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STATISTICAL ASSESSMENT OF THE QUESTIONNAIRE SURVEY QUALITY FOR TRANSPORT FATIGUE IN URBAN PASSENGER TRANSPORTATION

The article deals with the problem of determining the transport fatigue of mass transit passengers as one of the human body states. The transport fatigue is proposed to be evaluated using the questionnaire method with subsequent quality assessment by the mathematical statistics methods.

Keywords: *transport fatigue, questionnaire survey, reliability, validity, quality, correlation.*

Problem statement

Urban passenger transportation is the main element of a present city to determine the urban development rate and acceptable living standard of the urban population. Along with the obvious advantages of urban transportation, there are also social losses, among which environmental and noise pollution, road traffic accidents, and transport fatigue should be considered. In contrast to the first three negative consequences, for which the damage assessment methods have been developed, under existing conditions the transport fatigue remains a poorly studied result of mass transit operation.

Meanwhile, in material production, the negative social and economic results of transport fatigue have been already identified in the 60–70th of the XX century. These include: decrease in labor productivity and quality (spoilage percentage growth); increase in industrial injuries and working staff sickness rate [1–3]. In everyday life, the clear transport fatigue symptoms can be apathy, attention distraction, bad mood, irritability, deterioration of memory, and human body resistance [4, 5].

Abroad, attention is also paid to the study of transport fatigue, which is usually expressed through the external signs – mood, well-being, activity, motivation, etc. [6–8].

However, despite a number of studies in Ukraine and abroad, transport fatigue and total travel time still remain the indicators of transportation operation, a generally accepted economic assessment of which has not yet been developed on a state scale.

Thus, there is a scientific problem to quickly and qualitatively assess the transport fatigue impact on the urban population and to develop efforts to reduce it.

Analysis of recent research and publications

We believe the transport fatigue to be a part of psychical fatigue along with mental emotional, visual, and auditory ones. In turn, fatigue is one of the functional states of a human body [9] and should be estimated using special methods, the analysis of which is given below.

A functional human state can be determined using objective and subjective research methods [10–13]. The objective methods for studying fatigue include instrumental methods for the main mental processes and the dynamics of various physiological systems. As objective signs of fatigue or stress, the indicators of a human working capacity can be used, such as the labor productivity (or reject value, number of operational errors) and physiological indicators (brain current value, pulse rate, respiratory rate, signal-to-irritant response time, etc.). The most common instrumental techniques are the electroencephalogram (EEG) to reflect the brain activation level, electrocardiogram (ECG) to express the heart activity, and the electromyogram (EMG) to demonstrate the muscle activity.

The advantage of the objective methods lies in the fact that, firstly, they make it possible to objectively diagnose a human condition, and secondly, they allow quantitatively assessing the disturbances in the functioning of a particular system. The disadvantage of these methods is in using valuable medical equipment, the researcher's special medical education to correctly interpret the results obtained, low technique promptness.

The subjective methods are based on self-observation to obtain information about the current state or response to this state from the person under research. These methods come from the fact that a human is able to independently, "from the inside", describe the nature and intensity of changes in his own state, which can be indirectly expressed using a questionnaire survey [14].

The advantages of questionnaires include well-developed signs of a state (fatigue, stress, etc.), ease of answer and subsequent answers' processing, high method quickness, and verification of the obtained results by the mathematical statistics methods. The disadvantages are a poorly substantiated quantitative assessment of a state and a human's subjective perception of a state to lead to the resulting inaccuracy.

However, the application of the statistical techniques allows evaluating the reliability and validity of this approach and eliminating the inconsistent results.

Aim of the study

The purpose of the study is to develop and to estimate the transport fatigue technique via the questionnaire survey.

To achieve the aim of the study, the following tasks should be solved:

- selection of the survey technique to obtain human state statistical data;
- experimental studies to disclose the fatigue change in urban mass transit;
- estimation of the reliability and validity questionnaire survey technique.

Study material presentation

In psychophysiology and labor psychology [15, 16], questionnaire techniques are widely known to measure attention, concentration, and fatigue during working or studying. Comparing the answers to the pre-established values allows concluding the level of human performance, fatigue, attention concentration, etc.

However, in the case study, their application in a "pure" form can be rather limited, since they demonstrate only the final result and do not disclose the duration of the travel parameters' impact on the passenger, and the perception of these parameters by the passenger depending on gender, age, etc.

