Scheduling for Farm Work Planning based on Petri Net Model and Simulated Annealing

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Abstract

A practical farm work planning is important for agricultural production corporations to manage the farming work systematically and efficiently. Since the farm work planning corresponds to a NP hard scheduling problem, a satisfactory and rational farm work planning is difficult to be generated by conventional approaches. This paper proposes a new concept of applying the Petri net and simulated annealing (SA) algorithm to develop a farm work planning for the agricultural production corporations. The necessary data for farm work planning including the data of farming process and changes of uncertainties is recorded by a cellular phone equipped with a GPS (Global Positioning System) function and an Internet connection. Petri net mathematically and graphically describes the farming process, and simulates the farming activation and resource allocation. The marking that is one of properties of Petri net facilitates mastering the farming progress and the online status of the farmland and resources. According to the formulation of farming process, we developed the SA algorithm to obtain high-quality solutions approximated to the optimum solution for the farm work planning. In the experimental evaluation on the simulation data between the SA algorithm and conventional local search algorithm, the scheduled length by the SA algorithm was much shorter than that by the local search algorithm. The result revealed that the SA algorithm had high superiority to generate high-quality solution for the farm work planning.

Key words

Petri net, simulated annealing, agricultural production corporation, farm work planning, scheduling problem

Introduction

In Okinawa, sugarcane is major crop and approximately 50\% of the farmland is used for growing sugarcane, and nearly 70\% of the farmers engage its production. In recent years, some issues such as the increase in the number of aging farmers and low income have resulted in the abandonment of arable land. In order to avoid cultivation abandonment and implement efficient and stable farm management, some agricultural production corporations that manage large-scale farmland with full mechanization have been established. At present, there are approximately 40 sugarcane-farming corporations in Okinawa. On the other hand, Japanese government encourages the farmers to promote a cooperative system through expanding the scale of farming since the Japanese agriculture policy of The 1961 Agricultural Basic Law has been established. The policy includes of creation of trust of agricultural land by agricultural co-operatives and establishment of agricultural production corporations that cultivate farmland. Especially by The Agricultural Management Framework Reinforcement Law in 1993, the promotion of the integration of land into a special agricultural corporation had resulted in establishment of much more agricultural production corporations. By the government promotion policies, the number of sugarcane-farming corporations in Okinawa is expected to further increase to 80 in the future.

These sugarcane-farming corporations manage large-scale farmlands with full mechanization, but the sugarcane yield per unit area of these agricultural production corporations (about 4 tons per 1,000 m\textsuperscript{2}) is lower than that the average yield in

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Okinawa (about 5.8 tons per 1,000 m²) (Agriculture, Forestry and Fisheries Planning Division, Okinawa Prefecture, 2006). Most of the farm works begin late in the season and the optimal timing is missed because of poor management of farm works. Since an increase in the sugarcane yield is essential for the corporations, it is important for them to develop a farm work planning system for carrying out farm work in an organized and planned manner for efficient management. Although some of the farmers of these corporations are conscious of that the suitable farm work planning brings the efficient farming work, it is difficult for them to construct an optimum farm work planning. The daily work is intensive for the employees in the agricultural production corporations, and they are custom to work following by the traditional experiences. Furthermore, many uncertainties in the farming process such as changes of weather, machine and labour force conduct to the troublesome on planning their work by traditional method.

Outside of Japan, there are few researches on the farm work planning for agricultural production corporations. Contrastively in Japan, some researches had been devoted to the farm work planning on the information technology following by the establishment of agricultural production corporations. National Agricultural Research Center, Japan, has developed a Farming-systems Analysis and Planning System (FAPS) for the paddy rice production by the stochastic programming model (Nanseki, 1998). The FAPS system provides a decision support scheme for the operation risk and multiple management objectives for large scale farmlands, and has been widely introduced to some agricultural research center and farmers. Daikoku (2005) also developed a system for planning work schedule of paddling and transplanting in distributed fields, and Nanseki (2003) proposed a farming-systems database for farm planning. However, these systems did not support the daily schedule and the necessary resources allocated to work, and the farmers could not master the detail farming process for each farmland.

