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RESEARCH PAPER

A Crew Scheduling with Chinese Meal Break Rules

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Abstract: An efficient crew scheduling can significantly reduce the operational cost for transit enterprises. However, the crew scheduling problem, known to be NP-hard, is complicated by the fact that there are many restrictions on the shift generation. Moreover, there are some special requirements in China, for example, meal break is normally required to be taken during the conventional time ranges for lunch or dinner, which is called a Chinese meal break rule to distinguish from the western ones. It also makes the existing crew scheduling approaches encountering difficulties. On the basis of the "generate and select" approach to solve the crew scheduling problem, this paper proposes an approach to handling the Chinese meal break rule in the phase of "generate". Taking advantages of the characteristics of Chinese meal break rule and problem domain knowledge, a heuristic-based approach is proposed to select some promising relief opportunities (ROs). A shift generation approach is then devised to generate a large set of potential shifts that satisfy the Chinese meal break rule. Experimental results from 12 groups of real-world problem instances demonstrate the success of the proposed approach, which can greatly reduce the number of potential shifts generated. Therefore, it is suggested that the proposed approach be used to solve the large scale crew scheduling problems with Chinese meal break rule.

Key Words: urban transportation; crew scheduling; Chinese meal break; heuristics; shift generation

1 Introduction

Crew scheduling is one of the most important elements in public transport, which is well-known to be NP-hard[1]. An efficient crew schedule can save considerable amounts of money for transit enterprises. Therefore, some developed countries have initiated the research on computer-aided scheduling for public transport since the 1960s. Until recently, various approaches have been proposed and some of which have been successfully applied[2]. Among them, the integer linear programming (ILP)-based approaches is the most popular[3].

A classic ILP-based approach belongs to the family of 'generate and select' approach, which includes two phases: the first phase is to generate a large set of potential shifts and the second one is to select a subset from the large set to cover all the vehicle works[4]. Generally, the ILP technique is used in the 'select' phase. Although ILP-based approaches have been successfully used in many cases[4], two difficulties are often encountered. First, there is not a uniform 'generate' procedure that can deal with the 'generate' phase for various problems. Because the labor rules considered in different countries may have different characteristics, the existing 'generate' approach developed in one country may not be able to be directly applied in other countries. For example, the crew scheduling in China usually needs to respect the Chinese meal break rules, which requires each crew member to having his/her meal during the customary lunch or dinner time. Thus, the approaches developed in western countries may not be suitable for China. Second, when the scale of the problem to be solved is very large (most of the practical problems are large-scale), it is beyond the capability of an ILP solver because the number of valid potential shifts is too large. Therefore, most research studies[5–7] focus on the later difficulty. For example, some studies work on enhancing the ability of ILP solvers to deal with large-scale problems. The efforts on generating potential shifts are seldom reported although they are non-trivial. In fact, the difficulty in the 'select' phase is affected to some extent by the 'generate' phase, because the number of potential shifts is usually determined by the 'generate' phase. Therefore, research on how to reduce the scale of the problem in 'generate' phase is

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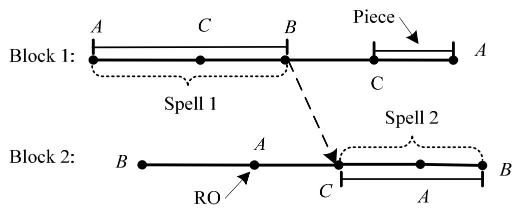

Fig. 1 Vehicle work and crew shift

an alternative efficient way to indirectly reduce the difficulties encountered in the 'select' phase. This study proposes an approach on the 'generate' phase to achieve the following two goals. The first is to generate the potential shifts which satisfy Chinese labor rules (including the Chinese meal break rules[8]). The second is to reduce the problem's scale without loss of the optimal or near-optimal solution. In the proposed approach, the relief opportunities (ROs) conform to Chinese meal break rules are first selected. Then, based on the selected ROs, a set of potential shifts satisfying all the labor agreement rules are produced. This approach significantly reduces the problem size by taking advantage of the Chinese meal break rules instead of employing artificial rules as usual. Therefore, it can effectively assist the existing 'generate and select' approaches in solving large-scale crew scheduling problems in China.

