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### CONTACTS

Phone: **+998 50 737 87 88**

Website: <https://ist-journal.uz>

Email: [innovationist2025@gmail.com](mailto:innovationist2025@gmail.com)

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# ASSESSMENT OF PHYSIOLOGICAL WORKLOAD OF WORKERS DURING THE PROCESS OF OPENING THE BOTTOM HATCHES OF A GONDOLA (SEMI-OPEN) RAILWAY WAGON

**Toshtemirov Inomjon Muqimjonovich**

Researcher, Department of Railway Operations Management  
Tashkent State Transport University  
Email: [Inomjon160382@gmail.com](mailto:Inomjon160382@gmail.com)

**Yusupov Azizjon Kahramonovich**

Associate Professor, Department of Railway Operations Management,  
Tashkent State Transport University  
Email: [yusupovaziztosh@gmail.com](mailto:yusupovaziztosh@gmail.com)  
ORCID: 0000-0002-0662-4610

**Abstract:** In this article, the worker's physiological workload during the process of opening the lower hatches of semi-open rail freight wagons located on an elevated track was assessed on the basis of sanitary and hygienic standards. In particular, taking into account dynamic and static muscle strain, awkward working posture, the height factor, and repetitive exertion, the worker's physiological workload was determined for two hatch-opening methods: opening from ground level and opening while positioned on an overpass. Based on the analyses performed, scientific conclusions were formulated that work carried out on the overpass is characterized by higher physiological strain due to a greater share of static load, and that ergonomic optimization and mechanization of working conditions are necessary.

**Key words:** physiological workload, work severity, open-top freight wagon, bottom hatch, trestle, ergonomics.

## INTRODUCTION

In railway transport, the process of opening the bottom hatches of gondola (semi-open) wagons, which are widely used for transporting bulk cargo, is considered a technologically demanding operation that requires significant physical effort. In particular, when working with loaded wagons positioned on elevated railway trestles, a considerable share of manual labor still remains.

In practice, the process of opening the bottom hatches is carried out under two different conditions. In the first case, workers stand at ground level and use a metal crowbar weighing approximately 6 kg to deliver upward-directed impacts to the hatch sectors and locking mechanisms. In this process, the striking motion is performed upward; that is, the worker lifts the heavy tool using the muscles of the arms and shoulders and applies impulsive force to release the sector mechanism. Such movements are characterized by axial loading on the lumbar spine, dynamic strain of the upper extremities, and repetitive impact forces.

In the second case, workers are positioned on the trestle and use a sledgehammer weighing approximately 5 kg to strike the sectors and locking mechanisms at waist height. Here, the impact direction is horizontal or downward, and the worker performs the task through a combined static-dynamic strain of the lower back, shoulder, and arm muscles. Under trestle conditions, additional risk factors arise, including working at height, limited workspace, and maintaining awkward postures.

These operations are impulsive in nature and require generating high mechanical force within a short period of time. The impact energy depends on the mass and velocity of the tool and imposes sudden loads on the musculoskeletal system. Repetitive impacts lead to fatigue of the arms, shoulders, and lower back muscles and increase the risk of developing occupational diseases in the long term.

According to sanitary and hygienic standards, repetitive impact movements, the use of heavy hand tools, and tasks performed in awkward working postures are given special consideration when assessing labor severity. The degree of work intensity is determined based on energy expenditure, the proportion of static load, the magnitude of applied force, and the frequency of movement repetition.

Therefore, the purpose of this study is to physiologically assess the impact of strike movements performed using a 6 kg crowbar and a 5 kg sledgehammer during the opening of bottom hatches of gondola wagons located on elevated tracks, and to determine the labor severity category under different working conditions.

## REVIEW OF LITERATURE ON THE SUBJECT

The study of the physiological and biomechanical foundations of heavy manual operations has developed at the intersection of movement physiology, occupational hygiene, and ergonomics. The theoretical basis of this field was established by Nikolai Bernstein, who interpreted movement as a complex functional act organized by the central control system (Bernstein N.A., 1966). The author substantiated the necessity of analyzing movement through temporal, spatial, and dynamic parameters [1].

Issues of occupational biomechanics were comprehensively examined by Don B. Chaffin and Gunnar B.J. Andersson in the book *Occupational Biomechanics*. They experimentally demonstrated that impact-type movements increase torque and compressive loads on the spine. In particular, repetitive strikes using tools weighing 5–6 kg significantly increase dynamic loading on the lumbar segments [2].

