Ballast cleaning of single-track railway lines: a strategic analysis

An essential prerequisite for track-bound ballast cleaning of railway track, requiring a high availability and, thus, a minimum of track possessions interrupting railway traffic, is the use of efficient technologies and highly productive machines. This article presents three different ballast cleaning technologies for single-track railway lines. Using the worksite organisation programme SOG, an acronym of, in German, "Sperrpausenoptimierung im Gleisbau" (i.e. track possession optimisation for track construction), developed by the Institute of Transport, Railway Construction and Operation of the University of Hannover, Germany, work sequences are established for each of the three technologies described, based on the given duration of track possessions, thus allowing their respective cleaning output to be calculated. On the basis of the results obtained, potential applications for the technologies examined can be determined.

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In conventional permanent way, the track skeleton, consisting of rails, sleepers and track fastenings, floats on the ballast bed. In order to enable the track to absorb the static and dynamic stresses resulting from railway traffic without damage, and to transfer them to the substructure, the stability and elasticity of the ballast bed should be sufficiently high. This requires a suitable size distribution of the ballast stones (low proportion of fine grain) and interlocking of the individual stones (high level of sharp angles).

However, over the years, high ballast pressures, in combination with dynamic traffic loads, cause frictional wear of the ballast stones, eventually leading to the fracture of individual stones and, thus, the ballast bed loses its stability. Also, the ballast is subject to fouling resulting from railway traffic (e.g. brake fines, spillage, residue from open toilet systems), as well as to environmental conditions. It follows that the track geometry corrections that have been effected by tamping and lining gradually also lose their durability.

When defined quality and safety standards are no longer met, operational measures such as, for instance, speed restrictions, have to be implemented. If the intolerable condition of the ballast bed coincides with the sleepers and the rail requiring renewal due to wear, then a "complete track renewal with ballast cleaning" should be performed. This article only addresses the issue of restoring the ballast bed to its original condition by means of ballast cleaning.

BALLAST CLEANING CONSIDERATIONS

In order to restore the ballast bed to its original condition, the ballast should either be cleaned or replaced completely. During ballast cleaning, the ballast is excavated and the re-usable portion separated from the spoil by means of screening and placed back into the track with the addition of new ballast, as required. Then, by means of tamping, the correct track geometry is produced, and after this, the track is stabilised (if large quantities of new ballast are required, the ballast is placed into the track and compacted in several passes, in order to achieve the correct track geometry step-by-step). In order to avoid continuous welded rail to be subjected to excessive stress, it should be cut and fish-plated before the work is carried out. After ballast cleaning, and once the desired track geometry has been achieved, the rails must be re-welded. In Fig. 1, the individual work processes, divided into preliminary and main operations, are shown.

Work sequence no.	Description of individual work processes
	Preliminary operations
1	Pegging of the track in level and line
2	Cutting of the continuous welded rail (CWR)
3	Fish-plating
	Main operations
4	Ballast cleaning and disposal of spoil
5	First tamping pass
6	Placement of new ballast for the second tamping pass
7	Second tamping pass
8	Placement of new ballast for the third tamping pass
9	Third tamping pass
10	Re-welding of the rail

Fig. 1: Work processes in the course of ballast cleaning

Whereas during ballast cleaning of double-track railway lines the adjacent track can, at least occasionally, be used for transporting spoil and ballast, other solutions are needed for ballast cleaning of single-track railway lines.

Ballast cleaning of single-track railway lines: spoil removal and ballast supply

On single-track railway lines, only the track under repair can be used to perform the ballast cleaning tasks. Thus, the removal of spoil from and the supply of new ballast to the worksite has to be performed both in front of and behind the ballast cleaning machine, respectively (see also Fig. 2).

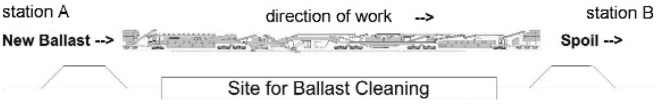


Fig. 2: Ballast cleaning worksite on a single-track railway line

Spoil removal

Material conveyor and hopper (MFS) units are ideal for transporting the spoil. A sufficient number of MFS units should be available, so that the full units can be taken away to be unloaded at a suitable location and returned in time for refilling before the units that remained in front of the ballast cleaning machine are full.