Having analyzed the available questionnaire methods for assessing well-being, psychical and emotional state, mood, and fatigue [17–20], to fully embrace the "functional state-to-travel parameters" interrelation a combined approach was presented. It is a 2-part questionnaire to reveal the "home-to-work" travel conditions and the subsequent passenger's functional state expressed as a ranked form.

Part 1 of the questionnaire displays the passenger's age, the travel parameters, and the passenger's subjective assessment of the adaptation time if the adaptation took place. The workplace adaptation description is based on the signs of fatigue (regardless of the cause) given in the questionnaire [21] that can be observed or felt by a human for a time after a mass transit travel.

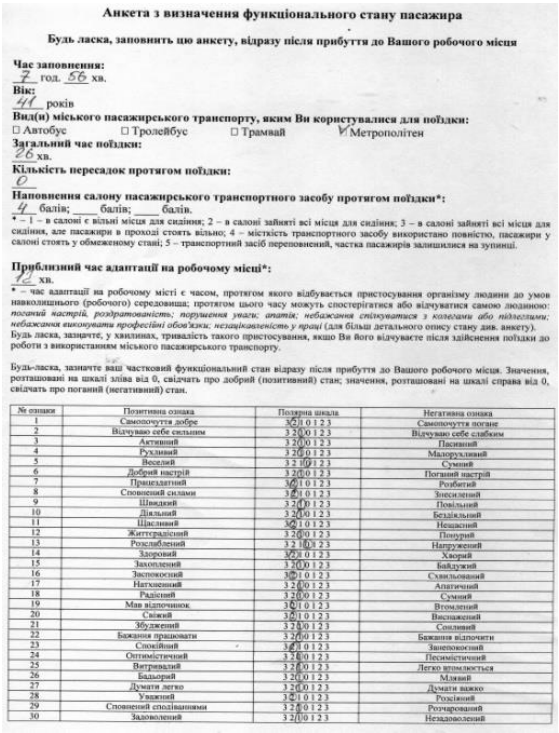
It should be noted that in the questionnaire, special attention is taken to the adaptation time, which in the paper [11] is substantiated as a universal transport fatigue indicator for all workers in the production and non-production spheres. The adaptation time is the time to accommodate a human body to a production environment. In [11] it is assumed that the longer the adaptation time, the greater the passenger fatigue after the trip.

Part 2 of the questionnaire is a table that contains 30 pairs of opposite characteristics to reflect the studied features of the state (well-being, activity, and mood) [17, 19]. In the survey form, a rating scale is located between the polar characteristics. The respondent is asked to correlate his state with a scaled rank. When processing the survey results, the ranks are recalculated into points from 7 to 1 in descending order (from positive to negative signs). For example, in the positive sign (left questionnaire part), the rank "3" corresponds to the score of "7" points, in the negative sign (right questionnaire part) the rank "3" takes the value of "1" points.

The quantitative technique result is presented as an arithmetic mean value. The average score is equal to 4 points (a respondent selected all the "0" ranks). Scores exceeding 4 points indicate a good state of the passenger; scores up to 4 inclusively indicate the unsatisfactory state.

The technique (part 2) should be used for psychical, mental, and emotional diagnostic examination of workable adults without any restrictions on gender, social, professional, and educational grounds. The developers declared its verification from the sample of 300 respondents [17, 19].

In this way, there are two fatigue indicators in the questionnaire – the average score and the adaptation time. This is necessary to assess the relationship between the functional state of a person (expressed in points) and the adaptation time, to estimate the quality of the questionnaire survey and the accuracy of the questionnaire completion.



Анкета з визначення функціонального стану пасажира

Будь ласка, заповнить цю анкету, відразу після прибуття до Вашого робочого місця

Час заповнення:
7 год. 56 хв.

Вік:
41 років

Вид(и) міського пасажирського транспорту, яким Ви користувалися для поїздки:
☐ Автобус ☐ Тролейбус ☐ Трамвай ☑ Метрополітен

Загальний час поїздки:
26 хв.

Кількість пересадок протягом поїздки:
0

Наповнення салону пасажирського транспортного засобу протягом поїздки*:
4 балів; ___ балів; ___ балів.
* – 1 – в салоні є вільні місця для сидіння; 2 – в салоні зайняті всі місця для сидіння; 3 – в салоні зайняті всі місця для сидіння, але пасажири в проході стоять вільно; 4 – місткість транспортного засобу використано повністю, пасажири у салоні стоять у обмеженому стані; 5 – транспортний засіб переповнений, частка пасажирів залишилися на зупинці.

