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ŽELEZNICE

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IX međunarodni simpozijum saobraćaja i komunikacija
NOVI HORIZONTI 2023

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Tabele, grafikone, crteže i fotografije staviti odmah posle pasusa u kojima se opisuju. Mogu da budu u jednoj ili preko obe kolone. Numerisati ih redom kako se pojavljuju. Njihove nazive pisati "italic" slovima uz levu marginu iznad tabela, a na sredini ispod grafikona, crteža i fotografija. Ispod svih njih, "italic" slovima u zagradama tipa "( )", navesti izvor podataka. Sadržaj unutar tabela pisati "normal" slovima u zagradama tipa "( )".

Upotrebljavati **osnovne jedinice SI (MKS)** mernog sistema. Ako se moraju koristiti druge, naznačiti ih. Jedinice se navode u zagradama tipa "[ ]".

Skraćenice i akronime označiti kada se prvi put upotrebe u tekstu, čak i ako su već nalaze u rezimeu. Opšte poznate skraćenice ne treba da se obrazlažu.

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Na sledećoj strani je model za pripremu radova

JOVAN JOVANOVIĆ*, ANA ANIĆ**, PETAR PETROVIĆ***

NASLOV RADA
NASLOV RADA NA ENGLESKOM JEZIKU

Rezime: tekst obima do 150 reči
Ključne reči: vreme, transformacija, koncentracija
Summary: prevod rezimea na engleski jezik
Key words: time, transformation, concentration

1. POGLAVLJE

1.1. Potpoglavlje

1.1.1. Potpoglavlje

Primer za formulu:

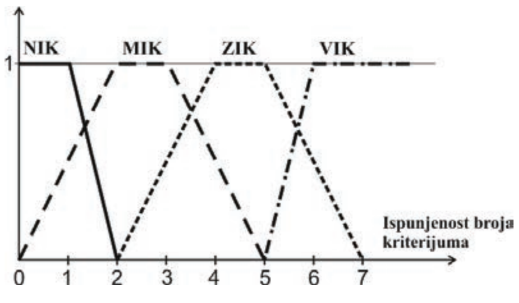
$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \times \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \quad (1)$$

Primer za tabelu:

Tabela 1. Naziv

Period dana	Srednji inter. sl. (min)	Iskoriš. kapac. (%)	Broj vozova		
			putnički	teretni	Σ
05–23	12,5	84	28	8	36
23–05	10,7	62	4	10	14
Ukupno			32	18	50

Primer za grafikon, crtež i fotografiju:



Slika 1. Naziv

Primer navođenja literature za rad objavljen u časopisu [1], knjigu [2], poglavlje u monografiji (knjizi) sa više autora [3], rad objavljen u zborniku radova sa konferencije [4] i članak preuzet sa veb sajta [5]:

LITERATURA

[1] Rongrong L, Yee L: *Multi-objective route planning for dangerous goods using compromise programming*, Journal of Geographical Systems, Vol. 13. No. 3, pp. 249-271, 2011.

[2] Law A: *Simulation Modeling and Analysis*, McGraw-Hill Inc, New York, 2007.

[3] Stojić G, Tanackov I, Vesković S, Milinković S: *Modeling Evaluation of Railway Reform Level Using Fuzzy Logic*, Proceedings of the 10th International Conference on Intelligent Data Engineering And Automated Learning, Ideal '09, Burgos, Spain, Springer-Verlag Berlin, Germany, 5788: pp. 695-702, 2009.

[4] Mladenović S, Čangalović M, Bečejski–Vujaklija D, Marković M: *Constraint programming approach to train scheduling on railway network supported by heuristics*, 10th World Conference on Transport Research, CD of Selected and Revised Papers, Paper number 807, Abstract book I, pp. 642-643, Istanbul, Turkey, 2004,

[5] Tod L, Tom R: *Evaluating Public Transit Accessibility ''Inclusive Design'' Performance Indicators For Public Transportation In Developing*, http://www.vtpi.org/tranacc.pdf, 2005.

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UVODNA REČ GLAVNOG UREDNIKA

Ovaj, specijalni broj časopisa ŽELEZNICE, posvećen je IX međunarodnom simpozijumu NOVI HORIZONTI saobraćaja i komunikacija 2023, koji je održan 24. i 25. novembra 2023. godine na Saobraćajnom fakultetu Doboj Univerziteta u Istočnom Sarajevu.

Organizator simpozijuma je Saobraćajni fakultet Doboj Univerziteta u Istočnom Sarajevu, a kao suorganizatori pojavljuju se značajne naučno-istraživačke institucije:

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Na simpozijumu je učestvovalo ukupno 172 autora iz 59 institucija iz 15 država sa 2 kontinenta. U Zborniku radova (dostupan na zvaničnom sajtu www.novihorizonti.rs.ba) objavljeno je 70 radova.

Na simpozijumu su učestvovali istraživači iz: Austrije, Srbije, Bosne i Hercegovine, Crne Gore, Češke, Hrvatske, Italije, Litvanije, Makedonije, Nemačke, Poljske, Rusije, Slovačke, Slovenije i Uzbekistana.

Posebno nas raduje činjenica da radovi iz oblasti železničkog saobraćaja i transporta čine dvadeset procenata ukupnog broja radova. Od ukupno 14 radova koji se bave problematikom železnice, Uređivački odbor ovog časopisa, u saradnji sa članovima Programskog odbora Simpozijuma, izabrao je šest radova koji su, uz saglasnost autora, objavljeni u celini u ovom, specijalnom broju časopisa ŽELEZNICE. Radove objavljujemo u originalu na jeziku na kojem su pisani i bez prevoda.

Posebnu zahvalnost uredništvo časopisa duguje dekanu Saobraćajnog fakulteta Doboj prof. dr Zoranu Ćurguzu, predsedniku organizacionog odbora Međunarodnog simpozijuma NOVI HORIZONTI 2023 prof. dr Bojanu Mariću i članu editorskog borda mr Vladimiru Malčiću, višem asistentu sa Saobraćajnog fakulteta Doboj, za saradnju i svesrdnu pomoć u vezi realizacije ovog broja časopisa.

Prof. dr Slavko Vesković

MILIVOJE ILIĆ*, NORBERT PAVLOVIĆ**, IVAN BELOŠEVIĆ***

FUZZY-FMEA PRISTUP ZA ANALIZU RIZIKA ELEMENATA SKRETNICE

FUZZY-FMEA APPROACH FOR RISK ANALYSIS OF SWITCH ELEMENTS

UDK: 656.2+625.1/.5:519.8

REZIME:

Skretnice predstavljaju ključni elementi železničke infrastrukture. Njeni pokretni delovi menjaju položaj u zavisnosti od toga da li predstojeća vožnja treba da se izvrši u pravac ili u skretanje. Sa većim brojem vozova njihovo opterećenje raste, pojačava se trošenje delova, i javlja se potreba frekventnijeg održavanja. U praksi se često dešavaju iskliznuća na skretničkim područjima, zbog čega sa apekta bezbednosti zauzimaju značajno mesto. U ovom radu posmatrani su elementi skretnice kao tehnički sistemi koji mogu da otkažu i dovedu do incidentne situacije. Primenjen je pristup analize rizika tehničkih sistema za utvrđivanje scenarija otkaza skretnice. Posmatrani su osnovni elementi skretnice koje su eksperti ocenili lingvističkim fazi ocenama u zavisnosti od faktora rizika. U tu svrhu korišćena je FMEA metoda koja definiše faktore rizika i to: ozbiljnost pojave defekta, verovatnoću pojave defekta i način detektovanja defekta. Ovi faktori su posmatrani kao kriterijumi u nastavku u procesu višekriterijumskog odlučivanja primenom TOPSIS metode. Cilj rada je da se na osnovu TOPSIS metode dobije koji su to kritični elementi i da se izvrši njihovo rangiranje. Rezultati rada pokazuju da se pristup analize rizika može uspešno primeniti kod detekcije i rangiranja elemenata skretnice, kao i za traženja novih rešenja u strategiji njihovog održavanja i konstrukcije.

Ključne reči: skretnica, višekriterijumsko odlučivanje, analiza rizika, FMEA, TOPSIS

SUMMARY:

Switches are key elements of railway infrastructure. Its moving parts change position depending on whether the upcoming running should be done in straight or in diverging. With a larger number of trains, their load increases, which affects the increased wear of parts, as well as the need for more frequent maintenance. In practice, derailments often occur at switch areas, therefore it is so important from the safety aspect. In this paper, the elements of the switch were considered as technical systems that can fail and lead to an incident situation. The approach of risk analysis of technical systems was applied to determine the scenario of switch failure. First, the switch was decomposed into basic elements that were evaluated by experts with linguistic fuzzy estimates depending on the risk factors. For this purpose, the FMEA method was used, which defines the risk factors: the severity of the defect occurrence, the probability of the defect occurrence, and the ease of failure detection. These factors are considered as criteria in the next step of the process of multi-criteria decision-making using the TOPSIS method. The aim of the work is to find out which are the critical elements based on the TOPSIS method and to rank them. The results of the work show that the risk analysis approach can be successfully applied in the detection and ranking of switch elements, as well as in the search for new design solutions in the strategy of their maintenance and construction.

Key words: switch, multicriteria decision making, risk analysis, FMEA, TOPSIS

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1. UVOD

Železnički sistem je jedan od najvažnijih transportnih sistema u svetu. Još od nastanka prve parne lokomotive, kroz dizel vuču i kasniju elektrifikaciju, ljudi su videli potencijal železnice u masovnom transportu ljudi i robe. Pored karakteristika kao što su: veliki transportni kapacitet, velike tehničke brzine, visok nivo bezbednosti, komfor i udobnost putnika, niska cena prevoza, povoljan uticaj na životnu sredinu; potpuno je jasno zašto je železnica jedan od najdominantnijih oblika transporta u svetu.

Pored mnogih elemenata koji čine železničku infrastrukturu, posebno su značajne skretnice. Skretnica je specijalizovano postrojenje veoma složene konstrukcije koje omogućava prelaz pojedinačnih železničkih vozila ili celih vozova sa jednog koloseka na drugi bez prekida kretanja (Ivić, 2005). Skretnica uglavnom ima dva koloseka, osnovni i odvojni kolosek. Osnovni kolosek je kolosek od koga se odvaja jedan ili više koloseka koje vode u skretanje. Izdvajanje odvojnih koloseka vrši se pod uglom koji se naziva skretnički ugao. Osnovni kriterijum za klasifikaciju skretnica je njihova konstrukcija. Shodno tome, skretnice su podeljene u četiri osnovne grupe: jednostruke skretnice, dvostruke skretnice, ukrsne skretnice i kombinovane skretnice. Jednostruke skretnice su one kod kojih se izdvaja samo jedan kolosek, dok su dvostruke skretnice one gde se dva odvojna koloseka odvajaju od osnovnog koloseka. Ukrsne skretnice su one koje uspostavljaju vezu između dva koloseka koji se ukrštaju (seku pod skretničkim uglom). Kombinovane skretnice su one koje omogućavaju prelazak vozila sa dva koloseka različitih širina na jedan kolosek kombinovane širine.

Iskliznuće vozova iz šina predstavlja jedan od najčešćih tipova železničkih nesreća i nezgoda. Pored izazivanja značajne materijalne štete i čestog ometanja saobraćaja, posledice iskliznuća mogu biti i povrede ili smrt ljudi u slučaju iskliznuća putničkog voza ili ugrožavanje životne sredine (npr. u slučaju izlivanja opasnih materija) izazvane iskliznućem. S obzirom na to da do iskliznuća može doći i na otvorenoj pruzi i u stanicama, posebno u zonama skretnica; potrebno je eliminisati ili smanjiti faktore koji dovode do iskliznuća iz šina i ugrožavanja bezbednosti saobraćaja. Neki od radova iz ove oblasti su radovi autora (Dindar i Kaevunruen, 2017; Dindar et al, 2017) koji su se bavili faktorima koji dovode do iskliznuća iz šina, kao i odnosima između težine posledice i učestalosti iskliznuća iz šina. U prvom radu autori su razmatrali koji faktori i pod kojim uslovima dovode do iskliznuća iz šina. Studija je pokazala da je nedovoljno održavanje skretnica najznačajniji faktor koji dovodi do iskliznuća iz šina. U drugom radu autori koriste FTA (analaza stabla otkaza) pomoću kojih mogu izračunati verovatnoće uticaja poddogađaja na učešće glavnog događaja, odnosno iskliznuća iz šina.

Brojni su radovi iz različitih naučnih oblasti koji sadrže neki oblik FMEA metode. Grupa autora na čelu sa (Oiang et al, 2022) razmatrala je model višestrukih perspektiva faktora analize rizika u FMEA metodi. Oni su predložili novu metodu klasifikacije kombinovanjem faktora rizika u parovima (S&O (ozbiljnost i pojava), S&D (ozbiljnost i detekcija), O&D (pojava i detekcija)). Autori su kombinovali FMEA i metod analize funkcionalne rezonance (FRAM) na primeru ledolomca na nuklearni pogon (Fu et al, 2022). U radu (Ebrahimi et al, 2022) Delphi-FMEA model je primenjen za određivanje prioriteta rizika u saobraćajnim nesrećama.

2. METODOLOGIJA KORIŠĆENA U RADU

U ovom poglavlju biće obrađeni osnovni koncepti metoda koje su korišćene u ovom radu. U pitanju su FMEA metoda, fuzzy pristup i fuzzy skupovi, kao i metoda višekriterijumskog odlučivanja TOPSIS.

2.1. FMEA

FMEA (Failure Modes and Effects Analisis) pripada grupi inženjerskih metoda i tehnika za poboljšanje kvaliteta. FMEA je metoda koja se koristi za procenu načina i efekata potencijalnih kvarova podsistema, sklopova, komponenti ili funkcija u sistemu. FMEA je induktivna, timska metoda koja zahteva vreme i dobro poznavanje sistema koji se analizira. Cilj metode je da se identifikuju smetnje i kvarovi koji mogu negativno uticati na pouzdanost celog sistema. FMEA se najčešće koristi u početnim fazama razvoja kako bi se osiguralo da se svi potencijalni kvarovi otkriju i eliminišu na vreme.

FMEA je veoma važna tehnika koja se koristi za identifikaciju i eliminisanje poznatih i potencijalnih grešaka sistema/podsistema. Cilj ove metode je povećanje pouzdanosti i sigurnosti sistema i veoma je važan u smislu analize rizika. Osnovni termini koji se koriste u FMEA su:

Kvar - odstupanje od planirane funkcije ili ponašanja; nesposobnost sistema, podsistema ili komponente da izvrši traženu funkciju.

Režim kvara - način na koji se element pokvari; oblik ili stanje elementa u kome se element nalazi nakon otkaza.

Uzrok kvara - proces ili mehanizam odgovoran za nastanak kvara. Procesi koji mogu izazvati kvar komponenti su npr. fizički kvar, defekt modela, proizvodni nedostatak, uticaj na životnu sredinu itd.

Efekat kvara - posledica kvara na funkcionisanje ili status elementa i sistema.

Osnovni koncept FMEA metode podrazumeva dekompoziciju sistema na njegove sastavne elemente, do nivoa koji je ocenjen kao značajan za analizu. Prvi korak je identifikovanje mogućih otkaza sistema, nakon čega se vrši analiza kritičnog otkaza, uzimajući u obzir faktore rizika: pojavu otkaza (O-Occurrence), ozbiljnost otkaza (S-Severity) i detekciju otkaza (D-Detection). Prioritetni rizici se određuju preko broja prioriteta rizika (RPN-Risk Priority Number), koji je predstavlja proizvod faktora rizika O, S i D. To je:

RPN= O*S*D (1)

gde je O verovatnoća kvara (otakza), S je ozbiljnost kvara (otkaza), a D je verovatnoća da se kvar (otkaz) otkrije. Ova tri faktora rizika mogu se vrednovati i ocenjivati na osnovu skala. Skale mogu biti univerzalne (npr. od 1 do 10) ili se mogu formulisati za specifični sistem koji se analizira. Na osnovu RPN-a, rangiranjem se jasno dobijaju kritični elementi, koji se mogu sortirati prema najvećem ili najmanjem broju, odnosno najvećem ili najmanjem riziku od otkaza.

2.2. Fuzzy pristup i lingvističke promenljive

Teoriju fuzzy skupova razvio je (Zadeh, 1965) kao konceptualni okvir za tretiranje neizvesnih i nepreciznih situacija koje postoje u stvarnom životu. Uključujući teoriju fuzzy skupova u metodologiju višekriterijumskog odlučivanja, (Bellman i Zadeh, 1970) uvode matematički precizan način tretiranja nejasnoće i subjektivnosti u dodeljivanju težine kriterijuma i ocene učinka svake alternative u pogledu kriterijuma evaluacije. Do sada su različite metode višekriterijumskog odlučivanja proširene u fuzzy okruženju i primenjene u različitim oblastima inženjeringa ili menadžmenta (Mardani et al, 2015, Shafabakhsh et al. 2014). U ovom radu je uključena primena fuzzy logike i TOPSIS metode sa ciljem rangiranja kritičnih elemenata skretnice.

Radi jednostavnosti, koristimo trouglaste fuzzy brojeve da predstavimo lingvističke varijable u ovom radu. U literaturi (Cheng i Lin, 2002), trouglasti fuzzy broj A = (a1, a2, a3) je određen tako da je a1 < a2 < a3 (videti sliku 1). Vrednost funkcije μÃ(x) označava stepen pripadnosti x u Ã, tako da veći μ Ã (x) znači veći stepen pripadnosti za x u Ã.

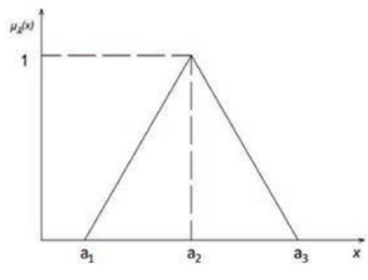
$$\mu\tilde{A}(x) = \begin{cases} 0, & x < a1 \\ \frac{x-a1}{a2-a1}, & a1 < x < a2 \\ \frac{a3-x}{a3-a2}, & a2 < x < a3 \\ 0, & x > a3 \end{cases} \quad (2)$$

Prema (Chen, 2000), rastojanje između dva trouglasta fuzzy broja A = (a1, a2, a3) I N = (n1, n2, n3) može se izvesti korišćenjem Verteks metode (3). Iako se jasna vrednost trouglastog fuzzy broja može prikazati korišćenjem različitih metoda defazifikacije, u ovom radu primenjujemo metodu Centroida (4).

