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Risk Assessment of Using a Contactless Method for Railway Surface Inspection as Alternative for Staff Inspection of Infrastructure

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Summary

Railway infrastructure managers are obliged to check technical condition of infrastructure in order to maintain safe traffic. Usually this is done using conventional methods and tools or directly through the inspections made by the technical staff. Technological development which is currently being experienced indicates the availability of new measurement methods that can be used to monitor the condition of railway infrastructure. However, the introduction of new methods for monitoring the infrastructure is usually a change affecting safety, which requires an assessment of the significance of the change for the maintenance of the required level of railway traffic safety. The authors assessed the significance of the change in the method of infrastructure monitoring and related risk assessment as a result of the use of the contactless method of checking the railway surface as an alternative method to staff inspections. Additional control measures or preventive measures for potential threats have also been indicated.

Keywords: staff inspection, infrastructure monitoring, UAV

1. Obligation of infrastructure managers to utilize a method of safety assessment and risk assessment and valuation

Pursuant to currently valid legal regulations, participants of the railway system, in particular railway carriers, railway infrastructure managers, entities in charge of railway rolling stock maintenance as well as manufacturers and service subcontractors, bear full responsibility for safety of the railway system [1, 2, 3, 4]. This is compliant with the rules defined in the directive on railway safety [5]. Ensuring appropriate safety level requires these entities to honestly identify threats and manage risks connected thereto. In addition, the continuously changing market and technological progress make it possible to utilize innovative solutions in railway transport incentivizes railway undertakings to introduce new methods and devices in their areas of activity. This in turn requires that the railway market participants ensure that the introduced changes are correctly managed and potential risks connected to them are effectively identified and controlled [6].

Thus, introducing a new method of railway infrastructure inspection requires ascertaining whether it is at least as safe and reliable as the process used before. In order to substitute staff inspections with aerial inspections, it is necessary to conduct an assessment of the change impact and to check whether the risks connected with the new method are at an acceptable level, This will be presented in the latter part of this article.

2. Performing staff inspection of railway infrastructure

One of the important reasons that curb railway manager development are high and constantly increasing costs of railway infrastructure maintenance. They comprise among others high costs of infrastructure repairs, the necessity to make capital-intensive investments, reconstruction and modernization as well as costs of continuous maintenance and systematic diagnostics of infrastructure. In particular, the recurring inspections and diagnostic examinations encourage managers to pursue solutions aiming at automatization of these processes.

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Railway measurement vehicles [7] with the function to record work, measurement location, or with GPS are already known on the market. These vehicles can also be furnished with optical or laser measurement devices [8], for instance for track geometry measurements [9]. Nevertheless, in such cases the vehicles require to be manned by qualified technical personnel and they also cause the railway line to be occupied during the measurements, which causes line throughput to decrease. Additionally, thus obtained data require time-consuming analysis [10].

In this article, the authors focused on railway surface inspection (visual) and on selected technical track tests which are most commonly performed by authorized personnel of a railway manager.

2.1. Conventional staff inspection

The obligation of regular inspections results from every authorized manager's internal regulations [11], which are a part of safety management system ensuring safe conduct of railway traffic. They are time-consuming processes requiring involvement of technical staff of the manger. Failure to conduct an inspection at the appointed time is a serious breach in infrastructure maintenance, one that generates risk of railway incident or accident [12].

The main task performed during inspections are visual checks of tracks wherein the condition of trackage is ascertained, as well as of traction network technical features and other fixed equipment, from the perspective of railway traffic safety. Track inspection is performer with frequency defined based on line category, intensity of its use and its technical condition; the maximum required number of inspections is two inspections per week. In addition, there is a necessity to perform diagnostics of railway infrastructure elements, e.g. to measure and assess technical condition of tracks and turnouts. Such diagnostics takes place once to twice per year. Furthermore, some of the managers introduced an additional requirement to perform inspections after two or more days without work in order to ensure that a given railway line supports safe railway traffic (check whether the path is passable and whether infrastructure was stolen from or damaged in a degree that would endanger safe railway traffic). It is assumed that the maximum efficiency when performing an inspection is 0.5 km/h. Such time-intensity of performed inspections requires significant involvement of staff in routine and time-consuming tasks [13, 14].

2.2. Contactless inspections

Technological progress and available aerial monitoring technologies [15] justify a statement that it is possible to configure a device so that it performs inspection of tracks and selected railway infrastructure elements; this would in most cases eliminate the need to perform staff inspections in favor of contactless aerial monitoring using unmanned aerial vehicles (hereinafter referred to as UAV) [16].

