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Preface

The 2007 International Conference Proceedings on Intelligent Systems and Knowledge Engineering (ISKE2007) contain 284 final accepted papers from 797 online submissions for ISKE2007. ISKE2007 is the 2nd in a series of conferences on Intelligent Systems and Knowledge Engineering. It follows the successful ISKE2006 in Shanghai, and is held at Southwest Jiaotong University, Chengdu, P.R. China, Oct. 15–16, 2007. All submitted papers went through a rigorous review process with an acceptance ratio of 36%.

ISKE2007 is a multidisciplinary meeting encompassing four keynote presentations and 23 technical sessions that aim at covering state-of-the-art research and development in all aspects related to intelligent systems and knowledge engineering with its missions:

- Discussing research on intelligent systems for solving problems in knowledge engineering.
- Bridging the gap between computational intelligence and knowledge systems via joint research between P.R. China and international research institutes and universities.
- Encouraging interdisciplinary research and bringing multi-discipline researchers together on intelligent systems for knowledge engineering and related fields.

All papers contributed to the proceedings reflect advances on intelligent systems for knowledge engineering in the following areas:

- AI and expert systems
- Artificial immune systems
- Bio-informatics
- Chaos theory
- Cognitive science
- Data mining
- DNA computing
- E-service intelligence
- Evidence theory
- Fuzzy set theory
- Genetic algorithms
- Hybrid methods
- Intelligent control
- Intelligent decision-making
- Intelligent information processing
- Intelligent recognition
- Intelligent robotics
- Interactive computational models
- Machine learning
- Many-valued logics
- Neural networks
- Probabilistic computing
- Rough set theory
- Support vector machine
- Swarm intelligence
- Uncertainty reasoning
- Other related theories and applications

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A Bilevel Model for Railway Train Set Organizing Optimization

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Abstract

Train Set Organization (TSO) is to arrange the train set in railway freight transportation. Bilevel programming techniques were proposed to solve the Stackelberg game in which play is sequential and cooperation is not permitted. In this paper, an optimizing model for TSO is developed by the bilevel techniques. First, we analyzed the multiple level nature of management on TSO and simplified it into two levels. Then, a bilevel model for TSO was developed. Finally, this model was further illustrated by applying it on a railway station.

Keywords: Train set organization, Bilevel decision making, Optimization model

1. Introduction

Railway transportation, as one of the most important vehicles ways, has always been playing an irreplaceable role in social economics. For railway freight transportation, about 80% of the whole transportation time is allotted to the operations of loading/unloading, transferring, and overhauling in railway technical stations [1]. The working state of technical stations, therefore, will influence the whole overpass ability of the railway network. Thus the research on the railway transportation optimization will be bound to focus on the operation of technical stations. The main methodologies used include scheduling theory [1], graph theory [1, 2], mathematical programming [1, 3], and operational theory [1]. Also, some scholars have addressed the problem of traffic controlling from multiple levels' angle [4-7].

Bilevel programming techniques are mainly developed for solving decentralized management problems with decision makers in a hierarchical organization, the upper the leader while the lower the follower. Both the leader and the follower try to optimize their own objective functions and the corresponding decisions do not control but affect those of the other level [8]. Bilevel techniques have been applied with remarkable success in different domains such as decentralized resource planning, electronic power market, logistics, civil engineering, chemical engineering, road network management and risk management [9-15].

Most current research by bilevel techniques on traffic controlling centers on the transportation network design [5,16] and traffic flow [4,6]. Little research has been conducted towards TSO problems from multiple levels' angle. In this paper, we used bilevel method to study the problem of TSO in the railway running and management. The rest of this paper is organized as: following the introduction in Section 1, Section 2 analyzed the bilevel nature from TSO. The model was then defined in Section 3. In Section 4, we took the operation in a railway station as an example to further illustrate this bilevel model. Finally, the paper was concluded in Section 5.

2. Problem analysis

The TSO, aiming at arranging the train set in railway freight transportation and with extraordinary professional and technical specialties, is one of the main subjects in railway transportation management. The objectives of TSO include: to make the transportation efficient and even; to use the transporting device reasonably; and to promote the cooperation among different departments involved in the freight handling procedure. The term of "organizing" here means arranging, deciding and managing, while "train set organizing" acts to arrange the train set, make decisions on related issues, and manage the procedure in railway transportation.

