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EVALUATION OF VIBROACOUSTIC COMFORT IN MEANS OF PUBLIC TRANSPORT IN POZNAŃ ON THE BASIS OF SURVEY RESEARCH

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This article presents results of survey research carried out among passengers of Poznań Municipal Transport Company. Poznań is one of the biggest cities in Poland. It covers area of 262 km^2 and is inhabited by 552,000 people. Municipal road infrastructure of Poznań includes: 1039 km of roadways, 105 km of bicycle routes, 125 km of railway network, additionally the city has 20 tram lines and 79 bus lines. Questions in the survey refer to evaluation of vibroacoustic climate in trams and buses while riding by passengers. The survey includes questions referring to pointing places in the vehicle of the highest and lowest level of noise and vibrations, phase of vehicle movement during which the highest level of vibrations and noise is generated. Additionally respondents made vibroacoustic evaluation of particular types of buses and trams riding in Poznań and indicated factors which they think have influence on comfort of the ride in means of transport. The survey research was completed with results of noise measurements registered inside selected types of buses and trams used in Poznań during a ride and at a stop.

Keywords: survey research, the noise inside the bus and tram, evaluation of comfort in the vehicle

1. Introduction

Public transport is an area of municipal services. It consists in providing universally accessible transport in the city and suburban areas [1]. An effective public transport can contribute significantly − especially in cities − to reduction of several phenomena, which are harmful for the environment: air pollution, noise, greenhouse gas emissions and energy consumption. Creation of comfortable atmosphere inside vehicles influences greatly attractiveness of means of transport. Because of the increasing public mobility, urban transport companies need to adapt their vehicle fleets to the growing needs of passengers. The survey carried out in Poznań in 2013 among 1094 people [2] has shown that the comfort of public transport (both in buses and trams) is affected by three factors: crowding, temperature in the vehicle and noise. According to the respondents, vibrations were not so annoying and had less impact on travel comfort. Other factors more important than the impact of vibration were: the number of seats, cleanliness in the vehicle, convenient entrance to the vehicle − low floor and safety. The dynamic development of bus and tram transport in Polish cities makes it impossible to create an appropriate vibro-acoustic comfort for passengers, because in Poland there are no applicable standards and legal provisions to regulate the issue of making measurements and determining acceptable levels. In the case of trams, for measuring noise and vibration, compliance with railway laws is very often recommended. However, the railway laws do not always correspond to the requirements and ranges used in trams. Moreover, in the case of buses, the existing standard from 1990 is not up to date due to the permissible noise

levels or measurement methods presented there. In addition, nowadays there are new sound sources − unknown back in 1990 − which appeared with introduction of fuel cells and hybrid systems in buses. This paper presents the results of survey conducted among passengers who use public transport in Poznań. The respondents were asked to evaluate the vibroacoustic conditions in buses and trams and to indicate the places in vehicles and phases of ride in which vibration and noise were the greatest. The survey was supplemented with noise measurements in selected types of trams and buses moving in Poznań. Measurements were made at standstill and during the ride. Low floor vehicles were selected for the tests. In the case of trams, these were Solaris Tramino and Siemens Combino tram cars, while the buses were Solaris Urbino vehicles of 12 m and 18 m. Selected objects are the newest types of vehicles used in the Municipal Transport Company in Poznań.

2. Survey research

The survey was conducted among the passengers of the Municipal Transport Company in Poznań and addressed issues related to the assessment of the vibroacoustic conditions in means of public transport during the ride. The survey was conducted in 2013. The form of survey consisted of 24 closed questions. The first eleven questions were related to general issues associated with the respondents: their age, education and social status. Then they were asked about the duration of travels by means of public transport and assessment of ride comfort. The next three questions concerned opinions about voice announcement stops. Questions 15 – 24 were an essential part of the survey and concerned the assessment of vibro-acoustic comfort in trams and buses during the ride. There were 1,094 participants in the survey, half of whom (547) were women and the other half were men. 18 − 30 years old people were the largest age group of respondents (44%) in the survey. 15% of respondents were in other two age groups: 31 − 40 and over 50. 14% of respondents were under 18. The age group with the smallest number of respondents − 11% were people aged 41 − 50. Most respondents in the survey indicated that they use public transport every day − 38%, several times a week − 27% and several times a month − 16%. Less than 10% answered "once a week", "once a month" and "less than once a month". First, the respondents assessed noise and vibration in means of public transport during the ride. Figure 1 shows a summary of the responses to the following question: "How do you assess noise and vibration during travels in vehicles of public transport in Poznań?"

