Research Note

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A Study on Hybrid Solving of Scheduling Problems by Swarm Intelligence Based on Business Trends

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Abstract

In recent work systems, a strong tendency to subdivide the working hours of each worker and to make shifts can be seen. Shift management is required in consideration of the declining birthrate and aging population and the shortage of human resources. Therefore, unlike the conventional full-time, research on shift scheduling centered on part-time is required. Therefore, in the beginning of this paper, while referring to the recent social background, we investigated the previous research of the hybrid method based on the swarm intelligence algorithm. It seems an effective solution method that uses swarm intelligence and GA and incorporates optimistic consensus. The study also applied for a patent by utilizing the swarm intelligence algorithm in the berth reservation system of a distribution center.

Keywords: Swarm Intelligence, Scheduling Problem, Optimistic Consensus, Berth Reservation System

1. Introduction

Following changes in the business environment and the diversification of working styles, a scrupulous shift management is needed, with shortened working hours and subdivided shifts. In addition, for fields that symbolize the contemporary work environment represented by low birthrates, aging citizens, and the shortage of human resources, new shift scheduling for new shift management is required.

However, in a workplace in which part-time workers account for the majority of the total workforce, the number of considerable conditions is larger, each condition is more complicated. In addition, the scale of each problem is greater in part-time workers' shifts than those of full-time workers. Most shift scheduling problems (SSPs) are NP-hard and their optimum solutions are difficult to obtain within a practical timeframe. Approximate methods with meta-heuristics have been used to solve these problems, but a more powerful solution method is necessary to solve a more complicated and larger SSP. To be on the safe side, it is difficult to give concrete figures because the calculation scale depends on a basis.

This study investigated previous studies on hybrid methods of combining solution methods using swarm intelligence, which has attracted the attention of many researchers in recent years. The study also examined a method to combine multiple solution methods.

2. Current situation of shift scheduling problems

A shortage of part-time workers, due to a decrease in the working-age population combined with low birthrates and an aging citizenry, is becoming a serious problem in the service industry. In some workplaces, scheduling full shifts is now difficult, which is causing workers to shoulder an increased workload. As a result, worker satisfaction is declining, causing more workers to resign and engendering labor shortages: in other words, the part-time worker shortage is creating a

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vicious circle. To prevent this outcome, many companies now shorten working hours by subdividing each the ratio of part-time workers to the total labor force has been increasing.

The problem of finding "the most effective way of allocating jobs to workers" when creating a work schedule is called an SSP in mathematical programming. In particular, the nurse scheduling problem (NSP)—creating a work schedule of nurses at a medical facility— has been studied as a typical SSP and the most attractive problem in combinational optimization problems. The model for a real problem has been created such that a method of obtaining the excellent solution under complicated conditions to some extent has been proposed[1]. As mentioned above, it is also difficult to give concrete figures because the calculation scale depends on a basis.

Conventional SSPs represented by NSP have allocated shift patterns such as "day shifts" and "night shifts" to workers on the assumption of full-time duties. In a workplace where part-time workers account for most of the total workforce, different starting times for work and working hours are necessary, so the number of shift patterns is quite large. Moreover, each worker's limitation for working hours and work pace, including service time zones and total working hours due to their unique circumstances, which were not investigated in previous studies, must be considered. Therefore, working conditions are quite complicated. An SSP can be solved as an optimization problem containing integer variables: the majority of SSPs are NP-hard. Estimating the relationship between the scale of a problem and the time when the computational complexity begins to increase is difficult, however. In the case of handling the same problem, the scale of its solution differs entirely according to its structure, in which numeric values are actually entered. Recently, due to the increase in computing power and the advancement of optimization algorithms, the performances of general-purpose solvers have been improved. As a result, large-scale problems can now be handled. While exact solution methods are seldom applied to large-scale problems with complicated conditions, such as integer programming problems (SSPs), using approximate methods with heuristics for these problems is realistic. Genetic algorithms (GAs) have been used as meta-heuristics. To solve an SSP consisting mainly of part-time workers, In which the size of the method is necessary.