There exist multiple levels among the running of TSO, i.e. the 'national railway network level' the top, the 'local bureau railway network level' the second, the 'stations' the third, and the 'operating group' the bottom. However, as the operating objects of both the national railway network and the local bureau railway network are train set,
while those of the two lower levels are trains, the organization of TSO can be generalized into two levels: the railway network the leader, and the stations the followers. Thus the bilevel programming technique can be used to analyze it.

The main concern of the railway network are to decide the trains type (pick-up-and-drop-train, district-train, transit-train, or through-train), the trains constitution, the trains number, and the detailed route of the departing train set. The objectives of the railway network include: improving the transportation capacity and service speed, reducing the cost, balancing the working rhythm among divisions, and assigning the break-up and make-up jobs among different stations rationally.

The tasks assigned to the station are to constitute normative train set required by the railway network from all kinds of freight wagons stopped by this station. Involved with these tasks, there also include a series of relevant operations, such as: collecting or delivering, shunting, loading/unloading, and wagon checking. The main concern of stations include: making the operating efficient, economical and safe; using the transportation devices such as track, shunting locomotive, and hump rationality; deciding the operation steps together with its schedules; and cooperating among steps within the schedule-frame of railway network.

Two levels though TSO can be divided into, the separate levels still share intrinsic consistency. For the upper level, when making a TSO plan, the railway network must consider the influence from the specific operating ability and device conditions of stations, while calculating the influence factors from itself such as the amount and destinations of trains and the track conditions; For stations located at the lower level, when implementing the working goals, they should try their best to harmonize between their own operation abilities and the working arrangement from their top counterpart.

The railway stations can be grouped into two classes: the "through stations" and the "technical stations". Compared with technical stations, through stations are usually small and their daily works, mainly on helping trains go through or two train set from opposite directions meet, are simple and the workload are small. Except for all the functions of through stations, technical stations are to make new train set by breaking up the old ones and adding transship trains and trains originated there. Tasks also include: arrival/departure operating, collection-and-delivering operating, shunting, loading/unloading, and wagon checking. We generalize these operations at technical stations as "shunting and transship operation".

For the reason of facilitating the modelling, we simplify the TSO by assuming that:

1) The railway transportation supply is less than the demand; the aim of TSO is to fully use the transportation ability to provide as much transportation as possible.
2) The topo structure of the railway network is a circle formed by train lines. This is to embody the continuous nature of the network and the transport circulation.
3) The main line is double-track with every track's direction fixed, which means there allowed two train set running in reverse directions between two stations simultaneously. This is to avoid the meeting problem of two train set with opposite running directions.
4) Within the railway set, there located only technical stations, and runs only one type of trains, the "district trains", which are from a technical station A and to the other technical station B. Between A and B there is no other technical stations.
5) The unit workload of "shunting and transship operation" for all technical stations are the same. In other words, every technical station share the identical amount of operating time for the same train set.

Based on these assumptions above, the decision-maker on the railway network wishes that the density of train set (calculated by the time intervals between any two adjacent running train set) and the length of train set (the number of trains of any train set) as large as possible to obtain the maximal transport capacity. However, for the sake of safety, the density has the upper limit set by railway network. And restricted by the motive power of locomotive and the useful length limit of arrival/departure track, the train set length has its upper limit as well.

Ignoring the constraints by the railway network, the stations, on one hand, wish the length of train set large because the larger the length, the more efficient the operating and the lower the unit operating cost. The operating efficiency is the amount of trains shunted and transshipped per unit time, while the unit operating cost is the cost for every single train. On the other hand, the operating time for shunting and transshipping, which influences the cost, will increase if the length of train set increases. However, the overall effect of the trains set length is that the general unit op-
erating cost will decrease with the increase of the
length of the train set length.