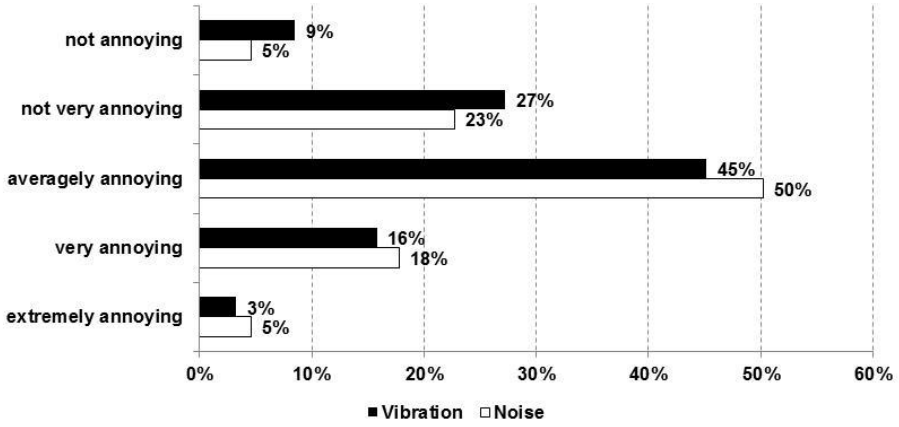

Figure 1: The distribution of answers to the question: **"**How do you assess noise and vibration during travels in vehicles of public transport in Poznań?**"**.

The distribution of answers to this question was quite similar both in terms of buses and trams. Half of the participants in the survey claimed that noise and vibrations during the rides in buses and

trams in Poznań are averagely annoying. Less than 30% of respondents chose the "not very annoying" response and less than 20% chose "very annoying". The remaining answers − ”extremely annoying” and “not annoying” − were chosen by less than 10% of respondents. The assessment of noise and vibration in means of public transport has been carried out with two criteria. Participants in the survey were asked to indicate where in the vehicle the vibrations and noise have been greatest during the ride and they were asked to indicate phases of the ride, during which both factors (noise and vibration) have been most significantly felt. The study was conducted separately for passengers using trams and buses. Figure 2 presents the results of the response to the question of where in the vehicle (bus, tram) the noise is greatest, and Figure 3 shows the results of the answer to the question of where in the vehicle (bus, tram) vibration is most significantly felt.

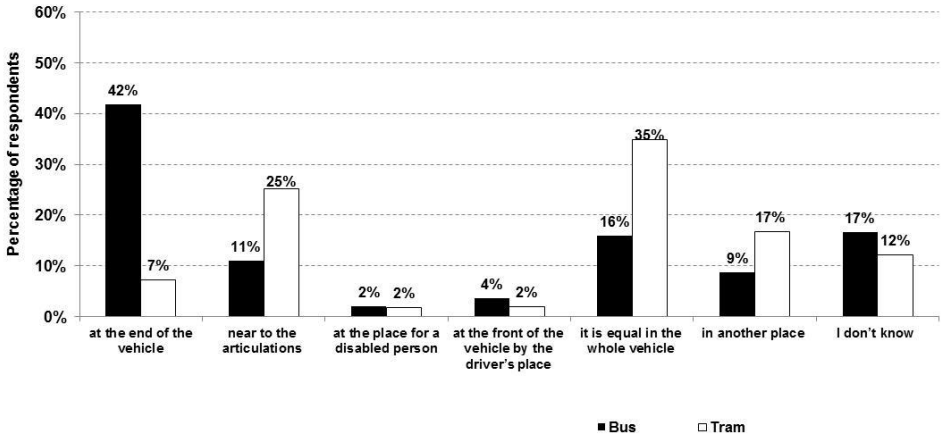

Figure 2: The distribution of answers to the question: “In which place in the vehicle (bus, tram) noise is the greatest?”.

