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# CONSIDERATIONS OF OUT-OF-GAUGE FREIGHT TRANSPORTATION IN RAILWAY INFRASTRUCTURE DEVELOPMENT AND MAINTENANCE PROJECTS

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**Abstract:** The demands of railway infrastructure development are increased to meet rail transport requirements, particularly, for those large scale equipment and oversized cargoes that are often beyond railway gauges such as vehicle/infrastructure structure gauges. Railway administrators have to check clearances between out-of-gauge trains carrying with these railway out-of-gauge freights (ROFs) and all of railway infrastructures along their routes, i.e., bridges, tunnels, platforms, signal equipment and over-head power lines to ensure its safety. Therefore, the safety of ROF transportation requirements should be taken into consideration in railway infrastructure development and maintenance projects. This paper presents methods for modelling of ROF loading outline and the minimum infrastructure structure gauges. A railway gauges double-checking algorithm has also been developed to calculate gap distances between vehicles and infrastructures which can provide useful information for railway designers, engineers and managers in the design, construction and maintenance of railway infrastructures. A case example of ROF transport routing problem is used to demonstrate the clearance safety requirements. The results show that gap distances between vehicles and infrastructures are major factors that can impact on ROF transportation safety, which should be integrated into the design, construction and maintenance projects of railway infrastructures.

**Keywords:** railway infrastructure, railway gauges, loading outline, clearance safety requirements, out-of-gauge freight transportation.

## 1. INTRODUCTION

Generally, trains and railway infrastructure structures are built to vehicle gauges and structure gauges, respectively, and there are safe clearances or gaps requirements between trains and infrastructure. As the safest and lower cost form of ground transportation, more and more cargoes, including lots of large scale equipment and oversized cargoes, are being attracted by railway transport. Railway out-of-gauge freights (ROFs) refer to these oversize cargoes which are much wider, longer or higher than other kinds of railway freights, and ROF loading outline is often beyond railway gauges such as vehicle gauges and railway infrastructure structure gauges (Zhang et al. 2016), and railway out-of-gauge trains carrying with ROFs are underlying factors for railway accidents. Railway companies have to locate unsafe railway infrastructure precisely and further carry out some necessary maintenance projects for these infrastructures with small clearances and high risks for ROF safety transportation. Moreover, the railway now finds itself in a situation where safety is a real and urgent issue, to be dealt with in a public culture of rapid change, short-term pressures and instant communications (An, 2006), and risk management is becoming increasingly important for railway companies (An, 2011; An, 2016). As an important component of railway risk management, railway administrators have to check and judge clearances safety requirements between out-of-gauge trains and all of railway infrastructures along their routes, i.e., bridges, tunnels, platforms, signal equipment, over-head power lines to ensure its safety. However, there are so many

small railway infrastructures gauges that lots of ROFs may be transported unsafely. Railway companies should reconstruct old infrastructures with small clearances or build new infrastructures with big clearances for railway transportation safety with high efficiency.

There was a time when trains were built to vehicle gauges, structures were built to structure gauges, and there was a large gap between the two (Johnson, 2008). It was immediately clear that gauge sensitive freight traffic did not, and would be unlikely to, operate on large sections of the network; it would be possible to determine a hierarchy of routes to be considered for enhancement. Wilson (2008) outlined the historical development and issues which affect railway vehicle gauge on the Great Britain rail network. Since ROFs loading outlines are often bigger than general railway freight, ROF safety transport is much more sensitive to the heritage structure gauges in the rail network. Thus, costly temporary maintenance tasks are often needed to solve ROF transport routing problem (namely ROF-TRP). The safety of ROF transportation requirements should be taken into consideration in the railway infrastructure development and maintenance projects in order to reduce such costly work. Also, if railway infrastructure gauges can meet clearance safety requirements for out-of-gauge trains running in the rail network, there must be larger safe gaps between other trains and infrastructures.

ROF safety transport is affected by gap distances between rail vehicles and infrastructures greatly. Few literatures were dedicated to analyse gap distances and check clearances between ROF loading outline and railway gauges. In practice, out-of-train dispatchers often check them simply by comparing ROF's widths and railway gauges at the same height, which has potential risks, i.e., neglecting controllable infrastructures. Thus, a safety gap distance calculation and gauges checking method is crucial for railway safety transport. Although Tang et al. (2012) has designed an optimal model for ROF transportation route, they did not refer to the gap distance calculation and gauges checking problem. If detail information about gap distance between ROF loading outline and railway gauges cannot be gained, it will lead to severe rail safety issues, i.e., train collisions with these infrastructures along routes due to unsafe clearances, and train derailment. Wang (2012) has studied railway out-of-gauge trains transport organization problems, and Zhang et al. (2016) have discussed non-crossing block sections setting rules for railway out-of-gauge train running on double-track railway line. In order to make maximum use of the restrictive and sensitive railway gauges, a new method to check gap distances and clearances precisely between ROF loading outline and railway gauges will be proposed and the needs of rail infrastructure development and maintenance projects on basis of ROF safety transportation will be studied at the first time in the paper.