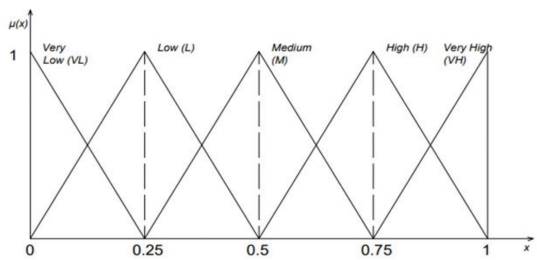
$$d(\tilde{A}, \tilde{N}) = \sqrt{\frac{[(a1-n1)^2+(a2-n2)^2+(a3-n3)^2]}{3}} \quad (3)$$

$$x_0(\tilde{A}) = \frac{a1+a2+a3}{3} \quad (4)$$

U okviru procesa donošenja odluka, stručnjaci često imaju tendenciju da koriste lingvističke varijable da bi se prilagodili nejasnoći sadržanoj u njihovim odlukama. Sledeći skupovi lingvističkih termina sa njihovim odgovarajućim trouglastim fuzzy brojevima (videti sliku 2) su usvojeni da izraze vrednosti lingvističkih varijabli kako bi se ponderisali faktori rizika i procenile ocene rizika od otkaza u odnosu na ove faktore.



Slika 1. Trouglasti fuzzy broj



Slika 2. Lingvističke promenljive

2.3. TOPSIS metoda

Metoda TOPSIS (**T**echniques for **O**rder **P**reference by **S**imilarity to **I**deal **S**olution) definiše rešenje iz krajnje grupe elemenata na osnovu mere udaljenosti od idealnog rešenja. Primena ovog principa mere udaljenosti od idealnog rešenja u TOPSIS-u eliminiše mogućnost subjektivnog odlučivanja (Olson, 2004). Rangiranje alternativa se zasniva na meri relativne bliskosti idealnom rešenju i meri relativne udaljenosti od anti-idealnog rešenja. Idealno rešenje predstavlja kombinaciju najboljih alternativnih vrednosti za svaki kriterijum, dok anti-idealno rešenje predstavlja kombinaciju najgorih alternativnih vrednosti za svaki kriterijum. Idealna i anti-idealna rešenja se definišu za svaki kriterijum posebno uzimajući u obzir da li je kriterijum minimizacionog ili maksimizacionog tipa. Algoritam TOPSIS metode sastoji se od sledećih koraka:

Korak 1: Formiranje matrice odlučivanja za alternative (A1, A2, ...Am) prema usvojenim kriterijumima (C1, C2, ...Cn), i kriterijumske funkcije (f1, f2, ...fn). Element matrice predstavlja vrednosti j funkcije kriterijuma za i-tu alternativu.

Korak 2: Normalizacija vrednosti matrice odlučivanja vrši se sa ciljem svođenja vrednosti na bezdimenzionalnu vrednost prema relaciji ispod (5).

$$x_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^{n} f_{ij}^2}} \qquad (5)$$

Korak 3: Određivanje vrednosti težinskih koeficijenata (w1, w2, ...wn) i formiranje otežane normalizovane matrice. Element matrice vij predstavlja proizvod vrednosti težinskog koeficijenta wij i normalizovane vrednosti alternative xij.

Korak 4: Određivanje idealnog rešenja (A*) i anti-idealnog rešenja (A-) kao kombinacije najbolje (vj*) i najgore (vj) vrednosti alternativa po svim kriterijumima (6).

$$A^* = \{ v_1^*, v_2^*, \dots, v_m^* \} \ , \ A^- = \{ v_1^-, v_2^-, \dots, v_m^- \} \qquad (6)$$

Korak 5: Određivanje relativnih mera udaljenosti alternativa od idealnih rešenja (7).

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \ , \ S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} , \ i = 1, \dots, m \qquad (7)$$

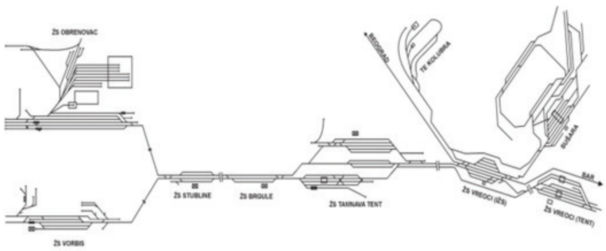
Korak 6: Određivanje relativne bliskosti idealnom rešenju (8).

$$C_i^* = \frac{S_i}{S_i^* + S_i^-} \ , \ i = 1, \dots, m \qquad (8)$$

Korak 7: Rangiranje alternativa prema relativnoj bliskosti idealnom rešenju.

3. ILUSTRATIVNI PRIMER

U ovom radu kao ilustrativan primer korišćena je mreža pruga industrijske železnice rudarskog basena „Kolubara" (videti sliku 3), odnosno skretnica kao sistem i njeni elementi kao podsistem u stanici Sušara. Osnovna delatnost Rudarskog basena „Kolubara" je proizvodnja uglja za proizvodnju električne energije. Rudarski basen „Kolubara" je vodeći proizvođač uglja u Srbiji, na čijim površinskim kopovima se godišnje proizvede oko 30 miliona tona lignita. Taj iznos je oko 70 odsto ukupne proizvodnje uglja u okviru „Elektroprivrede Srbije". Oko 52 odsto električne energije u Srbiji proizvodi se iz kolubarskog lignita.



Slika 3. Šematski prikaz mreže industrijske železnice „Kolubara"

S obzirom da je skretnica jedan od najvažnijih i najranjivijih delova železničke infrastrukture, potrebno je analizirati elemente skretnice i utvrditi koji od njih je najkritičniji, odnosno koji je izložen najvećem riziku od kvara. FMEA pristup je korišćen za analizu 13 komponenti jedne skretnice. Eksperti iz saobraćajnog inženjerstva (donosilac odluke 1 - DM1) i građevinarstva (donosilac odluke 2 - DM2) dali su svoje lingvističke ocene za faktore rizika: ozbiljnost (S), pojavu (O) i detekciju (D), koje su prikazane u tabeli. 4. Ovi faktori rizika se smatraju kriterijumima u modelu, dok se 13 komponenti skretnice razmatraju kao alternative.

Svaki donosilac odluka koristi lingvističke promenljive prikazane na slici 2 da bi dodelio ocene rizika elemenata skretnice (alternativa) u odnosu na specifični faktor rizika. Lingvističke ocene koje donosioci odluka daju ocenama alternativa i značaju kriterijuma prikazane su u tabeli 1 i tabeli 2. Lingvističke ocene prikazane u tabelama 1 i 2 su transformisane u trouglaste fuzzy brojeve. Fuzzy brojevi su agregirani na osnovu kojih se izvode subjektivne fuzzy težine kriterijuma i fuzzy ocene alternativa koje se odnose na svaki kriterijum kao u što je prikazano u tabeli

3. Nakon toga, vrednosti iz matrice se defazifikuju korišćenjem jednačine (4).

Tabela 1. Elementi skretnice i lingvističke fuzzy ocene prema faktorima rizika

RB	Elementi skretnice	DM_1			DM_2		
		S	O	D	S	O	D
1	Glavne šine	H	VL	H	H	L	H
2	Jezičci	VH	M	H	VH	H	H
3	Klizno jastuče	M	VH	L	M	VH	M
4	Spojna motka	M	M	L	H	M	L
5	Potezna motka	M	H	L	H	H	M
6	Postavljač	L	M	VL	M	M	VL
7	Vrh srca	VH	H	H	VH	H	H
8	Krilne šine	M	L	M	H	H	M
9	Šina vođica	VH	M	H	VH	H	H
10	Podložna ploča	L	L	H	M	M	H
11	Korenska podl. ploča	H	L	H	VH	M	VH
12	Prag	M	L	H	H	L	H
13	Tucanički zastor	H	M	L	H	M	H

Tabela 2. Značaj kriterijuma prema mišljenju eksperata

Kriterijumi	K_1 (S)	K_2 (O)	K_3 (D)
DM_1	VH	L	M
DM_2	VH	L	H

Tabela 3. Agregirane fuzzy ocene alternativa i subjektivni težinski koeficijenti kriterijuma

Kriter.	K_1 (S)	K_2 (O)	K_3 (D)
wj^s	(0,75; 1; 1)	(0; 0,25; 0,5)	(0,25; 0,63; 1)
A_1	(0,5; 0,75; 1)	(0; 0,13; 0,5)	(0,5; 0,75; 1)
A_2	(0,75; 1; 1)	(0,25; 0,63; 1)	(0,5; 0,75; 1)
A_3	(0,25; 0,5; 0,75)	(0,75; 1; 1)	(0; 0,38; 0,75)
A_4	(0,25; 0,63; 1)	(0,25; 0,5; 0,75)	(0; 0,25; 0,5)
A_5	(0,25; 0,63; 1)	(0,5; 0,75; 1)	(0; 0,38; 0,75)
A_6	(0; 0,38; 0,75)	(0,25; 0,5; 0,75)	(0; 0; 0,25)
A_7	(0,75; 1; 1)	(0,5; 0,75; 1)	(0,5; 0,75; 1)
A_8	(0,25; 0,63; 1)	(0; 0,5; 1)	(0,25; 0,5; 0,75)
A_9	(0,75; 1; 1)	(0,25; 0,63; 1)	(0,5; 0,75; 1)
A_{10}	(0; 0,38; 0,75)	(0; 0,38; 0,75)	(0,5; 0,75; 1)
A_{11}	(0,5; 0,88; 1)	(0; 0,38; 0,75)	(0,5; 0,88; 1)
A_{12}	(0,25; 0,63; 1)	(0; 0,25; 0,5)	(0,5; 0,75; 1)
A_{13}	(0,5; 0,75; 1)	(0,25; 0,5; 0,75)	(0; 0,5; 1)

U tabeli 4 je prikazana defazifikovana matrica, gde je od tri vrednosti iz tabele 3 prikazana jedna srednja vrednost, koja reprezentuje njih. Tabela 5 prikazuje subjektivne težinske koeficijente, koji su dobijeni tako da predstavljaju količnik određene vrednosti i ukupnog zbira tih vrednosti (npr. 0.92:(0.92+0.25+0.63) =0.51). U narednoj tabeli 6 prikazane su normalizovane vrednosti za sve alternative dobijene kao količnik određene vrednosti i kvadratnog korena zbira kvadrata svih tih vrednosti po određenom kriterijumu (npr. $0.75:(0.75^2+0.92^2+...+0.75^2)^{1/2}=0.297$). Ova tabela zapravo i predstavlja prvi korak i ulaz u TOPSIS metodu. Naredni korak predstavlja ponderisanje matrice, odnosno množenje svih vrednosti sa odgovarajućim težinskim koeficijentima što je prikazano u tabeli 7. Nakon toga prelazi se na određivanje idealnog i anti-idealnog rešenja (tabela 8), a zatim se određuje relativna mera udaljenosti alternativa od idealnih rešenja koristeći formule (7). Nakon toga određuje se relativna bliskost idealnom rešenju pomoću formule (8), videti tabelu 9. Na samom kraju je prikazan rang alternativa, odnosno kritični elementi skretnice.

Tabela 4. Defazifikovane vrednosti

Kriterijumi	K_1 (S)	K_2 (O)	K_3 (D)
wj^s	0,92	0,25	0,63
A_1	0,75	0,21	0,75
A_2	0,92	0,63	0,75
A_3	0,50	0,92	0,38
A_4	0,63	0,50	0,25
A_5	0,63	0,75	0,38
A_6	0,38	0,50	0,08
A_7	0,92	0,75	0,75
A_8	0,63	0,50	0,50
A_9	0,92	0,63	0,75
A_{10}	0,38	0,38	0,75
A_{11}	0,79	0,38	0,79
A_{12}	0,63	0,25	0,75
A_{13}	0,75	0,50	0,50

Tabela 5. Subjektivni težinski koeficijenti

Kriterijumi	K_1 (S)	K_2 (O)	K_3 (D)
wj_s	0,51	0,14	0,35

Tabela 6. Normalizovane vrednosti

Kriterijumi	K_1 (S)	K_2 (O)	K_3 (D)
wj^s	0,510	0,140	0,350
A_1	0,297	0,102	0,340
A_2	0,363	0,307	0,340
A_3	0,198	0,451	0,170
A_4	0,248	0,246	0,113
A_5	0,248	0,369	0,170
A_6	0,149	0,246	0,038
A_7	0,363	0,369	0,340
A_8	0,248	0,246	0,227
A_9	0,363	0,307	0,340
A_{10}	0,149	0,184	0,340
A_{11}	0,314	0,184	0,359
A_{12}	0,248	0,123	0,340
A_{13}	0,297	0,246	0,227

Tabela 7. Ponderisana matrica

Kriterijumi	K_1 (S)	K_2 (O)	K_3 (D)
A_1	0,152	0,014	0,119
A_2	0,186	0,043	0,119
A_3	0,101	0,063	0,059
A_4	0,127	0,034	0,040
A_5	0,127	0,051	0,059
A_6	0,076	0,034	0,013
A_7	0,186	0,051	0,119
A_8	0,127	0,034	0,079
A_9	0,186	0,043	0,119
A_{10}	0,076	0,026	0,119
A_{11}	0,161	0,026	0,125
A_{12}	0,127	0,017	0,119
A_{13}	0,152	0,034	0,079

Tabela 8. Idealno i anti-idealno rešenje

Kriterijumi	S	O	D
A*	VH	L	M
A-	VH	L	H

Tabela 9. Relativna bliskost idealnom rešenju i konačni rang

Kriterijumi	Si*	Si-	C	Rang
A_1	0,1301	0,0596	0,314	5
A_2	0,1550	0,0211	0,120	2
A_3	0,0717	0,1072	0,599	11
A_4	0,0606	0,1080	0,641	12
A_5	0,0780	0,0893	0,534	10
A_6	0,0200	0,1596	0,889	13
A_7	0,1568	0,0132	0,078	1
A_8	0,0856	0,0803	0,484	8
A_9	0,1550	0,0211	0,120	2
A_{10}	0,1062	0,1161	0,522	9
A_{11}	0,1409	0,0450	0,242	4
A_{12}	0,1171	0,0751	0,391	7
A_{13}	0,1026	0,0640	0,384	6

Slika 4. Prikaz najkritičnijih elemenata skretnice

4. DISKUSIJA REZULUTATA I ZAKLJUČAK

U ovom radu posmatrana je skretnica, kao jedan od osnovnih i neophodnih elemenata za funkcionisanje železničkog saobraćaja. Skretnica je sistem od nekoliko elemenata. Svi sastavni elementi su veoma bitni i neophodno je da budu ispravni za normalno funkcionisanje skretnice. Metodom FMEA detaljno je posmatrano 13 elemenata. Stručnjaci iz oblasti saobraćaja i građevinarstva dali su svoje stručne lingvističke ocene za 3 ključna faktora rizika, a to su ozbiljnost (S), pojava (O) i detekcija (D), zbog čega je u ovom modelu primenjen fuzzy pristup. Nakon toga, TOPSIS metodom višekriterijumskog odlučivanja, određeni su elementi skretnice sa najvećom mogućnošću otkaza, sve do onih elemenata sa najmanjom mogućnošću otkaza. Kriterijumi su bili faktori rizika, dok su alternative elementi skretnice, njih 13.

Rezultati su pokazali da su najkritičniji elementi vrh srca (7), jezičci (2) i šine vođice (9). Ovi rezultati pokazuju da su elementi koji predstavljaju ključne elemente skretnice upravo najugroženiji, s obzirom na to da trpe velika opterećenja od vozova. Potrebno ih je redovno kontrolisati i održavati. Elementi korenska podložna ploča (11), glavne šine (1) i tucanički zastor (13) su nešto manje izloženi riziku od najkritičnijih, ali ne treba zanemariti ni njihovo održavanje, jer njihov defekt ugrožava bezbednost saobraćaja i prekida saobraćaj. Elementi 3, 4, 5, 10 i 12 pripadaju grupi srednje rizičnih elemenata. Element sa najmanjim rizikom od kvara je postavljač (6).

Uz pomoć ovog modela mogu se na vrlo jasan i detaljan način odrediti potencijalno kritični elementi sistema, a kasnije i razmotriti koraci koje treba preduzeti u cilju smanjenja rizika.

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A SUSTAINABLE ALTERNATIVE FOR RAILROAD NOISE BARRIER

UDK: 656.2+502/504

SUMMARY:

Noise barriers are structures that inhibit the direct transmission of airborne noise emitted by traffic. They play an important role along railroad lines to protect residential areas from high noise pollution. Noise barriers are currently made of very energy-intensive materials such as concrete, glass, aluminum, impregnated wood, etc. In addition to the high costs and large amount of energy input during construction, a recycling process is rarely possible when the noise barriers should be replaced or demolished. Therefore, it is necessary to develop inexpensive and sustainable alternatives. With its low primary energy requirement, regional availability and complete recyclability, loam can be a best suitable alternative. Loam is produced in large quantities as excavated material during railroad and road construction. Hence, rather than disposing excavated material expensively, the direct utilization of it should be found out. In addition, loam offers an optimum sound insulation because of its mass and porous surface. The study identified and compared possible noise barriers techniques using loam. This contribution gives insight into (i) the building techniques could be suitable for noise barriers; (ii) the standards and regulatory frameworks as well as (iii) lifecycle costing and advantage of loam noise barrier as compared to the conventional ones.

Key words: Railway Infrastructure, loam, circular economy, excavated soil

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1. INTRODUCTION

Traffic noise is one of the major environmental nuisances. It increases drastically with increasing mobility. In Austria, there are numerous regulations governing noise abatement measures. In the case of active noise reduction, infrastructure operators primarily rely on structural measures at the noise source. In this regard, the Austrian Federal Railway, ÖBB Infrastruktur AG, for example, has built 950 kilometers of noise barriers along railroad lines. Over the past ten years, ÖBB has invested more than 20 million euros per year in noise protection measures (ÖBB INFRA, 2023). There are 1.393 km long (4,66 square kilometers) noise barriers along Austrian motorways and expressways (ASFINAG, 2020).

