A TWO-PHASE METAHEURISTIC FOR FARM WORK SCHEDULING

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Abstract: This paper proposes a two-phase metaheuristic approach to planning daily farm work for agriculture production corporations. The two-phase metaheuristic contains the optimization of resources assignment and searching schedule based on Genetic Algorithm and hybrid Petri nets model. In the experiment, the effect on optimizing the resource assignment and priority list, initializing population of GA with sorted chromosomes by waiting time, inheriting priority list from tasks in the previous resources assignment enhanced the evolutionary speed and solution quality. The computational experiment revealed high effectiveness for constructing farm work schedule with high ratio of resource utilization. The proposed approach also contributes a referential scheme for combining metaheuristic to solve scheduling problem under constraints.

Keywords: farm work planning, scheduling, metaheuristic simulated annealing, genetic algorithm, hybrid Petri nets, modeling, sugarcane

1. INTRODUCTION

In Japan, there are over 190,000 management units serving as farmers/agricultural production corporations (The Ministry of Agriculture, Japan, 2006), which lease and manage the geographically scattered farmlands with full mechanization in order to accomplish the low-cost and high-efficient cultivation in the corporation style. For these agricultural production corporations, an adequate farm work planning system may guide them to carry out farm work in an organized and planned manner for efficient management. However, constructing an optimum farm work plan is difficult for farmers in these corporations, because that making a rational schedule requires not only traditional experiences but also mathematical and statistical approaches.

In agriculture, some methods for farm work planning presented valuable references (Arjona et al., 2001; Daikoku, 2005; Haffar and Khoury, 1992; Nanseki, 1998; Tsai et al., 1987; Santiago et al., 2005; Suliman, 2000) have been developed. Astika et al. (1999) also proposed a stochastic farm work scheduling algorithm based on short range weather variation. These researches are usually designed for a specific farm work problem, especially unsuitable for the daily schedule of entire growth cycle for assigning necessary resources to field operations for geographically dispersed farms.

An integration farm work management has been developed for sugarcane production in Okinawa, south of Japan. It comprises farm data recording system (Guan et al., 2006), web-based management system, modeling (Guan et al., 2008) and scheduling system. In which farm data recording system serves indicating daily work schedule, recording daily farm work progress, changes of cancellation of work, machine breakdown and so on. Web-based management system provides a platform for maintenance of database and outputting analysis report. Modeling system models farm work flow and uncertainty into mathematical data, and acts a simulation tool for mastering overall status of farm work progress and resources. Farm work scheduling system plays most important role of providing workers with appropriate daily work schedule.

In this study, we propose a two-phase metaheuristic for farm work scheduling with uncertain resources and constraints. At the first phase, the resource assignment was optimized using simulated annealing (SA) algorithm; and at the second phase, the optimization is based on genetic algorithm (GA), which searches the optimal schedule according to firing rules of hybrid Petri nets (David and Alla, 2001). The study is applicable to address the problem of production scheduling with arbitrary idle time, processing time, supplement or cancellation of work, cooperative work, moving time of machinery, machinery breakdown.

2. PROBLEM DEFINITION AND FORMULATION

2.1 Constraints in practical farm work

For each farmland in an agricultural production corporation, there are a series of works from work of planting to harvesting in a crop growth cycle. Many farm machineries and workers are available for corresponding work. In order to more theoretically describe conditions in practical farm work, we designate N_F, N_W, N_R as the total number of farmlands, works in a crop growth cycle, and resources, respectively. Other notations and their description are listed in Table 1. Notice that m_{ij} represents amount of scheduled work W_j in F_i. W_j will be scheduled if $m_{ij} > 0$, otherwise, this work will be not performed in F_i.