The remainder of this paper is organized as follows. Section 2 analyses ROF loading outline and railway infrastructure structure gauges and their gap distances. A railway gauges double-checking algorithm is developed to calculate gap distances between ROF loading outline and infrastructure structure gauges in order to judge clearance safety requirements in Section 3. Then, a ROF transport routing model based on safe clearances is designed and its solution method is also put forward in Section 4. In section 5, discussions about railway infrastructure development and maintenance projects based on a case of ROF-TRP are given. The paper is finished in Section 6 with some conclusions and discussions for our future research.

## **2. ROF LOADING OUTLINE AND INFRASTRUCTURE STRUCTURE GAUGES**

Since ROF loading outline may beyond railway gauges and the freight train is general heavy, their maximum loaded weight, length and speed for freight trains, i.e. out-of-gauge trains,

must be restricted (Lei & Rose, 2008). For oversize cargoes, their transport routes should be selected on basis of railway gauges and clearances for safety. Meanwhile, large gap distances construction criteria should be taken into consideration in railway infrastructure development and maintenance projects to guarantee railway transport safety and reduce potential risks.

It's the first thing for a safety route that there are enough clearances or gaps between railway loading outline and infrastructure structure gauges. Also, there are many factors for shaping ROF loading outline, such as original outline (maximum height and width), loading vehicle's characteristics (i.e. vehicle type and number, possible highest or lowest vehicle floor's height, bogie center distance). In general, typical ROF loading outlines are shown in Figure 1.

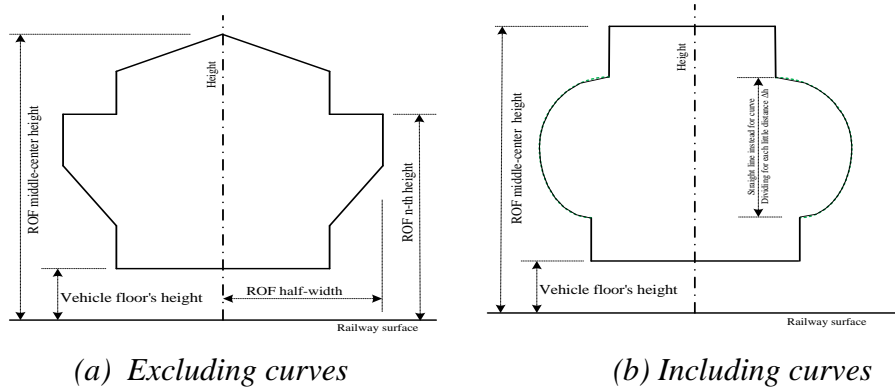


Figure 1: ROF loading outlines

In Figure 1, the horizontal axis is the railway surface and the vertical axis is the longitudinal center line of ROF loading vehicle and railway tracks; the highest loading height is named as middle-center height, and the lowest height is equal to its loading vehicle floor's height. For other heights from top to bottom, they are called 1<sup>st</sup>-side height, 2<sup>nd</sup>-side height, ..., n<sup>th</sup>-side height respectively. If there is a curve in a ROF loading outline (please see Figure 1(b)), it can be divided into straight lines for each small height  $\Delta h$ . ROF loading vehicles may be remarshaled many times at marshalling stations, and it's difficult to control ROF running directions (Wang, 2012). Also, in order to make maximum use of restrictive loading gauges, a systematic method for validation is essential for obtaining dependable results (Perez et al, 2008). Out-of-gauge dispatchers often consider that loading outline is exactly symmetrical to guarantee safety. Thus, a ROF loading outline can be recorded as shown in Table 1.