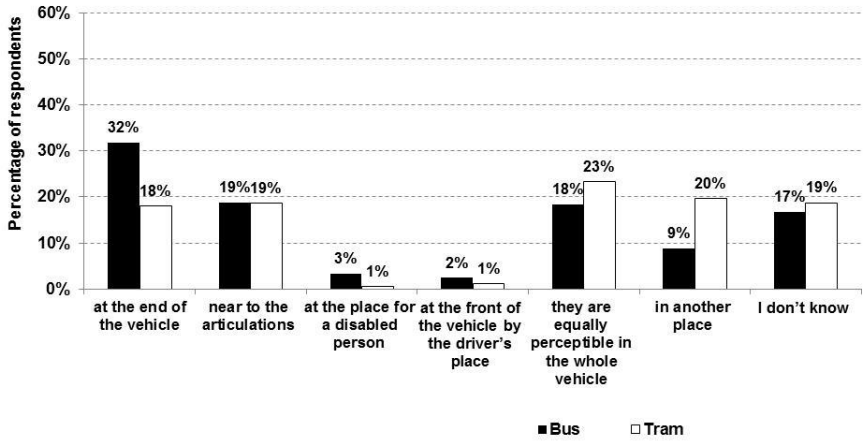

Figure 3: The distribution of answers to the question: “In which place in the vehicle (bus, tram) vibration is most significantly felt?”.

In the case of buses, there was a similar distribution of answers to the question of where in the vehicle noise and vibration are the greatest (Figure 2 − the bus). The greatest noise is generated at the end of the vehicle. This response was given by 42% of respondents. The next most common answers were: "it is the same in the whole vehicle" and "no opinion". These answers were chosen by less than 17% of respondents. The other answer options were chosen by less than 10% of people. As for the place in the vehicle where bus vibrations were most significantly felt, respondents answered similarly as in the case of noise (Figure 3 − bus). 32% of people indicated that this place

is at the end of the vehicle and 19% indicated that it is near the articulations. Less than 18% have chosen the "no opinion" answer or responded that vibrations are the same in the whole vehicle. The assessment of noise and vibration in trams was slightly different. 35% of respondents indicated that the tram noise (Figure 2 − tram) was the same in the whole vehicle. 25% of respondents answered that the greatest noise was near the articulations, 17% indicated the places over the wheels and 12% had no opinion. As for vibrations (Figure 3 − vibrations), to the question of where the vibration in tram was most significantly felt, the respondents were hardly able to indicate such place. 23% of respondents claimed that vibrations were equally perceptible in the whole vehicle. Less than 20% of the respondents had no opinion or indicated that vibrations were most significantly felt over the wheels, near the articulations and at the end of the vehicle. The next two figures illustrate the distribution of answers to the question: "In which phase of travel by means of public transport vibrations and noise are the greatest?" Figure 4 presents answers to the aforementioned question in the context of bus travel and Figure 5 − in the context of tram ride.

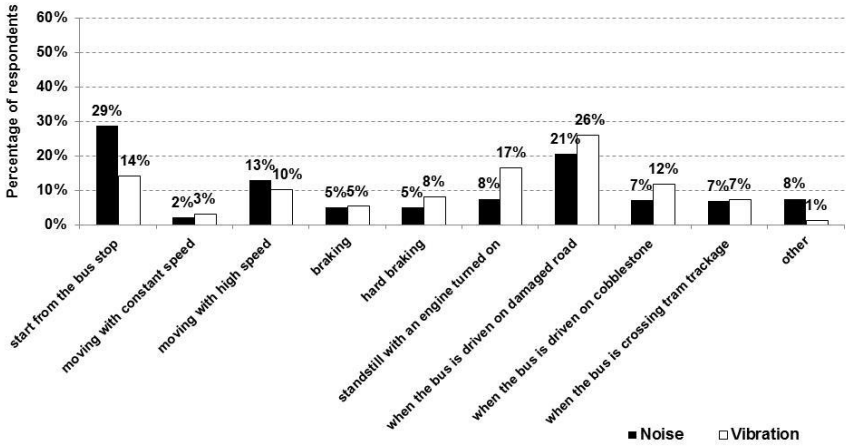

Figure 4: The distribution of answers to the question: **"**During which phase of bus travel noise and vibrations are the greatest?**"**.

