Railway conflict detection and resolution in the Korean railway system

S. M. Oh1,2, S. H. Hong1 & I. C. Choi2
1Policy & Operations Research Department, Korea Railroad Research Institute, Korea
2Department of Industrial Systems and Information Engineering, Korea University, Korea

Abstract

In this paper, we propose a railway conflict detection and resolution system (RCDRS) for the Korean railway system. First, we review several studies related to RCDRSs. Second, we analyze traffic patterns of five major Korean National Railroad (KNR) lines. We use five measures to characterize each line: track capacity, transportation mode, meet and overtake numbers, traffic intensity, and traffic diversity. Finally, we present an RCDRS schematic and RCDR model for the Korean railway system. We focus, in particular, on a two-phase RCDR model that coordinates all interconnected lines in the global network.

Keywords: conflict resolution, traffic control, real-time scheduling.

1 Introduction

A railway conflict detection and resolution problem (RCDRP) is to find a meet-pass-overtake plan that resolves a disrupted train schedule within relatively short response time. It is an NP-hard problem [1, 2]. An important factor in the RCDRP is the number of conflicts that can be resolved within a reasonable time. Even a problem with moderate traffic intensity and an 8-hour time-horizon can take up to 12 days to find an optimal schedule using a supercomputer to determine all possible meet-pass plans [1]. Although, the advance in computing power has made it possible to solve the problem much faster, it is still necessary to define a well-stated RCDR model and an efficient solution approach to handle problems with longer time-horizon.
The RCDRP can be categorized as of the same problem class as tactical train schedule problems. One difference, however, lies in the RCDRP’s restrictive real-time response option. Szpigel [3] has conducted pioneering research on RCDRP optimization solutions; Szpigel used a mixed integer programming (MIP) model to determine meet-overtake points and a branch-and-bound (B&B) method to resolve conflicts. Many studies have since examined this problem further.

North American railroads have a history of operating long-haul single-track lines for massive freight transportation. Rail companies have sought to reduce costs associated with traffic congestion, fuel consumption, and labor-law violations. Consequently, North American researchers have produced some of the earlier work on RCDRPs. Norfolk Southern Co. (Sauder and Westerman [4]) and Burlington Northern Co. (Harker [5]) both conducted early RCDR research. Australian researchers followed with additional studies. Both North America and Australia have faced similar operating conditions, namely, long-haul single-track lines and massive-freight transportation needs.

Recently, the European Commission (EC) constructed the European Railway Traffic Management System (ERTMS) framework to establish “interoperability” among various national railways. Under the ERTMS framework, several RCDR-related projects have been actively carried out.

Currently, the Korean National Railway (KNR) is upgrading its conventional central traffic control (CTC) system by integrating four regional CTC centers into one advanced centralized center. The CTC upgrade includes the development of an RCDRS, which will serve as a top-level decision support module in KNR’s new RTMS.

In this context, we outline an RCDRS for the Korean railway system from a systematic perspective. In Section 2, we review the literature and categorize relevant research works into several sub-categories. In Section 3, we describe the Korean railway system in detail, and provide traffic analysis pertinent to the Korean railway system. Section 4 presents an RCDRS schematic and RCDR model for the Korean railway system, and Section 5 provides conclusions.

2 Literature review

More than thirty research works appeared in literature, since Szpigel. We divide them into six categories using two classifiers, transportation-mode and methodology studies, and analyze problem characteristics for each category (Table 1). Transportation-mode approaches can be further divided into freight-mode and mixed-mode research. Freight-mode research has come mostly from North America and Australia, while mixed-mode research has worldwide roots, but especially in Asia and Europe.

Most freight-mode research has adopted the mathematical programming approach. Mixed-mode research has used various approaches, such as mathematical programming approaches, heuristic-based approaches, and descriptive approaches. There are several reasons for these methodological differences. First, most North American and Australian railroads operate long-
haul single-track lines dominated by freight-transport corridors. Since these corridors have commonly had relatively low traffic intensity, the response time option is less restrictive than in mixed-mode cases. Thus, optimization-based techniques are a possible solution approach for freight-mode research. On the other hand, mixed-mode researches are more recent ones, and consider more complicated operating conditions. As a result, mixed-mode models become more complex. If traffic intensity is high, the response-time option becomes more restrictive. Thus, various approaches have been adopted for mixed-mode cases.