Приблизний час адаптації на робочому місці*:
12 хв.
* – час адаптації на робочому місті є часом, протягом якого відбувається пристосування організму людини до умов навколишнього (робочого) середовища; протягом цього часу можуть спостерігатися або відчуватися самою людиною: *погані настрій, роздратованість, порушення уваги; апатія; небажання спілкуватися з колегами або підлеглим; небажання виконувати професійні обов'язки; незацікавленість у праці* (для більш детального опису стану див. анкету). Будь ласка, зазначте, у хвилинах, тривалість такого пристосування, якщо Ви його відчуваєте після здійснення поїздки до роботи з використанням міського пасажирського транспорту.

Будь-ласка, зазначте ваш частковий функціональний стан відразу після прибуття до Вашого робочого місця. Значення, розташовані на шкалі зліва від 0, свідчать про добрий (позитивний) стан; значення, розташовані на шкалі справа від 0, свідчать про поганий (негативний) стан.

№ ознаки	Позитивна ознака	Полярна шкала	Негативна ознака
1	Самопочуття добре	3 2 1 0 1 2 3	Самопочуття погане
2	Відчуваю себе сильним	3 2 1 0 1 2 3	Відчуваю себе слабким
3	Активний	3 2 1 0 1 2 3	Пасивний
4	Рухливий	3 2 1 0 1 2 3	Малорухливий
5	Веселий	3 2 1 0 1 2 3	Сумний
6	Добрий настрій	3 2 1 0 1 2 3	Поганий настрій
7	Працездатний	3 2 1 0 1 2 3	Розбитий
8	Сповнений сили	3 2 1 0 1 2 3	Знесилений
9	Швидкий	3 2 1 0 1 2 3	Повільний
10	Діяльний	3 2 1 0 1 2 3	Бездіяльний
11	Щасливий	3 2 1 0 1 2 3	Нещасний
12	Життєрадісний	3 2 1 0 1 2 3	Понурий
13	Розслаблений	3 2 1 0 1 2 3	Напружений
14	Здоровий	3 2 1 0 1 2 3	Хворий
15	Закоханий	3 2 1 0 1 2 3	Байдужий
16	Захоплений	3 2 1 0 1 2 3	Стривожений
17	Натхнений	3 2 1 0 1 2 3	Апатичний
18	Радісний	3 2 1 0 1 2 3	Сумний
19	Маю відпочинок	3 2 1 0 1 2 3	Втомлений
20	Свіжий	3 2 1 0 1 2 3	Виснажений
21	Збуджений	3 2 1 0 1 2 3	Сонливий
22	Бажання працювати	3 2 1 0 1 2 3	Бажання відпочити
23	Спокійний	3 2 1 0 1 2 3	Занепокоєний
24	Оптимістичний	3 2 1 0 1 2 3	Песимістичний
25	Витривалий	3 2 1 0 1 2 3	Легко втомлюється
26	Бадьорий	3 2 1 0 1 2 3	Млявий
27	Думати легко	3 2 1 0 1 2 3	Думати важко
28	Уважний	3 2 1 0 1 2 3	Розсіяний
29	Сповнений сподіваннями	3 2 1 0 1 2 3	Розчарований
30	Задоволений	3 2 1 0 1 2 3	Незадоволений

Fig.1. Completed questionnaire to survey the passenger functional state

An example of a completed questionnaire reduced to the passenger transportation field is shown in Fig. 1.

Thus, 16 respondents were belonging to different layers of the population aged between 18 and 60 years, who daily use public transportation for study or workplace trips in the city of Kharkiv. Within 5 working days, the test sample of 80 questionnaires was received to demonstrate a human functional state after a mass transportation travel. Unfortunately, the 2019-nCoV restrictions did not allow reaching the required number of 300–400 respondents.

Despite the above-mentioned universality and consistent results stated by the authors [19], the technique cannot be unambiguously accepted as a conclusive and reliable one. The questionnaire requires to be checked for reliability and validity by methods of mathematical statistics [22, 23].

Reliability is a test quality criterion to ensure the measurement accuracy to be stable to extraneous random factors.

To evaluate the reliability of the tests, the following methods are used [22, 23]: 1) retest method; 2) parallel forms method; 3) test splitting method.

So, a test reliability assessment is originated from calculating the correlation between two sets of results of the same test or its two parallel forms by the formula

$$r = \frac{\sum_{i=1}^{n} x_i y_i - \frac{\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n}}{\sqrt{\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}} \times \sqrt{\sum_{i=1}^{n} y_i^2 - \frac{(\sum_{i=1}^{n} y_i)^2}{n}}}, \quad (1)$$

where x_i, y_i are the individual scores from various parts of the test or questionnaire;

n is the number of observations.