3. Hybrid solution methods using swarm intelligence

Many researchers have recently examined swarm intelligence, which is based on the distinctive behaviors of animals and insects. Swarm intelligence is effective in solving a complicated and multivariate optimization problem. An artificial bee colony (ABC)[2] and firefly algorithm (FA)[3] are typical examples of swarm intelligence.

ABC comprises three phases, based on the behaviors of three artificial bee groups of employed, onlooker, and scout. In the phases of employed and onlooker bees, a local search is performed near the solution candidates. In the phase of scout bees, a solution candidate, which is not useful in the progress of the search, is abandoned and a new solution candidate is inserted into the search space to imitate the behavior of scout bees, which abandon an empty food source in foraging behavior.

FA was based on firefly flashing patterns to perform the search in accordance with the following three regulations: (1) a firefly is attracted by another firefly; (2) the force of a firefly to attract another firefly is proportional to the light intensity—a dark firefly is attracted by a bright firefly and the light intensity decreases as the distance between fireflies increases; and (3) the light intensity of a firefly is determined based on the objective function.

These solution methods have attracted the attention of overseas researchers. However, in Japan, there are no cases of applying optimization problems containing integer variables, such as scheduling problems. However, a study was conducted in which ABC and FA were used, and benchmark functions were solved as integer programming problems, although ABC could indicate the possibility of swarm intelligence, FA could not obtain the solution of a certain problem, which satisfied every constraint. Therefore, challenges remain[4].

There are solution methods to which swarm intelligence is applicable and inapplicable, to according to the problem. To develop a solution method applicable to a general-purpose model, the characteristics of each solution method should be utilized. Studies have sought to improve the search performance of a basic method by compensating for its defects in the form of combining algorithms in other methods to create a hybrid method, in which a) a swarm intelligence algorithm is combined with an evolutionary algorithm or b) a swarm intelligence algorithm is combined with another swarm intelligence algorithm.An arithmetic crossover-based ABC algorithm (AC-ABC) is a hybrid method in which ABC is combined with GA. In the phases of employed and onlooker bees in ABC, a search is performed by selecting one dimension of each individual at random. As a result, the diversity of individuals in a group can be maintained without falling into a local optima. However, it takes time to search for a decent solution. In AC-ABC, by using arithmetic crossover instead of search by onlooker bees, a search is performed across multiple dimensions and the searching speed is accelerated[5].

In a global search type artificial bee colony (GS-ABC), in which ABC is combined with GA, arithmetic crossover is not used, unlike AC-ABC; but the mutation probability α, the movement of which is similar to that of the mutation rate of GA, is introduced into the search of employed and onlooker bees. In the phases of employed and onlooker bees in the original ABC, local search is performed near solution candidates using Formula (1).

$$v_{ij} = x_{ij} + \phi_{ij} \cdot (x_{ij} - x_{kj}) \quad \cdots\cdots (1)$$

$$(i = 1, 2, ..., N_F)$$

In this formula, N_F represents the number of food sources, ϕ_{ij} represents the uniform random number of [-1,1], k is a food source for bees other than randomly selected i, which is selected at random, and j represents a dimension, which is selected at random. In the comparison of v_{ij} with x_{ij}, when the evaluation by v_{ij} is better than that by x_{ij}, x_{ij} is renewed by v_{ij}.

In GS-ABC, all the dimensions of individuals are searched using Formula (2) instead of Formula (1).

$$v_{ij} = \begin{cases} x_{ij} + \phi_{ij} \cdot (x_{ij} - x_{kj}) & if\ \gamma_{ij} < \alpha \\ x_{ij} & others \end{cases} \quad \cdots\cdots (2)$$

$$(i = 1, 2, ..., N_F, j = 1, 2, ..., D)$$

In this formula, D represents the number of dimensions, γ_{ij} represents the uniform random number of [0,1], and α represents the search parameter of 0.0–1.0.

By using the mutation probability α, a movement similar to the mutation rate of GA, the diversity of a population can be highly maintained. By selecting a large number of dimensions to be searched at one time using the search parameter, the convergence performance is improved[6]. In overseas countries, a method in which the arithmetic crossover of GA is incorporated into ABC has been proposed. In a crossover based ABC algorithm (CbABC), the phase of arithmetic crossover is added after search by employed bees (before search by onlooker bees) in order to accelerate the searching speed[7]. A hybrid method has been proposed, in which ABC is combined with differential evolution (DE)[8].