Noise barriers are mostly made of aluminum, concrete, wood, glass, gabions or a combination of those. In general, the construction sector requires enormous amounts of resources that accounts for about 50 % of all excavation material. The sector is responsible for over 35 % of total waste generation, 40 % of energy consumption and 36 % of greenhouse gas emissions in the EU (EC, 2022, EURACTIV, 2019). Life cycle assessment and ecoprofile comparison of noise barriers (4 m x 3 m) made of lava concrete and wood (Werner, 2019) shows that the cumulative primary energy consumption over the whole life cycle for concrete is 12726,7 MJ, for wood 10616 MJ as well as in terms of greenhouse gas emissions 895,7 kg CO2-eq and 176,4 kg CO2-eq respectively. The hot-spot analysis in the study shows that for wood, copper cover makes a total contribution of 60 % of the environmental impact points, with the subcategories of "heavy metal emissions" and "air emissions" and "land occupancy" being the main contributors. For concrete, the highest contributions are caused by the subcategories "global warming potential," various "emissions to air and water" from energy production, and "use of fossil energy resources." cement is the most significant contributor. The construction industry is urgently seeking ways to achieve sustainability and is pinning its hopes on new construction using recycled or renewable building materials.

One of the most promising materials for a sustainable construction is clay. Clay is one of the oldest building materials and has been used for thousands of years. Clay is available in almost all parts of the world. Clay is also produced as a waste product in road and rail construction that is deposited. However, instead of disposing of the excavated material at high cost, it could be used as a building material in a completely climate-neutral way. Clay can be 100 percent recycled and reused and is suitable for circular economy. This would have a positive effect on overall construction costs. Furthermore, clay is considered a particularly suitable nesting material for various insect species, which can contribute to the preservation of species and biodiversity. Clay is non-flammable, anti-allergenic and mold-inhibiting due to its pH value. Due to its permeable (porous and open to diffusion) structure, it also has a good acoustic behavior (Knapp, 2022). Although the use of clay to build houses or to seal foundations and walls is one of the oldest and most natural processes in construction, clay has not yet become a suitable alternative as a building material for noise barrier construction. The objectives of this contribution are to show to which extent clay can be used as an alternative sustainable building material for noise barrier construction. During the explatory study, the following research questions could be investigated: (i) which clay technologies can be considered and built as prototypes, (ii) which technical requirements and framework conditions in noise control construction in the railway system are to be considered, (iii) how the technical and economic efficieny of the clay noise barrier differes from the conventional ones.

2. METHODS

To answer the above research questions: an intensive literature review was conducted. That was strengthend by discussion with experts both from the field of railways (from Austrain and German Federal Railways - ÖBB and DB) as well as from clay construction fileld. This was implemented by organizing two expert's workshops. Moreover, statistical and acoustic calculations were performed followed by prototype development and simulations.

First general legal requirements (national and international (EU)) for specific construction measures were assessed. Furthermore, it is analyzed how far the legal basis can be adapted to noise protection construction made of clay. In the case of technical requirements, specific characteristics of clay construction as a noise barrier and its application in railroads are considered. Through an intensive exchange with stakeholders from the field, the framework conditions and possible synergies for the implementation of clay as a noise barrier in railroads are identified.

The project furthermore analysed clay construction techniques and their suitability for the puropose as noise barriers. The construction techniques such as tamped clay, cob walling, clay bricks, as well as composite clay are considered. The calculation of load carrying capacity as well as serviceability of the noise barriers in relation to the exerted mechanical loads such as wind load, aerodynamic loads due to train speed were calculated in rference to EUROCODE.

Those construction techniques are analysed and compared based the parameters such as stability (height-to-width ratio, maximum height, risk of tipping over, foundation, etc.); load-carrying capacity in Load-bearing capacity in relation to the pressure and impact of passing trains as well as weather resistance. Furthermore, a simplified life cycle cost (LCC) analysis is performed to compare the economic viability of clay noise barriers to the conventional noise barriers.

3. RESULTS AND DISCUSSION

3.1. Railroad noise barrier technical requirements

Noise barriers used in rail traffic have different requirements than those used on highways. Dynamic loads from pressure-suction effects, their fatigue effectiveness and resonance effects, design specifications, standards and guidelines on acoustic properties and stability are different from those for highways.

The operational and technical specifications specific to railroads are regulated by various national and international standards. In Austria, the following standards apply: (i) clearance gauge regulated by EisbBBV, (ii) danger space, safety space, lateral safety distance regulated by EisbAV, (iii) approval procedure regulated by EisbG among others. In addition, the Austrian Federal Railways - ÖBB Infrstruktur AG has special specifications for clearance gauges based on EN 15273-4. There are different railway track cross-sections depending on such as the type of the railway line, the clearance gauge used, the maximum permissible speed. Figure 1 shows an example of a standard ballast cross-section for a double-track railroad line. This comprises the entire superstructure, including overhead contact lines, control and safety technology and noise barriers.

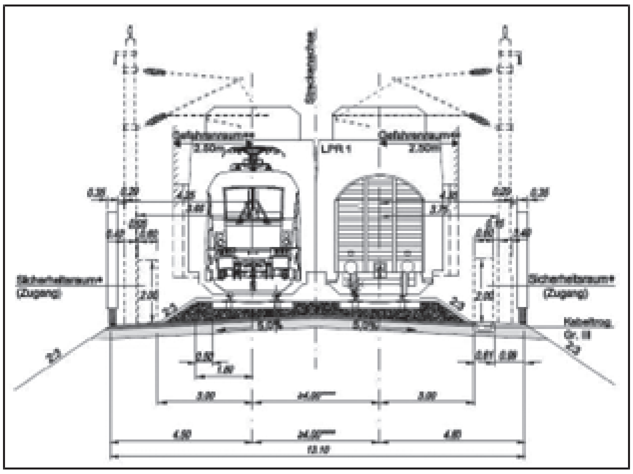

Figure 1. Standard railway double track crosssection of the ÖBB Infrastruktur AG

Noise barrier systems in the rail network are subjected to cyclic pressure/suction alternating stresses due to aero-dynamic excitations from passing trains. These stresses depend on the train speed and the distance of the noise barrier from the track axis among others. The design of the noise barriers for mechanical loads is carried out according to EN1990 and EN 1991.

3.2. Dimensioning and structural design

In this study four types of noise barrier types are analysed. The purpose is to estimate the dimensions of a noise barrier made of clay, the load carrying capacity and serviceability. Hence, the loads to be considered are divided into permanent, variable and extraordinary loads as described below.

3.2.1. Static stability

Regarding to the use of clay walls as noise barriers, the wall is required, not to tilt due to trains passing by or wind blows. For that, it is important to experience the dead weight of the compacted clay material, the required height of the building itself and the mechanical load acting on the building.

Height

Relating to the construction height, the size of the noise barrier in figure 1 is taken as a practical example to illustrate different noise barrier heights in relation to the distance to track axis as shown in figure 2 below. Considering the shielded area of the noise barrier; the minimum necessary height in reference to the distance to the track axis can be calculated by equation 1.

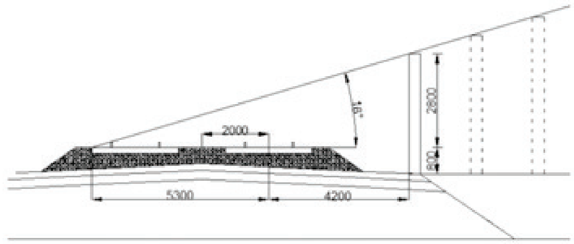

Figure 2. The relation of track distance and noise barrier height

$$h(a_g) = (a_g + 5{,}3) * \tan(16°) + 0{,}8 \text{ [m]} \quad (1)$$

Mechanical load

Forces and loads are taken from official standardisations as mentioned below. Those values are always multiplied by the prescribed safety factor 1,5.

Wind load

Using the EN 1991-1-4, the maximum value of wind load (q_w) is calculated for Vienna Simmering as an example for a windy place in Austria.

$$q_w = 0{,}982 \frac{kN}{m^2} \quad (2)$$

Mechanical load of passing trains

Due to the pressure-suction wave generated by trains at higher speed, noise barriers are stressed by another aerodynamic quantity. Likewise, EUROCODE is used to calculate those loads. The following graph (figure 3) shows the values of pressure-suction load at different speeds and distances to the track axis, taken from EN 1991.2:2003. In this study, a maximum speed of 250 km/h was assumed, referring to the highest velocity on train lines in Austria.

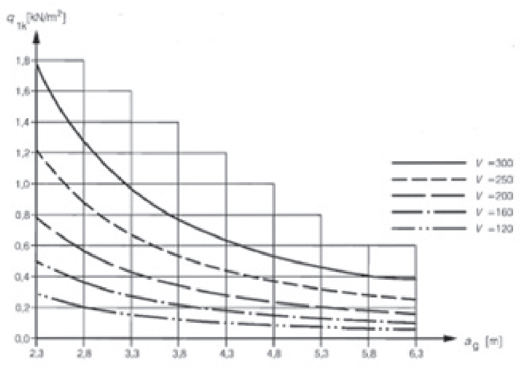

Figure 3. Pressure-suction-load, taken from EN 1991.2:2003

Mechanical calculation

To calculate the dimension and stability of a clay wall, following static system is used.

Noticeably, those loads (figure 4) cause bending stress on the clay wall. So, to finally prove its static stability the following conditions must be fulfilled.

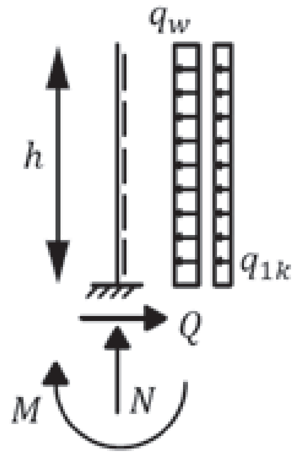

Figure 4. The static system applied for a noise barrier

N = Normal force, Q = shear force, M = Moment, h = height of noise barrier, qw = wind force, q1k = compression and suction force)

$$\sigma_{erf} < \sigma_{zul} \quad (3)$$

$$\sigma_{erf} = \frac{M}{W} \quad (4)$$

σ_{erf} = resulting maximum stress (tension or pressure) [N/mm^2]

σ_{zul} = maximum possible stress (tension or pressure) [N/mm^2]

M = maximum torque [m]

The value of σ_{zul} of clay material regarding tension is practically 0. Therefore, dead weight is used to compensate all tension stress in the building. Following figure 5 illustrates the idea. (σ_{Druck}= pressure stress)

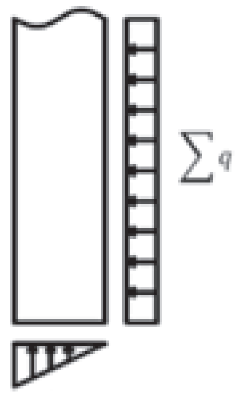

Figure 5. Elastostatic principle for a stable wall

To conclude, dimension and static stability are achieved by compensation of tension stress in the clay wall. This can be done by higher density of the material or wider structure.

3.3. Clay noise barrier prototypes

Rammed clay

This clay technology is built by using concrete formwork. The material is brought into the formwork and gets stamped. After demoulding, the compacted clay material stays in form by itself and can be used as a wall. The dead weight is 2,050 kg/m^3. The necessary width of structure (b) depending on the distance to the track axis (ag) is shown in the following figure.

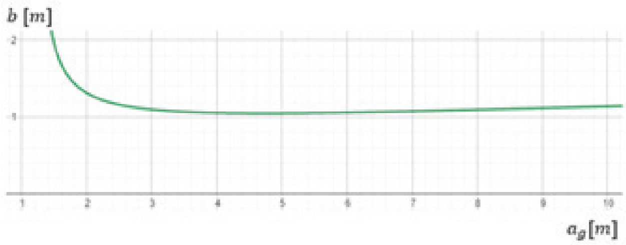

Figure 6: Width of the wall in dependence to track axis distance (rammed clay)

Cob clay

Different to rammed clay, cob clay does not require any formwork. The material is backfilled and gets brought in form by a spade. The dead weight is 1,550 kg/m^3. The calculated necessary width of the wall (b) in dependence to the track axis distance (ag) is shown next.

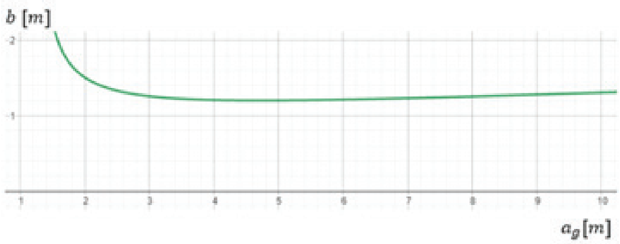

Figure 7: Width of the wall in dependence to track axis distance (cob)

Clay bricks

Clay bricks are blocks of clay, pressed in advance, and used as common bricks. The dead weight is 1,305 kg/m^3. Following figure shows the required width (b) in dependence to the track axis distance (ag).

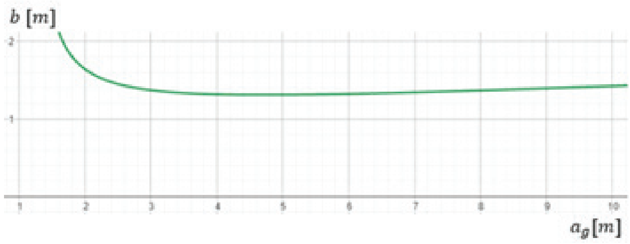

Figure 8: Width of the wall in dependence to track axis distance (clay bricks)

Clay fill

As a fourth technology, clay fill was investigated as a method that does not need any foundation. As the previous wall building methods always require a foundation out of concrete due to water sensitifity of clay, clay fills can be placed anywhere, no matter if the ground is wet or not. To achieve a smaller width, clay fills get supported by a gabion basket, shown in figure 9 below.

Figure 9: Possible gabion concept used as a noise barrier (Rau.de)

Clay walls can definitively be used as noise barriers and find their place in railway crosssections as shown in the figure below. However, it must be considered, that pure clay buildings must not be built without a water insensitive foundation. To leave out an environmentally harmful concrete foundation, gabions can be used to support clay fills.

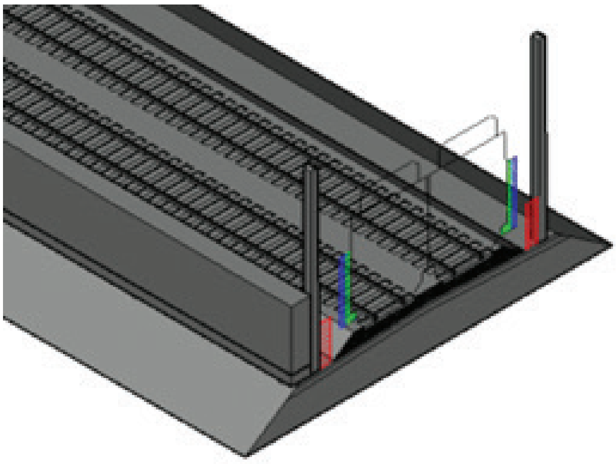

Figure 10: 3D model of a clay wall in a track crosssection

3.4. Applicable structural dimensions

According to a static calculation, the different types of clay construction techniques result in varied construction widths and heights. The corresponding values are: Rammed clay width 0,97 m and height 3,51 m; Weller clay width 1,12 m and height 3,51 m; Clay blocks Width 1,22 m and Height 3,51 m; Supported clay fill Bottom width 1,3 m and Height 3,51 m.

In regard to the placement of the noise barriers along the track line; positioning the clay noise barriers at the location where the conventional noise barriers usually be placed, i. e directly adjacent to the mast alley appears to be the most suitable from the economic point of view. That also fullfills the legal and technical railroad engineering requirements.

3.5. Lifecycle costing

The life cycle cost (LCC) analysis is used to compare the economic viability of clay noise barriers and the conventional noise barriers. The LCC analysis covers (i) investment costs (tendering, design and commissioning, and fabrication and erection), (ii) service life phase over life, (iii) end of life costs (demolition, deconstruction and disposal). The result of the comparison schows that a clear difference of € 6,34 per running meter annualy in favor of the noise protection wall made of clay.

4. CONCLUSION

Static calculations show that all types of clay building technologies and systurcutral design considered fullfill the mechanical requirements and can be used as noise barriers on railway lines. The above results show the necessary building dimensions and the placement of the noise barrier directly on the mast alley taking different design types of clay barriers in to consideration. Placement at a greater distance from the track axis does not make sense from an economic perspective, since the volume of the structure increases with increasing distance from the placement closest to the track on the mast alley. Hence the closest distance was considered in the calculation of the requeíred volumes of the clay mass.

The calculation of the LCC didn't take major uncertainties, including the removal of the material and the actual installation and removal situation into account. Those factors must therefore be checked individually with much more precise input values.

For the implementation of such a structure in a pilot project, only railroad lines with maximum line speeds of more than 160 km/h are recommended due to the aforementioned need for empirical investigations of the dynamic behavior.