Table 1: ROF loading outline (unit: mm)

No.	Location	Higher height	Lower height	Half-width
0	Middle-center height	> Floor's height		> 0
1	1 <sup>st</sup> -side height	> Floor's height		> 0
...				
n	n <sup>th</sup> -side height	> Floor's height	Floor's height	> 0

Thus, ROF loading outline can be further represented as

$$\mathbf{H} = \begin{pmatrix} h_{00} & h_{01} & w_0 \\ h_{10} & h_{11} & w_1 \\ \vdots & \vdots & \vdots \\ h_{n0} & h_{n1} & w_n \end{pmatrix} \cup \begin{pmatrix} h_{00} & h_{01} & -w_0 \\ h_{10} & h_{11} & -w_1 \\ \vdots & \vdots & \vdots \\ h_{n0} & h_{n1} & -w_n \end{pmatrix},$$

where  $h_{a0}$  ( $h_{a0} > 0$ ),  $h_{a1}$  ( $h_{a1} > 0$  or  $h_{a1} = \text{NULL}$ ),  $w_a$  ( $w_a > 0$ ) express the higher height, the lower height and the half-width at the  $a$ -th side height ( $a \in \{0, 1, 2, \dots, n\}$ ).  $w_a$  and  $-w_a$  indicate that half-width at the right and left of the longitudinal center line of railway tracks respectively. If  $h_{a1} = \text{NULL}$  ( $a < n$ ) or  $h_{a1} = h_{a+1,0}$  ( $h_{a1} > 0, w_a \neq w_{a+1}, a < n$ ), the two neighbour side-heights  $a$  and  $a+1$  are connected by an oblique line (see oblique lines in Figure 1(a)). Also,  $h_{00} > h_{10} > \dots > h_{n0} > 0$ ,  $h_{a0} > h_{a1}$  ( $h_{a1} > 0, \forall a$ ),  $h_{a1} \geq h_{a+1,0}$  ( $h_{a1} > 0, a < n$ ),  $h_{n1} > 0$ .

Another factor of the clearance is the railway structure gauge (Wilson, 2008; Johnson, 2008). There are bridges and tunnels gauges and other infrastructures (i.e. platforms, buildings, electrical equipment boxes, railway signal equipment and over-head contact line equipment) gauges in railway system (Wang, 2012; Zhang et al., 2016). For each railway intersection, there is a minimum comprehensive structure gauge which is determined by bridges and tunnels gauges, other infrastructures gauges in this intersection. It is not symmetrical in most conditions. When trains pass through these intersections, their loading outline must be within the minimum comprehensive structure gauges for safety, which can be expressed as

$$\mathbf{S} = \begin{pmatrix} h'_{10} & h'_{11} & w'_1 \\ h'_{20} & h'_{21} & w'_2 \\ \vdots & \vdots & \vdots \\ h'_{m0} & h'_{m1} & w'_m \end{pmatrix},$$

where  $h'_{b0}$  ( $h'_{b0} > 0, b \in \{1, 2, \dots, m\}$ ),  $h'_{b1}$  ( $h'_{b1} > 0$  or  $h'_{b1} = \text{NULL}$ ),  $|w'_b|$  ( $w'_b \neq 0$ ) express higher heights, lower heights, distances from the longitudinal center line (all units are mm), and  $m$  indicates the total number controllable locations for the gauge. If the controllable location on the minimum comprehensive structure gauge lies at the right of the longitudinal center line, the value of  $w'_b$  is positive; otherwise,  $w'_b < 0$ . If the controllable part is isolated from other equipment,  $h'_{b1} = \text{NULL}$ . Let  $\mathbf{S}_{ij}$  denote the minimum comprehensive structure gauge at the intersection  $e_{ij}$  between two railway adjacent stations  $p_i$  and  $p_j$  in a given rail network  $\mathbf{G}$ .

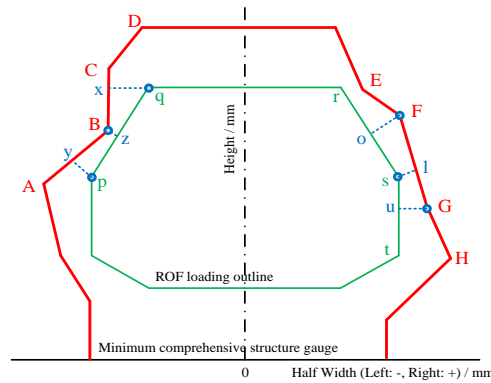


Figure 2: Gap distances between loading outline and railway gauges



In Figure 2, the outer red lines indicate the minimum comprehensive structure gauge and the inner green lines mean ROF loading outline. All gap distances at controllable parts (such as points A-H and p-t in Figure 2) of the minimum comprehensive structure gauge and ROF loading outline should be calculated. Then, the minimum one  $dis(\mathbf{H}, \mathbf{S}_{ij})$  can be expressed as  $dis(\mathbf{H}, \mathbf{S}_{ij}) = \min\{|py|, |qx|, |sl|, |Bz|, |Fo|, |Gu|, \dots\}$ . ROF loading outline consists of straight lines while structure gauges are composed of straight lines and isolated points (Wang, 2012). Thus, there are two cases for each ROF gap distance, which can be further determined by the following methods (the controllable parts  $r'$  and  $s'$  are at the ROF loading outline and the controllable part  $F'$  is at the minimum comprehensive structure gauge in Figure 3;  $y'$  is the pedal point): (i) Gap distance between the point  $F'$  and the straight line  $r's'$  is  $|F'y'|$  (Figure 3(a)); (ii) Gap distance between them is  $\min\{|F's'|, |F'r'|\}$  (Figure 3(b)).