Table 1: Category of RCDR Research.

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Transportation-Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Freight</td>
</tr>
<tr>
<td>Mathematical Programming</td>
<td></td>
</tr>
<tr>
<td>Approaches [Two-Phase]</td>
<td>Harker [5], 1989</td>
</tr>
<tr>
<td></td>
<td>Kraay and Harker [6], 1995</td>
</tr>
<tr>
<td></td>
<td>Kraay et al. [7], 1991</td>
</tr>
<tr>
<td>[Single-Phase]</td>
<td>Sauder and Westerman [4], 1983</td>
</tr>
<tr>
<td></td>
<td>Higgins et al. [10], 1996</td>
</tr>
<tr>
<td></td>
<td>Mills et al. [11, 12], 1991</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Higgins et al. [18], 1997</td>
</tr>
<tr>
<td>[Heuristic, AI]</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Descriptive Approaches</td>
<td>Petersen et al. [2], 1986</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further, double-track lines, which are common in a mixed-mode system, have a much higher track capacity than single-track lines. Under normal operations, only meet-overtake operations can occur, but meet-pass operations do not on double-track lines. Thus, disruption is much less likely in double-track line cases than in single-track line cases, and minor disruptions tend to be resolved spontaneously. This situation suggests that double-track lines have already benefited from RCDRS improvements and relatively few additional improvements can be made. Thus, various heuristic approaches are preferred in
the mixed mode. However, double-track lines have much higher construction costs than single-track lines.

Particularly, this paper focuses on the two-phase approach. Roughly speaking, two research groups may be classified in this category, one is that of Harker [5] and Kraay et al. [6, 7], and the other employs the COMBINE II approach [8]. The solution approaches in these two groups are somewhat different, although similar in concept.

3 The Korean railway system

3.1 The network system

The Korean railway network had 3,129 km of line in 2002 [31]. Figure 1 shows the topology of the Korean railway network; only major lines are included. In Figure 1, the double and single lines represent double- and single-track lines, respectively. The Korean railway network forms a tree-graph configuration, with the root located at Korea’s capital city, Seoul (SEL). Since nearly one-third of Koreans reside in the capital region, most rail passengers and goods flow to and from SEL and the regional capitals. The SEL to Busan (BUS) corridor handles over 70% of the nation’s total railway transportation. Busan is Korea’s second-largest city and largest port.

Figure 1: Topology of the Korean railway network.
Lines 1 and 2 are currently the most important lines in the Korean railway system. They link SEL to BUS and SEL to Mokpo (MOK), respectively, by conventional train service. Line 0 (the double dashed lines in Figure 1) represents the high-speed line (HSL), which is scheduled to begin commercial operation in April 2004. In the near future, HSL service will be extended to BUS and will share the traffic load along the SEL - BUS corridor. Until the entire HSL is finished, the high speed train will complete the remaining segment to BUS along Line 1. The high speed train is also scheduled to operate along Line 2.

Presently, three CTC centers handle Line 1 and a small portion of Line 2. Additionally, one CTC center manages Line 3 and one HSL-CTC manages Line 0. The rest of the network remains in “dark territory.”

### 3.2 Traffic analysis

As mentioned above, an important factor in RCDRP is the number of conflicts, which directly depends on the following three components: the number of meets and overtakes, traffic intensity, and traffic diversity. We used five measures to classify the operating characteristics of the major lines. Two measures relate to network topology and modeling; the remaining three (mentioned above) relate to the problem size. Table 2 provides the results of the analysis.