ACKNOWLEDGMENT

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BEZBEDNOST PUTNIKA NA PERONIMA U ŽELEZNIČKIM STANICAMA I STAJALIŠTIMA

SAFETY OF PASSENGERS ON PLATFORMS IN RAILWAY STATIONS AND STOPS

UDK: 656.2+625.1/.5

REZIME:

Savremena železnička infrastruktura treba da omogući konkurentnost i održivost putničkog saobraćaja. Osnovni uslov je da se obezbedi pristupačnost železničke infrastrukture i vozila za sve kategorije putnika. U radu se predstavljaju tehničke specifikacije interoperabilnosti koje treba da zadovolje peroni u novim i rekonstruisanim železničkim stanicama i stajalištima. Razmatra se bezbednost putnika koji se kreću i zadržavaju na peronu. Definiše se pojam bezbedne i opasne zone na peronu. Analizira se uticaj položaja stepeništa i lifta na potrebnu širinu perona. Date su smernice za određivanje sadržaja i minimalne širine bezbedne zone perona u novim i rekonstruisanim stanicama. U razmatranja su uključeni zahtevi bezbednosti prema potrebama svih putnika, uključujući invalidna lica u kolicima i lica sa privremeno i trajno ograničenom mobilnošću. Prikazane smernice imaju primenu u projektovanju novih stanica i rekonstrukcij.
Ključne reči: pristupačnost, interoperabilnost, lica sa ograničenom pokretljivošću

SUMMARY:

Modern railway infrastructure should provide the competitiveness and sustainability of passenger traffic. The essential requirement is to ensure the accessibility of railway infrastructure and vehicles for all categories of passengers. The paper presents the technical specifications of interoperability that have to be met by platforms in new and reconstructed railway stations and stops. The safety of passengers moving and staying on the platform is considered. The term safe and dangerous zone on the platform is defined. The influence of the staircase and elevator position on the required width of the platform is analyzed. Guidelines are given for determining the content and minimum width of the platform safe zone in new and reconstructed stations. Safety requirements for all passengers, including disabled persons in wheelchairs and persons with temporarily and permanently reduced mobility, are included in the considerations. The presented guidelines are applicable in the design of new stations and reconstruction.
Key words: accessibility, interoperability, persons with reduced mobility

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1. INTRODUCTION

Until the beginning of the 21st century, railway transport systems were developed independently in the frame of state borders, which significantly reduced their competitiveness in overall traffic transport. The modern railway transport system has to be a part of the transport system and a sustainable form from economic, social and ecological aspects. Furthermore, the European Union defined a common transportation policy in two White Papers (European Commission, 2001, 2011). This policy is based on regulated competition and connecting various modes of transportation, the reduction of congestion points in traffic systems and multi-modal transportation. The basis for the application of modern transport policy is the interoperability of the railway system at the level of the European railway network and beyond.

In this paper, the safety of passengers on platforms is considered. The consideration was based on the interoperability of the railway system and the transport chain, which connects different types of traffic, transporting passengers "door to door" in a simple, safe, competitive and comfortable way (Figure 1, left).

Based on the requirements defined in the technical specifications of interoperability (Commission regulation, 2014a, 2014b), the considered safety has to include all categories of passengers (Figure 1, right) who are offered the use of the railway infrastructure under equal conditions, without discrimination and with the protection of their dignity. In other words, the level of comfort and safety must be adapted to the needs of passengers with the greatest mobility reductions, with the possibility that all passengers can use the same infrastructure and vehicles.

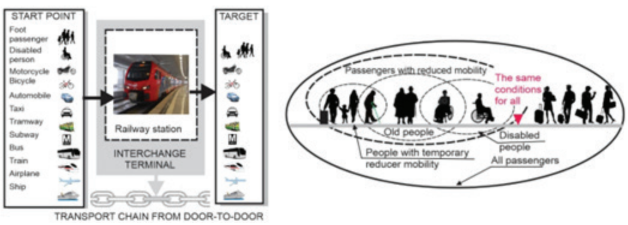

Figure 1. Integration of the railway station in the transport chain from door-to-door (left) and passenger categories according to mobility and disability (right)

The Serbian railways are an important part of the European railway network. Several publications have investigated the accessibility of the railway infrastructure, including:

- the application of accessibility standards in the Belgrade railway junction (Popović et al, 2009),
- guidelines and recommendations for modern passenger terminals on the European railway network (Popović et al, 2012),
- general guidelines for ensuring the competitiveness of railway passenger traffic with a focus on sustainability and accessibility (Popović and Lazarević, 2013),
- and analysis of legal framework and examples of practical application of accessibility standards in Czech Republic and the Republic of Serbia (Popović et al, 2018).

For the safety of all passengers on the platform, the platform has to be accessible without barriers, covered, well-lit, and slip-resistant. Moreover, its length and width are determined according to the needs and requirements of passengers and vehicles.

This paper considers the theoretical principle of human scale, as defined by Le Corbusier, which pertains to the design and organization of spaces to provide comfort and practicality for people. This principle is amended by inclusive design that benefits not only individuals with disabilities but everyone.

The considerations in this paper should guide the design of middle and side platforms according to the requirements of safe containment and movement of passengers. The paper specifies the safe and dangerous zone on the platform and gives guidelines for their dimensioning.

2. PLATFORM HEIGHT IN INTEROPERABLE RAILWAY STATIONS AND STOPS

The height of the platform is a significant safety factor for boarding and disembarking of passengers in the doorway area. Furthermore, the height of the platform has to be aligned with the requirements of the rolling stock and vice versa. Figure 2 shows the situation in America, where there are no interoperability standards for harmonization of the technical performance of vehicles and infrastructure respecting the needs of all categories of passengers.

To overcome such situations on European main railways, the technical specifications of interoperability PRM TSI (Commission regulation, 2014b) specify two platform heights of 55 cm and 76 cm regarding the top of the rail. It should be noted, full compliance with (Commission regulation, 2014b) is mandatory for projects which receive the Union's financial support for the renewal or upgrading of existing rolling stock or parts thereof or the renewal or upgrading of existing infrastructure, in particular a station or components thereof and platforms or components thereof.

Figure 2. Inconsistency of the platform height with the entrance to the vehicle (https://www.amtrak.com/content/dam/projects/dotcom/english/public/documents/corporate/businessplanning /Amtrak-Five-Year-Service-Plans-FY18-FY23.pdf, 28.08.2023.)

It is recommended that the Infrastructure Manager adjusts the platform heights to match the rolling stock and considers this during the tender process for the eventual purchase of new vehicles on the railway network under their management. Figure 3 shows two types of double-decker trains with the door position above and between the bogies. The Railways of Serbia opted for a platform height of 550 mm and therefore acquired double-decker trains with doors placed between the bogies (Figure 3, right).

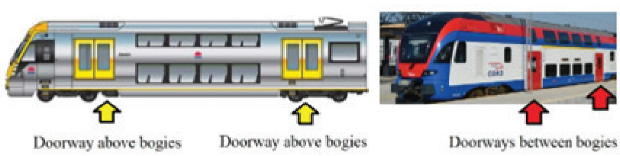

Figure 3. Doorway position at passenger double-decker train

Level access from a platform to the doorway of rolling stock is preferable. This access meets the following requirements: (a) the gap between the door sill of that doorway (or of the extended bridging plate of that doorway) and the platform does not exceed 75 mm measured horizontally and 50 mm measured vertically, and (b) the rolling stock has no internal step between the door sill and the vestibule.

3. SAFETY AND DANGER ZONES ON THE PLATFORM

The width of the platform should provide safety for all persons (passengers, officials and other persons) who stand, sit or move on the platform when trains are passing or arriving (Figure 4). The width of the platform includes the safety and danger zone. Following (Commission regulation, 2014b), the danger zone at the trackside edge of the platform is defined as the area where passengers are not allowed to stand or move when trains are passing or arriving. The width of the danger zone primarily depends on the speed of the train moving along the track.

Figure 4. Safety and danger zone (left) and passenger safety at the borderline

The border between these two zones is most often visually marked with a contrasting borderline. The minimum width of the borderline is 10 cm (Commission regulation, 2014b). This warning line is a part of the safety zone. However, the person who finds himself on the borderline has to be safe. The contact of luggage or loose clothing with the vehicle must not be allowed. Figure 4 shows an additional extension for luggage 23 cm, which for safety reasons is increased by min. 10 cm. Therefore, the width of the danger zone should be increased by min. 33 cm to avoid contact with a passenger moving along the borderline (Table 1).

Table 1. Recommended minimum width of the danger zone

Maximum speed (km/h)	Minimum width of the danger zone (cm)
90	83
120	93
140	103

There is a possibility of placing a physical barrier that limits the safety zone. Installing high or low barriers with automatic door opening when the train stops is the safest, but also the most expensive solution. Therefore, its application is limited. It is used most often on frequent platforms of metro stations.

The platform floor has to be sufficiently resistant to slipping and help the passengers understand how to use the platform. Furthermore, it has to include guide paths for visually impaired persons (Figure 4).

The width of the platform can be variable over the entire length of the platform. The minimum width of the platform (without obstacles) is defined by (Commission regulation, 2014b) and encompasses the width of the danger area plus the width of two opposing freeways of 80 cm (160 cm). This dimension may taper to 90 cm at the platform ends.

The safe zone includes space for movement and seating (if provided) for passengers on the platform (Figure 5). At large passenger stations, passengers are not allowed to stay longer on the platforms, so seating at the terminal and entry of passengers onto the platform is organized immediately before the train enters the station. In this way, the required width of the platform is significantly reduced (Figure 6). A staircase, ramps and an elevator to access the platform can be found in the safe zone.

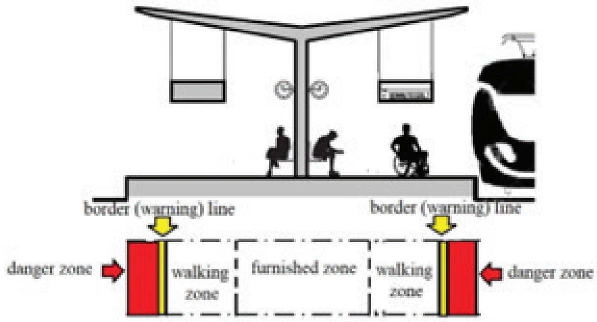

Figure 5. Zones on the middle platform

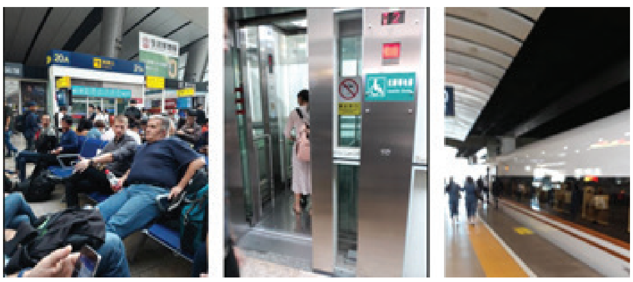

Figure 6. Terminal (left), access to the platform (middle and right) at Beijing railway station

The width of the staircase should be at least 2 m to allow two-way movement of passengers with luggage. For all passengers who are unable to use the stairs, it is necessary to provide access to the platform by elevator.

The dimensions of the elevator are defined based on the requirement to provide access to the platforms for people in wheelchairs (Figure 7). Lifts should be preferred to long ramps to shorten the time needed (Office for Official Publications of the European Communities, 2004).

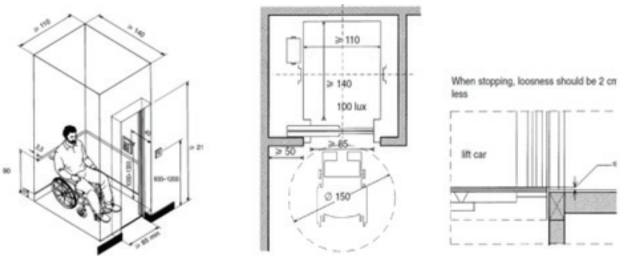

Figure 7. Minimum dimensions of the elevator for disabled persons by [COST Action 335]

Following (Commission regulation, 2014b) and from the aspect of passenger safety, the platform length shall be sufficient to accommodate the longest passenger train intended to stop at the platform in normal service in an interoperable railway station.

4. PLATFORM WIDTH

A centrally placed staircase (Figure 8, left), a seating area or an elevator on the platform represents a physical obstacle, which passengers bypass at the risk of being in a danger zone (Figure 8, right). On each platform where passengers are allowed to wait for trains, there shall be a minimum of one area fitted with seating facilities and a space for a wheelchair (Commission regulation, 2014b).

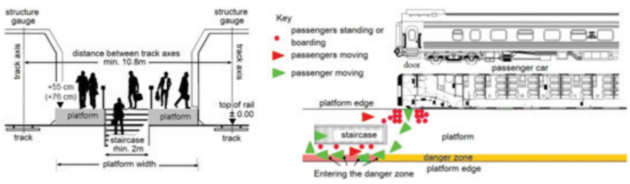

Figure 8. Width of the middle platform with centrally positioned staircase zone (left) and entering the danger zone by passengers (right)

Special attention is paid to the dimensioning of the space between the physical obstacle and the edge of the platform. Given that people in wheelchairs can be found in this zone, a width of at least 2,5 m from the obstacle to the edge of the platform should be applied at new and reconstructed stations (Figure 9) (Office for Official Publications of the European Communities, 2004). Based on the width of the physical obstacle and the required distance to the edge of the platform, the required width of the platform is defined.

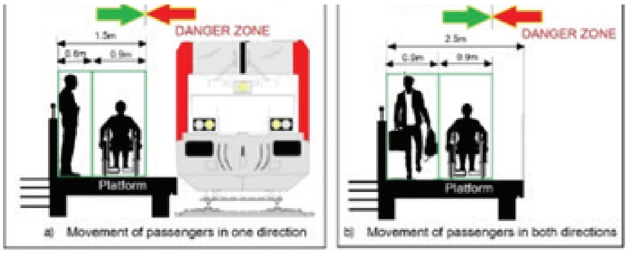

Figure 9. Movement of passengers between the physical obstacle and the edge of the platform

Figure 10 shows the width of the middle platform with a centrally placed staircase and elevator. In the case of reconstruction, when there is not enough space for central installation, the staircase and elevator can be designed at the end of the platform. In that case, the distance between the tracks should not be less than 9 m.

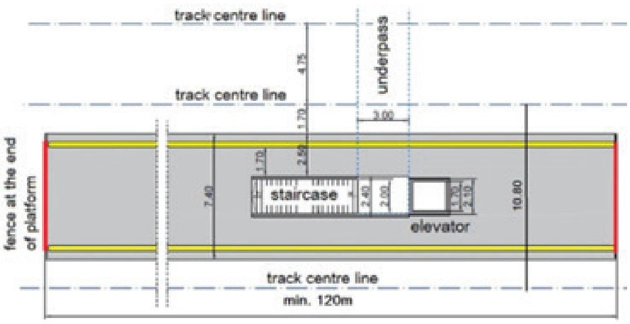

Figure 10. The minimum distance between tracks along the middle platform with the central position of the staircase

The side platforms connected by the underpass/overpass by PRM TSI are most often installed at railway stops. On the platforms, space can be provided for the installation of elevators, if needed. It is important to allow wheelchair users to access the railway infrastructure every 30 km along the railway line. Access for disabled people to the railway stops can be solved by setting up a stair platform lift. The minimum width of the side platforms is 2,5 m, if the staircase is placed at the end or on the side of the platform.

5. CONCLUSION

When designing the new and reconstructing the existing railway stations and stops, it is necessary to determine the required width of the safe zone for the passengers on the platform, taking into account the type and position of the infrastructure for access to the platforms, the permitted staying of passengers on the platform (organization of the seating area) and the necessary space for moving and standing. Access to the infrastructure using elevators for wheelchair users should be provided at a maximum distance of 30 km along the railway line. Also, the width of the danger zone primarily depends on the speed of the train and must be additionally increased to prevent contact with the vehicle when the passenger moves along the borderline. Special attention should be paid to the zones between the physical obstacle (e.g. stair railing) and the edge of the platform in order not to compromise the safety of passengers in wheelchairs.

It should be noted that, despite the evident increase in infrastructure investment, the expected increase in the number of passengers with reduced mobility (PRM) was not observed. To boost the number of PRM on railways, it's crucial to ensure a seamless transport chain from the door to door (i.e. the platform edge/vehicle floor). Additionally, the design guidelines must be regularly updated by incorporating feedback and recommendations from PRM.

ACKNOWLEDGEMENT

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IMPACT OF THE IMPLEMENTATION OF DIGITAL AUTOMATIC COUPLING ON WORKING CONDITIONS OF SHUNTING STAFF

POSLJEDICE IMPLEMENTACIJE DIGITALNO AUTOMATSKO KVAČILO NA UVJETE RADA MANEVARSKOG OSOBLJA

UDK: 656.2+629.45

SUMMARY:

The requirements for supply chains have changed significantly in the last decades, due to demands or challenges in competition. However, not only the requirements but also the technologies underwent a change. If we consider rail freight transport, digital systems for wagon data admission or route planning system are currently implemented. The freight wagons themselves, however, have remained in basic principles of the 19th century. For example, they do not have a power supply or a continuous data line to ensure the train integrity or supply sensors on the wagons with power. It is also necessary to couple and uncouple the screw couplings manually. Today coupling and uncoupling wagons is a physically demanding work and not without danger. Here, the use of a Digital Automatic Coupling (DAC) could have a positive impact of the operating procedure and reduce occupational risks. In the context of this work it is examined, how the implementation of the DAC influences the staff. For this purpose, conventional processes are analyzed and the effects of the DAC are examined. It is shown, how the various tasks and the responsibilities are shifted between different workers, like shunting staff and train drivers.

Key words: Shunting, Digital Automatic Coupling, work environment, Freight traffic

REZIME:

Zahtjevi prema opskrbnim lancima značajno su se promijenili u posljednjim desetljećima, kao rezultat promjena na području tršišnog natjecanja. Međutim, nisu se promijenili samo zahtjevi, već i tehnologije. Ako promatramo željeznički teretni promet, trenutno su implementirani digitalni sustavi za prijem podataka o vagonima i sustav planiranja ruta. Teretni vagoni, i dalje su utemeljeni na načelima 19. stoljeća. npr., nemaju napajanje ili kontinuiranu podatkovnu liniju koja bi osigurala cjelovitost vlaka ili opskrbu senzora na vagonima strujom. Nadalje, potrebno je ručno spajati i odvajati vijčane spojnice. Spajanje i odvajanje vagona je fizički zahtjevan i opasan posao. Uporaba digitalno automatskog kvačila (DAC) mogla bi imati pozitivan učinak na radni postupak i smanjiti profesionalne rizike. U kontekstu ovog rada ispituje se kako implementacija DAC-a utječe na osoblje. U tu svrhu analiziraju se konvencionalni procesi i ispituju se učinci DAC-a. Prikazuje se kako se različiti zadaci i odgovornosti prebacuju između različitih radnika, poput manevarskog osoblja i strojovođa.