Figure 3: ROF gap distance calculation methods

### 3. RAILWAY GAUGES DOUBLE-CHECK ALGORITHM

The correct calculation and checking method of gap distance between ROF loading outline and railway gauges is crucial for ROF safety transport, but it's ignored by Tang et al (2012). As shown in Figure 2, if gap distances are calculated based on controllable parts at the ROF loading outline (the former method), the minimum gap distance is  $|sl|$  and the controllable location is at the right of the loading outline. However, the actual smallest clearance is at the left of the longitudinal center line ( $|Bz| < |sl|$ ) and the real controllable location is at the left of the loading outline. Similarly, it's unsafe to calculate gap distance only based on controllable points at railway gauges (the latter method). There is an example (see Figure 4(a)) to demonstrate the latter one has also potential transport risks. If gap distances are calculated based on controllable parts (blue ones) at railway gauges, the train carrying with such ROFs can run at the intersection safely. However, ROF loading outline is beyond railway gauges in the intersection, i.e., the controllable parts (red cross ones) as shown in Figure 4(a).

From Figure 2 and Figure 4 (a), neither the former nor the latter method is secure and both methods have potential risks. Thus, gap distances should be calculated by all controllable parts both at ROF loading outline and railway gauges (namely double-checking), and the minimum gap distance between them and controllable infrastructure parts or locations will be determined. Railway gauges double-checking algorithm (RGDCA) can be described as,

**Input:** ROF loading outline  $\mathbf{H}$ , railway structure gauge  $\mathbf{S}_{ij}$ , safety allowance  $\delta$ .

**Output:** Minimum gap distance  $d_{\text{gap}}$  (mm), controllable infrastructure parts  $\mathbf{L}_{\text{gap}}$ .

- Step 1:** Assume temporary gap distance sets  $\mathbf{g}_H = \emptyset, \mathbf{g}_S = \emptyset, \mathbf{g}_{ROF} = \emptyset$ , and controllable infrastructure parts and its locations  $\mathbf{g}_{cpl} = \emptyset, d_{temp} = 0, d_{gap} = 0$ .
- Step 2:** Calculate gap distances  $d_{temp}$  based on controllable parts at ROF loading outline  $\mathbf{H}$ ; if  $d_{temp} \leq d_{fix}$ , then  $\mathbf{g}_H = \mathbf{g}_H \cup \{d_{temp} - \delta\}$  and store its information into the set  $\mathbf{g}_{cpl}$ .
- Step 3:** Calculate gap distances  $d_{temp}$  based on controllable parts at railway gauges  $\mathbf{S}_{ij}$ , if  $d_{temp} \leq d_{fix}$ , then  $\mathbf{g}_S = \mathbf{g}_S \cup \{d_{temp} - \delta\}$  and store its information into the set  $\mathbf{g}_{cpl}$ .
- Step 4:**  $\mathbf{g}_{ROF} = \mathbf{g}_H \cup \mathbf{g}_S, d_{gap} = \min\{\mathbf{g}_{ROF}\}, \mathbf{L}_{gap} = \{l_{gap} \mid l_{gap} \in \mathbf{g}_{cpl}, d_{temp} = d_{gap}\}$ .