Table 1. Definition of variables

Notation	Definition
F_i	Farmland $i, i \in \{1,\dots,N_F\}$
W_j	Work j, $j \in \{1,\dots,N_W\}$
R_k	Resource $k, k \in \{1,\dots,N_R\}$
A_i	Area of F_i
m_{ij}	Amount of scheduled work W_j in F_i, $m_{ij} \in [0, A_i]$
S_{jk}	$S_{jk} \in \{0,1\}$, 1: R_k is available to perform W_j, otherwise, 0
S'_{jk}	$S'_{jk} \in \{0,1\}$, 1: R_k is scheduled to perform W_j, otherwise, 0
v_k	Working speed of R_k
W_{ij}	Waiting time between end time of W_{j-1} and start time of W_j in F_i
$P_j(s), P_j(e)$	Pre-defined work period [start time $P_j(s)$, end time $P_j(e)$] for W_j
T_{ijk}	Task performed in F_i by R_k, for W_j
$t_{ij}^{R_k}(s), t_{ij}^{R_k}(e)$	Start (end) working time of work j in F_i by R_k
v'_k	Moving speed of R_k
D_{ab}	Distance between F_a and F_b, $a,b \in \{1,\dots,N_F\}$

A resource assignment must guarantee that at least one resource is assigned to perform W_k, and the total number of assigned resources is less than $\sum_k S_{jk}$, that is the total number of resources available to perform W_k. "A resource" is defined as a set of the minimum necessary machinery and labor for the farm work, not as an individual resource. If more than two resources are assigned to a same work k ($\sum_k S'_{jk} > 1$), it is possible to perform cooperative work. The cooperative farming work is defined as a process where multiple machines perform the same work, and the entry time of a resource to perform cooperative farming work is arbitrary.

$$1 \le \sum_k S'_{jk} \le \sum_k S_{jk} \qquad (1)$$

The amount of scheduled work m_{ij} are completed by certain resources R_k during $t_{ij}^{R_k}(s)$ and $t_{ij}^{R_k}(e)$ on working speed v_k . For any resource allocation scheme, the following equations exist:

$$\begin{bmatrix} t_{1j}^{R_1}(e)-t_{1j}^{R_1}(s) & t_{1j}^{R_2}(e)-t_{1j}^{R_2}(s) & \cdots & t_{1j}^{R_k}(e)-t_{1j}^{R_k}(s) \\ t_{2j}^{R_1}(e)-t_{2j}^{R_1}(s) & t_{2j}^{R_2}(e)-t_{2j}^{R_2}(s) & \cdots & t_{2j}^{R_k}(e)-t_{1j}^{R_k}(s) \\ & \vdots & & \\ t_{ij}^{R_1}(e)-t_{ij}^{R_1}(s) & t_{ij}^{R_2}(e)-t_{ij}^{R_2}(s) & \cdots & t_{ij}^{R_k}(e)-t_{ij}^{R_k}(s) \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_k \end{bmatrix} = \begin{bmatrix} m_{1j} \\ m_{2j} \\ \vdots \\ m_{ij} \end{bmatrix} \qquad (2)$$

To avoid the superposition of durations $\left[t_{ij}^{R_k}(s), t_{ij}^{R_k}(e)\right]$ and $\left[t_{pq}^{R_k}(s), t_{pq}^{R_k}(e)\right]$ $(p \in \{1,...,N_F\},\ \ q \in \{1,...,N_W\})$, we have the following conditions:

$$\forall i,j,p,q,k, t_{ij}^{R_k}(s) < t_{ij}^{R_k}(e)$$

$$t_{ij}^{R_k}(e) < t_{pq}^{R_k}(s) \cdots \text{if } t_{ij}^{R_k}(s) < t_{pq}^{R_k}(s)$$

(3)

For the purpose of timeliness work, start working time $t_{ij}^{R_k}(s)$ and end working time $t_{ij}^{R_k}(e)$ suffer from additional conditions stated in Equation (4), where $k' \in \{1,...,N_R\}$.

$$\forall i,j,k,k', t_{ij}^{R_k}(s) \ge max(P_j(s), t_{i(j-1)}^{R_{k'}}(e) + W_{ij})$$

$$t_{ij}^{R_k}(e) \le max(P_j(e), t_{i(j-1)}^{R_{k'}}(e) + W_{ij})$$

(4)

The works for farmland i are subject to *precedence constrained* relation [4]; in other words, a latter work W_j can only start after the completion of a former one W_{j-1} . This condition is defined by Equation (5).

$$\forall i,j,k,k', t_{ij}^{R_k}(s) > t_{i(j-1)}^{R_{k'}}(e)$$

(5)

Considering the moving time between farmlands, the start time of the next work should be the sum of completion time of the previous work and the moving time (Equation (6)).