The premise of the further analysis is that a UAV is furnished with relevant measuring equipment allowing it to measure the required broad range of values necessary for appropriate monitoring and diagnostics of railway infrastructure condition; this includes checking such elements as:

1) rails: transverse cracks, breaches in rail heads, rail burns, too large lash between rails, ends of rails touching, short inserts (below 6 m);
2) railroad ties: longitudinal displacement, skew displacement, biological wear;
3) tracks: horizontal and profile deformations, wet beds, weed infestation and damage to side slope on a railway embankment or in a cutting, trees located closer than 15 m from the track, obstacles on the track, lack of clearance, condition and legibility of signs (Z1 indicator, D1 sign) [17, 18];
4) railway crossings: flangeway cleanliness, if run-through slabs are put correctly, condition and legibility of signs (W6a, G3, STOP signs) [19].

In this article an analysis is performed of the significance of the change consisting in substituting the conventional method of railway infrastructure inspection by a manager's technical staff with contactless method of railway infrastructure inspection by means of a UAV furnished with specialized measurement equipment. Subsequently an analysis was performed of the significance of thus planned change with conclusion whether such planned change affects the safety of railway system. It was also concluded whether the change significantly influences safety of railway traffic.

The subject of the article does not include the analysis of the infrastructure inspection conducted by means of a UAV or verification of the correctness of thus obtained measurements. It should be mentioned that first tests of such a solution are ongoing.

3. Assessment of change influence on railway system safety and alalysis of change significance

Any organizational or technical change in a railway manager organization requires that assessment of influence of the change on railway system safety is performed as well as assessment of the significance the implemented change causes. Main rules of conduct in such cases are set forth in Railway Transport Act [20] and Commission Implementing Regulation (EU) No 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment and repealing Regulation (EC) No 352/2009 as well as art. 6 of Directive 2004/49/WE of the European Parliament and the Council on safety on the Community's railways.

3.1. Assessment of change influence on railway system safety

The first stage of the analysis is ascertaining whether the proposed change will influence a manager's railway system safety. This entity is the final user of the systems approved for operations and maintained by the competent technical personnel in the organization as well as by external entities. In accordance with the abovementioned regulations, the full responsibility for railway traffics and services rendered rests with the manager. At this stage it is necessary to define as precisely as possible the system to undergo the change. It is therefore necessary to gather such amount and scope of data that would make it possible to reliably classify the change influencing (or not) the safety. When analyzing the notion of change, it must be noted that legal requirements are only relevant to the changes classified by a manager as connected with safety. Changes not connected with safety do not trigger procedures connected with risk management. Due to the fact that the change in question consist in significantly altered manner of performing maintenance of part of infrastructure and manner of performing inspections based on which a determination is made whether railway traffic is possible, such change will most certainly influence a manager's railway safety system. Automating inspection procedures and assessing infrastructure condition on the basis of computer analysis of data gathered during UAV flight significantly decreases the role of technical personnel in the assessment; up to this time the personnel made decisions based on their knowledge and experience in the field of infrastructure maintenance. Due to the fact that regulations concerning inspections are most commonly part of safety management system (thereinafter referred to as SMS) or integrated management system (thereinafter referred to as IMS), implementing changes in the manner of inspections shall also require the change of the basic document of a manager which is SMS or IMS as well as the instruction on railway surface diagnostics [21, 22].

3.2. Analysis of change significance

Once concluding that the change of manner of railway surface inspection influences a manager's safety system, it is necessary to assess the significance of this change: is it significant or insignificant for safety system. Further process of implementing the change will depend upon this decision. It is therefore of paramount importance that the assessment of influence on safety be done reliably by qualified personnel. It is advisable that the party applying for the change performs such assessment since they possess the best knowledge on conditions and circumstances in which the change is to take place. Nevertheless, subcontracting this service to third parties is acceptable.

Based on a professional assessment, a manager decides the significance of a change on the basis of criteria listed by the legislator. Every criterion should be assessed from the point of view of significance of the change on the safety system and subsequently justified. In case of substituting staff inspections of infrastructure with infrastructure condition verification by means of UAVs, the change significance assessment is as follows (Table 1).

As a result of the performed change significance analysis, it has been assessed that for two out of six analyzed criteria in the table above the change is significant, it is therefore deemed that the change is significant overall. For a significant change there is a necessity to identify and valuate risks as well as obtain an independent assessment from the entity assessing risk management process. The entity role is to verify and confirm that the risk management process at the party applying for the change was performed correctly and comprehensively. The assessing entity should potentially indicate whether there are any additional activities or analyses necessary to be implemented for the manager in order to ensure the required level of railway system safety after the change has be implemented.

3.3. Identification, classification and valuation of risks

Performing risk assessment and valuation should be done by a manager's competent specialists. It may be the same team which performed the change significance assessment, it is nevertheless possible to create a partly or wholly new team; the guiding rule should be that the task should in the hands of the specialists who know very well the system in which the change is being implemented.

