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IMPACT OF TRAFFIC NOISE ON RAILWAY TRAFFIC SAFETY

Summary. Traffic noise is one of the dominant factors of ergo-assessment. The harmful impact of traffic noise on the engine driver as target group can be studied in isolation from other ergo-assessment factors only in the initial phase of research. The simultaneous action of several related factors in the system of ergo-assessment factors has cumulative effect on the perception and psychomotoric status of the railway traffic participants in the appropriate traffic situation. The initial partial research of traffic noise by a combination of several scientific methods needs to be eventually upgraded by studying the relations among several concurrent important or dominant ergo-assessment factors.

WPŁYW HAŁASU NA BEZPIECZEŃSTWO RUCHU KOLEJOWEGO

Steszczenie. Hałas jest jednym z dominujących czynników oceny ergonomicznej. Szkodliwy wpływ hałasu na maszynistę, jako docelową grupę, może być rozpatrywany jako wyodrębniona część oceny ergonomicznej tylko w początkowej fazie prowadzenia badań. Jednoczesne działanie wielu powiązanych czynników w systemie oceny ergonomicznej posiada kumulujący się wpływ na postrzeganie i status psychomotoryczny uczestników ruchu kolejowego w konkretnej sytuacji ruchowej. Wstępne badania częściowe nad hałasem poprzez połączenie kilku metod naukowych muszą być ostatecznie zaktualizowane, poprzez zbadanie relacji pomiędzy wieloma jednoczesnymi, ważnymi lub dominującymi czynnikami oceny ergonomicznej.

1. INTRODUCTION

The general characteristic of the traffic audible noise which is generated mainly by mobile sources is that it is of very intensive and different spectral composition. The carried out analyses show that audible noise caused by the operation of engines of all types, regarding other noise generators, occupies the third place on the scale of endangering human environment (following water and air) [1]. Special emphasis is on the variable character of the audible traffic noise with short, quite sudden intensive jumps that causes various physiological changes and the feeling of discomfort. Besides, the influence of traffic noise as a stressor should be emphasised since it significantly increases the adverse impacts of other stressors frequently present in the lives of modern people.

Should the usual approach to the study and research of the phenomenon of traffic and transport “effectiveness – efficiency – ecology” according to the world trends be substituted by the recent approach “effectiveness – efficiency – ergonomics”, then the hypothesis may be set that audible traffic noise can be studied from the position of the dominant factor of ergo-assessment in the system of several simultaneous ergo-assessment factors. The target group of subjects in this paper are engine drivers, since they suffer from the cumulative effect and change in the perception and psycho-motoric status due to simultaneous action of several factors of ergo-assessment, which also results in the reduction of safety and reliability of traffic flows in the transportation of goods and/or passengers, which is the classical example of the environmental impact on the procedures of traffic participants. This immediately raises the question of the intensity and the scope of impact of the working environment on the engine drivers, which requires answers to the following questions: which scientific method should be used to determine which factors of ergo-assessment are present, and how to divide them into dominant, important and negligible ones, respecting the interrelations that make the set a system of ergo-assessment factors.

Through the research of subjective factors of disturbance and permanent physiological and psychological changes in engine drivers, the cognitive ergo-assessment will determine the direction of further ergo-assessment and will not immediately clearly and unambiguously detect the scope of the set of ergo-assessment factors and the intensity of the influence of individual ergo-assessment factors, since individual subjective disturbances may be caused directly or indirectly by several single ergo-assessment factors, and the subjective experience of cumulative effect is individual differing from engine driver to engine driver, among other things, also because of the differences in individual endurance. Besides, before the concrete research using a scientific method it is necessary to verify the justification of the abovementioned hypothesis that the audible traffic noise is one of the dominant factors of ergo-assessment. Therefore, cognitive ergo-assessment is only one of the scientific research methods which should be implemented in the initial phase of ergo-assessment, in combination with other scientific research methods. The expected contribution of cognitive ergo-assessment includes: fast detection of dominant ergo-assessment factors, and orientational insight into the scope of the set of ergo-assessment factors and the intensity of the impact of certain factors of ergo-assessment on the overall ergo-assessment within the system of ergo-assessment factors. Cognitive ergo-assessment cannot measure exactly the intensity of the influence of single ergo-assessment factors on the overall ergo-assessment, but the ergo-assessment factors can be ranked among themselves regarding the intensity of one in relation to the other.