![Table 2: Traffic analysis of the Korean railway network.](image)

<table>
<thead>
<tr>
<th>Lines</th>
<th>Track Capacity (trains)</th>
<th>Transport. Mode (pass./ frei.)</th>
<th>Meets &amp; Overtakes</th>
<th>Traffic Intensity</th>
<th>Traffic Diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEL~DAE</td>
<td>76<del>96 /5</del>24</td>
<td>OUT:188 IN:221</td>
<td>5.2</td>
<td>9.1~10.6</td>
<td>24</td>
</tr>
<tr>
<td>DAE~DON</td>
<td>46/19</td>
<td>OUT:46 IN:54</td>
<td>9.2</td>
<td>14.0~14.8</td>
<td>28</td>
</tr>
<tr>
<td>DON~BUS</td>
<td>50<del>52 /15</del>17</td>
<td>OUT:28 IN:31</td>
<td>11.2</td>
<td>13.3~13.9</td>
<td>52</td>
</tr>
<tr>
<td>DAE~IKS</td>
<td>44/15</td>
<td>OUT:25 IN:25</td>
<td>11.8</td>
<td>24.5</td>
<td>38</td>
</tr>
<tr>
<td>IKS~MOK</td>
<td>25<del>43 /9</del>13</td>
<td>OUT:5 IN:7</td>
<td>16.7</td>
<td>40.0~71.2</td>
<td>0</td>
</tr>
<tr>
<td>SEL~WON</td>
<td>33/48</td>
<td>58</td>
<td>11.1</td>
<td>40.1</td>
<td>7</td>
</tr>
<tr>
<td>WON~JAE</td>
<td>22<del>30 /45</del>52</td>
<td>226</td>
<td>19.2</td>
<td>31.4~69.0</td>
<td>100</td>
</tr>
<tr>
<td>JAE~KYU</td>
<td>23<del>41 /43</del>71</td>
<td>126</td>
<td>16.4</td>
<td>45.3~83.5</td>
<td>93</td>
</tr>
<tr>
<td>IKS~RYU</td>
<td>35<del>42 /28</del>45</td>
<td>112</td>
<td>15.2</td>
<td>42.1~53.4</td>
<td>31</td>
</tr>
<tr>
<td>CHN~JAN</td>
<td>51<del>54 /20</del>24</td>
<td>31</td>
<td>12.4</td>
<td>53.3~57.4</td>
<td>41</td>
</tr>
</tbody>
</table>
All values in Table 2 are obtained through several processing steps using data from KNR’s statistical yearbook [31] and KNR’s reference train schedule for 2002.

*Track Capacity* refers to the maximum number of trains operating per day for each line. Lines 1 and 2 have higher capacity than the other lines.

*Transportation Mode (Passenger/Freight)* refers to the number of scheduled passenger trains and freight trains. All major lines of the Korean railway are categorized as mixed mode, as shown in Table 1. Thus, this column focuses on the proportion of passenger transport to freight transport. Passenger transport dominates on Lines 1 and 2. Freight transport dominates Line 3. The other lines balance both passengers and freight to varying degrees.

*Meets & Overtakes* refers to the number of scheduled meets and overtakes along a line. For double-track lines, two values are provided, representing each direction. From the *Transportation Mode (Passenger/Freight)* and *Meets & Overtakes* columns, we can determine that each train experiences approximately 0.4 ~ 2.3 overtakes along Line 1 and approximately 0.7 ~ 3.4 meets or overtakes along Line 3. Values for the rest of the lines are rather low. This column shows that all trains running along Lines 1 and 3 have closely related schedules.

*Traffic Intensity* means the time between two sequentially arriving trains; *Peak* and *Average* refer to traffic intensity in a peak hour and the average traffic intensity value for all daytime hours. Line 1 peaks at 19:00~20:00; other peaks vary according to the line. These columns show that the response time restriction is more severe on Lines 1 and 2 than on other lines.

*Traffic Diversity* values are obtained by Eqn. (1), where, \( i = \text{train index}, n = \text{total number of trains}, V(i) = \text{maximum operating speed of train } i. \)

\[
D = \frac{\sum_{i=1}^{n-1} \Delta V(i)}{\sum_{i=1}^{n} V(i)/n}
\]
\[
\Delta V(i) = |V(i) - V(i+1)|
\]

In Eqn. (1), \( D = 0 \) when all trains have the same maximum operating speed; as consecutive trains begin to show speed discrepancy, \( D \to 2 \). We normalized the D value in a range from 0 (minimum) to 100 (maximum). *Traffic Diversity* shows the potential of a conflict occurring; single-track lines show a higher conflict potential than double-track lines with respect to the reference train schedule for 2002. The conflict potential also relates to issues discussed in Section 2.

