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On Scheduling and Resource Assignment for Farm Workflows

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Abstract—This paper considers scheduling and resource assignment for farm workflows and presents metaheuristics for the problmes. The metaheuristics contain the optimization of resources assignment and scheduling. By using simulated annealing (SA) in the first phase, we have derived a deadlock-free strategy of resource assignment. The optimization of scheduling involves searching for an optimal schedule based on a genetic algorithm (GA) and the hybrid Petri nets model. The computational experiment revealed high effectiveness for constructing a farm work schedule with a high ratio of resource utilization.

1. Introduction

For 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 and result in increased production and economic growth. Nevertheless, making a rational schedule requires not only traditional experiences but also mathematical and statistical means. Although some farmers in these corporations are aware that a suitable farm work plan results in efficient field operations, it is difficult for them to construct an optimum farm work plan. Furthermore, many uncertainties in the farming process, such as changes in weather, machinery, and labor lead to troubles in planning work by the traditional method.

It is well known that a scheduling problem under uncertainty is a difficult optimization problem [1]. A schedule, in which prevalent uncertainty due to progressive and environmental changes is considered, has more serviceability and reliability than a schedule that is based on deterministic data. Considerable research has been carried out on scheduling problems under uncertainty [2, 3, 4, 5, 6], and an instructive survey on evolutionary optimization in uncertain environments has been offered in [7].

In this study, we have proposed metaheuristics for farm work scheduling with uncertain resources and constraints. In the first phase, the resource assignment is optimized by using a simulated annealing (SA) algorithm [10], and in the second phase, the optimization is based on a genetic algorithm (GA) [11], which searches for the optimal schedule according to the firing rules of hybrid Petri nets [12]. The study addresses the problem of production scheduling with respect to arbitrary idle time, processing time, supplement or cancellation of work, cooperative work, moving time of machinery, and machinery breakdown.

2. Petri Nets Modeling

For each farmland in an agricultural production corporation, there is a series of tasks ranging from work of planting to that of harvesting in a crop growth cycle. Considerable machineries and workers are available for any corresponding work. Here we designate N_F, N_W, N_R as the total number of farmlands, works in a crop growth cycle, and resources, respectively. And also we denote farmland $i, i \in \{1, ..., N_F\}$, by F_i, work $j, j \in \{1, ..., N_W\}$, by W_j, and resource $k, k \in \{1, ..., N_R\}$, by R_k.

Figure 1 illustrates the Petri nets model for scheduled farm work. The discrete part of Petri net comprises the discrete places that are drawn as single-line circles and the discrete transitions that are drawn as bars. The state of the resource R_k is represented by a token, which is a black dot within a place. The continuous part contains continuous places $\mathcal{P}_{ij}$ that are drawn as double-line circles, and continuous transitions that are drawn as boxes. The number in $\mathcal{P}_{ij}$ is interpreted as the amount of farm work. At the start time of W_j in F_i, the value in $\mathcal{P}_{ij}$ is set to m_{ij}, while the value in other places corresponding to F_i is set to zero. A continuous transition, whose naming is the same as that of task T_{ijk}, denotes performing the task in farmland F_i by R_k, for work j. Each continuous transition and place is associated with a predefined work duration $P_j(s) \rightarrow P_j(e)$ and a waiting time, respectively.

The cooperative farming work and breaks are modeled in the figure. For example, at the initial state, work W_1 in F_1 will be started by resources R_1, R_2 and R_3, cooperatively. The break time includes the normal break time and the time that may be consumed by uncertainties such as machinery breakdown, poor weather, and so on. For each resource R_i, the break and resumption for task T_{ijk} are modeled by the discrete part of Petri net connected to a continuous transition T_{ijk}, which consists two discrete transitions and two discrete places.

This hybrid Petri nets model acts as not only modeling the farm work process, but also scheduling farm work. Along with the execution of farm work, the tokens in a cor-