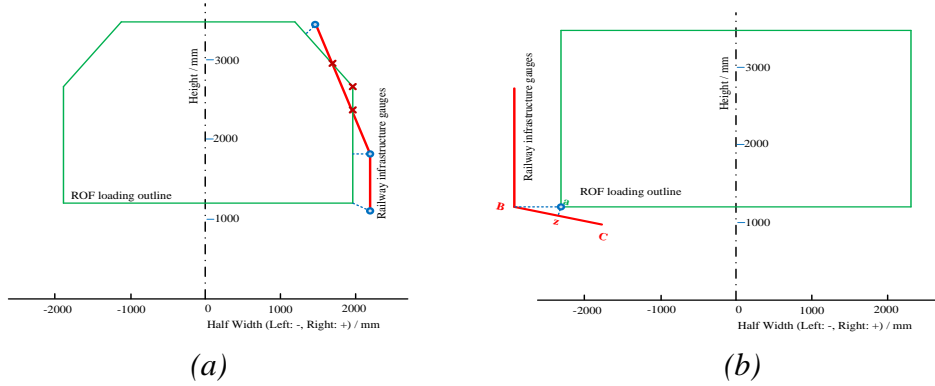


Figure 4: Comparison between different gap distance calculation methods

In the algorithm RGDCA, a constant  $d_{fix}$  is to exclude big clearances to reduce the size of gap distance sets. Temporary gap distance  $d_{temp}$  may be calculated by another simple method that is to compare half-width of the ROF and the distance (from controllable parts at structure gauges to the longitudinal center line) at the same height. Although such method may be easy to understand and safe in many situations (as shown in Figure 4 (a)), it has potential risks and leads to unpredictable train accidents. In Figure 4 (b), point “a” is a controllable part at ROF loading outline, while point “B”, “C” is controllable parts at railway gauges. Point “a” and “B” are at the same height. Point “z” is the pedal point at straight line “BC” from the point “a”. With such simpler method, the gap  $|aB|$  is so large that there is enough clearance and such ROF may pass through the intersection safely. However, the actual minimum distance is  $|az|$  and it cannot pass it through safely. Therefore, the proposed double-checking algorithm based on the proposed gap distance calculation method should not be ignored or replaced for safety.

#### 4. ROF TRANSPORT ROUTING MODEL BASED ON SAFE CLEARANCE

The key of ROF-TRP is to find the most economic route for ROF transport from its origin station to destination station in the railway network with the constraints of flow balance at each railway station and safe clearance requirement between ROF loading outline and railway infrastructure structure gauges along its path to guarantee ROF transport safety.

Let  $\mathbf{G} = (\mathbf{V}, \mathbf{E})$  express the rail network, in which  $\mathbf{V}$  expresses the railway stations set and  $\mathbf{E}$  is the railway intersections set. There is only ROF flow-out at the origin station  $o(o \in \mathbf{V})$ ,



only ROF flow-in at the destination station  $d (d \in \mathbf{V})$ , and there is equivalent flow-in and flow-out at other stations along the transport route. Let  $\varphi(i) = \{j \in \mathbf{V} | e_{ij} \in \mathbf{E}\}$  demonstrate the out-adjacent stations set of the station  $p_i$ , and  $\beta(i) = \{j \in \mathbf{V} | e_{ji} \in \mathbf{E}\}$  indicate its in-adjacent stations set. Thus, the flow balance constraint in the rail network  $\mathbf{G}$  can be expressed by,

$$\sum_{j \in \varphi(i)} x_{ij} - \sum_{j \in \beta(i)} x_{ij} = \begin{cases} 1 & i = o \\ 0 & i \neq o, d \\ -1 & i = d \end{cases} \quad (1),$$

where  $x_{ij}$  is the decision parameter of ROF-TRP and its value is 0 or 1. If the railway intersection  $e_{ij}$  is selected as one part of the ROF transport route,  $x_{ij} = 1$ ; otherwise,  $x_{ij} = 0$ .

It's unavoidable that ROF loading outline will change occasionally due to loading vehicle and track vibration problems (Lei & Rose, 2008). It's necessary to set a safety allowance  $\delta$  (mm) for the gap distance. The safe clearance constraint between loading outline  $\mathbf{H}$  and the minimum comprehensive structure gauge  $\mathbf{S}_{ij}$  should be expressed as  $dis(\mathbf{H}, \mathbf{S}_{ij}) - \delta > 0$ .

The objective function of ROF transport routing model for ROF-TRP is the total transport cost determined mainly by its total distance and out-of-gauge grade. The total distance of ROF transport route is  $\sum (x_{ij} d_{ij})$  (km), and  $d_{ij}$  is the distance between two adjacent stations  $p_i$  and  $p_j$ . The total transport cost can be further rewritten as  $\omega \mu \sum (x_{ij} d_{ij})$ , and  $\omega$ ,  $\mu$  represent the freight's weight (ton) and transport price per ton-kilometer (¥/t·km) respectively.