As a result of the change significance analysis, the most important risks resulting from the implemented change in the system were identified (Table 2). Various assessment methods can be utilized for assessment of identified risks. It should nevertheless take into consideration that the method utilized should be adequate to the analyzed change and the environment in which it is being implemented. In case of railway surface inspection, it was decided to use FMEA method (Failure Mode Effect Analysis). It is used by companies to prevent or minimize consequences of flaws present in products or production processes. Using the method consists in investigating any and all flaws possible to foresee before a given solution is approved; in case of already existing

Table 1

Analysis of significance of a change in railway surface (staff) inspection by utilizing automated measurements by means of UAVs [6, 23]

Requirement from Commission Regulation (EU) No 402/2013	Is the change significant?	Answer justification
System failure consequence: credible worst-case scenario in the event of failure of the system under assessment, taking into account the existence of safety barriers outside the system under assessment;	No	Failure consequence in case of an incident will be identical as when the measurements are performed by railway staff.
Novelty used in implementing the change: this concerns both what is innovative in the railway sector, and what is new for the organization implementing the change	Yes	Remote measurement of track system parameters by means of programmed UAVs furnished with specialized sensors and cameras is a country-wide innovation in railway.
Complexity of the change	Yes	The change is complex since it influences other railway system elements, i.e. railway vehicles operating on the infrastructure, people, cars.
Monitoring: the inability to monitor the implemented change throughout the system life-cycle and intervene appropriately	No	The measurements performed will be regularly monitored with control measurements performed by technical personnel. Automatically performed measurements will be assessed by the system itself. Additionally, it will be possible for a manager's technical personnel to monitor measurement capability and quality as need arises.
Reversibility: the inability to revert to the system before the change	No	The change is reversible in nature as it is easy to go back to performing inspections by means of technical staff.
Additionality: assessment of the significance of the change taking into account all recent safety-related changes to the system under assessment and which were not judged to be significant	No	The change has no additionality indicators since until now no changes deemed significant were made in the system in question.

Table 2

FMEA risk identification and assessment [24, 25, 26]

Risks/environmental aspects (potential risks/environmental aspects identified when implementing the change)	Potential consequences	Existing means of control	P	D	S	RPN
Using a device without homologation	Erroneous measurement, adverse influence on train radiocommunication and traffic control devices	Systematic (daily) device control	1	1	9	**9**
Device not calibrated before measurements commence	Erroneous measurement	Device auto-check with alert in case no calibration is performed before operation	2	1	10	**30**
Local weather conditions making it impossible to perform measurements	Erroneous measurement, failure to measure	Verification by a dispatcher and technical personnel; performing inspection conventionally	3	3	10	**90**
Interference from traction network on the device operation	Erroneous measurement, failure to measure	Testing the device with active traction network; switching traction network off for measurements	2	9	9	**162**
Collision with devices outside the clearance gauge (poles and traction network, bridges)	Erroneous measurement, damages to persons or property	Programming flight route including existing obstacles; automatic collision-avoidance systems used by UAVs	3	2	9	**54**
Emission of interference onto railway traffic control devices	Improper functioning of railway traffic control devices or measurement equipment	Testing the device with active railway traffic control devices	1	2	10	**30**
Emission of interference onto train radiocommunication equipment	Improper functioning of train radiocommunication equipment, railway incidents	Systematic checks of radiocommunication equipment with devices on	3	3	10	**90**

Risks/environmental aspects (potential risks/environmental aspects identified when implementing the change)	Potential consequences	Existing means of control	P	D	S	RPN
Collisions with birds and other flying objects	Damage to measurement equipment, collision with persons or other vehicles	Automatic collision-avoidance systems to avoid collision with other flying objects; device check before measurements	4	2	9	**72**
Collision with a railway vehicle moving in the opposite direction	Damage to vehicle, railway incident or accident	Programming flight route, automatic collision-avoidance system	5	2	10	**100**
Rain or snow during measurements	Erroneous or incomplete measurement, failure to measure	Weather monitoring by a dispatcher	4	3	9	**108**
Strong wind or gusts of wind	Failure to measure	Weather monitoring by a dispatcher	3	6	9	**162**
Unclean track or track shoulder	Erroneous measurement, failure to measure	Verification of the unclean stretch by technical personnel	4	5	6	**120**
Power failure in the device	Failure to measure	Verification by a dispatcher and technical personnel	2	1	8	**24**
No connection with the Internet	No possibility to transmit measurement data	Verification of completeness of data transmitted by a dispatcher	2	2	10	**40**
No GPS signal (device disoriented)	Damage to device, collision with persons or other vehicles	Programming flight route and verification of GPS coverage during controlled flight	1	3	9	**27**
Low temperature, icing of the device	Shortened time of device operation, incomplete measurement	Weather monitoring by a dispatcher	3	4	8	**96**
Incorrect readout and interpretation of measurements by the device	Erroneous data and reports	Measurement devices calibration before and after measurements	4	6	10	**240**
Failure to train personnel on operating the device	Damage to device, erroneous measurements	Trainings technical personnel on operating the device as scheduled	2	3	7	**42**
Failure to train personnel in conservation and maintenance of the device	Improper device operation and erroneous measurements	Trainings of technical personnel who perform maintenance of the device as scheduled	2	3	8	**48**
Failure to maintain or incorrect maintenance of the device	Damage to device, erroneous measurements	Device maintenance activities planned and performed as scheduled	2	3	8	**48**