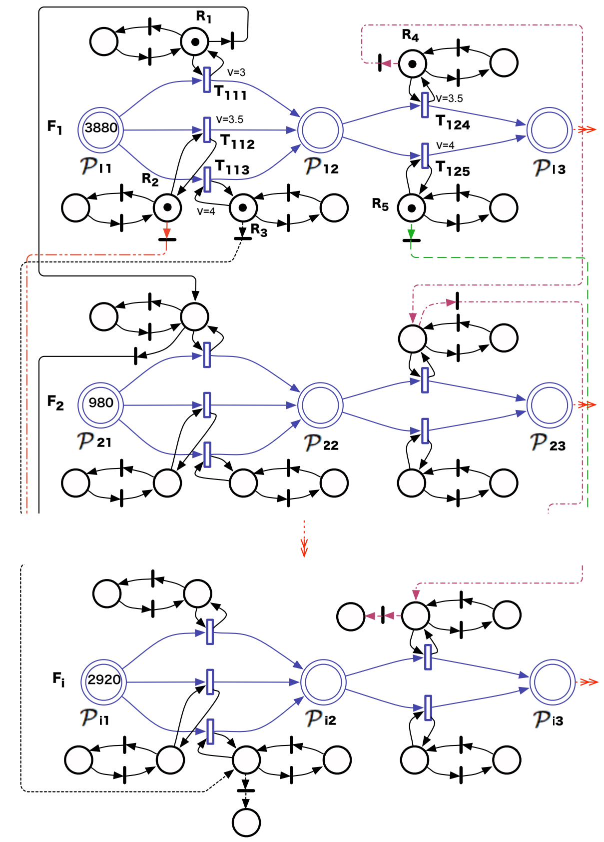

Figure 1: Hybrid Petri nets model for scheduled farm work

responding place vary with time. Therefore, monitoring the marking of the hybrid Petri nets, that is a vector representing the present amount of tokens, implies that we monitor the farming progress and the state of farmlands and resources. By using hybrid Petri nets, major constraints arising in a scheduling problem can be formulated graphically, and there is no necessity to define any variable or constraint mathematically. As a result, a substantial reduction in the complexity of problem formulation is achieved [13]. A detailed description of the hybrid Petri nets modeling for the farm work flow can be found in [9].

3. Resource Assignment and Scheduling Algorithm

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

Assigning resources in the first phase conduces to deadlock prevention in the system, a situation where two or more competing works await the release of resources and neither obtains the necessary resources. A conventional SA is used for an optimization. The independent variable x in the SA procedure is set to a resource assignment. x', that is, another independent variable in the neighboring region of x, represents an alterable resource assignment for cooperative work.

By using the resource assignment, the second metaheuristic GA searches for priority lists and generates the schedule according to the hybrid Petri nets model. We have applied one-point order crossover, one-bit reverse mutation and roulette selection like those in traditional GAs. An elite reservation has also been incorporated.

The priority list is encoded into a chromosome of the GA, in which the tasks (genes) are grouped by work W_j. The operations of crossover and mutation are restricted to between the tasks in the same work j. The fitness function evaluates the sum of the moving time and the idle time between the tasks. This objective is achieved by simulating activities of the hybrid Petri nets model, where the firing rules of hybrid Petri nets are summarized as:

1. The scheduled work must be completed.
2. Arbitrary cooperation work is possible if work j in F_i is uncompleted.
3. The work must be completed in the predefined work period.
4. The next work W_j must wait for the duration of the waiting time after completing work W_{j-1}.
5. The moving time between farmlands should be considered.
6. Breaks may occur at arbitrary time.
7. If a resource R_k is scheduled to carry out work W_j, but W_j is already completed by cooperative work, then R_k is scheduled to the next task.
8. The firing operation stops when all tasks are completed.

Rules (1)−(5) satisfy the problem constraints. Rule (6) corresponds to online scheduling or reactive scheduling. Rule (7) protects a deadlock-free condition during the firing operation in the system. The schedule will be generated when the firing operation stops and recorded together with the priority list if it has the current best fitness.

4. Experimental Evaluation

The scheduling program contains two portions: reactive scheduling and online scheduling. The reactive scheduling computes and updates the schedule for the entire growth cycle at the completion time of the last farm work in a workday, while online scheduling provides workers with the newest schedule in a short time when the status of resources or environments is changed. The experiment in this paper was made for reactive scheduling.

The experiment data is referred to a sugarcane producing corporation, which manages 76 farmlands by using considerable machinery. The major farm works for cultivating sugarcane in the spring growth cycle, that are defined as W_j in the paper, involve the plowing, planting, irrigating, weeding, fertilizing, and harvesting work within a predefined work period. The number of suitable resources required for these works is assumed to be 2, 1, 1, 1, 1, 1, and 3, respectively. By referring to the available resources, cooperative work can be carried out for the work of plowing and harvesting. All the constraints are considered in the proposed algorithm.

Our algorithm is packaged in C in order to integrate other subsystems. The computing platform is Mac OS X 10.5 operation system running on a Mac Pro with Quad-Core Intel Xeon and 4GB RAM. The computation time depends on the parameters of the SA, GA, and time increment in the hybrid Petri nets and is approximately 10 h when $N = 200$, $\alpha = 0.02$ in the SA, population size = 20, generations = 200 in the GA, and time increment = 10 min in the hybrid Petri nets. Since the program runs from the completion time of the last work in a workday to the start time of the first work in the next day, less than 12 h are allowable.