As the removal of spoil is carried out in the direction of work, it has no impact on subsequent stages of work, so long as continuous removal is ensured by a sufficient number of MFS units.

The quantity of spoil excavated per hour depends, besides on the existing ballast profile and the level of fouling of the ballast, largely on the output of the ballast cleaning machine. Thus, the number of MFS units used should suit the work progress of the ballast cleaning machine.

Ballast supply

For the supply of new ballast, self-discharging ballast wagons are best suited. Again, the number of wagons used should suit the work progress of the ballast cleaning machine.

Depending on track availability, as many wagons as needed for the entire section to be treated during the track possession can be towed. Alternatively, wagons can return during installation work to collect any further new ballast needed. In this case, the machines for subsequent stages of work, i.e. the tamping machine, the ballast profiling machine and the dynamic track stabiliser, can only enter the site under repair after the last ballast transport has been completed. This results in the strategy to use as many wagons as possible for the final ballast transport, so that it will take place as quickly as possible. This relationship is illustrated in Fig. 3.

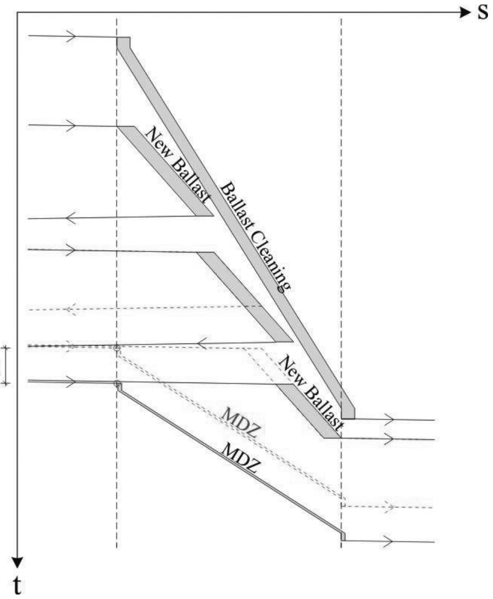


Fig. 3: Influence of the number of ballast wagons during the last ballast transport on the starting time of subsequent work processes

The decisive parameter for the necessary ballast quantity to be carried on each supply journey is the level of fouling of the ballast, which cannot be influenced by the technology used and, therefore, has to be regarded as given. The necessary quantity also depends on the length of track under repair and, thus, on the output of the machines and on the duration of the track possessions.

BALLAST CLEANING OF SINGLE-TRACK LINES: COMPARING THREE DIFFERENT TECHNOLOGIES

An essential prerequisite for track-bound ballast cleaning of railway track, requiring a high availability and, thus, a minimum of track possessions, is the use of efficient technologies and highly productive machines. For ballast cleaning, there are various machines on the market, each with a different output and functions, thus allowing them to achieve different levels of efficiency.

In Fig. 4, three different ballast cleaning technologies for single-track railway lines are presented, one with an average output, one with a high output and one with a very high output, using Plasser & Theurer machines which, due to their output, are suitable to work on sites with short track possessions.

BALLAST CLEANING TECHNOLOGY		**1**	**2**	**3**
Output		**average**	**high**	**very high**
Ballast cleaning machine without consolidation unit		RM 76 (195 m/h)	RM 80 (230 m/h)	RM 2002 (350 m/h)
MFS units continuously transport the spoil for disposal		MFS 100 (68 m^3, approx. 100 t)		
Supply of new ballast using self-discharging ballast wagons		ballast wagon (54 m^3, approx. 80 t)		
1st Mechanised Maintenance Train (MDZ 1)	Tamping machine	09-32	09-32	09-3X
	Ballast regulating machine	SSP 203	SSP 203	SSP 110
	Dynamic track stabiliser	DTS 62 N		
2nd Mechanised Maintenance Train (MDZ 2)	Tamping machine	09-32	09-3X	09-3X
	Ballast regulating machine	SSP 203	SSP 110	SSP 110
	Dynamic track stabiliser	DTS 62 N		

Fig. 4: The three different ballast cleaning technologies examined with respect to ballast cleaning of the 1,000 km, single-track model line

Each technology embraces the use of a ballast cleaning machine, MFS units for the removal of spoil, self-discharging ballast wagons for the supply of new ballast, and a mechanised maintenance train (MDZ), consisting of a tamping machine, a ballast profiling machine and a dynamic track stabiliser, for producing the correct track geometry with simultaneous consolidation and stabilisation of the track. The application of the dynamic track stabiliser allows the cleaned track to be reopened for traffic at full line speed immediately after completion of the work.