Key words: Manevriranje, digitalna automatska spojka, radno okruženje, teretni saobraćaj

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1. INTRODUCTION

Currently the freight transport sector needs to react in order to achieve the Green Deal targets for emissions caps in the transport sector. It is necessary to drastically reduce emissions in land-based transport. This can be achieved by reducing emissions in the individual modes of transport or by shifting to more climate-friendly modes of transport. (CER (on behalf of Rail Freight Forward), 2020a)

For example, it is planned to increase the modal split in rail freight transport to 30 % by 2030. However, in order to achieve this goal, corresponding optimizations in rail transport are necessary. Many rail freight corridors (RFC) are already well utilized today. In urban centers, some of the rail networks are at their capacity limits. (CER (on behalf of Rail Freight Forward), 2020b)

In addition, although technical systems are already being used in rail freight transport to handle traffic, for example software solutions for recording wagon data, the freight wagons are largely in their original condition. This means that they are only mechanically coupled and braked via a main air line. For coupling and uncoupling, it is necessary for a shunter to enter the track area and perform this activity manually. This operation is not only time consuming but also dangerous. In addition, the manual UIC screw coupling is an obstacle to completely automating shunting in marshalling yards. There are approaches here, for example, research has been carried out in Austria in recent years on a prototype uncoupling robot. However, this could only be used locally at large stations and could not bring any improvements in small area stations. (Egger et al., 2019)

Currently, various European projects are working on the implementation of a Digital Automatic Coupling (DAC) system. In the course of international projects (e.g. European DAC Delivery Programme / Europe's Rail Joint Undertaking) and national projects, this idea is being implemented. This paper presents considerations that have been developed in part in the Digital Automatic Coupling in Infrastructure Operations (DACIO) Project. (FH St. Pölten Forschungs GmbH, 2021)

For this purpose, a process from as-built shunting is analyzed. This will then be looked at using a DAC and the improvements for employees will be identified.

1.1. Digital Automatic Coupling

The DAC is a center buffer coupling system which, in addition to a mechanical and air coupling, also ensures the power supply and data supply. Several center buffer coupling systems already exist worldwide. For example, the SA3 type coupling, which is mainly used in Russia, and the AAR type, which is used in America. Whereas with the UIC screw coupling all coupling and uncoupling operations have to be carried out manually, with the center buffer coupling systems at least the coupling operations are automated. The DAC would therefore be an innovation in this sector and would enable corresponding technical functionalities. (Rilo Cañás et al., 2022)

Table 1 shows the different technical levels of the DAC with their functionalities.

The power and data line can, for example, optimize train preparation, brake tests and, through sensor technology, wagon technical inspection. However, these are so-called enabler functions that require further adaptations to the freight cars and traction units, but the DAC makes them possible in the first place.

As a coupling type the Scharfenberg coupling type is chosen as a coupling design:

Table 1: Different DAC Levels Source: (Hecht et al., 2020)

Functionality	AK-1	AK-2	Level 3	Level 4	Level 5
Automatic mechanic coupling	Yes	Yes	Yes	Yes	Yes
Automatic main air-pipe coupling	Yes	Yes	Yes	Yes	Yes
Automatic power coupling	No	No	Yes	Yes	Yes
Automatic data coupling	No	No	No	Yes	Yes
Automatic Decoupling	No	No	No	No	Yes

Figure 1: DAC Type Scharfenberg from Voith. Source: (Voith GmbH & Co. KGaA, 2022)

2. METHODS

Methodologically this paper can be divided into two parts. The first one is an analysis of the existing processes and the second part consists the considerations of the implementation of the DAC. Basically, freight transport can be divided into four sub-areas: Shunting preparation, shunting execution, train preparation and train running. In the course of this work, the focus is on shunting preparation and shunting execution. Although these activities are comparable throughout Europe, Austria is chosen as the region to be studied. In particular, the infrastructure of the Austrian Federal Railways (ÖBB). For this purpose, a rulebook and process analysis is carried out at the beginning, which leads to initial findings on the processes. Based on these findings, a schematic overview of the respective activities could already be created. An analysis of the processes in operation on site brought further refinements for this part of the work. Based on this, the respective target states are considered with the DAC. For this purpose, the DAC is implemented in the fine-ranking process. In doing so, not only the process components are examined, but also the respective activities for the staff. It will be deduced how this changes the work environment.

3. RESULTS

As mentioned, the first part is to analyse the shunting process in general. In this stage, the different tasks involved in the process of assembling and disassembling train formations are identified. On the other hand, categories are established to group these activities according to their main objective: Uncoupling of wagons, Shunting movements, Coupling, Inspection of wagons, departure arrangements. Thus, it is possible to obtain a process diagram based on these two initial dimensions.

Two important distinctions have been taken into account in the rail shunting operations performed in the freight yards, which do not have a hump: Flying shunting (pushing off) and displace shunting (pushed and pulled by a shunting locomotive). In the first case, special attention is focused on the preparation and shunting activities for those wagons that must be pushed in a controlled manner.

3.1. Detailed Shunting Process

Based on the most common shunting operations needed to modify the train formations, the seven most representative operational cases were then defined, excluding the case of Marshalling yards with Hump-yard systems (classification yards). They are the change of direction of a train, which means that the locomotive has to be shunted to the other train side. But not only the position of the locomotive can be changed. Also, the position of freight wagons within the train can be changed. Therefore, a fine row or reordering is needed. Also there can be wagons added to a train or taken from a train. It is also considered as an extra case if wagons are stabled on a loading track within the station area. For industrial sidings there are also assumed two additional cases. One for picking up freight wagons in an industrial siding and the second for delivering wagons to an industrial siding.

3.2. Current situation

Based on the definitions described above and on the analysis of real cases by professionals in the operation, it was possible to structure a process diagram for each case, identifying the main activities and the personnel involved (Dispatcher, Train driver, Shunting stuff and Wagon inspector) in the different stages.

The driver concentrates on the activities related to the movement of the train and shunting operations with the different groups of wagons, whether with a line locomotive or a shunting locomotive. All the checks emanating from both the Shunter and the Dispatcher are also added before proceeding to move the train. (ÖBB Infrastruktur AG, 2021)

The activities associated with the coupling and uncoupling of wagons are performed by the shunting Staff in-between two wagons, coupling them. The activities include the physical coupling and uncoupling of the UIC screw coupling and main air pipe. Before or after that the opening and/or closing of valves as well as the partial or total testing of the brake system has to be done. Other activities are related to the wagons: Verify the correct information of the transported cargo (freight documents), add or remove the end of train signal if it corresponds to the end wagon, add or remove the drag shoes in case the wagon must be secured or not. Finally, there are the operational support activities: Assisting the driver in pull situations (because the driver cannot see the line ahead), request, check, and steering manual turnouts on the route. (ÖBB Infrastruktur AG, 2021) In bigger railway stations a Wagon inspector carries out a technical examination of the wagons. In industrial sidings a simplified wagon inspection is made by the shunting staff. (Wagner et al., 2021)

The corresponding components of the fine-series process can be seen in Figure 2, whereby the shunter activities, which will be affected by the DAC are marked yellow:

3.3. Adapted situation

While the driver's activities are largely unaffected by the implementation, there are improvements in all activities that relate to the checks that emanate from both the Shunter and the dispatcher before proceeding to move the train.

In the case of the activities associated with the Shunter, those are associated to the coupling and uncoupling of the wagons are of great relevance. The big change has to do with the fact that the Shunter's workplace, between the wagons. The shunting staff don't has to be in between two freight wagons, and also the time on the track in general can be reduced. It should be noted that for uncoupling of the DAC Level 4, although it requires manual operation, it is possible to operate it from the side of the train. Other activities related to the wagons that have to do with verifying the correct information can be assisted

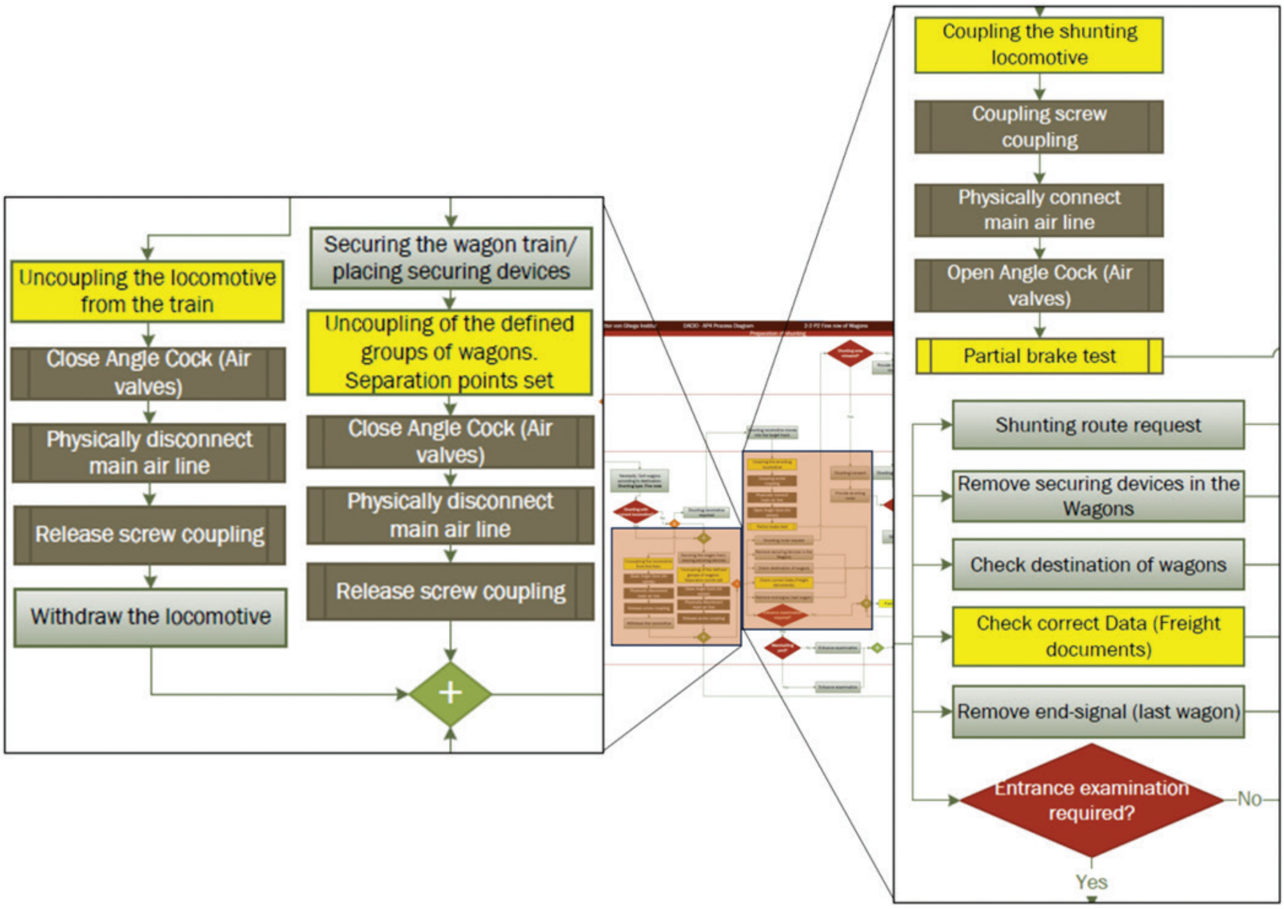

Figure 2: Conventional process of fine row of wagons

thanks to the digital information flow between the wagons. Finally, operational support activities remain unchanged. Figure The corresponding components of the fine-series process with the DAC Level 4 or Level 5 can be seen in Figure 3. The changed steps are marked green.

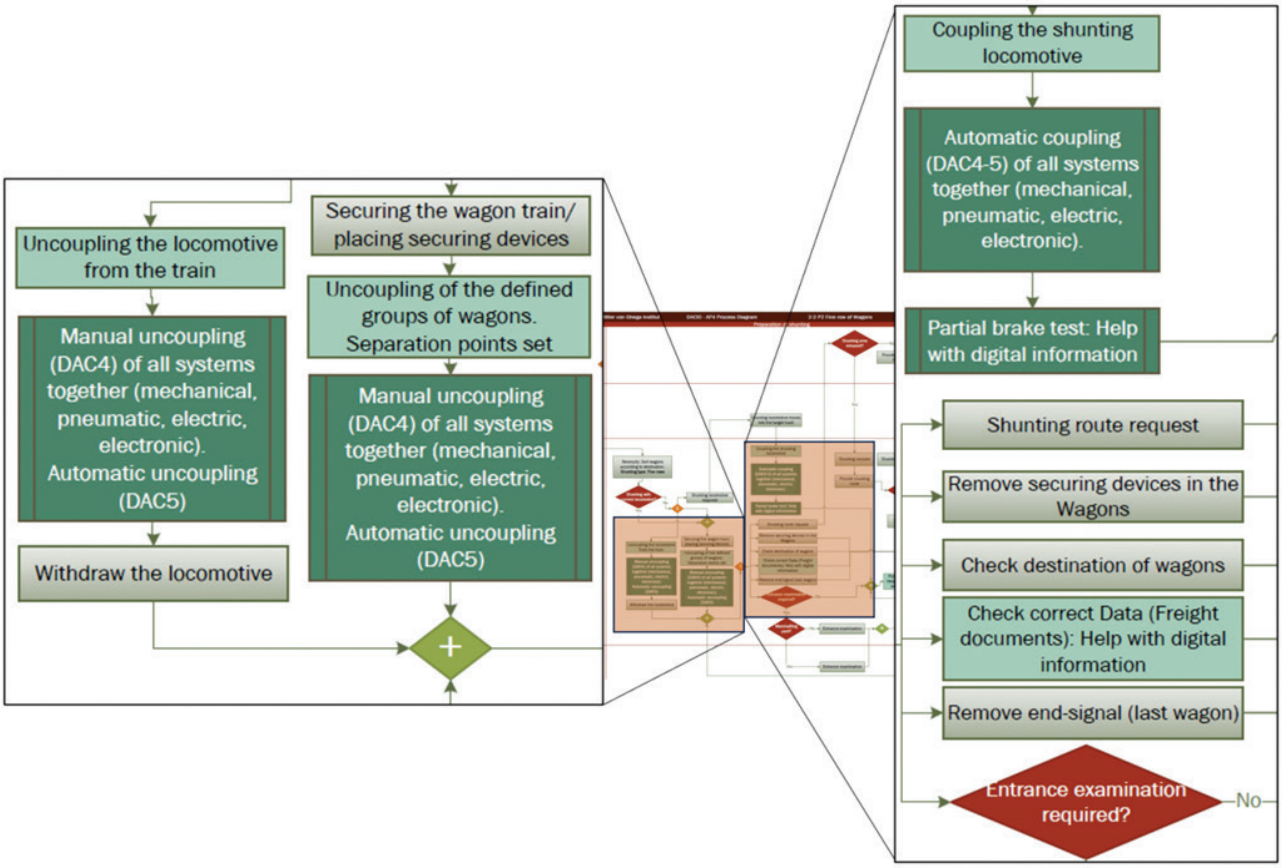

Figure 3: Adapted process of fine row of wagons

3.4. Impact on professional profile

The new modifications due to the DAC in the processes of assembling and disassembling train formations have consequently a rethinking in the definition of the required professional profile, mainly due to the following three aspects. Data Utilization: Possibility of performing remote tasks, in a shorter period and a higher data quality. This accelerates the planning, preparation, document inspection and follow-up processes. Automation: The new designs ensure automation throughout much of the process. In others where it is not possible (decoupling at level 4) there is a substantial improvement in working conditions (less risky). For both cases, partial or permanent supervision by personnel is required in case of failures. Data and control: The project will allow each car to report information related to the systems and even the ability to perform diagnostics and thus detect certain deficiencies. Another possibility that is still under study is to reinforce the control of the braking systems and thus cover the functionality of partially or totally securing the wagons. It is therefore proposed that the changes in the professional profiles will finally focus on the inspection, supervision and troubleshooting. For this purpose, a greater specialization related to the previous aspects is required for the personnel. Especially to the new coupling system functionalities, diagnostics, preventive and corrective activities, risks, etc. Although if the total occupational risk decrease significantly due to reduced exposure, there has to be further investigation, if new occupational risks also arise due to technological change. (Alay et al., 2023)

Therefore, it is possible to address a strategy of reassigning personnel, so that those roles that disappear do not result in the reduction of personnel, but rather cover the new needs and thus the new roles demanded. This requires a strong transition program that allows people to be trained and thus provides more attractive and secure job opportunities with great projection. (Alay et al., 2023)

4. DISCUSSION

The implementation of the DAC is expected to be gradual and with it come dynamic scenarios, which we must consider in all areas when thinking about implementation process. The level of coupling automation (type 4 - type 5) is therefore a significant criteria, which is triggering the activities and functions to be performed by the trained personnel. It leads to a dynamic and prolonged change management. The technological changes will be made gradually. Especially if there is not a transition phase there will situations where trains with the new coupling systems deliver data, but other trains do not deliver data. To this end, it is important to think about the necessary interfaces as well as the requirements and functionalities to be integrated. (Tyrinopoulos & Milioti, 2022)

Finally, one of the most relevant aspects of the DAC project has to do with the overall impact of digitization on the workforce. This is not trivial, but it can be generally identified, that there are opportunities, remaining gaps and barriers and mixed conditions. As a barrier it can be seen, that there has to be a scepsis from the workers. Therefore the staff should be integrated, in adapting their new job roll, because there are fundamental changes from a simple mechanical system to a system with electrical components, which is more complex and offers more functions (supervision and breakdown/maintenance services). There has to be an appropriate training on the new functions. Which leads not only to new function in existing job roles but also to new professions (platform workers, IT). Also, the harmonization of rules and procedures but also the legal framework has to be done. The reduced occupational risk can also improve the possibility to find more workers, especially young people. On the other hand there should be mentioned, that also if new employees are needed, they cannot be found so easily so automation and the change process can attract these jobs. That can be reached by a reduction of manual activities and the redeployment of functions between different positions. But also for the transition phase there should be considerations of the mixed scenarios. (Tyrinopoulos & Milioti, 2022)

5. CONCLUSION

It can be concluded, that the development of the DAC will bring improvements in operational efficiency and safety. On the other hand, digitization also brings in the railroad field new functions to support in the operation, collecting online information and thus improving the management of other stakeholder processes.