Since the farming processes can be characterized as a working-flow program in computer science, we proposed a new mathematical tool — Petri net for modeling and simulating the farming processes. Petri nets are widely used to model the discrete event system such as computer systems, manufacturing systems, communication systems and so on (Murata 1989). In comparison with PERT (Program Evaluation and Review Technique) model (Cotrel 1999), which is another working-flow model widely used in the planning and scheduling of large and complex projects, Petri net has its superiorities in presence of dynamic changes in uncertain environments. However, few researches apply Petri net into agriculture, and certainly, there are no research on the farm work planning on Petri net up to the present. In the farm work planning system, Petri net is a model that describes the farming process, and simulates the farming activation on the allocation of the resources such as of the machines, labour forces and so on. Performing the activities in a Petri net will generate the scheme of resource allocation and simulate the present status of the farmland and resources. Different allocation of the resources produces a large number of possible farming schedules. Therefore, the problem of solving an optimum farm work planning from all possible farming schedules is turned to an optimization problem. Because the resources are limited in the agricultural production corporations, the farming scheduling problem is usually considered the resource-constrained project scheduling problem (RCPSP), which is well known as a NP hard problem (Sampson et al., 1993). The algorithm to obtain high-quality solution for the farm work planning requires considering the large number of variables and constrains corresponding to the large-scale farmlands and limited resources in the agricultural production corporation. These are several approaches to solve the optimization problem, such as problem-domain heuristics, Monte Carlo method, simulated annealing (SA), genetic algorithms and tabu-search (Pham et al., 1998). We applied the SA algorithm for obtaining the high-quality solution for the farm work planning in our research.

In this paper, we present a farm work planning system applying the Petri net model and SA algorithm. First, we introduce preliminary notes of Petri net and SA algorithm. Next, the system structure of farm work planning is described in detail. After that, the simulation of farming process and evaluation of the simulation result are presented. The paper ends with a discussion and some conclusions.

Preliminaries

Petri net

A Petri net is a graphical and mathematical modeling tool for describing and simulating the dynamic and concurrent activities of systems. Petri nets were invented in 1962 by Carl Adam Petri. As a modeling language, it is not only graphically depicts the structure of a distributed system as a directed bipartite graph, but also mathematically represents the formal deduction in state equations or algebraic equations. A Petri net comprises of place nodes, transition nodes, and directed arcs connecting places with transitions and so on (Murata 1989).

A Petri net is a particular kind of directed, weighted and bipartite graph consisting of two kinds of nodes, called places and transitions, where the places and transitions are drawn as circles and bars or boxes, respectively. The arcs between places and transitions are labeled with their weights (positive integer), and these labels are usually omitted for unit weight. A distribution of tokens, the black dots in places of a net, is called a marking. Transitions act on input tokens by a process known as firing. When a transition fires, it consumes the tokens from its input places, per-
forms some processing task, and places a specified number of tokens into each of its output places. Fig. 1 illustrates the components and behaviors of an original Petri net. It also shows the transference process from the initial state to the final state by the action of firing.

**SA algorithm**

SA algorithm (Laarhoven et al., 1987) is one of meta-heuristic algorithms to solve the global optimization problems. Its concept is based on the manner in which liquids freeze or metals recrystallize in the process of annealing. The recrystallized liquids or metals in thermodynamic equilibrium have lower internal energy than the initial one by slowly cooling proceeds. By the analogy of this physical process, each step of the SA algorithm replaces the current solution by a random neighborhood solution, which is chosen with a probability that depends on the difference between the corresponding function values and on a global parameter $T$ (called the temperature). The global parameter $T$ is gradually decreased during the process. Let $E(x)$ be the energy (or evaluation cost) at independent variable $x$, and $T$ the temperature. During the process of decreasing $T$, the probability of selecting current $x$ is determined by the following equation (1):

\[
\begin{align*}
  P(x' \rightarrow x) = \begin{cases} 
    1 & \text{if } E(x') \leq E(x) \\
    e^{- \frac{(E(x) - E(x'))}{T}} & \text{otherwise}
  \end{cases}
\end{align*}
\]

where $x'$ is another independent variable in the neighboring region. SA algorithm will return the solution when the termination condition reaches $T = 0$.

**System description**

Fig. 2 shows the system structure for the farm work planning. A cellular phone equipped with an Internet connection and built-in GPS functions is selected as the terminal to record the data of farming progress and changes of uncertainties at the farmland. The web pages for collecting the farming data are obtained from the web server via the Internet and displayed on the cellular phone screen through its built-in web browser. The web server responds to the web requests from the cellular phone and transmits the web pages back. The CGI (Common Gateway Interface) programs are run on the web server in order to record the farming data, display the field map, address system errors, and save the data on the database server. The built-in GPS function in the cellular phone is utilized to produce a field map of the measured position to indicate the location of the operator. The function that displays the GIS map using the position information obtained from the GPS function of the cellular phone is not only used for identifying the working field but also for validating whether the field identifying number is correct or not. Some free software, Apache 2.0 (Linux) and PHP 5.1.6 are used as the web server and the CGI language support platform, respectively. The detail of recording the farming data by a cellular phone was proposed by Guan et al. (2006).