processes, it consists in investigating already occurring or potential flaws. Its final aim is to assess risk connected with planned or approved solution. Thus FMEA allows to realize the rule to minimize system flaws [27].

FMEA method is widely used because it is effective when analyzing complex processes and implementing new technologies in situations of risks to humans and the environment and when a device is used in disadvantageous conditions. FMEA should also aid in detecting potential factors that could impede or even make impossible realizing a process or manufacture a product. Correct execution of FMEA requires undertaking the following steps [28]:

- define the system undergoing analysis,
- produce a list of possible flaws or failures in reference to the defined system,
- produce a list of probable consequences of the indicated flaws,
- produce a list of causes of the indicated flaws,
- analysis of potential flaws
- define risks connected with flaws,
- plan and implement countermeasures and gauge their effectiveness.

For each flaw/failure, the following parameters are defined on a 1–10 scale:

- Flaw occurrence probability (P),
- Flaw detectability (D),
- Flaw severity for infrastructure (S).

The expert team performing FMEA defines values for P, D, S on the basis of the weights agreed on in advance for each team and for each parameter; for instance in case of an unlikely or very seldom flaw occurrence, P parameter should be set at 1–2, whereas for high or very high frequency of flaw occurrence the parameter should be 9–10. Similar approach is used when defining severity parameter S and detectability parameter D.

For analytical purposes, the risk priority number RPN is used, the product of P, D and S parameters. He higher the product, the more significant the flaw for the implemented change [29].

$$RPN = P{\cdot}D{\cdot}S.$$

It is assumed that a flaw is significant when its risk priority number exceeds 121. It should be noted that the higher the RPN, the more significant and severe the risk is for the entity applying for the change. RPN value exceeding 150 denotes a product-critical risk.

Abbreviations used in the tale below:
P – risk occurrence probability,
D – risk detectability,
S – risk severity, significance,
RPN – risk priority number.

Based on the risk matrix, the following risk levels are identified [30]:
1) unacceptable risk, significantly threatening safety, corrective measures to be taken immediately – risk level 1, RPN > 150;
2) risk is acceptable, suitable countermeasures should nevertheless be taken – risk level 2, 120 < RPN ≤ 150;
3) risk is acceptable and no actions are necessary – risk level 3, RPN ≤ 120.

In accordance with the performed identification and valuation of risk, unacceptable risk priority numbers occur in three cases (pos. 6, 14, 17). In order to approve the new solution for operations, additional control measures or countermeasures for risks with risk priority numbers RPN > 120 must be developed by a team of experts. Afterwards it needs to be checked whether after implementation of countermeasures the risk priority numbers decrease below 120. If yes, the new inspection technology will be able to be used. Nevertheless, regardless of the risk assessment method used, it is necessary to perform continuous monitoring of the implemented change which, due to its innovative character, may point towards new circumstances conducive to formation of new risks.

4. Conclusion

Dynamic development of new technologies, their increasing availability and decreasing costs cause that with increasing cost of staff and lack of availability of employees, innovative solutions are more and more often sought after by railway undertakings. Relatively hermetic and slow-changing railway is facing the challenge of safe implementation of new technologies which will allow railway transport to develop and decrease costs of operating in this sector. Regulations introduced by European Union legislation and national law indicate the guidelines to be fallowed and duties to be fulfilled when implementing changes in railway undertaking operations. It must be remembered that the legislator place responsibility for correct implementation of changes on entities applying for the changes; they were at the same time given freedom concerning the choice of method of risk assessment and valuation, introducing means of additional control or countermeasures.

In case of the change consisting in substituting (staff) inspection of railway surface with railway surface inspection using UAVs furnished with appropriate measurement equipment, the change is possible to be implemented. Analysis of influence assessment on railway system safety indicated that the change influences the safety and that the influence is significant. This means that the safety management process at an infrastructure manager's should be verified by an independent assessment entity. In addition, due to the fact of exceeding acceptable risk priority numbers, preventive measures minimizing risk should be implemented in the indicated cases. It is recommended that additional monitoring measures be defined in the first phase of new method implementation in order to maintain the required level of safety of railway operations.

It may be assumed that after these measures are performed, implementing the modern inspection method will be possible, safe and beneficent to infrastructure managers.

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