Using the worksite organisation programme SOG, an acronym of, in German, “Sperrpausenoptimierung im Gleisbau” (i.e. track possession optimisation for track construction), developed by the Institute of Transport, Railway Construction and Operation of the University of Hannover, Germany, work sequences are established for each of the three technologies described, based on the given duration of the track possessions, thus allowing their respective cleaning output to be calculated. On the basis of the results obtained, potential applications for the technologies examined can be determined.

The quoted outputs for the ballast cleaning machines take into account the difficult work conditions that can be expected in reality when lines are cleaned for the very first time. These conditions do require the use of experienced operators, well-maintained machines and an uninterrupted workflow.

Task definition: ballast cleaning a 1,000 km single-track line, within a period of 10 years

In the following, the extent to which the ballast cleaning technologies presented in Fig. 4 are suitable to achieve the defined task of ballast cleaning a 1,000 km single-track railway line, within a period of 10 years, is assessed.

Description of the model line

The 1,000 km model line used in the assessment is a single-track, broad-gauge, heavy-haul railway line with heavily fouled ballast, requiring frequent corrections of the track geometry. The line features approx. 200 km of passing track, also heavily fouled.

The characteristics of the model line can be summarised as follows:

- a 1,000 km single-track line and approx. 200 km of station track (passing points);
- 60 passing points of 2.5 km in length at, on average, 16.5 km intervals;
- track gauge: 1,600 mm;
- continuously welded rail (CWR);
- line speed: V_{max} = 80 km/h;
- 8 trains in each direction daily = 16 trains per day;
- axle load: 31.5 t.

With an average distance of 16.5 km between passing points, the worksite length between two stations, which feature double track for passing purposes, is 14 km.

Task definition

Ballast cleaning of the entire line should be completed within 10 years, thus requiring an annual cleaning output of 100 km of plain track and 20 km of station track. The spoil cannot be deposited at the side of the track.

As, due to climatic conditions (rain season), work can only be performed during 10 months of the year, 2.273 km of plain track needs to be cleaned per week. Based on a seven-day working week, this requires a daily output of at least 325 m of plain track. In addition, 500 m of station track must be cleaned per week, which is less problematic in terms of track possessions, as these feature double track.

For the cleaned track sections, the track geometry corrections spread over a two-year cycle, which implies that the required amount of track geometry correction work gradually decreases over time, in line with the amount of ballast already cleaned. Also, after sections of track have been cleaned, it must be possible to immediately reopen them for traffic at the full maximum permissible line speed of 80 km/h.

Worksite organisation using the SOG programme

Using the worksite organisation programme SOG, it is possible to plan the work sequences as time-travel lines and to derive alternatives for differing boundary conditions. In principle, the level of detail is freely selectable. The more detailed the individual stages of work are defined, the more accurate the model representation of the entire work sequence will be.

For the planning of the ballast cleaning work of the 1,000 km model line, a level of detail is chosen whereby the work processes listed as main operations in Fig. 1 are calculated and represented as individual time-travel lines. Each time-travel line includes the travel time to the worksite, the setting up of the work units, the work itself, the taking down of the work units, and the departure from the worksite.

Track possession alternatives

First, suitable track possession alternatives have to be worked out which, for the 1,000 km model line, have been defined as follows:

- *relatively short track possessions of varying duration (3h, 4h and 5h):* this alternative takes into account that traffic density is unevenly distributed over the day. In this case, the track possessions should be scheduled in the periods with the least traffic volume;
- *longer track possessions lasting, for instance, the entire weekend:* defined as continuous track possessions using multiple work crews, this alternative allows work to be performed without interruption, with changing work shifts. It takes into account that traffic density is unevenly distributed over the week. In this case, the track possessions could, for instance, be scheduled during the weekends;
- *two track possessions of different duration:* one track possession could be used for the cleaning operation and a first and second pass of the MDZ, and the second one for the placement of new ballast and the third pass of the MDZ. This alternative reflects the idea of combining a longer track possession during the night with a shorter possession during the day (or during the following night).