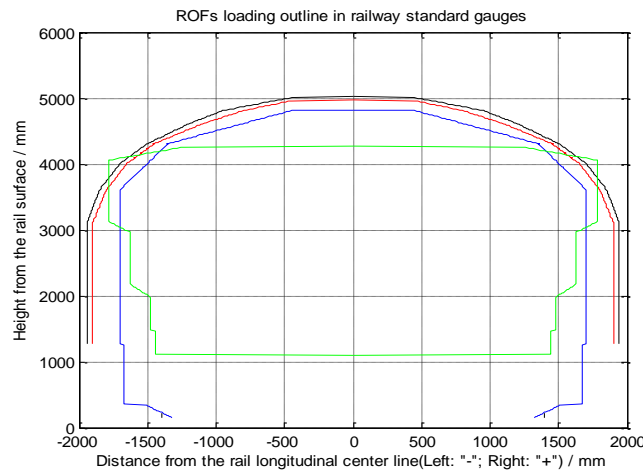


Figure 5: Railway standard gauges and ROF out-of-gauge grades

Transport price per ton-kilometer  $\mu$  may rise due to features of railway freights and the gap distances. For ROF transportation, its price floating ratio  $\varepsilon$  is different according to the oversize extent and gap distances between loading outline and railway standard gauges, measured by out-of-gauge grades. As shown in Figure 5, if ROF loading outline (the green lines) is between the vehicle gauge (the blue lines) and the first standard gauge (the red lines), ROF is subordinate to the first out-of-gauge grade; if ROF loading outline is between the first standard gauge and the second standard gauge (the black lines), ROF is subordinate to the second out-of-gauge grade; if ROF loading outline is beyond the second standard gauge, ROF

is subordinate to super out-of-gauge grade. Although different parts at the ROF may have different out-of-gauge grades, the most severe one is taken as the final judgment criteria. As shown in Figure 5, ROF loading outline is beyond the second standard gauge at the height of 4,000 mm, which is the most severe one, thus, it's a super out-of-gauge cargo. Bigger the out-of-gauge grade, higher the floating ratio; the floating ratio has an upper bound. Thus, the basic transport cost  $f(o, d)$  (unit: ¥) can be calculated by  $f(o, d) = \omega\mu(1 + \varepsilon) \sum (x_{ij}d_{ij})$ .

Taking the minimum transport cost as the optimal objective function, a ROF transport routing model with the constraints of flow balance and railway safety clearances can be formed as,

$$\min f(o, d) = \omega\mu(1 + \varepsilon) \sum (x_{ij}d_{ij}) \quad (2)$$

Subject to

$$\sum_{j \in \phi(i)} x_{ij} - \sum_{j \in \beta(i)} x_{ij} = \begin{cases} 1 & i = o \\ 0 & i \neq o, d \\ -1 & i = d \end{cases} \quad (3)$$

$$dis(\mathbf{H}, \mathbf{S}_{ij}) - \delta > 0 \quad (4)$$

There are millions of infrastructures related to railway gauges in the whole railway network, and it's impossible for railway out-of-gauge dispatchers to check all gauges of intersections for each ROF transport task, which will take a long time to find all controllable locations at railway infrastructure in the whole rail network. The ideal solution of above model is to find some possible ROF transport routes firstly, gained by the k-shortest algorithm (Eppstein, 1998) from its origin and destination stations, and then check the minimum gap distance and clearances between ROF loading outline and railway gauges along these possible routes.

Under ideal conditions, ROF loading outline should be within all minimum comprehensive structure gauges at all intersections along its route. But it's not the situation for some ROFs safety transport. Railway structure gauges are fixed and unchangeable and it may be difficult to find a safe path for these ROFs whose loading outlines are beyond the railway structure gauges too much. And thus, there may be no feasible safe path from ROF's origin station and its destination station. It's also mean that railway companies cannot complete such ROF transport safely. However, railway companies have to organize and complete the task because most of ROFs are key infrastructures for national economy and defence construction and these tasks are often assigned by the government. In such case, railway companies have to carry out some costly railway infrastructures temporary maintenance projects in advance to remove or enlarge controllable infrastructures, i.e., railway signal equipment located at rail intersections, along selected routes in order to provide safe clearances and make out-of-gauge trains pass through them safely. In some situations, when out-of-gauge trains have passed them, these controllable infrastructures may be rebuilt to its normal conditions. If there are larger gaps or gauges criteria during original rail infrastructure development and maintenance projects, temporary controllable infrastructures maintenance tasks can be reduced greatly.

In addition, the safety clearance requirements for railway freight transport can be concluded by the case example of ROF-TRP and the gap distances between ROF loading outline and the minimum infrastructure structure gauges can be also gained (Controllable infrastructures and parts will be located), both of which can provide useful information for railway designers, engineers and managers in the design, construction and maintenance of rail infrastructures.

## 5. CASE STUDY AND DISCUSSION

There is a ROF transported from *Siping* Railway Station to *Jieji* Railway Station in China rail network. Its characteristics are as follows, weight: 55.00 ton, length: 13 200 mm, maximum height: 4 250 mm, maximum width: 3 660 mm. Also, its loading outline is shown in Table 2.