The analysis above, we can include that, for the variable of the length of train set, the two
levels share the same objective: the larger the
level the better. For the variable of the den-
sity of train set, the decision makers at the upper
level pursue its minimum while those at the lower
level wish it change with the train set length in
the same direction. Generally speaking, the shunting
and transhipping time in stations is larger than the
safe time intervals of any two adjacent running
train set, so the variable of the density of train set
is determined by the lower level, the stations, while
the variable of the length of train set is controlled
by the top level, the railway network.

3. Model building

Based on the analysis above, the bilevel model of
TSO is built as:

\[ \begin{align*}
\max & \quad F(x, y) = a_1 \cdot \sum_{i=1}^{n} w_i \cdot y_i \\
\text{s.t.} & \quad \sum_{i=1}^{n} w_i \cdot x_i < m \\
& \quad \sum_{i=1}^{n} w_i \cdot y_i > c_1 \\
& \quad c_1 \leq x_i \leq c_2 \\
& \quad y_i \geq c_4
\end{align*} \] (1a)

Leader Decision-maker of the railway network

Formulation:

(1a) means the leader aims at obtaining the
maximum throughput capacity within certain
period of time. \( \sum_{i=1}^{n} w_i \cdot x_i \) means
the maximum number of trains going through the
network per day, and \( a_1 > 0 \) is the maximum number of trains of any train
set regulated by the "Safety Terms". When the
trains are empty, the main concern is not to
exceed the length limit. When the trains are
loaded, the weight limit becomes the decisive
factor. However, for the sake of safety, when
computing, both the length and weight must
meet the requirements. No matter whether it
is the weight or length, the ultimate limit is
put on the number of trains.

(1b) means the minimum time interval between any
trains is regulated by the "Safety Terms", \( b_1 \) and \( b_2 \) is the weight set for the influencing
power by the length and density to the unit
cost.

(1c) means the lower and upper number limits
of the trains for technical stations to shunt and
tranship per time unit.

(1d) means the minimum time interval between any
trains is regulated by the "Safety Terms".

Explanation:

1) Variables:
   - \( x_i \): the length of train set for the \( i \)-th station,
   - \( y_i \): the density of train set for the \( i \)-th station,
   - \( a_1 \): the time interval. If \( a_1 = 24 \), then
   - \( \frac{a_1}{\sum_{i=1}^{n} w_i \cdot y_i} \) is the number of train set
     going through the network within 24 hours,
   - \( a_1 \cdot \sum_{i=1}^{n} w_i \cdot y_i \) is the number of trains going through the network per day, and
   - \( m \): the maximum number of trains of any train
     set regulated by the "Safety Terms".

2) Coefficients and constants:

- \( n \): the number of technical stations in the railway
  network
- \( w_i \): the relative weight for the \( i \)-th station in the
  railway network
- \( b_1 \): the lower limit for the number of train
  set
- \( b_2 \): the upper limit for the number of train
  set
- \( c_1 \): the lower limit for the number of train
  set
- \( c_2 \): the upper limit for the number of train
  set
- \( c_3 \): the lower limit for the number of train
  set
- \( c_4 \): the upper limit for the number of train
  set
- \( c_5 \): the lower limit for the number of train
  set
- \( c_6 \): the upper limit for the number of train
  set

3) Formulas:

(1a) means the leader aims at obtaining the
maximum throughput capacity within certain
period of time. \( \sum_{i=1}^{n} w_i \cdot x_i \) means
the number of trains shunted and transhipped
per time unit.

(1b) means the length of train set has its upper
limit imposed by the locomotive's motive
power and the arrival-departure track's useful
length. When the trains are loaded, except for
the length limit, there is still weight re-
striction set upon the train set, which means,
the weights of goods loaded together with the
weights of trains can not exceed its upper limit.

(1c) means any two adjacent running train set
can not be too close for the sake of safety. \( c_1 \) is
the minimum time interval between any trains
list according to the "Safety Regulation."