Regardless of the assessment method used, the test reliability is acceptable if the correlation value is within 0,8–1 [23, 24].

The retest method of assessing the reliability assumes that the same test is used twice in one group of respondents. As mentioned above, it is based on calculating the correlation between the individual scores of the respondents according to the results of the first and second tests. In this method, the time factor plays a significant role – the period cannot be large. During this time, concerning transport fatigue, the living and travel conditions as well as the workplace that are of the key impact may change.

The method of parallel forms involves testing the same group of respondents twice with tests that are identical in content, structure, and include tasks equal in difficulty, differentiating ability, i.e., parallel forms of the test. The main difficulty in applying this method is that the developer needs to create a new test, identical to the first one, and prove the identity, and this is a very laborious procedure.

The splitting method is convenient in practical application, since it is reduced to single testing. It is from the assumption that the two halves of the test are parallel, and involves dividing the test into two parts: even and odd test tasks.

After analyzing all the reliability approaches, the retest method was chosen for its simplicity and clarity. From the above-stated, we believe that a one-week break between the questionnaire surveys (No.1 and No.2) is sufficient, as the questionnaire is not a test of knowledge and does not contain information that can be memorized to deliberately falsify the final result (memorizing the test tasks and answers).

Sample fragment of human body state data is presented in Table 1.

Table 1

Sample fragment of human body state data

Survey No. 1			Survey No. 2		
No.	Adaptation time, min.	Score	No.	Adaptation time, min.	Score
1	12	4	1	15	4,1
2	15	3,9	2	12	4
3	20	3,6	3	14	3,9
4	10	4,6	4	8	4,7
…	…	…	…	…	…
80	25	3,5	80	20	3,8
"Time-to-score" correlation value		-0,87	"Time-to-score" correlation value		-0,81
Adaptation time correlation value					0,83

To assess the relationship strength between the human states expressed in points from survey No. 1 and survey No. 2, a pair correlation analysis was performed using Microsoft Office Excel 2010 [25]. Correlation value of 0,851 indicates a close relation between the scores [23, 24, 26].

However, this value is influenced by random factors, therefore, when it is necessary to check its statistical significance by calculating the Student's *t*-test [27]

$$t_{calc.} = \frac{r \cdot \sqrt{n-2}}{\sqrt{1-r^2}}, \quad (2)$$

where *r* is the calculated correlation coefficient for the pair of scores.

Then

$$t_{calc.} = \frac{0{,}851 \cdot \sqrt{80-2}}{\sqrt{1-0{,}851^2}} = 126{,}18 \cdot$$

If the $t_{calc.} > t_{tab.}$ condition is satisfied, then the coefficient value can be considered as a non-random and statistically significant one. In accordance with [23], at *t* (0,05;78) the tabulated *t*-criterion value is

1,991 for the 0,95 confidence level. Since the correlation coefficient is nonrandom and is of proper significance.

In practice, it can be found that a good correlation between the average score of a human state in questionnaires No.1 and No.2 does not bring the same good ratio to the workplace adaptation time. In other words, a low correlation between the "time-to-score" values will indicate that the adaptation time does not correspond to the actual state of the passenger expressed in points, and refuses the survey purpose and quality. The reason for this may be a respondent's disinterest and negligence when completing the questionnaire, changes in living and workplace trip conditions, social status, etc. Due to this, the "adaptation time-to-average score" correlation must also be checked. The correlation analysis results are also shown in Table 1. In both surveys, the correlation is sufficiently close and negative, i.e. a worse human "after-trip" state meets to a longer adaptation time.

According the Student's *t*-test these correlation coefficients are also significant and non-random, as $t_{calc.} > t_{tab.}$, 136,62>1,991 and 104,73>1,991, respectively, at the 0,95 confidence level.

As can be seen in Table 1, adaptation time demonstrates a good correlation of 0,83 too. The *t*-test procedure also revealed the high adaptation time significance and low random influence (105,09>1,991).

Another important indicator of the test or questionnaire quality is validity. Validity is the testability to generate the results to be adequate with its purpose [22, 23]. There are two approaches in determining the test validity.

The first approach involves comparing the functional state scores with the scores of independent experts (or medical test scores) and subsequent correlation coefficient calculation as suggested above.

The second approach originates from the statistics and test theory [28]. It is known that the second indicator of adequacy or validity can be the determination coefficient directly or the following value

$$V = 1 - r^2, \quad (3)$$

where r^2 is the determination coefficient, r^2 = 0,724.