Of great importance is the training of the personnel involved and the redefinition of roles and functions in change management, which will not be immediate. Hybrid operating scenarios are to be expected in which high-tech trains and conventional (non-equipped) trains coexist. It is therefore important to prepare personnel not only for the future scenario, but also for the transition scenario.

Finally, automation brings with it new technologies that require greater specialization of operating personnel, a greater effort in personnel training processes and complex change management in processes and protocols, both operational and risk prevention. The presence of more technology also means the opportunity to attract new highly qualified professionals, especially women and young people.

ACKNOLODGEMENT

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RAIL FACTOR AND ITS PERCEPTION IN SMALLER REGIONS - LOVOSICE CASE STUDY

UDK: 656.2+314/316:32/34

SUMMARY:

Objectives The paper aims to observe the passengers´ attitude towards modal choice regarding the rail factor, a possible preference of the rail-based public transport modes in otherwise similar transport supply conditions. The existence of the rail factor is surveyed regarding the tolerance of the passengers towards the expected longer station approach times or travel times with the regional railway line to be reintroduced in comparison to the existing regional bus lines. Approach Before the reintroduction of the railway line no. 113 Most - Lovosice, an online survey with the passengers along the line was conducted. The respondents were asked about modal choices regarding their requirements on the operation frequency and conditions of a possible change in favor of rail-based modes. Results The respondents found the train more comfortable, and it is likely to be chosen for the unspecified general journey. However, the regional train should not be considerably slower than the competing bus should the passengers switch in favor of the train. Contribution The collected SP data combined with the RP data (transport survey) form the basis for a determination of the rail factor role in regional transport as shown with the case study of the reintroduced line no. 113.
Key words: regional railway line, modal choice, modal attractivity, travel time

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1. INTRODUCTION

When perceiving means of public transport with similar service and performance characteristics, the passengers approach to them is different (Cain et al, 2009) and rail-based means are supposed to be superior. The phenomenon of rail factor or rail bonus (rail bias) has been described as an inherent, intangible, and even emotional-based passenger preference (Scherer, 2012) for rail-based public transport systems (railway, trams, trolleybuses) over road-based ones. It is often experienced that the new rail-based mode can attract more passengers than the initial bus lines with similar characteristics in terms of tangible modal choice variables such as travel time, travel costs, number of transfers or accessibility. This tendency is also to be seen with cities of comparable size where one city has an electric-powered public transport mode and this city reports a higher modal share of public transport. A similar effect is expected to be present with regional transport, although the accordingly comparable services in the scarcely populated regions are hardly to be found.

According to previously presented research, opinions on the relevance and even presence of the rail factor are mixed and may even be dependent on the geographical and socio-demographic conditions. In general, more studies concerning urban systems seem to be conducted. Axhausen et al. (2001) presented a before-after study of the reverse change from tram to bus service with the conclusion of a small but existing influence of the rail factor in favor of the tram. An influence of the positive rail factor towards the tram by different passenger types explained by intangible variables such as vehicle atmosphere, travel information and subjective comfort was presented by Bunschotten et al. (2013) who also estimated a positive influence on the ridership as 12 %. Contrary to that, Ben Akiva and Morikawa (2002) argue the factors are not specific to rail and there is no rail bonus provided the high-quality BRT system is to be considered. Among the studies focusing on regional rail, both Megel (2002) and Barth et al. (2020) stated the positive rail factor influence differs with age groups and passenger modal captivity.

Despite the attitudes commonly accepted by practitioners, the impact of the rail factor has never been truly researched as there were not any before-after data sets for the Czech conditions. This situation changed with the reopening of the disused regional railway line no. 113 between Lovosice and Most in the Ústí Region which meets the worldwide phenomenon of regional railway modernization (Veit et al., 2018). Together with consequent transport surveys in the relevant regional bus and railway lines (Metelka and Janoš, 2022), a sociologic survey was organized to determine the passengers attitudes towards the new concept and potential modal changes.

2. METHODS

The survey was conducted at the beginning of December 2019 shortly before the reintroduction of the regular train service on the upgraded railway line no. 113 Lovosice - Most after 12 years without train service compensated by regional bus lines. Because of the time consent, the online form was chosen as the best means to attract a higher number of participants, especially those who reside along the railway line. Because the questions were mainly focused on line no. 113 and its surroundings, the passengers that do not reside in the Ústí Region or do not commute to it were omitted from the results.

The total number of participants was 164 and their characteristics influencing the results are demonstrated in the following sections.

2.1. Demographic structure

Considering the age stratification of the respondents a realistic representation of the population in the Ústí Region was achieved as there were over 70 % of the people who belonged to major age groups 27-40 years and 41-65 years (see Table 1). The group of school children and students as typical public transport users in two age groups 0-15 and 16-26 years nearly 25 % of the respondents. The former age group was less frequent than with the normal population (less than 2 %) due to the distribution channel of the survey (local websites of the villages and the Region etc.) and related unwillingness to fill in the online form. A similar problem was encountered with the people older than 65 years where the shares were despite the short amount of time over 4 %.

The classification according to economic activity shows that over 70 % of the passengers are standard taxpayers and 16,5 % represent high school or college students. The reasons for lower shares of retired people (6 %) and the absence of elementary school students were mentioned above.

Table 1. Demographic structure of the participants (N=164)

Age of the participants	0-15	16-26	26-40	40-35	66+
Share	1,2%	23,8%	34,8%	36,0%	4,3%

2.2. Relationship to public transport

Most of the respondents (over 63 %) use public transport for regular journeys whereas about 28 % are occasional users. Many of them may use annual or seasonal passes (Kříž and Janoš, 2019) and thus form some kind of captive riders as the transport supply is less variable in the small region and the ownership of the passes reflects the frequency of use. In these groups of public transport riders, over 60 % use the regional bus service between Most and Lovosice. The rest of the respondents claim that despite not using public transport now they are not strictly against it. This fact confirms that no captive drivers participated in the survey as there is hardly any reason for them to fill in the form. The most frequent reasons for not using public transport are car ownership long travel times reached by public transport and long distances to public transport access points.

3. RESULTS

In this chapter, the perception aspects of the regional railway line are presented.

3.1. Comfort

As only the stated preferences were collected an objective methodology of the qualitative assessment could not be applied. Therefore, the presented data are focused on the subjective perception of the participants.

When comparing regional buses and regional railways in general without further localization the train is strictly preferred (see Table 2). For a non-specific regional journey, almost 80 % of the respondents choose a train and a similar number of participants perceive the train as more comfortable than the bus. The data indicate that if there are similar key performance characteristics e.g. travel time with the bus and the train, the train may carry more passengers than the bus with the same parameters. Such a result was expected in terms of the rail factor influence.

Table 2. General modal preferences of the respondents (N=164)

Aspect	Train	Bus	No difference
Preference for general regional journey	79,3 %	20,7%	-
Perceived as more pleasant and comfortable	79,3 %	8,5%	12,2%

3.2. Frequency

The respondents who stated they did not know the planned operational concept for the reopened railway line no. 113 were asked about the operation frequency of the new line on workdays. The desired operation frequencies that alone may convince the respondents to take the train are shown in Figure 1.

Some 70 % of the respondents answered in favor of the new operation concept (train every 60 min during peak hours with the period fluctuation (Drábek and Pospíšil, 2018) to 120 min during off-peak hours) with the 60 min headway being strongly preferred. The results fully correspond to the authors´ expectations and support the claim that an attractive regional public transport supply may be reached if there is at least a 60-minute headway on offer in the core network during peak hours.

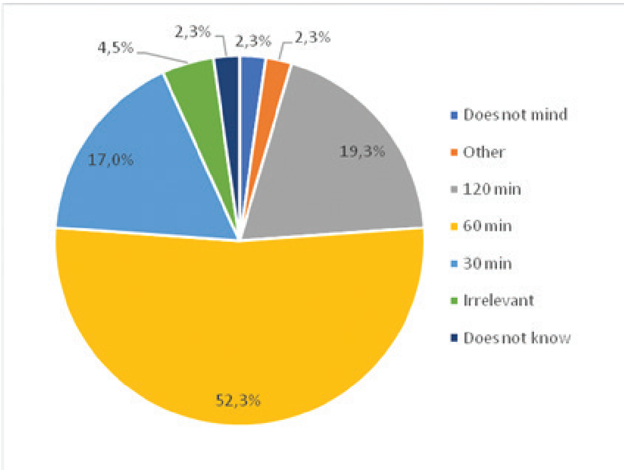

Figure 1. What is the minimum headway during the weekdays for you to start using the train? (N=88)

3.3. Travel time

The same group of respondents was asked about their door-to-door travel time perception regarding different modal choice possibilities. The original door-to-door travel time reached by a regional bus was set to 30 min and the reaction to possible travel time extension when switching to the regional railway was a subject of the survey. The respondents were introduced to a realistic span of travel times usually reached by short or medium regional public transport journeys between 20 and 60 min.

The results are shown in Figure 2. Approximately one-third of the respondents were unwilling to any door-to-door travel time extension and even wanted to shorten the door-to-door travel time reached by train whereas more than 20 % even wanted to shorten the travel time by one-third. This phenomenon may be caused by a public image of the train as a fast means of transport and travel time reductions may fit in. However, another third accepts the original travel time, and the last third could cope with a travel time extension.

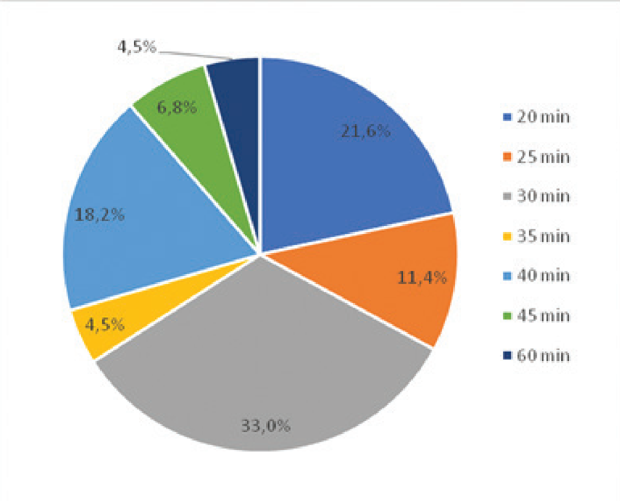

Figure 2. If your door-to-door travel time by bus is 30 min, what travel time would you accept by train with the same journey? (N=88)

The original hypothesis with prevailing preservation of the original travel time and slight preference in favor of mild travel time extension could therefore not be confirmed. It also shows that the passengers are quite sensitive to door-to-door travel time value and if there is room for its change or a tolerance of its extension, minor changes such as 5 min are less important. However, the influence of the rail factor may be contained in the fact that even with the train being less accessible (usually longer distances to its stops in comparison with bus stops), the overall travel time seems to remain the same which indicates the willingness of the respondents to approach the more distant train station and to compensate for this discomfort by faster and more comfortable train ride.

3.4. Potential modal shift

Despite the reintroduction of the disused regional railway line no. 113 with 60 or 120 minute headways since December 2019, the Ústí Region decided against reducing any of the bus lines between Most and Lovosice so the new train line is a significant extension of the regional public transport supply. After some evaluation of the new concept, related partial bus line reductions and the modifications of the transport supply in favor of the new railway line are to be expected since not only operation concept changes but also the inevitable infrastructure means for travel time reduction were introduced. Only the combination of these factors in contrast to the mere reintroduction of the railway operation may contribute to relevant modal split changes.

All respondents were asked if they were going to use the train as a potential substitution for the bus with similar timetable features. The results presented in Figure 3 show that the train is an acceptable alternative for more than 80 % of the respondents. Only 10 % of people would switch to individual transport and for 3 % such change would be the subject of an official complaint. These results may also mean that the new operational concept was designed to successfully meet the needs of its customers and that the rail-based mode with similar timetable features may compensate for the minor discomfort its distant access points may cause.

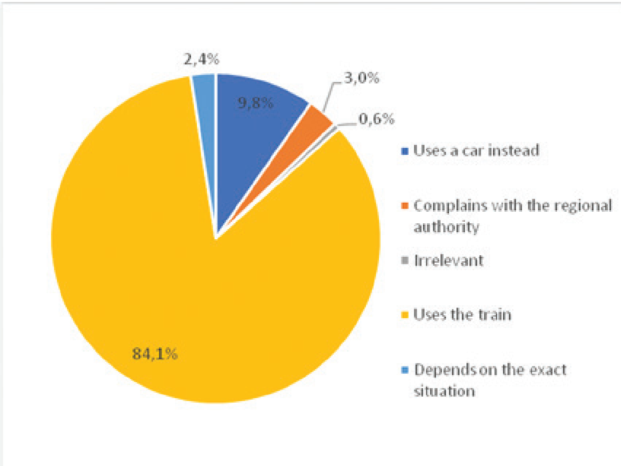

Figure 3. What would you do if there was a significant reduction of the current bus lines in favor of the train with a similar timetable? (N=164)

4. DISCUSSION

According to the data obtained from the SP-survey, if the passengers must choose between a train and a bus the train is preferred because of its comfort, speed, ability to carry bicycles or the on-board restroom. These qualitative aspects are similar to the intangible values identified by Bunschotten et al. (2013). Therefore, a better perception of the regional railway in comparison to the regional bus is present.

However, if the train cannot achieve at least similar values as the bus in terms of door-to-door travel time, the advantages mentioned above become neglected as the passengers are unwilling to accept longer journey times only because they can travel by train. This statement confirms the results given in the discussed foreign studies as tangible values must correspond to each other for the intangible rail factor to be estimated (Axhausen et al., 2001).

Despite the best efforts of the researchers, the collected data and the related claims are somehow limited by the data collection method. The online form used for the survey was not able to fully represent all the relevant age groups, especially the typical public transport customers. It does not include the proportional shares of the youngest schoolchildren that form an essential part of the public transport customers as captive riders in the regional bus lines. The online form may have been an obstacle for the elderly or retired passengers, too, resulting in potential changes in preferences (Megel, 2002).

In addition, the qualitative attitude of the participants may be influenced by the fact that the people with a natural interest in the railway mode are more likely to fill in the form. This fact was also confirmed by the absence of captive drivers with higher preferences for individual transport in suburban and rural areas (Braun Kohlová, 2009) in the survey. However, only the answers from the participants of the Ústí Region were considered to prevent undesirable preferences towards the popular railway mode based on pure fandom.

5. CONCLUSION

The study was conducted in separate stages using the opportunity to obtain before-after data sets collected with the reopening of the disused railway line upgraded to meet the standards of the substitute bus lines. The sociological survey confirmed the importance of the tangible variables used in macroscopic transport models (i.e. travel time), it, however, implied that should those be comparable, the rail-based public transport system is more likely to be chosen.

The Stated Preferences given by the passengers are to be further verified using the Revealed Preferences collected in a transport survey that was conducted after the pandemic in 2021 (Metelka et al., 2022) and is required to incorporate statistical measures to reflect the persisting influence of the reduced mobility with the passengers. The survey may help to determine if the passengers´ preferences and their transport behavior as stated preference correspond to their willingness to use the train rather than the regional bus lines as revealed preference. The comparison of the passenger numbers collected before the railway line reintroduction and after it may support the existence of perceived higher attractiveness of the rail-based transport modes called rail factor and further contribute to its research in the conditions of the Czech Republic.

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BESKONTAKTNO MERENJE PARAMETARA GEOMETRIJE KOLOSEKA

NON - CONTACT MEASURMENT OF TRACK GEOMETRY PARAMETERS

UDK: 656.2+625.1/.5

REZIME:

Sa tendencijom razvoja i unapređenja železnice, povećavanjem brzina na železničkim prugama i zahtevima za povećavanjem propusne moći pruga usled porasta obima saobraćaja, proprocionalno rastu i izazovi u pogledu održavanja železničke infrastrukture. Beskontaktnim merenjem parametara geometrije koloseka i analizom rezultata merenja moguće je kreirati kvalitetne planove i strategije upravljanja održavanjem železničke infrastrukture u kratkom vremenskom periodu i pravovremeno preduzeti mere za otklanjanje registrovanih grešaka na koloseku. Na taj način se bezbednost podiže na znatno viši nivo, izbegavaju neplanirani zatvori koloseka, omogućava redovitost saobraćaja i umanjuju troškovi neadekvatnog i neplanskog održavanja železničke infrastrukture.
Ključne reči: železnička infrastruktura, upravljanje održavanjem, merni sistemi, gornji stroj, šine

SUMMARY:

With the tendency to develop and improve the railways, increasing the speed on the railways and the requirements for increasing the throughput of the railways due to the increase in the volume of traffic, the challenges of maintaining the railway infrastructure also grow proportionally. By non-contact measurement of track geometry parameters and analysis of measurement results, it is possible to create high-quality plans and management strategies for the maintenance of the railway infrastructure in a short time and take timely measures to eliminate registered errors on the track. On that way, safety will be raised to a significantly higher level, unplanned track closures will be avoided, regular traffic will be enabled and the costs of inadequate and unplanned maintenance of the railway infrastructure will be reduced.
Key words: railway infrastructure, railroad maintenance, measuring systems, superstructure, rails

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1. UVOD

Kvalitetno održavanje železničke infrastrukture predstavlja preduslov za bezbedno funkcionisanje železničkog saobraćaja. Kako bi Upravljač infrastrukture kvalitetno održavao železničku infrastrukturu, neophodno je da razvije funckionalnu strategiju održavanja. Značajnu ulogu u formiranju strategije održavanja železničke infrastrukture čini snimanje parametara geometrije koloseka.

Evropski komitet za standardizaciju CEN (Comité Européen de Normalisation) izdao je serije standarda EN 13231 (deo 1 – 5) i EN 13848 (deo 1 – 6) kojima se definišu jedinstveni kriterijumi za ocenu kvaliteta geometrije novih i remontovanih koloseka, odnosno koloseka u eksploataciji, na osnovu merenja parametara geometrije koloseka, čija je primena obavezna u svim zemljama članicama (Pančić i Mićić, 2015).