2. RESEARCH ALGORITHM OF ERGO-ASSESSMENT FACTORS SYSTEM

The authors of this paper have planned the following research algorithm:

1) Interviewing physiological-psychological changes and subjective factors of perceiving disturbance as typical representative of target group of engine drivers with several years of experience, and in order to acquire basic knowledge about the system of ergo-assessment factors, because of the need of forming the questionnaire and designing the criteria for results processing.
2) Trial survey of physiological-psychological changes and subjective factors of perceiving disturbance on a smaller number of engine drivers in order to test the contents of the survey, the very procedure of survey and procedure of results processing.
3) Surveying the physiological-psychological changes and subjective factors of perception of disturbance in a greater number of engine drivers, and in order to make partial conclusions that in the later phase of research need to be included in the synthesis of results of all the simultaneously applied scientific and research methods.
4) Study of the influence of technical and technological preconditions on the total psycho-physical load of engine drivers: influence of different sections in operation of the same locomotive or the same composition, running regime, types of locomotives or compositions, dominant sources of noise in single types of locomotives or composition, work of the engine driver in different driver's cabs in the same locomotive or composition, microclimate in the driver's cab, etc....

5) Concrete measurements of equivalent level of audible traffic noise in dB for frequency filter A in real situations in driver's cabs of single locomotives driver's cabs, respecting the work - rest interval stipulated by valid ordinances. The level of audible noise is objective physical value measurable by means of acoustic instruments in the locomotive driver's cab.
6) It should be determined whether the engine driver in the driver's cab of the studied locomotive is exposed to potential traffic noise of a different spectrum, e.g. simultaneously audible traffic noise and infrasound. The infrasound can cause permanent damage of the hearing at levels in excess of 150 dBA [2]. The interaction between the factors of infrasound and safety is interesting for further research, since in the case of half of the drivers of motor vehicles at infrasound level of 105dB and frequency range of 2-15Hz there is a 10-percent increase in the reaction time [3].

3. RESEARCH METHODOLOGY OF ERGO-ASSESSMENT FACTORS SYSTEM

Past research, as well as the interview of the traction instructor in Chapter 4 of this paper confirms the justification of the hypothesis that the dominant factor of ergo-assessment of traffic noise is just one of several simultaneous factors of ergo-assessment in the system of ergo-assessment factors, but that there are also clear and provable interactions and relations with other simultaneous important and/or dominant factors of ergo-assessment, and with different intensity of influence on the total ergo-assessment of the studied traffic system.

In railway composition of a passenger train the results of measurements of the level of audible noise in the passenger spaces in coaches show the dependence on the running speed of the composition and on the position of measurement within the composition and coach, then on the structure of the passenger coach and the materials used for dampening or absorption of audible noise, and finally on the type of propulsion. Diesel engines at all frequencies cause higher level of audible noise than Otto engines, and the same difference is even more intense in the absence of regular service maintenance during exploitation [4]. Unlike Diesel engine compositions, where the dominant noise is observable in standing due to continuous operation of the propulsion engines, in electric railcars there is observable audible noise of the auxiliary devices for braking and cooling of propulsion engines [5]. Unlike during the standing period, in traffic flow, the dominant source of audible noise for all the speeds of rail vehicles is the noise caused by the wheels rolling along the tracks.

Apart from the running speed, the noise of wheels and tracks depends also on the geometrical configuration of the railway line, because in negotiating curves the wheels generate greater noise, not only due to rolling but also due to wheel sliding along the tracks. The noise level is increased by 20dB when the train passes over the bridges and other elevated structures, caused by the vibrating components of these structures [6]. By analyzing the measurement results of the level of noise in the settlement Retkovec in Zagreb, situated immediately along the Zagreb-Vinkovci railway line, the conclusion was made that the highest levels of audible noise along the railway line occur in the case of cargo trains passage [7]. Similar statements have been given by the interviewed examinee, so that this means that the most threatened group in the target group of engine drivers for the study of the influence of audible noise are the engine drivers in driver's cabs of Diesel and electric locomotives when these are used for the traction of cargo compositions, since they feature the highest influence of the audible noise factors on the ergo-assessment factor safety with increase in the train running speed, both on their own safety, and on the safety of all the other participants in the overall traffic process.