Table 2: ROF loading outline of the case study (mm)

Location	Higher height	Lower height	Half-width
Middle-center Height	4250	-	1231
1 <sup>st</sup> -side height	4050	3290	1780
2 <sup>nd</sup> -side height	3050	2170	1830
3 <sup>rd</sup> -side height	1970	1470	1750
4 <sup>th</sup> -side height	1470	1170	1400

Consideration of gap distances between ROF loading outline and railway standard gauges (please see Figure 5), it's a super out-of-gauge freight. Thus, the price floating ratio  $\varepsilon$  is 10% (its upper limitation). Taken the average price of China railway freight transportation in a given year as the ROF transport price per ton-kilometer  $\mu = 0.1551$  ¥/t-km, the objective function can be rewritten as  $f(o, d) = 55.00 \times 0.1551 \times (1 + 10\%) \sum (x_{ij} d_{ij}) \approx 9.38 \sum (x_{ij} d_{ij})$ .

With the proposed method in the paper, there are three possible routes for such transport tasks. R1 is *Siping* - *Zhengjiatun* - *Taipingchuan* - *Baicheng* - *Jieji*; R2 is *Siping* - *Changchun* - *Chuangchun North* - *Songyuan* - *Da'an North* - *Baicheng* - *Jieji* and R3 is *Siping* - *Zhengjiatun* - *Taipingchuan* - *Da'an North* - *Baicheng* - *Jieji*. After calculating gap distances and checking the clearance safety requirements, it's concluded that there are some unsafe intersections coloured with red in these possible paths, which further means that there are no large enough clearances for the out-of-gauge train passing them through safely.

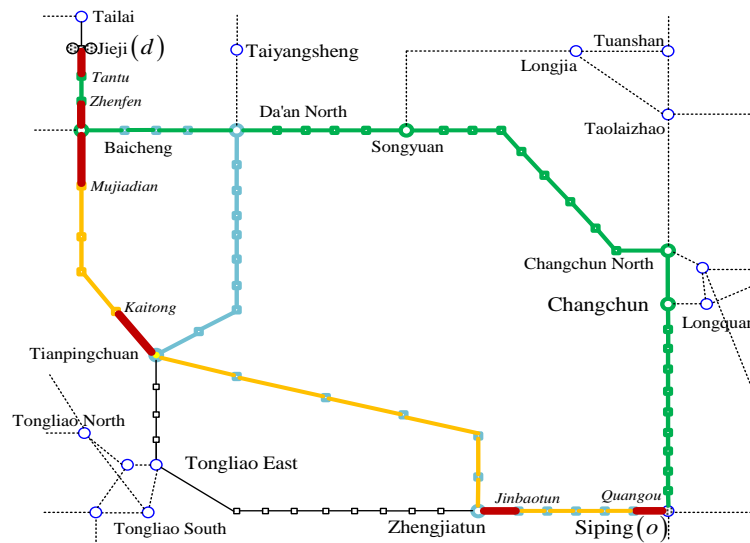


Figure 6: Possible ROF transport routes

Therefore, railway companies have to implement some necessary railway maintenance work or projects to remove or rebuild controllable infrastructures for rail safety transport. They have to gain some detail information of these unsafe infrastructures in advance. As for such case, they are located at railway intersections of *Baicheng-Zhenfen* and *Zhenfen-Jieji* in the longest route of R2, at the railway intersections of *Siping-Quangou*, *Jinbaotun-Zhengjiatun*, *Taipingchuan-kaitong*, *Majiadian-Baicheng*, *Baicheng-Zhenfen* and *Zhenfen-Jieji* in the shortest route R1 and at the railway intersections of *Siping-Quangou*, *Jinbaotun-Zhengjiatun*, *Baicheng-Zhenfen* and *Zhenfen-Jieji* in the route of R3 (as shown in Figure 6). Moreover, other related calculation results of these possible routes are shown in Table 3.

*Table 3: Comparison of calculation results*

<b>ROF transport route</b>	<b>R1</b>	<b>R2</b>	<b>R3</b>
Minimum gap distance (mm)	< 0	< 0	< 0
Other unsafe small gaps/clearances (mm)	1.00	1.00	1.00
	10.00	10.00	10.00
	12.00	12.00	12.00
	15.60	15.60	15.60
	19.00	19.00	19.00
Number/distance of safe intersections	14/310	30/666	24/488
Number/distance of maintenance intersections	6/134	2/51	4/79
ROF routing distance (km)	444	717	567
Values of the objective function (¥)	4164.72	6725.46	5318.46

If railway infrastructures gauges were big enough, there would be safe for all of these routes, which would mean that out-of-gauge trains carrying with these ROFs could run along with the shortest distances path (R1) and the total minimum transport cost were 4164.72 per ROF. Unfortunately, as shown in Table 3, there are 134 km with unsafe transport conditions in 6 railway intersections, 51 km with unsafe conditions in 2 railway intersections, and 79 km with unsafe transport conditions in 4s intersections. Small gaps, i.e. less than 20.00 mm, leads to some unsafe clearances, which will impact ROF transport safety greatly. For each route, the number of railway intersections needing maintenances can be gained as shown in Table 3.