Standard EN 13848-1 *Primene na železnici - Kolosek - Kvalitet geometrije koloseka - Deo 1: Definisanje parametara geometrije koloseka* definiše osnovne parametre geometrije koloseka i minimalne zahteve za metode i merne sisteme i analize dobijenih rezultata. Standardom EN 13848-2 *Primene na ,železnici – Kolosek – Kvalitet geometrije koloseka – Deo 2: Merni sistemi – Vozila za merenje parametara geometrije koloseka*, utvrđuju se minimalni zahtevi za principe i sisteme merenja parametara geometrije koloseka, sa ciljem dobijanja rezultata koji su uporedivi prilikom izvođenja merenja na istom koloseku. Standardom EN 13848-3 *Primene na železnici – Kolosek – Kvalitet geometrije koloseka – Deo 3: Merni sistemi – Mašine za građenje i održavanje koloseka* utvrđuju se minimalni zahtevi koji moraju da ispune merni sistemi ugrađeni u mašine za građenje i održavanje koloseka, kako bi se ispunili uslovi za određivanje ocene kvaliteta geometrije koloseka upotrebom jednog ili više parametara koji su definisani standardom EN 13848-1. Standardom EN 13848-4 *Primene na železnici - Kolosek - Kvalitet geometrije koloseka - Deo 4: Merni sistemi - Ručni i laki uređaji*, definiše minimalne zahteve koje je potrebno da ispune ručni merni sistemi i merna kolica za merenje parametara geometrije koloseka, u cilju ocene kvaliteta geometrije koloseka, a na osnovu standarda EN 13848-1. Standard EN 13848-5 *Primene na železnici – Kolosek – Kvalitet geometrije koloseka – Deo 5: Nivoi kvaliteta geometrije koloseka – Kolosek na otvorenoj pruzi, u skretnicama i ukrštajima*, propisuje minimalne zahteve za nivoe kvaliteta geometrije koloseka i utvrđuje granice sigurnosti za svaki parametar definisan u EN 13848-1, koji se meri primenom odgovarajućih mernih sistema definisanih u EN 13848-2, EN 13848-3 i EN 13848-4. Poslednji deo standarda, EN 13848-6 *Primene na železnici - Kolosek - Kvalitet geometrije koloseka - Deo 6: Određivanje kvaliteta geometrije koloseka*, definiše određivanje kvaliteta geometrije koloseka, koji je zasnovan na parametrima definisanim u EN 13848-1 i navodi različite klase geometrije koloseka koje treba uzeti u razmatranje (Pančić i Mićić, 2015; https://iss.rs/sr_Latn/, 05.08.2023).

S obzirom da je merenje parametara geometrije koloseka najvažniji, ali ne i jedini, pokazatelj kvaliteta geometrije koloseka, u najsavremenijim shvatanjima održavanja železničke infrastrukture pojavljuje se više različitih mogućnosti u pogledu konstrukcije i usavršavanja mernih sistema za vršenje merenja parametara geometrije koloseka. Dva osnovna načina merenja parametara geometrije koloseka su kontaktno i beskontaktno merenje. Oba načina se mogu primeniti za merenje apsolutne i relativne geometrije koloseka. U ovom radu, razmatraće se beskontaktno merenje parametara relativne geometrije koloseka, pri čemu će se kao ugledni primer prikazati sistem merenja geometrije koloseka mernim kolima u vlasništvu Akcionarskog društva za upravljanje javnom železničkom infrastrukturom Infrastruktura železnice Srbije „Sever 1435", rezultati merenja i diskusija rezultata.

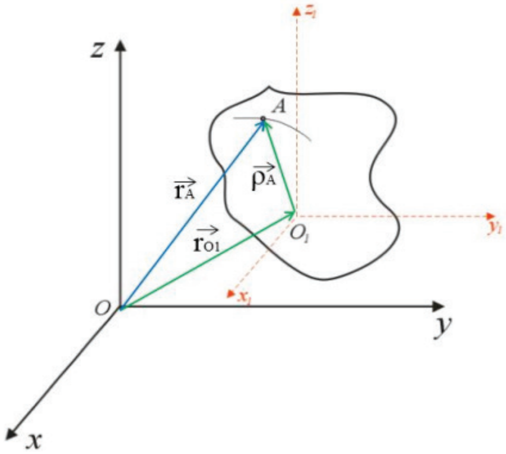
2. RELATIVNA GEOMETRIJA KOLOSEKA I PRINCIPI MERENJA BESKONTAKTNIM MERNIM SISTEMIMA

2.1. Relativan, prenosan i aposlutan položaj tačke u prostoru

Beskontaktno merenje geometrije koloseka može se koristiti za merenje relativne geometrije koloseka. Ukoliko se parametar geometrije koloseka meri u nekoj tački A, koja je čvrsto vezana za neko telo i kreće se zajedno sa unapred definisanim pokretnim koordinatnim sistemom, takvo kretanje naziva se relativno kretanje tačke u prostoru (slika 1). Pored toga, postoji prenosno i apsolutno kretanje tačke. Prenosno kretanje tačke A predstavlja kretanje unapred definisanog pokretnog koordinatnog sistema Ox1y1z1 u odnosu na neki nepokretni koordinatni sistem Oxyz. Kretanje tačke A u odnosu na nepokretni koordinatni sistem Oxyz naziva se apsolutno kretanje tačke. Apsolutno kretanje tačke $\vec{v}A$ predstavlja zbir vektora relativnog $\vec{v}r$ i prenosnog kretanja $\vec{v}p$, kako je prikazno u izrazu (1).

$$\vec{v}A = \vec{v}p + \vec{v}r \tag{1}$$

Na slici 1 prikazane su sve prethodno navedene vrste kretanja.

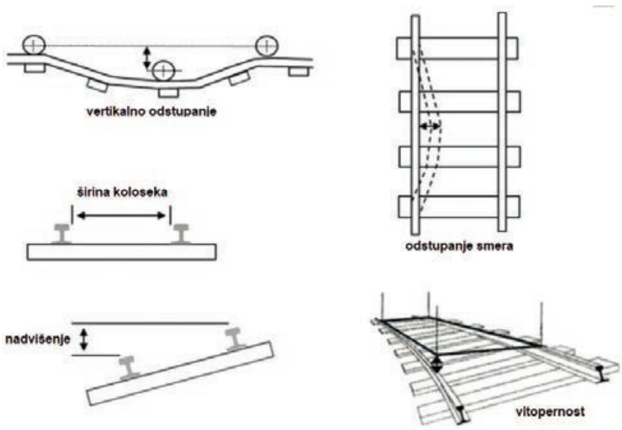


Slika 1. Vrste kretanja tačke u prostoru u odnosu na pokretni i nepokretni koordinantni system (http://mfmehanika.weebly.com/uploads/1/4/7/3/14731462/predavanje_3.pdf, 11.08.2023.)

Na prethodno opisan način funkcioniše i beskontakno merenje relativne geometrije koloseka. Bitno je napomenuti da relativna geometrija koloseka podrazumeva merenja parametara geometrije na osnovu kojih se određuje kvalitet koloseka u eksploataciji dok, sa druge strane, merenje apsolutne geometrije koloseka predstavlja merenje parametara geometrije u odnosu na položaje geodetskih tačaka definisanih projektom. Relativna geometrija ključna je za kreiranje planova održavanja, za izradu planova sanacije i obnove koloseka, dok se apsolutna geometrija koristi za trasiranje pruga, izradu projekata obnove koloseka i za potrebe planiranja radova na mehanizovanom održavanju koloseka odnosno vraćanje železničke pruge u prvobitni projektovani prostorni položaj.

Na slici 2 prikazani su parametri relativne geometrije koloseka koji se dobijaju metodama beskontaktnog merenja. U nastavku su date definicije osnovnih parametara geometrije koloseka (Pančić i Mićić, 2015):

- *vertikalno odstupanje*, odstupanje nivoa gornje površi glave bilo koje šine u vertikalnom pravcu, izraženo kao pomeranje u odnosu na srednji vertikalni položaj (referentna linija), koje pokriva unapred definisane talasne dužine i koje se sračunava na osnovu uzastopnih merenja (duž koloseka);
- *širina koloseka*, najmanje rastojanje između pravih koje su upravne na dodirnu površ i dodiruju obe glave šine, koja se nalazi na unutrašnjoj bočnoj površi glave šine, u zoni 0 do 14 mm ispod dodirne površi;
- *odstupanje smera vozne šine*, odstupanje uzastopne pozicije neke tačke u bočnoj ravni za bilo koju šinu, izraženo kao odstupanje u odnosu na srednji horizontalni položaj (referentna linija), koje pokriva unapred definisane talasne dužine i koje se sračunava na osnovu uzastopnih merenja (duž koloseka);
- *nadvišenje*, razlika visina naspramnih voznih površi glava šina i računa se na osnovu ugla dodirne površi i horizontalne referentne ravni i
- *vitopernost*, promena nadvišenja na datom rastojanju duž koloseka.



Slika 2. Parametri geometrije koloseka dobijeni dobijeni merenjem relativne geometrije prema EN 13848 – 1 (Kite i dr., 2020)

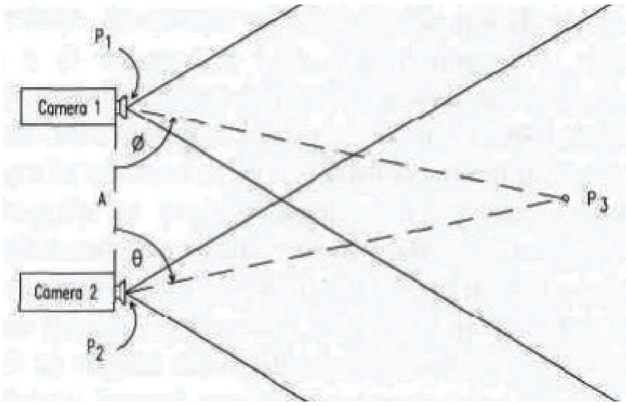
2.2. Beskontaktni merni sistem SOKOL na mernim kolima „Sever 1435"

U današnje vreme, s obzirom na značaj merenja parametara geometrije koloseka za održavanje železničke infrastrukture, sve je više proizvođača koji primenjuju najnovije tehnologije kako bi konstruisali nove i unapredili postojeće merne sisteme. Kako je prisutna sve veća potreba za izgradnjom pruga za velike brzine i održavanje takvih pruga podrazumeva brzo i efikasno reagovanje u kratkom vremenskom roku, izbegavanje dugačkih zatvora koloseka i obustave saobraćaja, cilj proizvođača je da konstruišu takvu mernu opremu, koja će omogućiti veliku brzinu merenja, prikaz rezultata u realnom vremenu i njihovu trenutnu analizu i generisanje izveštaja. U Republici Srbiji, za potrebe snimanja parametara relativne geometrije koloseka, koriste se merna kola „Sever 1435", prikazana na slici 3, koja funkcionišu po principu beskontaktnog merenja.

Slika 3. Merna kola „Sever 1435"

Beskontaktni merni sistem tipa SOKOL ugrađen na merna kolima „Sever 1435" omogućava merenje parametara geometrije koloseka brzinama od 0 do 250 km/h (https://tvema.com/638, 14.08.2023.). Zbog ograničenja brzine mernih kola usled nabavke novih mernih sistema, trenutna brzina snimanja parametara geometrije koloseka je ograničena na 110 km/h. Opseg snimanja parametara geometrije koloseka velikim brzinama omogućen je kombinacijom dve metode: aktivne optičke triangulacije i inercijalne navigacione metode. Aktivna optička triangulacija podrazumeva emitovanje laserskih zraka preko sistema ogledala i prijemnih video kamera. Senzor na poznatoj udaljenosti od lasera registruje reflektovani zrak, koji pada pod poznatim uglom. Na osnovu sličnosti trouglova i primenom trigonometrijskih digitalnih funkcija, računaju se položaji tačaka. Aktivni triangulacioni sistemi postavljaju kontrolisani izvor svetlosti (laser), u jedno od temena trougla, tako da taj izvor bude usmeren ka šini koja se nalazi u temenu trougla. Senzor se postavlja u preostalo teme i takođe je usmeren ka šini. Svetlost od izvora se reflektuje od šinu, a deo reflektovane energije pada na detektor. Periferna pozicija tačke koju detektor registruje (slika 4), omogućava kvantitativno merenje nepoznatog ugla φ, i određuje udaljenost pomoću sinusoidnog zakona.

Inercijalni navigacioni sistem (IMU) koji se koristi u sklopu mernog sistema služi za merenje parametara navigacije (tačaka) u prostoru, pri čemu se za obradu podataka koriste računari i senzori. Promene kretanja tačaka na šinama u prostoru detektuju se merenjem njihovog translatornog kretanja (akcelerometrima) i rotacije, odnosno merenje ugaone brzine sistema u odnosu na inercijalni referentni okvir (žiroskopima). IMU određuje svoju početnu



Slika 4. Princip aktivne optičke triangulacije (http://www.kelm.ftn.uns.ac.rs/literatura/mur/04.triangulacija.pdf, 24.08.2023.)

poziciju i brzinu, iz nekog drugog izvora (izmeri je operator, GPS sa satelitskim prijemnikom i slično), a zatim izračunava svoju poziciju i ažurira brzinu integrisanjem informacija dobijenih od senzora. Merni sistem pruža korisniku podatke o parametrima geometrije koloseka u trodimenzionalnoj projekciji, u realnom vremenu (Uzunović i Lemeš, 2022). Spoljašnja jedinica mernog sistema prikazana je na slici 5.

Merni sistem se jednostavno montira na ram obrtnog postolja mernih kola. Dizajn jedinica mernog sistema je lagan, lak za montažu i demontažu. Laseri koji su implementirani u merni sistem SOKOL spadaju u klasu 3b – mogu izazvati oštećenje vida ukoliko se ljudsko oko izloži direktnom uticaju lasera (Uzunović i Lemeš, 2022). Laseri koji emituju zračenje na šinu, vidljivi su ljudskim okom u tamnim uslovima (slika 6). Kada je laser uključen i sistem se nalazi u režimu merenja parametara geometrije koloseka, uključena je treptuća narandžasta svetlost koja upozorova na rad lasera.


Slika 5. Spoljašnja jedinica beskontaktnog mernog sistema


Slika 6. Laserski snop na šini vidljiv ljudskim okom u tamnim uslovimasistema

3. TIPOVI GREŠAKA GEOMETRIJE KOLOSEKA I GENERISANJE IZVEŠTAJA

Tokom snimanja relativne geometrije koloseka, svi rezultati se prikazuju na računarima koji se nalaze unutar mernih kola „Sever 1435" i kojima rukuju operateri. Rezultati se prikazuju u približno realnom vremenu, sa kašnjenjem prikaza rezultata u softveru usled potrebe obračuna, pri čemu se kašnjenje manifestuje u rasponu 100 – 200 m. Svi snimljeni podaci merenja se čuvaju u memoriji računara i odmah su spremni za dalje analize, koje podrazumevaju izbor odgovarajućih parametara na osnovu kojih će softver izvršiti proračune izmerenih vrednosti i prikazati greške u relativnoj geometriji koloseka. U slučaju merenja pruga u eksplataciji, u softveru se vrši rekalkulacija izmerenih parametara geometrije koloseka na nekoj deonici sa podacima o graničnim vrednostima dozvoljenih grešaka u geometriji koloseka, po klasama pruga, u skladu sa standardom EN 13848-5 P*rimene na železnici – Kolosek – Kvalitet geometrije koloseka – Deo 5: Nivoi kvaliteta geometrije koloseka – Kolosek na otvorenoj pruzi, u skretnicama i ukrštajima* (slika 7), dok se za potrebe prijema radova na novom ili rekonstruisanom koloseku prilikom merenja parametara geometrije koloseka koriste granične vrednost iz standarda EN 13231-1 *Primene na železnici – Kolosek – Prijem radova – Deo 1: Radovi na koloseku u zastoru od tucanika - Otvorena pruga, skretnice i ukrštaji*. Standardom EN 13848-5 propisane su tri granice dozvoljenih grešaka u geometriji koloseka za svaki parametar: AL (GU) – granica upozorenja; IL (GI) – granica intervencije, IAL (GHI) – granica hitne intervencije . Svaka od ovih granica zahteva preduzimanje odgovarajućih aktivnosti na održavanju železničke infrastrukture i pravovremenom reagovanju Upravljača. Kada se registruje parametar geometrije koloseka čija je izmerena vrednost veća

En-13848

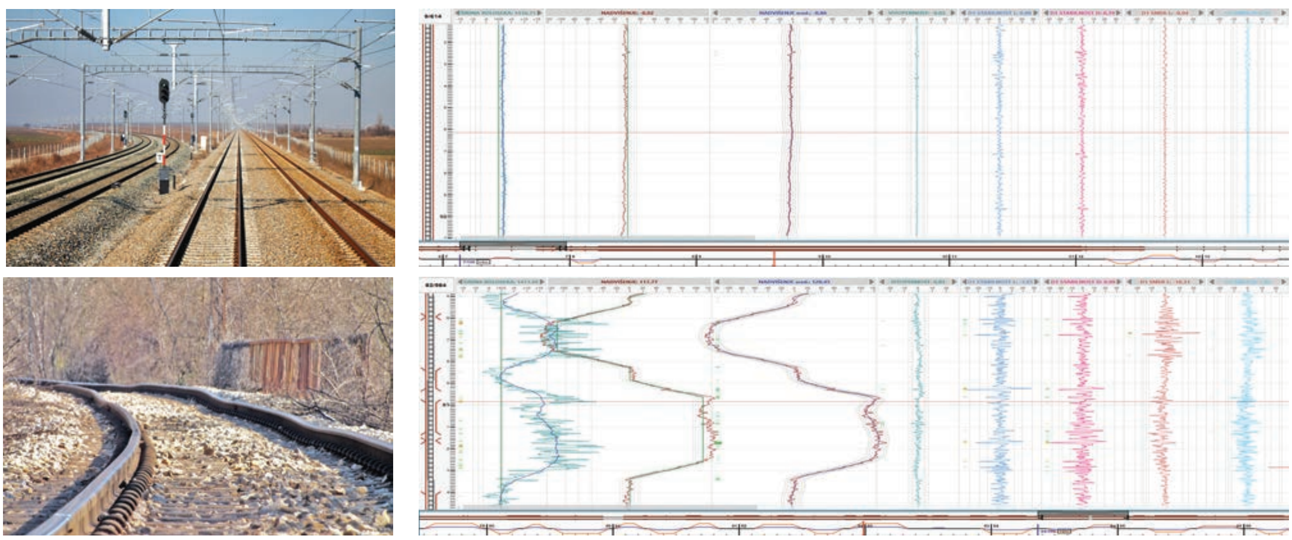
	Class 1 0-80 km/h						Class 2 80-120 km/h					
	GHI	GI	GU	GU	GI	GHI	GHI	GI	GU	GU	GI	GHI
ŠIRINA KOLOSEKA (mm)	-11	-9	-7	25	30	35	-11	-9	-7	25	30	35
NADVIŠENJE (mm)	-15	-11	-6	6	11	15	-13	-9	-5	5	9	13
VITOPERNOST (mm)	-7	-5	-4	4	5	7	-7	-5	-4	4	5	7
D1 STABILNOST (mm)	-28	-19	-12	12	19	28	-26	-16	-10	10	16	26
D1 SMER (mm)	-22	-16	-12	12	16	22	-17	-12	-8	8	12	17
D0 STABILNOST (mm)												
D0 SMER (mm)												
D2 STABILNOST (mm)												
D2 SMER (mm)												