Participants assessed in the survey that the greatest noise is generated when the bus starts from the stop and when it is travelling on the damaged road. These answers were given by more than 20% of the respondents. The third most common answer was high speed driving − 13% of respondents. The other answer options were chosen by less than 10% people. As for vibrations, the respondents assessed that they are most intensely felt in the following phases: travelling on a damaged road (26% of respondents), standstill with an engine turned on (17%), start from the bus stop (14%), when the bus is driven on cobblestone (12%) and when it is driven with high speed (10%). The other answer options were chosen by less than 10% people.

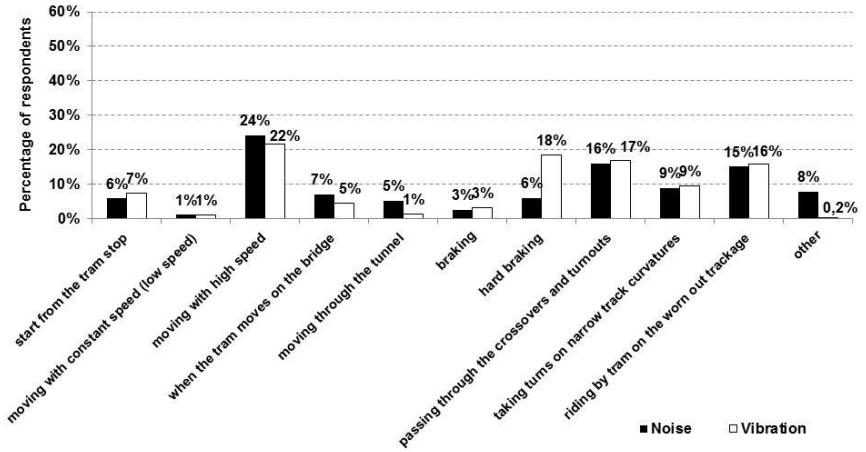

Figure 5: The distribution of answers to the question: **"**During which phase of tram ride noise and vibrations are the greatest?**"**.

As for indicating phases of ride in which noise and vibrations in the tram are the greatest (Figure 5), the distribution of answers is as follows: noise is the greatest when the tram is driven with high speed. This answer was chosen by 24% of respondents. The next phases of the ride with the highest number of responses were: "passing through the crossovers and turnouts" (16% of respondents) and "riding by tram on the worn out trackage" (15% respondents). As for vibrations, respondents most frequently indicated that these were most significantly felt when the tram was moving at a high speed. 22% of the respondents have given this answer. The next phases of the ride, during which the respondents felt vibrations the most, were: "hard braking" (18%), "passing through the crossovers and turnouts" (17%) and "riding by tram on the worn out trackage" (16%). The other answer options were chosen by less than 10% of people, in categories of both noise and vibrations.

The last questions in the survey concerned indicating the loudest, the quietest, the most and the least unpleasantly shaking vehicles operated by the Municipal Transport Company (Miejskie Przedsiębiorstwo Komunikacyjne) in Poznań. In the case of trams, the respondents indicated that the best vibroacoustic conditions are in low-floor trams (68% of responses) and worst are in trams of old type with high floor (45% of responses). In the case of buses, respondents have indicated − similarly both in the case of noise and vibrations − that they have no opinion on the subject (40% of respondents) or that noise and vibrations are the same in all vehicles (20% of respondents).

3. Experimental research

The next phase of research on the comfort of tram and bus travel consisted in making experimental measurements of noise in selected tram and bus types during the travel and at stops. The newest types of low-floor vehicles were selected for the research. In the case of trams, these were Solaris Tramino and Siemens Combino, while the buses were various construction variants of Solaris Urbino: 18 and 12 meter-long vehicles. For the study, the authors developed own measuring method, basing on the guidelines from the two railway standards: "PN-EN ISO 3381 Railway applications − Acoustics − Measurement of noise inside railbound vehicles" and "PN-90/S-04052 Measurement of noise inside motor car. Limit of sound level [3, 4]" The standards were used in this study because there are no legal provisions in Poland that would regulate the issue of evaluation of noise in vehicles of public transport (buses and trams) at standstill and during the travel. The noise assessment was done with the use of 10 measurement microphones installed in the passenger compartment. The microphones were similarly located in buses and in trams. The first measuring microphone was at the front of the vehicle at the driver's cab and the tenth microphone was located

at the end of the vehicle. Figure 6 shows sample locations of ten measuring microphones in the Solaris Tramino tram.