(1d) means the followers wish that the cost is
as low as possible. The first part of (1d) means
the more the length of trains set, the more ef-
ficient of the shunting, and the lower the unit
cost. The second part means the longer the train
set remains in the station, the higher the
4. Case study

In this example, we take the railway freight operation in a railway station "Station A" into consideration. Station A is a technical railway station with the duty of managing both the passenger transportation and freight transportation within the precinct of its Railway Bureau. The data collected from Station A cover the duration between November 1, 2006 and December 31, 2006. Suppose the trains shunted and transshipped are to the direction of Station B, which is another station located near Station A along its downlink. And the weight distribution of trains is listed in Table 1, with the locomotive is SS1(137 ton, 1.9 unit length).

<table>
<thead>
<tr>
<th>WT</th>
<th>WS (ton)</th>
<th>Load (ton)</th>
<th>%</th>
<th>EL</th>
</tr>
</thead>
<tbody>
<tr>
<td>E53</td>
<td>38</td>
<td>40</td>
<td>3</td>
<td>2.1</td>
</tr>
<tr>
<td>P64A</td>
<td>26</td>
<td>58</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>G70</td>
<td>23</td>
<td>55</td>
<td>9</td>
<td>1.1</td>
</tr>
<tr>
<td>G60</td>
<td>23</td>
<td>55</td>
<td>9</td>
<td>1.1</td>
</tr>
</tbody>
</table>

The terms in Table 1 are explained as:
- WT: wagon type, the type of wagon used.
- WS: weight, the weight of the empty wagon.
- Load: the weight of the goods loaded.
- EL: equivalent length, the equivalent length of a wagon is calculated from the front clamp to the rear clamp, with the unit length as 11 meters. If the equivalent length is "1.1", then its actual length is 11 x 1.1 = 12.1 meters.

According to the model defined by (1), the coefficients are calculated and discussed below:
- $a_1$: as the computation is within the "Basal Daily Working Plan", which is to arrange the wagons assignment and schedule necessary operations based on the "Trains Running Chart", "Trains Shunting Plan", "Detailed Rules on Technical Station Management", and constraints set by operating spots, the computing of the freighting wagon organization is limited within a working day of 24 hours. So $a_1$ is set to 24.
- $m_i$: limited by the pulling ability of the locomotive and the territorial landform, such as grading, within Station A’s precinct, the weight of train set must not larger than 3500 tons. The departure track used for trains set to the direction to Station B is Track IV, Filled II, whose effective length is 800 meters. Deduced by 30 meters of braking distance, which is left for trains to stop safely, the maximum length for the trains set is 860 meters. Taking the constitution of the trains listed in Table 1, we set 1 "unit train" as a virtue train whose equivalent length, denoted by $t_1$ (me ters), and weight, denoted by $w_1$ (ton), are calculated below:

$$
\begin{align*}
    t_1 &= 2.1 \times 0.03 + 1.5 \times 0.09 + 1.1 \times 0.09 + 1.1 \times 0.5 + 1.1 \times 0.35 \\
         &= 1.142 \\

    w_1 &= (38 \div 40) \times 0.03 + (26 \div 68) \times 0.03 + (23 + 58) \times 0.09 + (23 + 55) \times 0.5 + (23 + 55) \times 0.35 \\
         &= 66.95
\end{align*}
$$

The maximum number of such empty "unit train", denoted by $m_i$, is $(860 - 1.9 \times 11)/(1.142 \times 11) = 66$, and the maximum number of such loaded "unit train", denoted by $m_i$, is $(3500 - 137)/66.95 = 50$.

- $b_1$ and $b_2$: we set the weights and length of trains on the cost of the station as 0.4 and 0.6 respectively.
- $c_0$ and $c_0$: the least number of trains Station A can shunt and transship is 30 per hour, while the max number is 150.
- $c_0$: the least time for Station A to complete the shunting and transshipping for a train set is 0.68 hour.

Thus, the bilevel problem defined by (1) is spe-
5. Conclusions and future study

In this paper, the bilevel nature in train set organization has been first put forward by abstracting and simplifying railway trains management. First, the bilevel model is developed. Then, this model was applied to Station A for a real case study. The testing result obtained from Station A was reasonable and could be helpful to its trains organization. However, as a lot of practical details have to be ignored for articulating the model building, this model has its limitations when applied directly for TSO decision making. Future efforts will be focused on relating more practical and randomly occurred issues from field work.

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References