The set of ergo-assessment factors can be considered a dynamic system of ergo-assessment factors in space or time, according to expression (1), because of the existence of relations among single factors of ergo-assessment.

$$S = (K,R)_{s,t} \tag{1}$$

where:
S – dynamic system of ergo-assessment factors,
K – components of the set of ergo-assessment factors,
R – relations (interactions) among components of the set of ergo-assessment factors,
s,t – space-time frame.

All this complicates greatly the concrete studies, since ergo-assessment of the considered traffic system needs to be studied by means of the ergo-assessment factors system, which is difficult to achieve scientifically, and it is necessary to introduce certain assumptions. According to the definition of the system, the ergo-assessment factors have to be able to have interaction over the relations in the system. Thus, it is not completely effective to research the partial influence of the dominant factor of ergo-assessment audible traffic noise, but such a partial approach is very efficient in the initial phase of research due to strong interactions of the dominant factor of ergo-assessment with other dominant and important ergo-assessment factors, resulting in the reduction of the cumulative effect on the traffic participants. There is no scientifically verified known method by means of which the intensity of the influence of individual ergo-assessment factor on total ergo-assessment of the traffic system can be simply and quickly measured. However, by means of cognitive ergo-assessment and the research of relations in the ergo-assessment factors system, all the factors can be roughly divided into three groups: dominant, important or negligible ones. An important factor of ergo-assessment that should not be neglected is the speed of the traffic means, since, through the relations in the ergo-assessment factors system it changes the intensity of the influence of several dominant ergo-assessment factors, among others, also of the intensity of influence of audible traffic noise factors.

The level of noise on different positions according to Figure 1 has been measured in the electric railcar composition of passenger train HŽ 6-111 by the Croatian Railways (HŽ) operator, with a total of two driver's cabs, one in section A and the other in section B, on the regular railway line from Zagreb to Ogulin and back. The levels of audible noise were measured on the railway line sections with smooth curves, without tunnels and bridges, thus reducing the influence of geometrical configuration of the line on the dominant noise of wheel rolling along the tracks at higher travelling speeds.

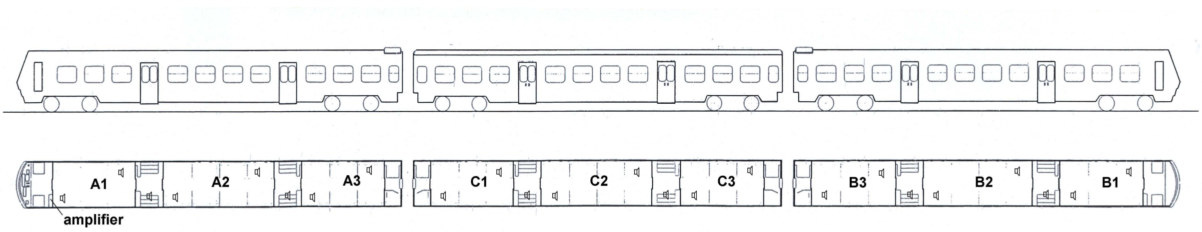

Fig. 1. Measurement points in electric railcar composition of the passenger train HŽ6-111. [5]
Rys. 1. Punkty pomiarowe w elektrycznych wagonach składu pociągu pasażerskiego HŽ6-111. [5]

The measurements proved the interaction between the dominant ergo-assessment factor of the level of audible noise with the following important factors: running speed of the composition and positioning of the measurement point at various positions within the passenger space in the composition.