Then, for each of the three track possession alternatives, a worksite organisation plan has to be established, based on a systematic planning of the work sequences, and taking into account:

- *the different work steps of the different machines:* in this respect, it should be noted that the use of a ballast consolidation unit is not assumed in the planning of any of the three technologies examined, as it is not standard equipment on the ballast cleaning machines;
- *the number of mechanised maintenance trains (MDZs):* the work organisation plans for all three technologies include the use of two MDZs with different outputs (Fig. 4). Thus, only the different ways of distributing the three tamping passes between the two MDZs need to be evaluated. In the case of the 1,000 km model line, due to the high extent of ballast fouling, two placements of ballast are required to meet the total demand, and each has to be followed by a tamping pass. Therefore, the MDZ can only enter the worksite for carrying out the second and third pass after the ballast train, and has to evacuate the worksite before the ballast train returns to collect further ballast;
- *the number of material conveyor and hopper (MFS) units:* it is assumed that a spoil disposal site is available relatively close to the worksite, so that the MFS units can be unloaded after a relatively short transport time and be back at the worksite within 20 minutes of having left it (all MFS units are unloaded simultaneously).

Each of the three technologies examined uses a ballast cleaning machine with a different output, which leads to different durations for filling the MFS units, for the expected volume of one filled MFS unit per approx. 50 m of track (broad gauge). As a result, each technology requires a different number of MFS units, as shown in Fig. 5 (the figures shown in Fig. 5 result from calculations, based on the assumption that it takes 8 minutes to transfer ballast from one MFS unit into the next and that the ballast cleaning machine works continuously). Fig. 5 also shows the impact of a longer spoil transport lasting 30 minutes.

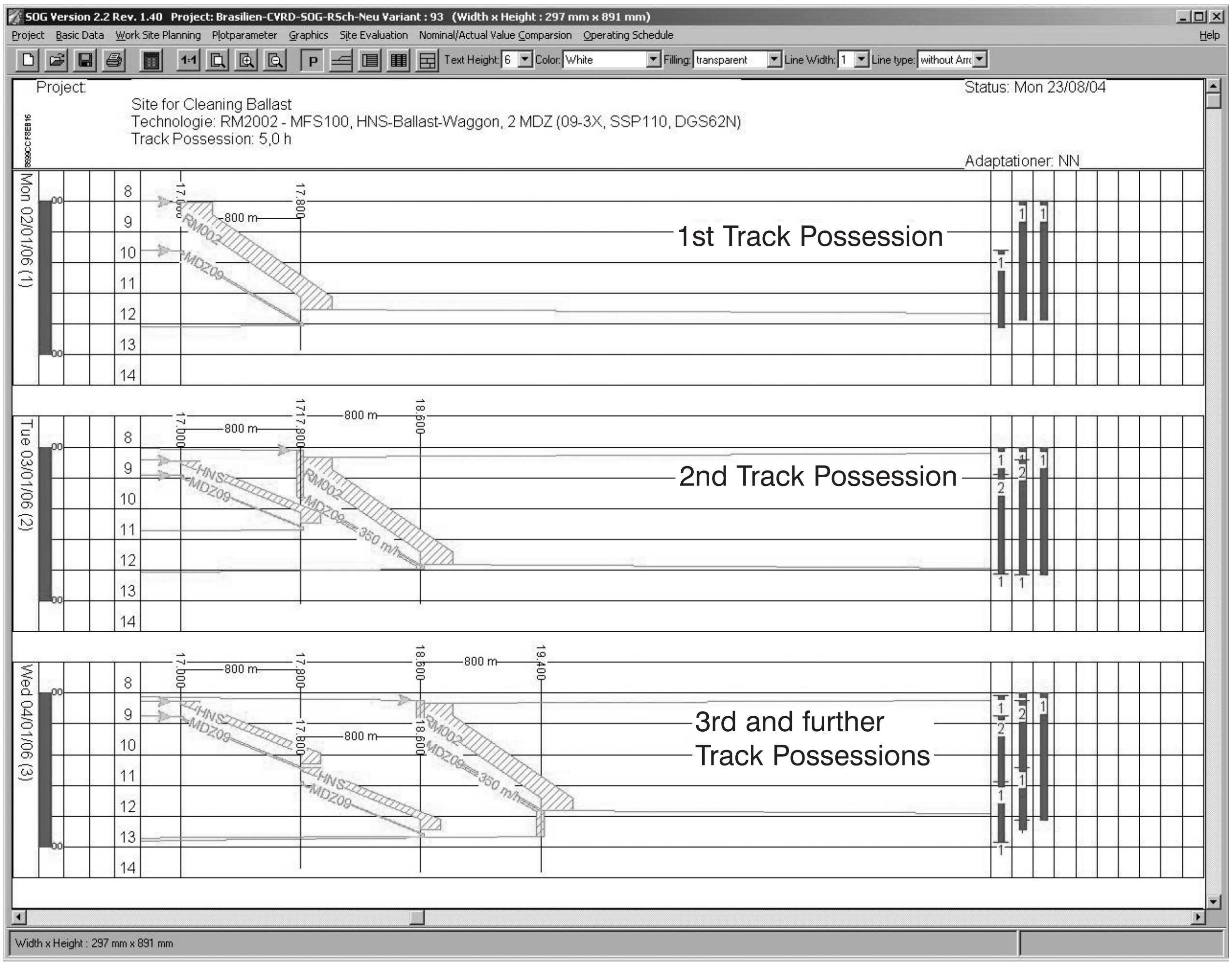
Ballast cleaning machine	Output (m/h)	No. of MFS units		Filling duration/MFS unit (min)	No. of MFS units required for continuous ballast cleaning for a spoil transport	
		per 50 m of track	per hour		every 20 min.	every 30 min.
RM 76	195	1	4	15	6	8
RM 80	230	1	5	13	7	10
RM 2002	350	1	7	9	16	24