The data stored in the database server consist of records of farming works, the data of resources and farming progress, etc. The resource data mainly contain the name, quality, properties and status, and the data of farming progress represent the status of the scheduled works for each farmland. The database server is implemented with MySQL 5.0.27.

The farming work management includes an interface for transferring the necessary data such the progress data to the scheduling system, managing the data on the database server, storing the scheduled result, and transmitting the scheduled result as indication work to the farmers who are handling with a cellular phone. The farming work management also provides some functions such as updating the rank of farmland and the changes of resources, and so on. Because the farming work management is designed on the web site, both computer and cellular phone are possible to access the web pages on the web server.

The input data of the scheduling system is the necessary data for scheduling computation, and the output is the scheduled result. The scheduling system, which is most important components of the farm work planning, contains a real time scheduling module for the changes of uncertainties and an entire scheduling module for annual growth cycle of sugarcane. In this research, we only discuss the entire scheduling module for annual growth cycle of sugarcane. The source code for scheduling computation is written by the standard ANSI C on a Linux operating system.
Farm work planning design

Modeling the farming flow by Petri net

Since sugarcane is major crop in Okinawa, we focus on the development of sugarcane producing farm work planning for sugarcane-farming corporations. The growth cycles of sugarcane are divided into spring growth cycle, summer growth cycle and perennial growth cycles. The farm works for the sugarcane of spring growth cycle in one farmland is more than of other two growth cycles. The major farm works in one farmland consist of the plowing, seeding, planting, fertilizing, irrigating and harvesting work. Each of the farm works requires such resources as labour forces and machines and so on.

In order to model the farming flow of sugarcane production by Petri net, we define the farming operation as the transition, condition or status as the place, resource like labour force and machine as token. Fig. 3 shows the Petri net model modeling the farming flow in one farmland. The circles, that are places, denote the status of the farmlands or resources. The tokens indicate the resources of labour forces or machines. The transition is corresponding to carrying out the farming work. The places for the farmlands are set with a waiting time for altering to another status. According to the characteristics of Petri net, when the conditions and tokens satisfy the firing condition, transitions are enable for execution. It

Fig. 2 System structure for the farm work planning

Fig. 3 Petri net modeling the farming work flow of sugarcane production
implies that the corresponding cultivation can be carried out when satisfying the condition of cultivation and having necessary labour forces and machines for the work. The working time for a farm work is the firing time of a transition. When the farming work is completed, the farmland alters into a new status while the labour forces and machines are ready for other work. The integral model for multiple farmlands in one agricultural corporation is based on this elementary model (Guan et al., 2006).

Generating possible farming schedules

The possible farming schedules are generated by the priority list, which contains a set of priority queues of farming works. We define the number of farmlands as \( i = (1, 2, 3, \ldots, n) \), works in one farmland as \( j = (1, 2, 3, \ldots, m) \), respectively. Thus the priority list shows as \( J_{11}, J_{31}, J_{12}, \ldots, J_{nm} \), where the length of the priority list is the product of \( n \) and \( m \), and \( J_{nm} \) means the work \( m \) in the farmland \( n \). Fig. 4 shows a priority list, where the initial condition is assumed those two farmlands, two labour forces, and one machine are available for schedule. In each farmland, there are three necessary farming works, which are simulated based on Petri net model. When one of farming work is carried out, the corresponding transition acts on firing. The firing operation conducts the transmission of tokens and status alteration of places. In company with the firing operation, the farming works and resources are allocated on the corresponding workday. Likewise, the Petri net model simulates the firing operation according to the works in the priority list, and finally reaches the status as shown in the lower part of Fig. 5. The upper table in Fig. 5 represents the generated schedule involving the description of farming work, necessary labour forces and machines in the scheduled workday.

Improving Priority List by SA algorithm

At the above steps, all possible priority lists are factorial of the number of the works in all farmlands if there is of no additional constrain, so that it is impossible to obtain the optimum schedule in reasonable time. Furthermore, in common agricultural production corporations, the machines and employees are limited because of input cost. And that large number of variables and constrains will also appear due to the large number of the farmlands, changeable weather, and different situations of the crops, machines and employees. In general, the problem of solving a reasonable allocation of the resources under limited conditions is addressed as RCPSP, so that we apply SA algorithm to calculate an approximate schedule. The time to complete all of works in priority lists is defined as schedule length. The shorter schedule length means that the scheduled works in all farmlands according to the schedule are early completed.