$$\forall a,b,j,k, t_{aj}^{R_k}(s) \ge t_{bj}^{R_k}(e) + D_{ab}/v'_k$$

(6)

Based on the above conditions, the objective of farm work scheduling is formulated as the following equation:

$$\min(\sum_{a,b,j,k}[t_{bj}^{R_k}(s)-t_{aj}^{R_k}(e)]) \qquad (7)$$

where task $t_{aj}^{R_k}$ is a latter task of $t_{bj}^{R_k}$ ($t_{bj}^{R_k}(e) \ge t_{aj}^{R_k}(s)$). Minimizing idle time between works conduces to high ratio of utilization of machinery. The objective is same with minimizing make-span in common scheduling problem.

2.2 Formulating farm work scheduling on hybrid Petri nets

Hybrid Petri nets informally contain a discrete part and a continuous part of Petri net. Figure 1 illustrates a hybrid Petri nets modeling for scheduled farm work. The discrete part of Petri net is comprised by discrete places drawn as single-line circles, and discrete transitions drawn as bars. The state of resource R_k is represented by token, which is a black dot within place. The continuous part contains continuous places P_{ij} drawn as double-line circles, and continuous transitions drawn as box. Continuous transition, whose naming is same as task T_{ijk}, denotes performing the task in farmland F_i by R_k, for work j. Each continuous transition, place is associated with predefined work duration $P_j(s) \rightarrow P_j(e)$ and waiting time W_{ij}, respectively.

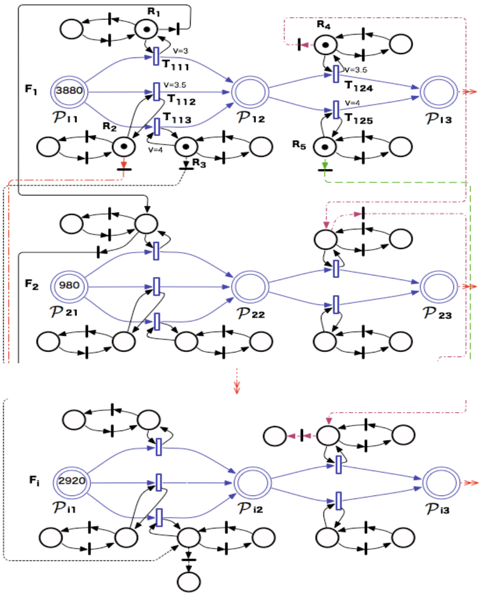

Fig. 1. Hybrid Petri nets modeling for scheduled farm work

This hybrid Petri nets not only acts on modeling the farm work process, but also scheduling farm works. Using hybrid Petri nets, a substantial reduction in the complexity of problem formulation is achieved. A detailed description on hybrid Petri nets modeling for farm work flow can be found in (Guan et al., 2008).

3. EXPERIMENTAL RESULTS

A farm work schedule includes assigning resources and arranging work sequence. At the first phase, a scheme of assigning resources is determined and optimized. At the second phase, the work sequence is designated as a priority list in which works are arranged according a specific priority. The priority list is optimized for minimizing the idle time between tasks, according to firing rules of hybrid Petri nets.

3.1 Optimizing resource assignment and priority list

Figure 2 displays the contrastive effect on optimizing resour-ce assignment and priority list correspon-ding to different gen-eration size in GA. The curves are drawn by current best fitness against execution time. “gen-100" represents the evolution process for high frequency of optimizing resource assignment but short computation time for optimizing the priority list. Comparing with “gen-100", “gen-1000" emphasizes optimizing priority list but results in reduction of frequency for optimizing resource assignment at same computation time.

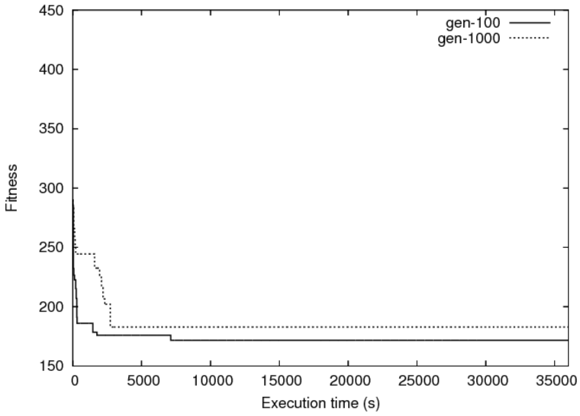

Fig. 2. Effect on optimizing resource assignment and priority list

In the figure, not only speedy evolution but also good solution quality appears in “gen-100", especially at early evolution stage. It reveals that increasing the frequency of optimizing resource assignment conduces to speedy evolution and convergence in computation. It is considered that resource assignment is an important factor for producing an efficient schedule.