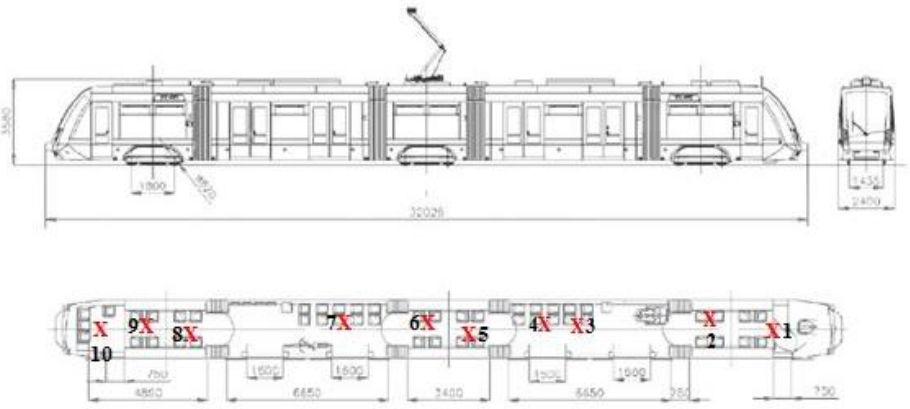

Figure 6: Distribution of measurement points in the passenger compartment of the Solaris Tramino tram (own study based on [5]).

Prior to making the basic measurements, noise at standstill was measured in all buses and trams selected for testing (ten vehicles of each type). During the tests at standstill, in trams, all devices that should be running at stops were turned on. In the case of buses, engines were at idle. The following sound levels were recorded in the passenger compartments: in Solaris Tramino trams − 50 dB, in Siemens Combino trams − 60 dB. In the case of buses the distribution of sound levels was as follows: Solaris Urbino 18 m buses − 65 dB and Solaris Urbino 12 m buses − 68 dB.

Figs. 7 and 8 show the average results of noise measurements in public transport during the ride. Figure 7 relates to the distribution of the sound level in buses while Figure 8 is related to the distribution of sound levels in trams.

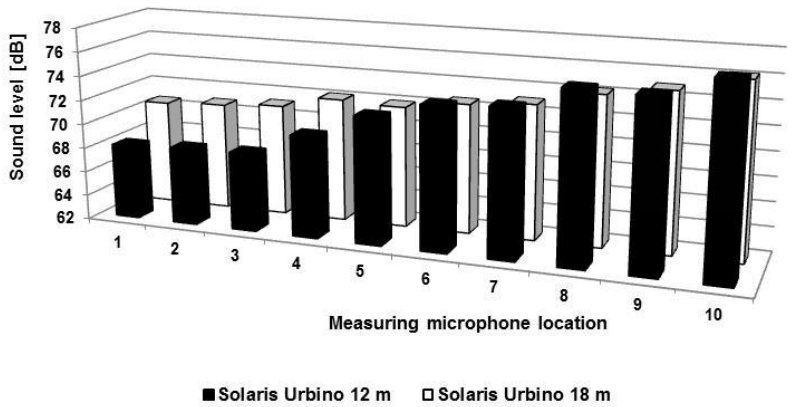

Figure 7: Sound level distribution in Solaris Urbino buses.

The measurements made during bus rides showed that in 18 m articulated buses recorded sound levels ranged from 68 to 77 dB. The lowest levels were recorded in the front of the vehicle at the location of the first four measuring microphones. In these locations results ranged from 66 to 71 dB. At the rear of the vehicle at the location of the 10th microphone, sound level was 78 dB. The difference in recorded sound levels in the front and rear of the vehicle was 11 dB. Analysis of measurement results from Solaris Urbino 12 m buses shows that recorded sound levels ranged from

71 to 76 dB. The distribution of sound levels recorded by the individual measuring microphones was similar to the one measured in Solaris Urbino 18 m buses. The lowest sound levels − 71 dB were recorded the front of the vehicle and the highest − 76 dB at the end of the vehicle. The difference in sound levels between the front and the end of the Solaris Urbino 12 m vehicle was 6 dB.