In our SA algorithm, the evaluation function is set to evaluate the schedule length, and the objective function is to obtain the schedule of minimal schedule length. Another independent variable in the neighboring region is defined as the priority list \( x' \), which is generated from the original priority list \( x \) by crossing the two farming works in \( x \). If a priority list \( x \) is \( [J_{11}, J_{31}, J_{12}, \ldots, J_{nm}] \), then priority list \( x' \) may be \( [J_{31}, J_{11}, J_{12}, \ldots, J_{nm}] \) by exchanging the farming work \( J_{11} \) and \( J_{31} \) in the neighboring region. The pseudo code of our algorithm is described as Fig. 6. The number of loops is set as \( N = 200 \) in advance in the experiment. The termination condition in procedure SA is set as \( T < 0.1 \) and that the loop times reach 5,000 since has no improvement. The schedule-day in specified period in procedure genPlan is defined beforehand according to the crop’s growth cycle. For instance, the specified period for the harvesting work is designated from the end of December to March. The task \( j \) is only available for arrangement into the schedule during the specified period.

Simulation result

Fig. 7 illustrates the simulated farming schedule for one growth cycle and the scheme of resource allocation. The simulated schedule for the sugarcane of perennial growth cycle is planned...
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with five works in a farmland. The upper part of the graph indicates that on the workday, the farming work is to be carried out in specified farmland. The unit of x-axis is set as days, and the number of farmlands is 80, but only four farmlands are displayed in this figure. In a farmland, a bar indicates a work and the work description is distinguished from the style of the bars. The lower part shows the allocation scheme of the machines corresponding to the schedule. The initial priority list was randomly created and the computing time was about five seconds.

An evaluation on the performance of the proposed SA algorithm in comparison with common local search algorithm was conducted with the specified conditions while the number of farmlands was assigned to 50, 100, 150, 200 and 250 (Fig. 8). The schedule length was designated for the evaluation. In the experiment, we defined $L_0$ as the schedule length calculated by a specified initial solution (Priority List), and $L_f$ as the final schedule length of generated by scheduling algorithms. For the SA algorithm, $\mathbf{\Delta L} = L_f - L_0$ that are indicated as the vertical axis at the upper part of the Fig. 8, implies the improved schedule length from the initial solution. From the graph, we found that $\mathbf{\Delta L}$ by the SA algorithm was much larger than that by the local search algorithm, namely, the schedule length computed by SA algorithm was much shorter than that by local search algorithm. Hence, it is considered that according to the farming schedule generated by the SA algorithm conduces to early completion of the farming work.

The lower part of Fig. 8 shows the execution time of SA program and local search algorithm.

Fig. 8 Experimental evaluation between SA algorithm and local search algorithm

Fig. 6 The pseudo code of SA algorithm

```plaintext
00: procedure SA
01: begin
02: initialize temperature $T (=1)$;
03: define the number of loops $N$ for searching neighbour solution;
04: initialize priority list $x$ (randomly generated);
05: generate farming schedule $S_0$ by procedure genPlan;
06: evaluate the schedule length $L_0$ of $S_0$;
07: initialize minimum schedule length min to $L_0$;
08: while(termination condition was not reached)
09: for i = 1 to N
10: generate another priority list $x'$ in neighboring region of $x$;
11: generate farming schedule $S_{i'}$ by procedure genPlan;
12: evaluate the schedule length $L_{i'}$ of $S_{i'}$;
13: if($L_{i'} < L_0$) then
14: replace $x$ with $x'$;
15: else
16: randomly generate a probability $p$;
17: if($p < \exp(L_0 - L_{i'})/T$) then
18: replace $x$ with $x'$;
19: endif
20: end if
21: if ($L_{i'} < \text{min}$) then
22: replace $\text{min}$ with $L_{i'}$;
23: memorize $x$;
24: endif
25: end for
26: replace $T$ with $(T - T \times \alpha)$, where $\alpha = 0.01$;
27: end while
28: end
29: procedure genPlan (priority list $x$)
30: begin
31: initialize schedule $s$ to NULL;
32: for j = 1 to (number of tasks in $x$)
33: get task $j$;
34: initialize Boolean variable arranged to false;
35: set the schedule-day in specified period;
36: while(arranged is false)
37: if (resources are available in schedule-day) then
38: append task $j$ to $s$;
39: set arranged to true;
40: else
41: move schedule-day forward;
42: end if
43: end while
44: end for
45: return schedule $s$;
46: end
```

Fig. 7 Simulated result of the farming schedule and scheme of resources allocation
The generated schedule is transformed into the specified format and stored into the database server (See Fig. 2). From the database server, CGI programs perform reading the simulated work schedule, and displaying the schedule on the screen of the cellular phone or a web-based interface as shown in Fig. 9. The date duration between the start date and end date, the worker and the number of the farmland is possible to be specified in the work schedule. The work schedule is listed by the date, the number of region and farmland, work name, machines, workers, scheduled start time and end time.