Fig. 5: Number of MFS units required for each of the three ballast cleaning technologies examined

Other considerations also have to be taken into account. For instance:

- for the operations during the track possessions, the work sequences shown in Fig. 6 serve as a basis. From the third to the last but two track possession, the work processes performed remain identical. The ballast cleaning machine is used during all track possessions except the last one. In the course of the last track possession, the last but one cleaned section is tamped a third time, and the last cleaned section is tamped a second and a third time. An additional track possession is scheduled for the remaining in-situ re-welding of the rails;
- the length of track that can be cleaned within a single track possession decreases towards the middle of the worksite, due to the increasing travel distances for spoil removal and ballast supply. Then, as the worksite moves closer and closer to the next station or passing track, it increases again. Therefore, the results that will be shown for track lengths cleaned per track possession are average values;
- the supply of new ballast poses a specific problem when cleaning long sections of track, such as during weekend track possessions. In this case, the supply of ballast cannot be carried out in a single trip, as the ballast demand for 1.5 t/m rapidly adds up to significant volumes. Thus, the ballast wagons that have been emptied have to return to collect further new ballast, whilst the ballast cleaning machine continues working. This means that the MDZ either has to travel back to the station each time the ballast train makes its return trip, or it has to wait before it starts work until the last ballast transport has been completed.

Assuming a carrying capacity of 80 t per ballast wagon and a requirement of 0.75 t/m for each of the two passes of the MDZ, then for every 1,000 m of cleaned track, each pass of the MDZ requires 800 t of new ballast, i.e. 10 wagon loads. Thus, in order to minimise the time needed for the supply of new ballast, a sufficient number of ballast wagons and traction units should be available.


SOG Version 2.2 Rev. 1.40 Project: Brasilien-CVRD-SOG-RSch-Neu Variant : 93 (Width x Height : 297 mm x 891 mm)

Project:
Site for Cleaning Ballast
Technologie: RM2002 - MFS100, HNS-Ballast-Waggon, 2 MDZ (09-3X, SSP110, DGS62N)
Track Possession: 5,0 h

Status: Mon 23/08/04

Adaptationer: NN

Text Height: 6 Color: White Filling: transparent Line Width: 1 Line type: without Arr

Width x Height : 297 mm x 891 mm

Fig. 6: Work sequences during the first three track possessions

Worksite organisation for the model line: results

Fig. 7 shows the results of the analysis carried out with respect to the three different ballast cleaning technologies examined (RM 76, RM 80 and RM 2002) and for the track possession alternatives described, considering a worksite of 14 km in length.