3.2 Strategies of initializing population of GA

Generally, the waiting time between works (W_{ij}) has considerable influence on evolution of solution quality. In practical, however, the waiting time between works is most same because of uniform farm works in all farmlands. In the case of most same waiting time between works, the effect on solution quality under sorting works by W_{ij} in the initial population is shown in Figure 3.

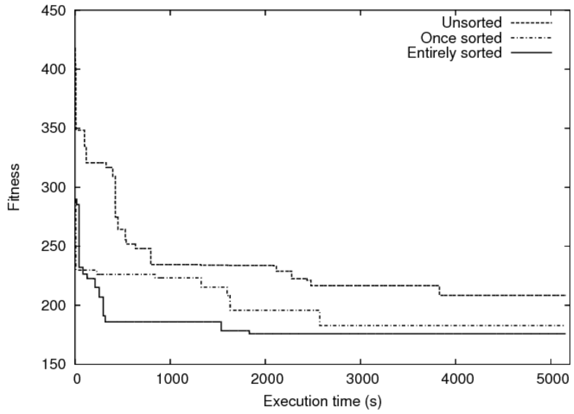

Fig. 3. Effect on initializing population by sorted chromosomes

The curves show evolution process star-ted from three initialized populations with raw chromosomes (un-sorted), one sorted chromosome and entirely sorted chromosomes. It is obvious that evolution speed of the curve titled “Unsorted" is slowest in comparison with that of other two curves. Both high evolution speed and solution quality are obtained in case of initializing population by entirely sorted chromosomes. For the curve representing one sorted chromosome, the fitness will suffer from other constraints like moving time, so that both evol-utionary speed and sol-ution quality are wea-ker than the curve titled “entirely sorted". Beca-use of the chromoso-mes sorted by most same waiting time, the-se chromosomes may have further variations. Therefore, the populat-ion comprised of entir-ely sorted chromoso-mes by W_{ij} may enhance the possibility of approaching best sequence. These three curves distinctly illustrate that sorting tasks by waiting time between tasks contributes to speedy evolution.

Inheriting best priority list for the previous resource assignment starts at initializing the population for the second resource assignment. From on computation for the second resource assignment, the priority list is optimized, and present best work sequence for each resource is ascertained. Inheriting the present best work sequence for chromosomes in the initial population can reserve and further improve solution quality. We investigated the effect on inheriting present best priority list at different inheriting rate, and the comparison result is shown in Figure 4. In order to avoid the relevant influence on sorting chromosomes by waiting time between tasks, we initialized the popula-tion with unsorted chr-omosomes by waiting time between tasks.

In Figure 4, “cpr-0%" represents that the chromosomes in initial population are entirely randomly generated; “cpr-10%" means that 10% chromosomes inh-erit from the best pri-ority list from the pre-vious resource assign-ment, and the remain-ing chromosomes are randomly generated. Although several curves cross at the beginning of evolution, the final best fitness is arranged by descending order of inheriting rate. The comparison result firstly validates that partial inheriting operation may improve evolution speed and solution quality. And secondly, inheriting operation for all chromosomes (“cpr-100%") exhibits high evolution speed and also solution quality among all cases. In conventional consideration, inheriting operation for all chromosomes in the initial population may bring disadvantage because of same chromosomes without variety. Nevertheless, in the experiment, the chromosomes generated by inheriting operation still own their varieties because that resource assignment is renewed and the chromosomes are generated randomly before inheriting operation.