The acceptable value of the test validity is usually in the range of 0.2–0.4. This value means a part (or percentage) of random factors, the influence of which was not taken into account in the test or questionnaire.

Then the value of the test validity will make

$$V = 1 - 0{,}724 = 0{,}276.$$

The value of validity is not verified for significance, but in order to substantiate the determination factor statistical significance it is convenient to apply the *F*-statistics calculation [27]

$$F_{calc.} = \frac{r^2 \cdot (n-2)}{1-r^2}, \quad (4)$$

$$F_{calc.} = \frac{0{,}724 \cdot (80-2)}{1-0{,}724} = 204{,}61 \cdot$$

In accordance with [27], at *F* (0,05;1; 78) the tabulated *F*-criterion value is 3,96. Since $F_{calc.} > F_{tab.}$ the determination coefficient is nonrandom and significant too at the 0,95 confidence level.

Thus, it can be concluded that the calculated indicators of the reliability and validity of the functional state questionnaire demonstrate an acceptable quality of the survey results.

Conclusions

The questionnaire approach presented makes it possible to find the transport fatigue value, expressed both in points and in a universal indicator – the passenger's workplace adaptation time.

The statistical analysis demonstrated a sufficiently high quality of the questionnaire survey, which was proposed to be assessed by reliability and validity.

It was established that reliability is the testability to generate a stable result, free from random errors and independent of the time of use. As an indicator of reliability, the correlation coefficient was taken, which showed a high resulting value of 0,851.

At the same time, the test validity is the consistency of the results with the test purpose. The validity value of 0,276 is statistically significant and lies within the recommended limits.

So, the further research areas are to improve the survey quality by increasing the sample size to the required values and distributing the questionnaires in cities of the different population to reveal the persistent trends in the passengers' transport fatigue formation.

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СТАТИСТИЧНА ОЦІНКА ЯКОСТІ АНКЕТНОГО ОБСТЕЖЕННЯ З ВИЗНАЧЕННЯ ТРАНСПОРТНОЇ ВТОМИ НА МІСЬКОМУ ПАСАЖИРСЬКОМУ ТРАНСПОРТІ

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Міський пасажирський транспорт є головною складовою сучасного міста, й визначає як темпи його розвитку, так й відповідний рівень життя міського населення. Поряд з очевидними перевагами міського транспорту існують і соціальні втрати, серед яких слід враховувати збитки від екологічного та шумового забруднення, дорожньо-транспортних пригод та транспортної втоми. На відміну від перших трьох негативних наслідків, для яких розроблені методи оцінки, за існуючих умов транспортна втома залишається недостатньо вивченим результатом функціонування міського транспорту. Виходячи з аналізу методів визначення транспортної втоми, було запропоновано анкетний метод її вивчення як одного зі станів організму людини. Даний метод у порівняні з інструментальними методами має певні переваги: добре розроблені ознаки стану втоми, відносна простота відповідей та їх подальшої обробки, оперативність методу, перевірка якості отриманих результатів методами математичної статистики. Таким чином у опитувальнику є два показники втоми – середній бал та час адаптації. Це необхідно для оцінки сили взаємозв'язку між функціональним станом людини, вираженим у балах, та часом адаптації, а також для оцінки якості опитування та точності заповнення анкети респондентами. Статистичний аналіз продемонстрував достатньо високу якість опитування, яке було запропоновано оцінювати за надійністю та валідністю. Було встановлено, що надійність – це здатність тесту генерувати стійкий результат, вільний від випадкових помилок і незалежний від часу використання. Надійність тесту запропоновано оцінювати через порівняння результатів опитування, яке проводиться з часовим проміжком, що дорівнює один тиждень. В якості показника надійності був прийнятий коефіцієнт кореляції, який показав високе результуюче значення, що склало 0,851, і є статистично значущим та невипадковим. У той же час, валідність тесту – це показник, що оцінює відповідність результатів меті тесту та ступінь охоплення чинників, які можуть завдавати впливу на транспортну втому. Величина валідності складає 0,276, яка також є статистично значущою і знаходиться в рекомендованих межах (0,2 – 0,4). Отже, перспективними напрямками досліджень є покращення якості обстеження за рахунок збільшення обсягу вибірки до необхідних значень (300 – 400 респондентів) та розповсюдження анкет у містах з різною чисельністю населення з метою виявлення стійких тенденцій у формуванні транспортної втоми пасажирів.

Ключові слова: *транспортна втома, анкетне обстеження, надійність, валідність, якість, кореляція.*