The level of noise was measured by means of B&K 2231 sound level meter, for the frequency filter of audible noise A, and the position of measurement at the seat level in the passenger space. All the passengers were seated, and the contribution of the passengers to the measured level of audible noise was minimal. The dominant partial emission of various sources of noise changes also the level of the total emission of audible noise absorbed by the passenger at individual positions, and this can be made uniform by good sound insulation of the coach as a whole. In the standing train the measured level of audible noise is minimally 61.8dB at the position A3 to maximally 65dB at position A2. It is known that in extra-rural areas the influence of audible noise already at the level of 66dB starts the narrowing of the blood vessels and prolongation of the engine driver's reaction time, if exposed to such noise [1]. Additionally, it is necessary to measure the equivalent level of audible noise in the drivers' cabs in section A and in section B, depending on the following criteria: running speed of the train composition and geometrical configuration of the line, and to study the influence of audible noise on the engine driver depending on the duration of exposure. Good sound insulation of the drivers' cabs in all the traffic means would annul the negative influence of audible noise on the safety of all the traffic participants in the studied traffic process, because of the action of audible traffic noise on the engine driver in the driver's cab of the locomotive with the worst sound insulation or with the source of audible noise of the highest level in the vicinity.

4. INTERVIEWING OF A TYPICAL REPRESENTATIVE OF THE TARGET GROUP OF ENGINE DRIVERS

The interview was carried out in July 2008 partly in the form of free conversation with the interviewee, and partly using in-advance prepared questions in the form of a questionnaire for the subjective factors of disturbance regarding audible traffic noise. The interview was structured on the basis of written notes, and after being proofread regarding proper terminology it was given to the interviewee for authorization. The objectives that the authors would like to achieve by surveying a larger number of engine drivers include: partial cognitive ergo-assessment of the influence of audible traffic noise on the engine driver's actions, ergo-assessment of the cumulative effect due to simultaneous action of several factors of ergo-assessment on the engine driver, and setting of new hypotheses as well as confirmation of the justification of the existing ones.

The interview was carried out anonymously since the interviewee is still in active employment (full data known to the authors). The interviewee is a male person, 47 years of age, with a total of 29 years of service, out of which 23 years working as an engine driver with an experience in operating all types of locomotives and compositions, and over the last 6 years employed as a traction instructor. The interviewee is in good physical condition, 183cm tall and weighing 90kg. He has the secondary school qualifications for the profession of the engine driver for all locomotives, and according to his personal subjective experience he says that the external anthropo-measures, and particularly the height of the engine driver, do not influence significantly the visibility from the driver's cab of the locomotive due to multiple adaptability of the seat of the engine driver.

For the audible traffic noise the interviewee said that he found audible noise extremely disturbing at his workplace in the driver's cab, most intensively regarding the subjective experience of the intensity of disturbance in relation to other factors of disturbance according to Table 3, regardless of the type of the locomotive or composition. As sources of continuous and periodical audible noise that disturbs him, he mentioned various sources according to Table 4, depending on the types of locomotives and compositions. He confirmed that measures are being undertaken for protection against noise, and that he has been educated on the adverse impact of audible noise on engine drivers. He also confirmed the intensive subjective experience of sleep disorder at home after work, as well as when sleeping in the 8-hour rest interval in turnround, for the driving regime without shifts, of passenger or cargo composition, according to in-advance provided answers in Table 1.

Table 1

Possible influence of audible traffic noise on the interviewee at the locomotive driver's cab

Provided answers:	
X	Change of mood. *Interviewee's remark:* during rest and driving periods
X	Headache
X	Disorientation in the working space.
X	Reduced concentration in performing the tasks
	Impossibility to perform the tasks
X	Difficult communication with colleagues, raising of the voice. *Interviewee's remark:* in case of Diesel locomotive
X	Worse audibility of the colleagues' speech and sound signals and messages
X	Partial loss of hearing after leaving the locomotive. *Interviewee's remark:* in case of Diesel locomotive
X	Psychic fatigue and/or overwork
X	Longer time of reaction
X	Sleep disorder in 8-hour rest interval in turnround (see Table 2).
X	Sleep disorder in the rest interval at home, for driving regime with no shifts (see Table 2).
	Nothing mentioned

Table 2

Possible disturbances due to noise during sleeping in the regime without shifts, in operating a passenger i.e. cargo composition