DE sometimes falls into a local solution in the early stage. Although ABC is difficult to fall into a local solution, its search takes a long time. In particular, the searching speed decreases in the late stage of calculation. In the hybrid differential artificial bee colony algorithm (HDABCA), which is a hybrid of ABC and DE, (1) initialization, (2) search by employed bees, (3) search by onlooker bees, and (4) search by scout bees are completed using ABC, and (5) the best food source is renewed. Before returning back to (2), the best fitness is delivered to DE as the initial value, and search is performed multiple times which are equivalent to the number of individuals.

Specifically, a mutant vector is created at each search point in the mutation section, which corresponds to mutation in GA, the candidate vector of each search point is created in the crossover section, which corresponds to the arithmetic crossover in GA, the created candidate vectors are selected, the termination condition is judged similar to ABC and returns back to (2)[9].

A hybrid method in which a swarm intelligence algorithm is combined with another swarm intelligence algorithm has been studied. In a modified artificial bee colony (MABC), in which ABC is combined with FA, search by employed bees, search by onlooker bees, and search by scout bees are improved based on ABC in order to accelerate the searching speed. In MABC, a formula used for search by employed bees and a formula used for search by onlooker bees are modified to use the value of the best food source. Moreover, a formula, which is similar to the movement formula in FA and considers the distance between a scout bee and the position of a food source with a better value, is used for search by scout bees[10].

4. Method to be proposed

In almost all previous studies, hybrid methods were verified using benchmark functions of linear programming problems. Some studies conducted in overseas countries used hybrid methods to solve a traveling salesman problem (TSP). However, only a few studies applied hybrid methods to integer programming problems (SSPs, or Integer programming problem represented by SSPs). In ABC, one variable (dimension) is randomly selected in one search and recalculation (search) is performed only for the randomly selected variable. Therefore, ABC takes time. In previous studies, to compensate for the defect of ABC, multiple dimensions were selected using GA or an algorithm similar to GA. By selecting multiple dimensions as search targets at once using search parameters, many solution methods improved their performances to reach optimum solutions.

The solution of an SSP (integer programming problem) is more difficult to obtain than that of a linear programming problem. Therefore, the validity of a method to solve an SSP must be verified.

Determining the suitable solution method for a general-purpose model is difficult. Whether hybrid methods, which were previously studied in Japan and elsewhere, are suitable for a general-purpose model is still unknown. This study proposes a solution method into which the consultation algorithm[11] in computer shogi programs is incorporated.

The consultation algorithm in computer shogi programs is to select the best move from candidate moves in the form of majority decision, which have been obtained by multiple thought algorithms. The result obtained by the consultation algorithm is better than that obtained by a single algorithm. The consultation algorithm includes a "simple majority rule" and "optimistic consultation[12]." The swarm intelligence and GA perform a multi-point search using multiple solution candidates as search points and select the best solution from multiple solution candidates. When voting is performed following the simple majority rule, the simple majority rule casts a vote to No. 1 of each solution method. Therefore, the simple majority rule cannot select the best move.

This study then examines the optimistic consultation to select the best solution instead of the simple majority rule. The optimistic consultation considers not only a move, similar to GA mutation rate, output by each thought algorithm but also the score of the move, and selects the move of an algorithm, which returns the highest score. Specifically, when the number of individuals is set to 30, the optimistic consultation selects a solution candidate with the highest score from a total of 30 solution candidates consisting of 10 genes in GA, 10 food sources in ABC, and 10 fireflies in FA. The optimistic consultation repeats this operation at every search (generation). When a program (solution method) is developed, into which this "(optimistic) score" is incorporated, the validity of the developed program is judged whether the score of a solution candidate selected by the developed program is higher than the score of a solution candidate selected from 30 individuals (solution candidates) by a single solution method.