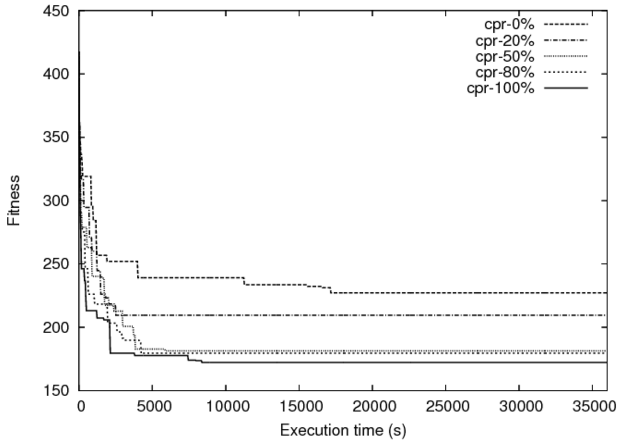

Fig. 4. Effect on inheriting the present best priority list

3.3 Scheduling result

The information on generated schedule with best fitness is listed in Table 1. Resource $R_1 \to R_2$, $R_7 \to R_9$ are available to perform W_1 and W_6 , respectively. In the schedule, ten tasks will be performed cooperatively. The average rate of utilization for each resource reaches 93.9%, in which the moving time is not counted. The total amount of work, that is the amount of all works in all farmlands, is less than the product of total area of farmlands and number of works. This is because that some farm works have no necessity to schedule, or the amount of scheduled work is less then area of the farmland. The schedule length here represents the time period between the start of the first task and the completion of the last task. The schedule length is applicable to farm work in a growth cycle, because that the sugarcane producing corporation usually requires time to carry out extra farm works entrusted by individual farmers. These extra farm works may increase income for the corporation.

Table 1. Information on generated schedule

Resource	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9
Moving time (h)	20.2	16.3	15.5	25.2	24.0	25.2	14.7	16.5	11.7
Idle time (h)	1.0	0 .0	0.0	0.0	0.0	0.0	0.0	1.83	0.33
Number of tasks	52	52	47	76	71	74	46	53	46
Work Duration (h)	297.7	298.7	308.0	436.5	406.2	463.2	210.0	208.0	209.7
Rate of utilization	0.932	0.945	0.950	0.942	0.941	0.946	0.930	0.921	0.944
Times of performing work cooperatively				10					
Total number of farmlands				76					
Total area of farmlands (hectare)				9.36					
Total amount of work (hectare)				49.2					
Schedule length (h)				2306.0					

3.4 Discussion

In this study, two-phase optimization is adopted for solving the farm work scheduling problem. In single phase optimization, the conflict of resource utilization has to be inspected for deadlock removal. In contrast, assigning resource first at two-phase optimization may reduce infeasible solution greatly, and deadlock caused by resource conflict may not exist. Moreover, inheriting operation at the second phase avoids resuming search from an unknown origination; so that the searching efficiency is improved. On hybrid Petri nets model, the breaks caused by uncertainties during the farming process and online status of resources were well handled. The computation results validated the rationality of the proposed approach.

The computing consumed many hours because of the big problem size for practical farm work planning. The computing time is most consumed by iteration of GA and simulation on hybrid Petri nets. Although the computation time is within allowable scope, the proposed algorithms should be further improved. The effective method for speedy convergence such as subtour exchange crossover, Partially Mapped Crossover (PMX) and Edge Recombination Crossover (EX) are expected to better than the one-point order crossover adopted in this research. In addition, parallel computing is attractive strategy for speeding up the computation.

For agricultural production corporation, some extra farm works entrusted by individual farmers should be also taken into account. These extra farm works are possibly treated as stochastic object if referring to historical data. In addition, the weather may also be stochastic variable derived from weather forecast. These constraints with probability distribution lead us to consider stochastic scheduling for farm works.

As discussed above, our extension works will focus on reduction of computation time, online scheduling and stochastic scheduling for uncertainty.

4. CONCLUSION

In this study, a two-phase metaheuristic was developed for farm work scheduling under constraints. The experiment results on solution evolutionary reveal that speedy evolution and good solution quality were obtained by emphasizing resource assignment optimization, initializing priority lists sorted by waiting time between works, and initializing priority lists inherited from present best task sequence in the previous resource assignment. The generated schedule with high ratio of resource utilization was applicable for practical farm work plan in some agricultural corporations, when considering conventional activities such as cooperative work, moving time of machinery, waiting time between works.

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