Provided answers:		Interviewee's remark:
I have difficulties falling asleep:	**X**	in 16-hour rest interval, at home, and in the case of shift-less driving regime
I wake up frequently:	**X**	in 16-hour rest interval, at home, and in the case of shift-less driving regime
I sleep restlessly:		
I cannot get any rest:		
I do not sleep long:	**X**	sleeping during the day maximally up to 3 hours in the 8-hour rest interval in turnround

All the subjective disturbances from Tables 1 and 2 do not have to be caused only by audible traffic noise, because that influence of total ergo-assessment has been proven in nature according to the existence of the system of several simultaneous factors of ergo-assessment. However, according to the knowledge from technical and scientific literature [9] subjective disturbances of the interviewee can be, among other things, related also to partial action of audible traffic noise.

Table 3

Structure of subjective disturbances and intensity of disturbance of interviewee, ranked from the most intensive subjective experience to the least intensive one

Ord. No.	Description of subjective disturbances, permanent physiological and psychological changes, technical and technological preconditions, driving regime, and any other activities and events during and/or after driving that were subjectively strenuous for the interviewee
1	Continuous and periodical audible traffic noise, emitted from different dominant sources depending on the type of locomotive or composition. The interviewee mentions subjective disturbance that among other factors may be caused also by audible traffic noise, according to Tables 1, 2.
2	Intensive psychical effort and stress when passing level crossings because of traffic accidents, or suicides. Almost all the engine drivers known to the interviewee have had such an experience in their careers, and the common permanent or temporary physiological and psychological change due to such experience is high blood pressure.
3	Exhaust gases from engines and oil evaporation.
4	In shunting Diesel locomotive - dust, the engine driver's head during driving is always outside the locomotive, because of the open window. Besides, the driver's cab of the shunting locomotive is fitted with air-conditioning.
5	Fog, rain and snow. Subjective perception of disturbance and effort is more intensive if adverse weather conditions are in combination with night driving. The biggest problem is fog, at high running speeds, or in shunting diesel locomotives where the engine driver does not see the shunter with flag or shunting signals.
6	The problem of visibility from the engine driver's workplace in case of Diesel locomotive. Diesel locomotive has one driver's cab and two operator's places (the engine driver sits on the right, and the assistant on the left), and the change in the direction of the composition movement is done without turning of the locomotive. When Diesel locomotive moves forward with the longer section in front of the driver's cab, the engine driver on the right workplace does not see the left side and depends on the visual inspection of the signals done by the assistant sitting on the left workplace.
7	Reporting for work at night, at three o'clock in the morning, after waking at two o'clock in the morning, is characteristic for suburban electric railcars in Zagreb.
8	Fatigue and sleepiness during night driving in driving regime without shifts on open railway line sections. As a younger engine driver with fewer years of working experience he had more difficulty in coping with night driving. A special experience of the interviewee is that during one ride outside Zagreb he could not remember one section of the route, although he pressed and released with his foot at regular intervals the deadman control (in some locomotives it has to be kept pressed by foot). The interviewee claims that the engine driver can doze off fully failing to perceive the environment, at the same time pressing and releasing the deadman control at regular intervals.
9	Permanent physiological and psychological changes in engine drivers. On the traction instructor's workplace in communication with engine driver colleagues, as well as from personal experience, he found out that the most frequent professional diseases in engine drivers are: problems with spine and hemoroids because of long sitting posture, then stomach disorders because of dry food consumption while travelling, and high blood pressure because of suicides and/or traffic accidents at level crossings.

Table 4

Subjective experience of intensity of disturbance of the interviewee because of audible traffic noise in the driver's cab of the locomotive, depending on the type of locomotive or compositions, assessed from 1 to 4, with grade 1 for the highest subjective experience of disturbance intensity