2 Crew scheduling problem

In public transport, the goal of crew scheduling is to assign a group of notional crews to implement all vehicle blocks in a day. A block represents a set of journeys to be operated consecutively by one vehicle during a day, beginning with a pull-out from, and ending with a pull-in, to a depot. Usually, it contains a sequence of locations called relief points which allow crew member to take a break. The time when the break takes place is called relief time. The relief time and the relief point form a time/location pair, which is called relief opportunity (RO). The vehicle task between any two consecutive ROs is defined as a piece of work (piece for short). One or more consecutive pieces on a vehicle form a spell of work. A shift may contain several spells separated by one or more breaks. In addition, a shift generally starts working with sign-on activity and finishes working with sign-off activity[4,9]. In our context, according to the practical situations from Chinese public transport operations, we consider three types of shift, which are straight shift, split shift, and tripper shift. A straight shift consists of two or three spells which have at least one meal break between them. For split shift, there is a long rest break between two consecutive spells. Tripper shift only contains one spell. Fig. 1 displays an example of two blocks in a vehicle schedule, where each dot denotes a relief point coded by a single alphabet.

Crew scheduling consists of assigning a set of shifts to cover all vehicle blocks. Its objective is to minimize the number of shifts and the operational cost. Meanwhile, any shift must conform to a set of labor rules or constraints. Some common rules are listed below[9,11].

(1) The continuous working time of a crew must be within a predefined time range $[T_{\min}, T_{max}]$.

(2) The overall working time of a shift must be within a predefined time range $[TS_{min}, TS_{max}]$.

(3) The overall driving time of a shift must be within a predefined time range $[TW_{min}, TW_{max}]$.

(4) The meal break time of a straight shift must be within a predefined time range $[TB_{min}, TB_{max}]$.

(5) The long break time of a split shift must be longer than a predefined time duration TBS_{min}.

Besides the common rules, various special rules may exist in different countries or enterprises. For example, in western countries, crews must have a meal break after a certain continuous working time (e.g., 3 to 5 h). However in China, the meal break must be taken within a conventional time period for lunch or dinner. It is believed that such a rule is good for crew memebers' health. Therefore, the Chinese meal break rule can be generally presented as follows.

(6)The crews' meal break must be taken during the predetermined time range $[t_{\text{satrt}}, t_{\text{end}}]$, e.g., the lunch time must be within the time range [11:00, 13:00] and the dinner be within the range [17:30, 19:30].

Assume the set of all pieces to be covered is denoted by $I=\{1, 2,\cdots, m\}$ and the set of all potential shifts $J=\{1, 2,\cdots, n\}$, the crew scheduling problem can be formulated as an ILP formulation:

$$\min \quad \sum_{j=1}^{n} c_j x_j \tag{1}$$

$$\text{s.t.} \quad \sum_{j=1}^{n} a_{ij} x_j \geq 1 \quad \forall\, i = 1, 2, \cdots, m \tag{2}$$

In this formula, decision variables

$$x_j = \begin{cases} 1 & \text{if shift } j \text{ is selected} \\ 0 & \text{otherwise} \end{cases}$$

c_j is the cost associated with shift j and

$$a_{ij} = \begin{cases} 1 & \text{if shift } j \text{ covers piece } i \\ 0 & \text{otherwise} \end{cases}$$

Formula (1) is the objective function. Constraint (2) ensures that each piece is covered by at least one shift.

As can be seen from the formula above, the scale of the problem is directly related to n (i.e., the number of all potential shifts), which is affected by the number of ROs. Suppose the number of vehicle block is p and each vehicle block averagely contains r ROs (i.e., $r-1$ pieces). If the labor rules and relevant constraints are ignored, $p \times r \times (r-1)/2$ spells will be generated for all vehicle blocks. Assume the maximal number of spells in a shift is k, theoretically we can calculate the possible number of potential shifts: