regarding this problem are discussed.

2. Literature review

The research on agricultural production scheduling has played a key role in improving agricultural production efficiency and agricultural economic development (Hernandez et al., 2014; Borodin et al., 2014; Tan and Çömden, 2012; Ortuño and Vitoriano, 2011). Bohle et al. (2010) studied the wine grape harvest scheduling problem. The robust optimization approach was adopted to optimize the harvest scheduling problem because there were many uncertain factors (such as weather and maturity). We reviewed the crop harvest scheduling problems including production scheduling. At present, many of the studies focused on agricultural economic crops with production operation like sugar cane (Thuankaewsing et al., 2015; Jiao et al., 2005), forest management (Dong et al., 2015), soybean and rape seed (Schöffel et al., 2015; Foulds and Wilson, 2005). Kusumastuti et al. (2016) reviewed crop-related harvest and processed planning. Related papers on agricultural harvest scheduling in recent years are listed in Kusumastuti et al. (2016). Hypothetical models have been widely researched for the harvest scheduling of agricultural economic crops; conversely, case studies are quite less. Edwards et al. (2015) obtained the optimal scheduling for agricultural harvesting and cultivation by a tabu search. Stray et al. (2012) developed a decision support system (DSS) for sugarcane harvest scheduling in South Africa. The operational results of DSS indicated that the DSS can improve the production efficiency and profits. The vehicle routing problem (VRP) was applied to optimize the process of production and harvest in most of the above-mentioned studies. The focus has rarely been placed on agricultural commodities, such as wheat and rice.

In Europe and America, each piece of arable land area is relatively larger than that in China because the population density is small. The planting patterns in American and Europe are significantly different from those of China. Most research has focused on the combine-harvester routing of large-scale arable land. Bochtis et al. (2014) reviewed agricultural machinery management applying intelligent machines and autonomous vehicles' route and harvest scheduling. Bochtis et al. (2012) designed a decision support system to optimize route planning in terms of a minimized risk for soil compaction for agricultural vehicles carrying time-dependent loads. Bochtis et al. (2010) designed path planning for in-field navigation, aiding to improve a combine-harvester's route and harvesting efficiency. Bochtis and Sørensen (2010) combined VRP and operational fields that contained harvesting and cultivation to plan more effective machine routes in large-scale arable land. The above research focused on machines' cultivation routes in the field, while our study focused on assigning harvesting task for agricultural machines or the combine-harvester task assigning problem, which is different from normal VRP, and it is a variant of production scheduling.

Many researchers have proposed a linear programming model for combinatorial optimization in agricultural (dos Santos et al., 2011; Aleotti et al., 1997). Annetts and Audsley (2002) proposed a model maximizing net profits and minimizing environmental impact for farm planning. Maatman et al. (2002) developed a two-stage stochastic programming model based on uncertainty factors, such as weather.

The combinatorial optimization problem can be solved by a heuristic algorithm when the mathematic is complex in agricultural research (dos Santos et al., 2011; Blanco et al., 2009). In the study of agricultural harvest scheduling, sugarcane harvest scheduling was solved by a tabu search in Stray et al. (2012). Bakhtiari et al. (2013) adopted ant colony optimization to solve the harvest scheduling model. A heuristic algorithm found the optimal result in complex systems in many other works (Li et al., 2014, 2013). Those works inspired the design of the heuristic algorithm in our paper.

Research on optimized agricultural cultivation machine scheduling can improve farm profits and production efficiency based on the results of existing literature. However, wheat harvest scheduling in Chinese case (each piece of fragmental farmlands' area is small and land is controlled by smallholder farmers) is seldom touched. This paper presents an operational model for this problem and designs an algorithm to calculate the model.

3. Study location and background

In China, wheat is the second largest grain crop. Wheat acreage is approximately 24,069 thousand hectares (China Statistical Yearbook, 2015). In addition, the local government has developed improvements to agricultural production and production efficiency.

To the middle and lower reaches of the Yangtze River, Huaguang village (116.982–116.965° E and 32.810–32.819° N) (see Fig. 1), geographically belongs to Huaiyuan district. The village is flat, and rice is planted when wheat is totally harvested in the summer.

We selected five production teams (Xinzhuang, Qianqiao, Qingniandui, Houqiao, Jianghe) as the research object in south Huaguang village. The five production teams and their arable land, population, lands per farmer, quantity of household and lands per household were collected from investigations (see Table 1). Based on the collective ownership of rural land, every family obtains a randomly small area of fragmental farmlands (average area is 0.296 acre) to assign fragmental farmlands more fairly. All wheat was harvested by 12 sets of combine-harvesters belonging to the same type. All fragmental farmlands were designed to be divided into regions whose area was different. The regions were numbered (see Fig. 2). Each household has more than one piece of fragmental farmland because of the land contract policy in China. Farmers need to wait to harvest fragmental farmlands when adjacent fragmental farmland is being harvested by a combine-harvester. As show in Fig. 3, number 1 indicates that this fragmental farmland has been harvested, number 2 indicates that the fragmental farmland is harvesting, numbers 3 and 4 indicate that the fragmental farmland is waiting for harvesting. The farmland which is