In order to distinctly illustrate the annual schedule and the difference of performance between SA algorithm and local search algorithm, the simulation result shown in Fig. 7 and Fig. 8 is under the assumption that the area of the farmland is ten times of actual area referring to the sugarcane-farming corporation. The data used for Fig. 9 is similar to actual data which stores in the database server. Since the system is designed under the consideration of further development and practical application, we need only change the parameters in the system to adapt the actual data when applying this research to practical farm work planning.

Discussion

In this study, Petri net model and SA algorithm were used to generate a farming schedule for sugarcane production. We assumed that the number of farming works in a farmland was invariable, and ignored the uncertainties during the farming process. Both Petri net model and SA algorithm were designed in their elementary function. We modelled the farming workflow for a farmland and simulated how the farming schedule was generated on Petri net model. By simulating the behaviours of Petri net displayed as a visible graphic, we implemented the resource allocation only by manage the tokens in a place of Petri net if the resources were changed. Not only the initial status but also the progressive status of farmland and resources could be illustrated in the Petri net model. It indicates that the online status changes, resources allocation and present status during the farming procedures in entire farm work planning are possible to be simulated on a Petri net model.

However, a wide range of factors have to be taken into account in order to make actual farm work planning. For instance, the number of planned works in a farmland is possible to change by the observation of farmland situation. So that an elementary Petri net is insufficient for describing the farming work flow and SA algorithm is also required to correspondingly improve. A more practical farm work planning system should be robust against the environmental changes and deviation from the last generated farm work planning. Generally, the uncertainties in the farming work contain the changes of resources such as labour forces, machines and farmland status, weather and so on. For instance, the reasons to cancel the farming work contain machine failure, unexpectedness for the farmer, awful weather and so on. The changes of these uncertainties are recorded from a cellular phone which is handled by the worker. At the changes during the farming work, the ratio of completion work in a farmland is required to record on the cellular phone. Considering with the uncertainties during the farming process, we are planning to improve the elementary Petri net to a hybrid Petri net, which can describe the changes of the number of planned works in a farmland and deal with the limitation of heterogeneous resources.

In the experimental evaluation, the SA algorithm exhibited its superiorities on searching an approximate solution for the farm work planning than traditional local search algorithm. However, the computation time of generating a farm work planning reached about several minutes. In the farming work, when the farmers submit the changes of uncertainties, the newest schedule is expected to soon return to the cellular phone. It implies that the time for waiting the rescheduled result is limited in several seconds in order to avoid communication timeout error. Therefore, the real time scheduling module for the changes of uncertainties is rather necessary for the scheduling system. The real time scheduling module is aimed to reschedule the farming works in a specified short period, for example, in one week. After completion of the farming work in the workday, the entire scheduling module for annual growth cycle will start rescheduling computation for the farm works in all farmlands. Hence, our scheduling system requires two programs on SA algorithm to calculate the real time schedule and the entire schedule in annual growth cycle. In this research, we developed the entire scheduling module for annual growth cycle of sugarcane, and the real time scheduling module for the changes of uncertainties are planned in future works.

The daily progressive data, location of farmland and the data of
Changes of uncertainties were recorded by the cellular phone. The precision of the GPS function of the cellular phone was sufficient to determine the current working field. It took about one minute to input a set of records of the farming data by using a cellular phone (Guan et al. 2006). The programs for transmitting the indication work to the cellular phone by Email or online web pages were developed on the web server.

As for the farm works in specific farmland are preference in comparison with the works in other farmland, we consider marking the corresponding rank for each farmland. Moreover, the other indicators except for the schedule length such as moving distance are also significant for evaluating the quality of the solution. Consequently, it is better for us to design the scheduling algorithm as optimum of multiple objective problems.

As discussed in the above paragraphs, we will improve both Petri net model and scheduling algorithm in the presence of uncertainties, and evaluate our system in sugarcane-producing corporations in the future.

Conclusions

The agricultural production corporations require a rational daily farming plan to manage their farming works in large-scale dispersive farmlands. According to this needs, we presented an approach of developing a farm work planning for the agricultural production corporations by Petri net model and SA algorithm. Our simulation results revealed that Petri net was applicable to model and simulate the farming flow, and SA algorithm had superiority to generate the high-quality solution for farm work planning. After the improvement of Petri net model and scheduling algorithms, it is possible to more practically apply this system to plan the farm works in these agricultural production corporations.

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