In FA, a firefly with the highest score emits the strongest light and strongly attracts many fireflies. Therefore, the score of a solution candidate selected by a hybrid method containing FA may be higher than that selected by a single solution method. Similarly to MABC, if the formula in ABC used for the search at each stage is changed to use the value of the best move, the accuracy and convergence performance of ABC may be improved.

5. Related application

The reception rule of a distribution center is either "reception on a first-come-first-served basis (**Fig. 1**)" or "advance reservation system (**Fig. 2**)." In the reception on a first-come-first-served basis, approvals for vehicles to access berths are issued in time order, starting with the earliest reception time. Therefore, delivery trucks attempt to enroll at the reception desk as early as possible. Although the distribution center can simply apply the reception rule, a standby time is easily prolonged as the number of delivery vehicles increases. As a result, suppliers are negatively affected by the prolonged standby time.

In the advance reservation system, suppliers reserve desirable time zones through long-distance communication, such as the Internet, telephone, and facsimile. Based on information obtained from suppliers, the distribution center allocates berths for the arrival of goods for the supplier (the scheduling of berths) and then informs the supplier of the allocated berths. Compared with the reception on a first-come-first-served basis, a standby time is more difficult and suppliers' desirable times are more easily accepted by the distribution center in the advance reservation system. However, the distribution center must acquire operational abilities, know-how, and skills for the advance reservation system[13].

As an example of applying this study, a scheduling problem was solved after being formularized as a combinational optimization problem based on the efficiency of operations in the distribution center's warehouse while considering suppliers' desirable times. In the scheduling problem, staff members were replaced with vehicles and time frames and berths were allocated instead of daily duty shifts, based on staff scheduling.

Fig. 1 Image of reception on a first-come, first-served basis

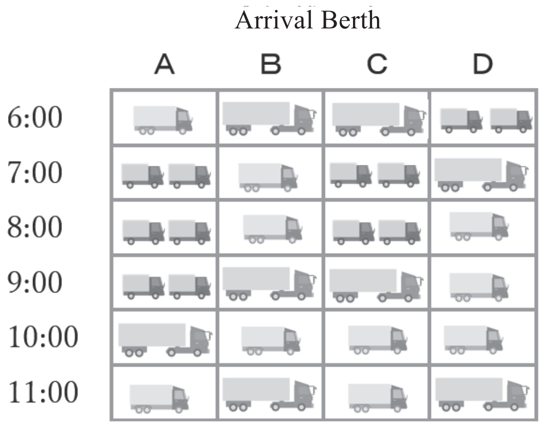

Fig. 2 Image of advance reservation system

To solve the problem of "time to wait for cargo (cargo waiting time)," which is a major factor for drivers' long working hours, the number of delivery trucks in each time zone is scheduled and equalized by using the model for an SSP and a solution method. By applying a method of allocating shifts according to time zone, which was used in a workplace consisting mainly of part-time workers,

6. Conclusion and the future direction

This study investigated previous studies on hybrid methods based on swarm intelligence algorithms as methods for the model of an SSP in a workplace consisting mainly of part-time workers in the method using swarm intelligence and GA, into which the optimistic consultation of computer shogi contemporary business environment. To solve an SSP consisting mainly of part-time workers, in which the size of the complicated problem and the rotation of workers differ according to the workplace, the solution programs is incorporated, is useful. In the future, we will embed the proposed solution method in a hardware and the validity of the proposed method will be verified using multiple models.

7. References

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ビジネストレンドに配慮したスケジューリング問題の群知能による
ハイブリッドな解法に関する一考察

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概　　要

近年の勤務体系においては，各労働者の勤務時間を細分化してシフトを組む傾向が強い。少子高齢化や人材不足に配慮したシフト管理が求められている。したがって従来のフルタイムとは異なり，パートタイム中心のシフトスケジューリングの研究が求められている。そこで本稿の前半では近年の社会背景に言及しつつ，群知能アルゴリズムをベースとしたハイブリッド手法の先行研究についての調査を行った．また，パートタイム勤務者中心の職場でのシフト管理への適用に加え，物流センターのバース予約システムにも群知能アルゴリズムの活用を図り，特許を出願した。今後の研究としてはプログラムの実装を進め，複数のモデルで検証することを考えている。

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