	Class 3 120-160 km/h						Class 4 160-230 km/h					
	GHI	GI	GU	GU	GI	GHI	GHI	GI	GU	GU	GI	GHI
ŠIRINA KOLOSEKA (mm)	-10	-8	-6	25	30	35	-7	-5	-4	20	23	28
NADVIŠENJE (mm)	-11	-8	-4	4	8	11	-9	-6	-3	3	6	9
VITOPERNOST (mm)	-7	-5	-4	4	5	7	-5	-4	-3	3	4	5
D1 STABILNOST (mm)	-23	-14	-8	8	14	23	-20	-12	-7	7	12	20
D1 SMER (mm)	-14	-9	-6	6	9	14	-12	-8	-5	5	8	12
D0 STABILNOST (mm)												
D0 SMER (mm)												
D2 STABILNOST (mm)							-20	-9	-6	6	9	20
D2 SMER (mm)							-12	-7	-3	3	7	12

Slika 7. Granične vrednosti parametara geometrije koloseka u ekpslataciji po klasama pruga, prema EN 13848-5

od definisane granične vrednosti IAL (GHI), tada se moraju hitno preduzeti aktivnosti na sanaciji greške, privremeno prilagoditi brzina na spornoj deonici do hitnog otklanjanja greške ili zatvoriti deo pruge na kome je greška evidentirana sve do otklanjanja iste (SRPS EN 13848-5, 2017).

Prikaz podataka u približno realnom vremenu omogućava operateru na mernim kolima da prati stanje geometrije koloseka tokom merenja. Na slici 8 prikazani su primeri deonica pruga sa dobrom i nezadovoljavajućom geometrijom koloseka, kao i dijagrami merenja parametara geometrije koloseka mernim sistemom SOKOL relevantni za prikazane deonice. Na dijagramima se može uočiti da se pri dobrom kvalitetu geometrije koloseka (slika 8, gore) ne zapaža skokoviti prikaz dijagrama, uz manifestovanje manjih pikova dijagrama za svaki mereni parametar, dok se na dijagramu sa nezadovoljavajućim kvalitetom geometrije koloseka (slika 8, dole) uočavaju izrazito skokoviti prikazi dijagrama merenih parametara geometrije koloseka, sa jako izraženim

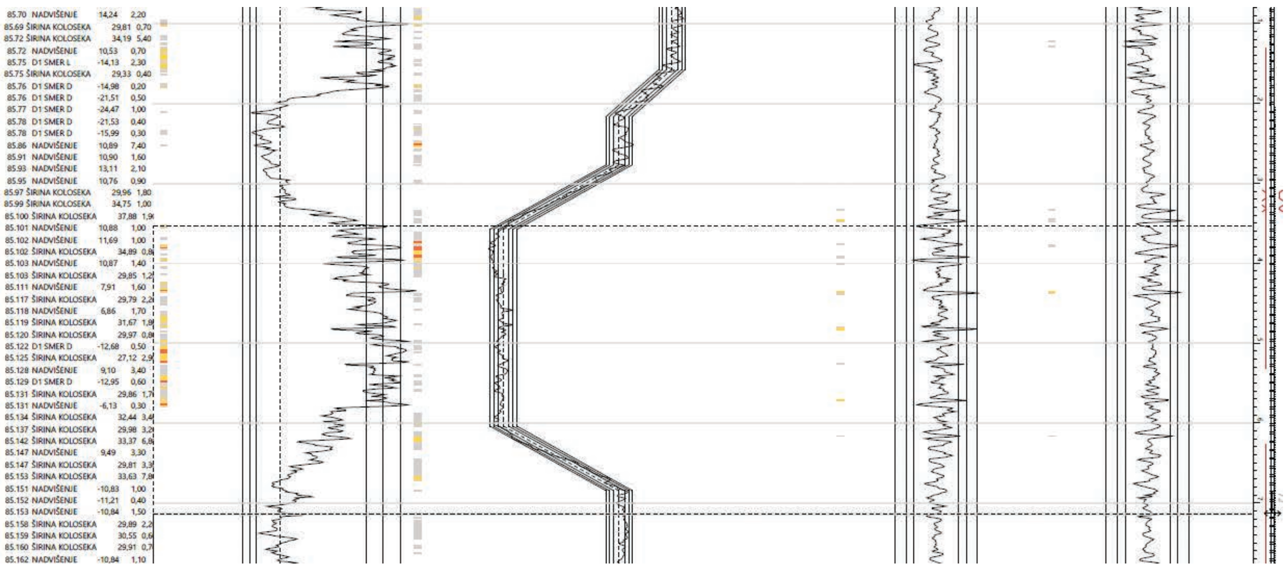


Slika 8. Prikaz dobre (gore) i loše (dole) geometrije železničke infrastrukture i reprezentativni dijagrami

pikovima, koji zapravo predstavljaju greške u geometriji koloseka. Takvi pikovi su najčešće preliminarni pokazatelj da će na koloseku biti evidentirana greška u geometriji. Radi lakog čitanja dijagrama, uvozom graničnih vrednosti parametara geometrije koloseka u skladu sa odgovarajućim standardom, na dijagramima se pojavljuju po tri granične linije sa obe strane osovine koloseka, koje predstavljaju granične vrednosti, pri čemu se prelaskom linija dijagrama preko graničnih linija, dolazi do podatka o evidentiranju greške u geometriji koloseka i nivou jačine te greške.

Softver mernog sistema omogućuje upoređivanje informacija o stanju kvaliteta geometrije koloseka sa prethodno unetom bazom podataka ili bez unete baze podataka pruge koja se snima (SRPS EN 13848, 2017). Bazu podataka izrađuje Upravljač infrastrukture u odgovarajućem tabelarnom formatu, koja treba da sadrži sve projektne elemente neophodne za ispitivanje geometrije koloseka. Povlačenje baze podataka u softver mernog sistema se vrši jednostavno. Vizuelnim pregledom pruge iz mernih kola i rezultatima beskontaktnog merenja geometrije koloseka, moguće je na brz i efikasan način evidentirati mesto na koloseku na kome se pojavljuje određni tip greške u geometriji i izvršiti potrebnu intervenciju. Ukoliko se greške na koloseku razmatraju nakon obavljenih mernih vožnji, korisniku softver pružiti tri vrste izveštaja, prikazanih na slici 9, i to: grafički izveštaj sa prikazom dijagrama mernih vožnji i naznačenim greškama u zavisnosti od kilometarskog položaja pruge, izveštaj o izolovanim greškama koloseka duž cele pruge na kojoj je vršeno geometrijsko snimanje i izveštaj sa sumarnim greškama koji se sastoji od grešaka u geometriji koloseka po svakom kilometru pruge i ocene stanja koloseka na osnovu broja evidentiranih grešaka i standardne devijacije (TQC std).

Na osnovu dobijenih izveštaja sa mernih vožnji, Upravljač infrastrukture može formirati planove održavanja koloseka u zavisnosti od prioriteta i mogućnosti na terenu. Pored osnovne funkcije



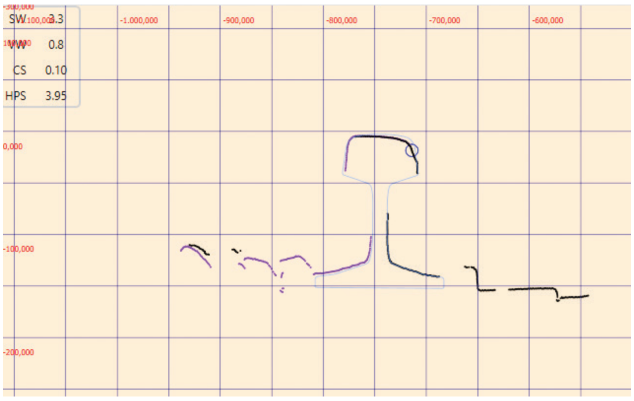
#	Param	Start	End	Threshold	Extremum	Length	Degree	Class	Rec. Class	Speed	Rail Type
27	PROŠIRENJE	85.075	85.075	25.00	29.33	0.40	GU	1		60	49E1
28	D1 STABILNOST D	85.076	85.079	12.00	18.32	3.30	GU	1		60	49E1
29	D1 SMER D	85.076	85.076	-12.00	-14.98	0.20	GU	1		60	49E1
30	D1 SMER D	85.076	85.077	-16.00	-21.51	0.50	GI	1		60	49E1
31	D1 SMER D	85.077	85.078	-22.00	-24.47	1.00	GHI	1	0	60	49E1
32	D1 STABILNOST L	85.077	85.079	12.00	14.01	1.70	GU	1		60	49E1
33	D1 SMER D	85.078	85.078	-16.00	-21.53	0.40	GI	1		60	49E1
34	D1 SMER D	85.078	85.079	-12.00	-15.99	0.30	GU	1		60	49E1
35	D1 STABILNOST D	85.090	85.091	12.00	13.64	1.10	GU	1		60	49E1
36	NADVIŠENJE sred.	85.092	85.094	6.00	7.82	1.90	GU	1		60	49E1
37	VITOPERNOST	85.095	85.096	-4.00	-4.35	0.90	GU	1		60	49E1
38	PROŠIRENJE	85.096	85.098	25.00	29.96	1.80	GU	1		60	49E1
39	NADVIŠENJE sred.	85.097	85.097	-6.00	-6.02	0.10	GU	1		60	49E1
40	PROŠIRENJE	85.098	85.099	30.00	34.75	1.00	GI	1		60	49E1
41	PROŠIRENJE	85.099	85.101	35.00	37.88	1.90	GHI	1	0	60	49E1
42	PROŠIRENJE	85.101	85.102	30.00	34.89	0.80	GI	1		60	49E1
43	NADVIŠENJE sred.	85.102	85.102	6.00	6.03	0.10	GU	1		60	49E1
44	PROŠIRENJE	85.102	85.104	25.00	29.85	1.20	GU	1		60	49E1
45	PROŠIRENJE	85.116	85.118	25.00	29.79	2.20	GU	1		60	49E1
46	D1 STABILNOST D	85.117	85.119	-12.00	-13.61	1.10	GU	1		60	49E1
47	PROŠIRENJE	85.118	85.120	30.00	31.67	1.80	GI	1		60	49E1

Summary:

Param	GU		GI		GHI	
	Len, m	Count	Len, m	Count	Len, m	Count
PROŠIRENJE	0.00	0	0.00	0	0.00	0
SUŽENJE	0.00	0	0.00	0	0.00	0
D0 STABILNOST L	0.00	0	0.00	0	0.00	0
D0 STABILNOST D	0.00	0	0.00	0	0.00	0
D1 STABILNOST L	19.60	18	4.20	4	0.00	0
D1 STABILNOST D	6.80	5	1.10	1	0.00	0
D2 STABILNOST L	0.00	0	0.00	0	0.00	0
D2 STABILNOST D	0.00	0	0.00	0	0.00	0
D0 SMER L	0.00	0	0.00	0	0.00	0
D0 SMER D	0.00	0	0.00	0	0.00	0
D1 SMER L	0.00	0	0.00	0	0.00	0
D1 SMER D	0.00	0	0.00	0	0.00	0
D2 SMER L	0.00	0	0.00	0	0.00	0
D2 SMER D	0.00	0	0.00	0	0.00	0
NADVIŠENJE	71.50	16	25.40	6	198.90	3
NADVIŠENJE sred.	60.20	24	10.30	8	6.10	3
NADVIŠENJE max.	0.00	0	0.00	0	66.20	5
VITOPERNOST	6.50	7	3.50	3	0.60	1
Total	**164.60**	**70**	**44.50**	**22**	**271.80**	**12**
Ocena stanja koloseka	**Nezadovoljavajuće**					

Slika 9. Grafički izveštaj (gore), izveštaj izolovanih grešaka (dole levo) i sumarni izveštaj (dole desno) sa merne vožnje

mernog sistema SOKOL, ovaj sistem može meriti i profil šine i pružiti podatke o habanju šine (slika 10), što je od velikog značaja za održavanje i negu šina u koloseku.



Slika 10. Profil šine dobijen prilikom merenja parametara geometrije koloseka

4. DISKUSIJA REZULTATA MERNIH SNIMAKA

Mogućnosti beskontaktnog sistema za merenje parametara geometrije koloseka su velike. Generalno, rezultati merenja relativne geometrije koloseka beskontaktnim mernim sistemima koji funkcionišu po principu aktivne optičke triangulacije i inercijalnog navigacionog sistema su izuzetno pouzdani. Mnoge naučne studije pokazale su da rezultati dobijeni ovim metodama imaju izuzetno precizne i pouzdane vrednosti svih merenih parametara, pogotovo ukoliko se uzme u obzir korišćenje IMU navigacionog sistema za precizno lociranje.

Proizvođači merne opreme za ispitivanje parametara geometrije koloseka i dalje razvijaju svoje merne sisteme. U budućnosti, beskontaktno merenje geometrije koloseka će biti preduslov za brzo i efikasno odžavanje železničke infrastrukture. U poređenju sa kontaktnim mernim sistema, prilikom merenja beskontaktnim mernim sistemima nema opasnosti od mehaničkih krahova elemenata sistema, jer ne postoji kontakt mernog sistema sa elementima koloseka, odnosno šinama. Primera radi, kod kontaktnog merenja geometrije koloseka, merenje se najćešće vršilo preko specijalnih mernih kolica koja su ostvarivala kontakt sa šinama pri čemu su se beležili rezultati parametara geometrije koloseka.

Rezultati dobijeni ovom metodom su lako čitljivi i pouzdani. Softver generiše tri tipa izveštaja, u kojima se lako mogu uočiti greške koje prelaze granične vrednosti, pri čemu su greške tipa IAL (GHI) označene crvenom bojom, radi lakšeg uočavanja. Pored toga, na dijagramima merne vožnje, bojama (zelena, žuta i crvena) su označene one vrednosti parametara geometrije koloseka koje prelaze granične vrednosti. U izveštajima izolovanih grešaka, dat je pregled svih grešaka koje su evidentirane na pruzi na kojoj se vršilo merenje, sa podacima o kilometarskom položaju greške, tipu greške i dužini na kojoj je evidentirana greška. U sumarnim izveštajima, prikazane su liste svih tipova grešaka geometrije koloseka u skladu sa EN 13848-1 koje su registrovane na svakom punom kilometru pruge na kojoj se vršilo geometrijsko snimanje, kao i ocena kvaliteta geometrije koloseka.

5. ZAKLJUČNA RAZMATRANJA

U ovom radu su predstavljene osnovne karakteristike beskontaktnih mernih sistema i rezultati merenja relativne geometrije koloseka ovim sistemima.

Kao glavne prednosti ovakvih sistema mogu se izdvojiti veliki opseg brzina pri kojima se merenja mogu izvoditi do 250 km/h, dobijanje rezultata u realnom i približno realnom vremenu, dobijanje preciznih rezultata relativne geometrije koloseka bez potrebe ostvarivanja bilo kakvog kontakta između šina i elemenata mernih sistema, mogućnost analize i generisanja detaljnih izveštaja merenja u skladu sa relevantnim graničnim vrednostima u zavisnosti od svrhe merne vožnje, jednostavno održavanje spoljašnje jedinice mernog sistema i mogućnosti detaljnog merenja profila i habanja šina. Kao mane ove metode mogu se istaknuti nerazvijenost metoda istovremenog merenja i apsolutne geometrije koloseka, potreba za posebnom pažnjom i preciznošću prilikom provere podešenosti beskontaktnog mernog sistema i usaglašenosti sa mehaničkim merilima, neophodno obezbeđenje neprekidne stabilne internet konekcije i GPS signala, kao i otežan pristup informacijama o konstruktivnim karakteristikama beskontaktnih mernih sistema, s obzirom da iste proizvođači i konstruktori često čuvaju kao poslovne tajne. Na osnovu analiza beskontaktnog merenja geometrije koloseka opisanih u ovom radu, dolazi se do zaključka da je ovakva metoda izuzetno poželjna za primenu na mreži Upravljača, čime se omogućuje kreiranje planova održavanja i sanacije grešaka na koloseku u eksplataciji, sa primarnim ciljem očuvanja bezbednosti i redovitosti železničkog saobraćaja.

U daljem razvoju beskontaktnog merenja relativne geometrije koloseka moguće je razmatrati poređenja rezultata dobijenih ovom metodom sa rezultatima dobijenim metodom merenja apsolutne geometrije koloseka, kao i konstruisanje novih i unapređenje postojećih mernih sistema kojima je moguće dobijati rezultate merenjem aposlutne i relativne geometrije koloseka istovremeno, čime bi se značajno smanjili troškovi mernih vožnji i korišćenja mernih sistema, kao i povećala frekvencija realizacije mernih vožnji.

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