Figure 2 displays the contrastive effect on optimizing resource assignment and priority list corresponding to the different generation sizes in the GA. The curves are drawn by using the current best fitness against execution time. “gen-100” represents the evolution process for the high frequency of optimizing resource assignment but a short computation time for optimizing the priority list. Compared with “gen-100”, “gen-1000” emphasizes optimizing the priority list but results in a reduction in the frequency for optimizing resource assignment at the same computation time.

In the figure, not only a fast evolution but also a good solution quality appears in “gen-100”, especially at an early evolution stage. It reveals that increasing the frequency of optimizing resource assignment is conductive to a fast evolution and convergence in computation. It is considered that resource assignment is an important factor in generating an efficient schedule. Notice that increasing the frequency of optimizing the resource assignment does not weaken the optimization in the second phase. A strategy of inheriting the present best priority list is adopted for reserving and further improving the quality of the solution in the second phase, which will be discussed next.

Generally, the waiting time between works (W_{ij}) has considerable influence on solution quality. The best schedule can be derived from sorted tasks according to the order of W_{ij} if all W_{ij} are different and other constraints are ignored. In practice, however, the waiting time between works is almost the same because of the uniformity of farm works in all farmlands. In the case when the waiting time

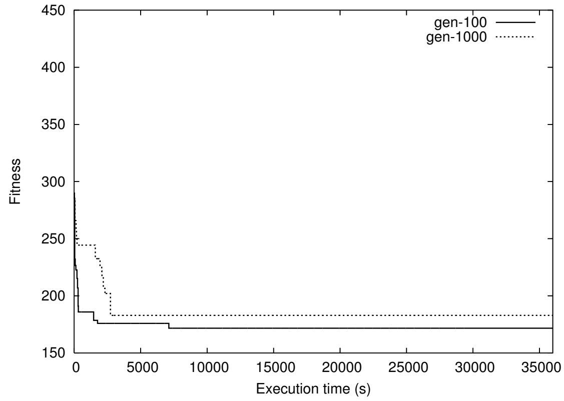

Figure 2: Evolution based on optimizing resource assignment and priority list

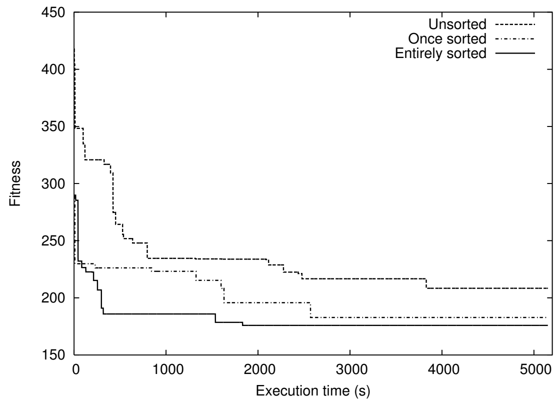

Figure 3: Effect of initializing population by sorted chromosomes

is almost the same between works, the effect on solution quality while sorting works by W_{ij} in the initial population is shown in Figure 3.

The curves show the evolution process that started from three initialized populations with raw chromosomes (unsorted), one sorted chromosome, and entirely sorted chromosomes. It is obvious that the evolution speed of the curve titled “Unsorted” is the slowest in comparison with that of other two curves. Both high evolution speed and solution quality are obtained in the case when the initializing population comprised the entirely sorted chromosomes. For the curve representing one sorted chromosome, the fitness will suffer from other constraints like moving time; therefore, both the evolution speed and solution quality are weaker than those of the curve titled “entirely sorted”. Because the chromosomes are sorted by almost the same waiting time, these chromosomes may have further variations. Therefore, the population comprising the entirely sorted chromosomes by W_{ij} may enhance the possibility of approaching the best sequence. These three curves distinctly illustrate that sorting tasks by the waiting time between tasks contributes to fast evolution.

5. Conclusions

In this study, metaheuristic approach was developed for farm work scheduling under constraints. The experimental results on solution evolutionary reveal that a fast evolution and good solution quality were obtained by emphasizing the resource assignment optimization, initializing the priority lists sorted by using the waiting time between works The generated schedule with a high ratio of resource utilization was applicable for devising a practical farm work plan in some agricultural corporations, when considering conventional activities such as cooperative work, moving time of machinery, and waiting time between works.

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