Type of locomotive or composition	Number of driver's cabs and driving places	Subjective experience of disturbance intensity	According to subjective experience of the interviewee dominant sources of audible noise:
electric sets	two driver's cabs with one driving place each	**4**	- noise and vibrations from air compressor dominate, supportable level of audible noise. The interviewee says that it is more difficult to drive the train from the driver's cab in section A as compared to driver's cab in section B for the train, and the results of measuring level of noise in the passenger cabin in section A indicate the same, because of the increased noise due to the air compressor installed in section A.
electric locomotive	two driver's cabs with one driving place each	**2**	- reduced load of compressor with 10 bars to the ambient pressure, discharge in the form of intensive pulse - ventilator for cooling the rheostat of electro-dynamic brakes, continuous noise
Diesel locomotive	single driver's cab with two driving places (left and right)	**1**	- powerful and noisy Diesel engine with turbo-compressor in a very short locomotive - switched on electric heating of the train increases fuel consumption, as well as the level of audible noise - audible noise of periodical character emitted from: locomotive protection, sirens and signalling devices
Diesel engine sets	two driver's cabs with one driving place each	**3**	- audible traffic noise is a much bigger problem in passenger spaces than in train driver's cabs, no dominant source of noise that would be especially emphasised

It is indicative that the subjective experience of the intensity of driving complexity fully overlaps with the subjective experience of intensity of disturbance because of audible traffic noise, which additionally confirms the justification of the hypothesis about audible traffic noise as dominant factor of ergo-assessment, with great influence on the reliability and safety of the engine driver's work. There is a hypothesis that there are differences in the system of ergo-assessment factors depending on the type of locomotive or composition. It is reasonable to set also the hypothesis that the Diesel locomotive is the noisiest, with the poorest visibility from the driver's cab, and that it is most difficult to drive the composition in which it is the driving vehicle, so that it should be used in practice as little as possible as the driving means in the passenger composition, if this is allowed by the configuration of the railway line. The justification of these hypotheses needs to be confirmed by surveying subjective factors of disturbance on a larger number of engine drivers, and this survey will provide also a detailed insight into the structure of the ergo-assessment factors system depending on the type of locomotive or composition.

This imposes the need to research the hypothesis that the subjective experience of the intensity of total psycho-physical load for the engine driver is the highest when the noisy and hard-to-manoeuvre Diesel locomotive with poorer visibility from the driver's cab is used for the traction of the composition intended for the transport of passengers. However, the justification of this hypothesis needs to be confirmed by surveying the subjective factors of disturbance of a greater number of engine drivers with many years of experience in driving.

5. CONCLUSION

Because of the wide range of the influence of audible traffic noise on the engine driver and strong interactions with many other simultaneous factors of ergo-assessment we may consider the hypothesis about the audible traffic noise as the dominant factor of ergo-assessment justified, independent of the type of locomotive or composition. It is efficient in the initial phase to study the partial influence of audible traffic noise on the engine driver's actions, for different locomotives or different train compositions, and at their different running speeds, with positioning of the engine drivers in different driver's cabs of the same locomotive or the same composition, or on the left or the right position in the same driver's cab, and this is for realistic situations in realistic traffic sub-processes and processes a very good step forward. However, from the aspect of total ergo-assessment this is not a recent enough approach. In realistic situations, in the "engine driver – locomotive – traffic situation" system (driver's cab is only a narrower segment of the total traffic situation and we cannot treat it as an environment), most often along with traffic noise simultaneously additional more or less influencing factors and/or different stressors occur, so that the recent approach to ergo-assessment understands, apart from partial study of traffic noise also integral and systemic research of the relations and connections among several factors of ergo-assessment, as well as the analysis of the cumulative effect on the traffic participants due to their simultaneous occurrence. It is effective after the detailed research of relations in the system to neglect only the unimportant factors of ergo-assessment, if they feature a negligible intensity of influence on the total ergo-assessment, and if they have no significant relations with the dominant factors of ergo-assessment. In the shortage of other adequate scientific methods, surveying and interviewing subjective perceptions of disturbance and physiological and psychological changes in engine drivers in cognitive approach to research have no alternative, and in spite of all their drawbacks they are becoming important and irreplaceable. The scientific method of measuring the level of intensity of traffic noise by measuring instruments is the statement of the amount of physical value of the level in dB as a consequence of the imposed technical and technological preconditions, and the same is close to the behaviouristic approach to the problems of studying the traffic noise phenomenon, since nothing tells us about the influence of the traffic noise on the perception and psycho-motoric status of the engine driver with adequate traffic situation.

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