In addition, for making better railway infrastructures maintenance plans, more specific information of railway controllable infrastructures or parts should be gained. Figure 7 shows the locations of unsafe clearances or gaps at certain equipment between *Baicheng-Zhenfen*. The unsafe railway infrastructure parts whose gap distances are less than 0 are shown as red crossings in Figure 7, which also means that ROF loading outline is beyond railway gauges at these infrastructures and the train cannot pass them through safely. Also, controllable locations with unsafe clearances, i.e. 1 mm, 10 mm, 19 mm, can be shown in Figure 7. With such information, railway engineers can get more clear maintenances aims and criteria, i.e., the location of these unsafe controllable infrastructures and requirements for new safe railway infrastructures gauges, in the railway infrastructures maintenance projects or schemes.

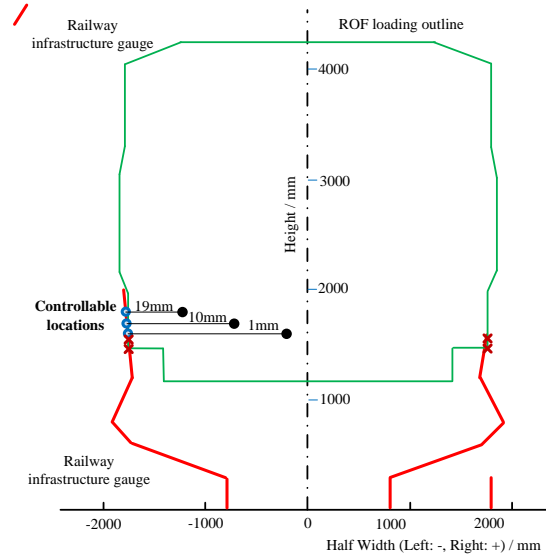


Figure 7: Locations of unsafe clearances at the intersection Baicheng-Zhenfen

From above analysis, it's concluded that that distances between vehicles and infrastructures are major factors that can impact on ROF transportation safety. Besides, with the proposed methodology, some useful information, i.e., detail intersections and mileages of controllable infrastructures and locations with unsafe clearances for such transport task, can be gained for railway infrastructures maintenance projects to guarantee railway transport safety. Specific bridges, tunnels, platforms, signal equipment or over-head power lines can be also achieved from the analysis of the minimum comprehensive structure gauge, which consists of railway bridges gauges, tunnels gauges and other infrastructures gauges. As for such case, the passing platform at *Baicheng* Railway Station is needed to be maintained to widen rail infrastructure structure gauge for ROF safety transport. With these useful information, railway designers, engineers and managers can make better railway infrastructures maintenance plans for safety.

Once railway infrastructures have been designed and constructed, railway gauges will be fixed and unchanged. For ROF safety transportation, railway companies often have to spend much more money and human resources to maintain them for safe clearances during the railway system operation phase. It's much easier and more convenient for railway companies to take such factors into consideration during railway infrastructures design and construction phases, which can save costs and human resources greatly. Nowadays, more and more ROFs with different characteristics are becoming main sources of railway freights due to its lower transport cost and higher secure level. Therefore, in order to implement ROFs transport tasks safely, reduce transport and maintenance cost and improve freights volume for railway companies, ROF safety transportation based on gap distances or safe clearances should be integrated into the design, construction and maintenance projects of railway infrastructures.

## 6. CONCLUSIONS

First, controllable railway infrastructures with unsafe clearances can be gained precisely and useful information about safe clearances requirements and gap distances criteria for railway infrastructures maintenance projects at railway intersections along ROF safe transport routes can be also gained from the results. Railway companies can apply the proposed method in the paper to make decisions about ROF-TRP and necessary infrastructures maintenance projects.

Second, railway gauges double-checking algorithm can avoid discarding controllable parts and equipment with high potential risks which may be neglected by railway out-of-gauge dispatchers, which can also provide useful information for railway designers, engineers and managers in the design, construction and maintenance of railway infrastructures. Thus, ROF safety transportation requirements should be taken into consideration in railway infrastructure design, construction and regular maintenance projects. Such considerations can help reduce unnecessary costly temporary maintenance projects, which may be the last choice for railway companies to transport ROFs safely assigned by the government. More detail safe clearance requirements based on ROF transport for specific railway infrastructures, i.e. bridges, tunnels, platforms, signal equipment and etc., should be further analysed and quantified for railway infrastructure development and maintenance projects, which are out next research tasks.

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