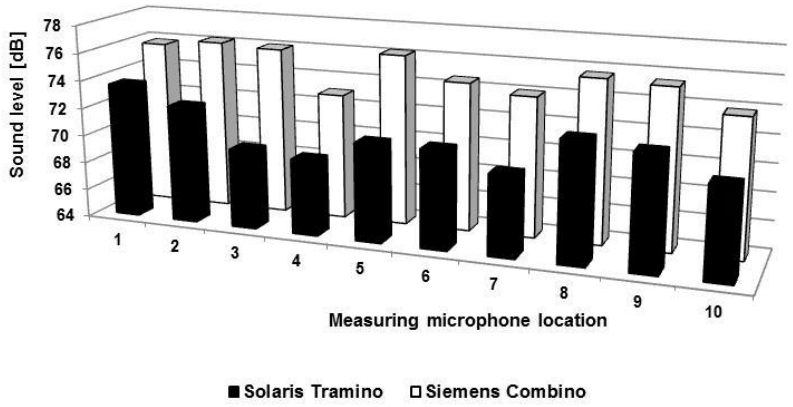

Figure 8: Sound level distribution in selected tram types.

On Solaris Tramino trams, the sound level distribution was between 67 and 76 dB. The highest sound levels were recorded at the front and rear of the tram car at locations of measuring microphones No 1, 2, 8 and 9. In the middle of the tram car, lower sound levels were recorded: from 69 to 71 dB [5]. The noise measurements made in the Siemens Combino tram showed that the sound levels' distribution in the tram car during the ride was more or less even. The obtained results were in the range of 72 − 79 dB. In tram cars of this type, it is not possible to indicate the locations with the highest and lowest sound levels. The recorded sound levels were slightly lower in locations of the measuring microphones No 3, 4 and 7.

4. Conclusion

Basing on the measurements made in surveys and experimental research, the following conclusions can be drawn: Participants have indicated in the survey that noise and vibrations occurring in trams and buses are averagely annoying or not very annoying. Most of respondents could not indicate a place in a vehicle where vibroacoustic phenomena were most intense during the travel by public transport. The respondents were answering that they do not know, or that vibroacoustic phenomena are evenly intense in the whole vehicle. In the case of buses, phases of the ride, during which the greatest noise is generated, are: starting from the bus stop, driving the bus on the damaged road and driving at high speed. As for trams, distribution of answers to this question was as follows: “going with high speed”, “passing through the crossovers and turnouts” and “going on a worn out trackage”. The bus and tram phases in which the vibrations are most significantly felt are as follows: in the case of buses the respondents most often indicated: driving the bus on the damaged road, standstill with engine turned on and starting from the bus stop. In the case of trams, these were the following phases: moving with high speed, hard braking and passing through the crossovers and turnouts.

With regard to experimental research, the conclusions are as follows: Buses that generate the highest sound levels both at standstill and while being driven are Solaris Urbino 12 m type. The following results were recorded in Solaris Urbino buses at standstill: in 18 m articulated buses: 63 − 68 dB and in Solaris Urbino 12 m buses: 66 − 70 dB. Recorded sound levels in Solaris Urbino

12 m buses at standstill were on average 2 − 3 dB higher than the results recorded in Solaris Urbino 18 m buses at standstill. During the ride, sound levels in buses increased to 68 − 77 dB. Tests carried out in trams show that the highest sound levels, both at standstill and during the ride, were recorded in Siemens Combino tram cars. At standstill, average sound levels were about 10 dB higher in these tram cars compared to results recorded in Solaris Tramino tram cars. Sound levels in trams increased to 69 − 76 dB during the ride. The highest sound levels were recorded in Siemens Combino tram cars (74 − 76 dB) and the lowest were in Solaris Tramino tram cars (69 − 73 dB). In Solaris Tramino tram cars it was possible to indicate areas where the lowest and the highest sound levels were recorded. In Siemens Combino tram cars, the sound levels' distribution was more even.

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