BALLAST CLEANING TECHNOLOGY			1 RM 76	2 RM 80	3 RM 2002
Metres (m) of track cleaned per track possession (average values)	2 MDZ	3 h	298	352	552
		4 h	488	580	901
		5 h	687	813	1,266
		11 h + 5 h	1,673	2,013	-
		11 h + 7 h	-	-	3,083
	3 MDZ	11 h	1,673	2,013	3,083
No. of track possessions per 14 km track section (incl. in-situ re-welding of rail)	2 MDZ	3 h	49	42	28
		4 h	31	27	18
		5 h	23	20	14
		11 h + 5 h	10	9	-
		11 h + 7 h	-	-	5
	3 MDZ	11 h	10	9	5
Total hours of track possessions per 14 km track section (incl. in-situ re-welding of rail)	2 MDZ	3 h	147	120	84
		4 h	124	108	72
		5 h	115	100	70
		11 h + 5 h	149	117	-
		11 h + 7 h	-	-	82
	3 MDZ	11 h	99	82	61
Duration of continuous track possession (h), incl. in-situ re-welding of rail	2 MDZ	Continuous track possession	119	101	85
	3 MDZ		82	77	50

Fig. 7: Results of the analysis carried out with respect to the three different ballast cleaning technologies examined (RM 76, RM 80 and RM 2002), for the track possession alternatives described and a worksite length of 14 km

A few of the findings are discussed and explained in the following:

— when looking at the "total of track possession hours", it can be observed that, for each of the three technologies, it decreases when the duration of the individual track possessions increases. It is at its lowest for continuous track possessions, which can be explained by the fact that in this case unproductive travel and machine set-up/close-down times are minimised;

— track possession alternative "11h+5h" or "11h+7h": this alternative allows the ballast bed to be cleaned completely during the first track possession of 11 hours, and the MDZ to perform its first two passes, after which the cleaned section of track can be reopened for traffic. The duration of the second, shorter track possession, which should be planned in accordance with the output of the ballast cleaning machine and the MDZ, should be sufficiently long to allow the final placement of new ballast and the subsequent third and final pass of the MDZ to be performed on the track section already cleaned during the first track possession. For Technologies 1 (RM 76) and 2 (RM 80), a second track possession of 5 hours is favourable, and for Technology 3 (RM 2002) a track possession of 7 hours.

If three MDZs were available, the second track possession could be eliminated altogether, for all three technologies, as the third MDZ could, already during the initial track possession of 11 hours, produce the target track geometry of the sections already cleaned, and compact and stabilise them sufficiently for re-opening for traffic at the full line speed;

- matching machine outputs: the analysis of the three different technologies has shown that it is of great importance to match the outputs of the different machines used to each other. For instance, only the ballast cleaning machines used by the three technologies examined, including that of Technology 1 (RM 76), have a capacity of treating 300 m of track during a three-hour track possession. However, if only two MDZs are available, their output is barely sufficient to keep up with that of the ballast cleaning machines. This problem is most apparent when working with the very high output technology, using the RM 2002 (Technology 3), where only a three-sleeper tamping machine or a similar machine is able to produce the required output.

Looking at the results with the question in mind which of the three technologies and track possession alternatives examined would be most suitable for ballast cleaning the 1,000 km, single-track model line, Technology 1 (RM 76) for a track possession of 3 hours can be excluded as, in this case, the required daily cleaning output of 325 m cannot be achieved. All other alternatives would be feasible solutions for the defined task.

During the track possessions of 3 and 4 hours, an acceptable cleaning output, in terms of operational efficiency, can be achieved. A traffic density of 16 trains per day, as in the case of the model line examined, should enable track possessions of 3 and 4 hours.

However, if longer track possessions at night with subsequent shorter track possessions (e.g. track possession alternatives “11h+5h” or “11h+7h”) are possible, in terms of operations, then these should be strongly favoured, because unproductive travel and repeated machine set-up/close-down operations add to the worksite costs, as both machines and personnel are employed for longer periods.

CONCLUSIONS

The analysis presented in this article has shown that, using track-bound technologies, it is feasible to efficiently perform ballast cleaning of single-track railway lines, without interrupting traffic.

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