4 Schematic and models of an RCDRS

From a topological point of view, the network can be divided into two parts (Figure 1). The first corresponds to Line 3, and the second corresponds to the GN. In GN, a disruption in one branch may affect normal operation on other branches. In this case, control over the entire GN is necessary. The two-phase
approach is appropriate for this problem. In the two-phase model, the entire GN problem is disaggregated into several relatively small problems. Thus, we could adopt a single phase-2 model for Line 3 and a two-phase model for the GN.

The disaggregated small problems correspond to the “pacing problem” in Harker [5] and Kraay and Harker [7], and to the conflict resolution system (CRS1) in the COMBINE II approach [8]. We refer to these problems as “phase-2 problems.” These phase-2 problems are coordinated by a single problem, or “phase-1 problem.” The phase-1 problem corresponds to the “inter-line planning problem” in Harker [5] and Kraay et al. [6] and to CRS2 in COMBINE II [8].

However, Harker [5] and Kraay et al. [6, 7] do not present the feedback control loop between the phase-1 and phase-2 models. In this single hierarchical control scheme, it is not guaranteed that the solutions of the phase-1 problem always hold for the time window constraints set of phase-2 problem, especially for an extremely complicated and busy network. Furthermore, unfortunately, a detailed model of COMBINE II is not yet publicly available.

Thus, we propose an RCDR framework to fit the Korean railway system. In order to derive the proper framework, we summarize the requirements for the two-phase RCDR model from Table 2. First, the individual objective function should be built according to Transportation mode. For example, if the passenger-mode dominates the line, then the punctuality-related term should be weighted; otherwise the freight-mode dominates, the fuel cost-related term should be weighted. It is another different aspect that coordinating the phase-2 models with heterogeneous objective functions from the state-of-the-art researches. Second, Meets and Overtakes directly indicates the problem size of each line. Single-track lines show higher values in Traffic Diversity; this means that RCDRS for the single-track lines are needed first.

![Figure 2: Schematic of an RCDRS for the Korean railway system.](image-url)
Also, Traffic Intensity shows that Line 1 acts as a bottleneck for the GN. Thus, the output range of the individual models for the branches from Line 1 is restricted by the operating condition of Line 1.

Another important requirement for the two-phase RCDR framework is that the coordinating process has to represent the dispatchers’ coordinating process in proper.

Figure 2 presents an RCDRS schematic for the Korean railway system. In Figure 2, RCDRS1 and RCDRS2s correspond to phase-1 and phase-2 models, respectively. In normal operation, RCDRS1 keeps the current feasible solutions for all interconnecting nodes, which are from the individual RCDRS2s. If any RCDRS2 detects a conflict from its responsible line, it solves its phase-2 problem to resolve the occurred conflicts, and sends the solution to RCDRS1. Then, RCDRS1 checks the feasibility of the updated schedule for the other keeping schedules. If the updated schedule is feasible, then RCDRS1 accepts the solution, otherwise, it coordinates for the related RCDRS2s to find the feasible solutions. In coordinating, RCDR1 considers all heterogeneous objective functions of the relevant RCDRS2s. Since this framework is quite similar with dispatcher’s work process in practice in the Korean railway, it can be seen as a very promising coordinating process in RCDRP.

5 Conclusion

In this paper, we proposed an RCDRS for the Korean railway system. To draw a proper RCDRS schematic and build a reasonable model, we reviewed and categorized relevant literature and analyzed the Korean railway system in detail. Based on the review and analysis, we proposed an RCDRS schematic and a two-phase system model. A further study including mathematical RCDRS modeling and analytical solution approaches for the RCDR problems is under way.

We present the following conclusions regarding the model.

- For the GN, the state-of-the-art researches are not guaranteed that the solutions of the phase-1 problem always hold for the time window constraints set of phase-2 problem, especially for an extremely complicated and busy network. In order to compensate this problem, we proposed a new two-phase approach framework.
- The framework for the two-phase approach is quite same with dispatcher’s work process, so that it can be seen as a very promising coordinating process in RCDRP.
- The heterogeneous objective functions, which are apparent characteristics of Korean railway system, present another different aspect from the state-of-the-art researches.

References