Etienne Grandjean, in *Fitting the Task to the Human*, developed key ergonomic principles and emphasized that awkward working postures and repetitive impact movements cause excessive strain on the musculoskeletal system. The author showed that forceful actions performed below or above waist level increase energy expenditure and accelerate fatigue [3].

In the field of labor physiology, the works of V.I. Medvedev and A.A. Kosilov substantiate the need to assess physical workload based on energy expenditure, heart rate, and the proportion of static load. Their studies indicate that repetitive muscular tension increases the load on the central nervous system [4].

Recommendations developed by the World Health Organization identify heavy manual labor and repetitive impact movements as occupational risk factors. WHO recommends classifying labor severity based on energy expenditure and muscular strain [5].

Documents of the International Labour Organization also classify the use of heavy hand tools and operations performed at height as high-risk types of work and recommend mechanization wherever possible [6].

The standard GOST 12.1.005-88 and the current sanitary regulations (SanPiN) establish criteria for categorizing labor severity into classes IIa, IIb, and III. These criteria are based on energy expenditure (kcal/hour), movement intensity, and duration of static strain [7].

In research on industrial safety and work at height, R.S. Bridger, in *Introduction to Ergonomics*, notes that additional muscle activity is required to maintain balance during operations performed on elevated platforms, which increases overall physiological workload [8].

Thus, the analysis of scientific literature shows that although the physiological and biomechanical effects of impact operations performed with heavy hand tools have been widely studied, the comparative hygienic assessment (ground level versus elevated trestle conditions) of opening bottom hatches of gondola wagons on raised railway trestles has not been sufficiently investigated. The present study aims to address this gap.

## RESEARCH METHODOLOGY

During the unloading of bulk cargo through the bottom hatches of a gondola wagon positioned on an elevated railway track, the worker performs labor operations characterized by significant physical strain. According to the initial data, one wagon contains a total of 14 hatches, arranged with 7 on each side of the wagon. The hatch opening process is carried out using a crowbar weighing 6 kg (Figure 1).



Figure 1. Fragments from the unloading process through the bottom hatches of a gondola wagon positioned on an elevated track

Since the wagon is located on an elevated track, the worker operates approximately 2.8 meters below the hatch level. During the opening process, the worker uses the crowbar to strike the sector and locking mechanisms of the hatch. Each hatch includes 2 sectors and 2 locking devices (latches), and each sector requires 2 strikes to be released. As a result, a total of 8 strikes are required to open a single hatch.

On average, 2.2 seconds are required to deliver one strike. Thus, the strike-related operations alone demand considerable time and energy per hatch. In addition, the worker spends an average of 3.15 seconds moving from one hatch to the next. These factors, combined with the continuous repetition of the work cycle, significantly increase overall labor expenditure.

The main movements performed during the hatch opening process involve high-amplitude arm motions, maintaining body balance, and active engagement of the back, shoulder, and arm muscles during impact. In particular, upward-directed strikes with the crowbar increase the load on the spine and upper extremities. When performed over extended periods, this leads to rapid fatigue, reduced work productivity, and an increased risk of occupational injuries.

Therefore, from a physiological perspective, manually opening the bottom hatches of gondola wagons on elevated tracks is associated with a high level of labor intensity, highlighting the need for mechanization of this process. The implementation of mechanized technical solutions for hatch opening would reduce workers' physical strain, improve occupational safety, and enhance the overall efficiency of the unloading process.

Initial data:

- number of hatches per wagon: 14;
- number of elements in each hatch: 2 sectors and 2 locking devices (latches);
- number of strikes required to open each sector and each locking device: 2 strikes;
- time required for one strike:  $t_s=2,2$  seconds;
- time required for a worker to move from one hatch to the next:  $t_m$ =seconds.

The total number of strikes required to open one hatch is determined as follows:  $N_{z1} = 2 \cdot (n_s + n_z)$  (1)

where  $n_s$  and  $n_z$  are the numbers of strikes delivered respectively to the sector and the locking device (latch).

For one wagon ( $n_l=14$ hatches), the total number of strikes is determined as:

$$N_{z,tot} = N_{z1} \cdot n_l \quad (2)$$

The time required to open one hatch is calculated as:

$$T_{z1} = N_{z1} \cdot t_s, h. \quad (3)$$

Taking into account the transition time, the total time spent per hatch is:

$$T_1 = T_{z1} + t_m, h. \quad (4)$$

The total time required to open all bottom hatches of one wagon is:

$$T_{wagon} = T_1 \cdot n_l, h. \quad (5)$$

During the hatch opening process, the crowbar is lifted from shoulder level to the impact point with high amplitude, which significantly increases the worker's biomechanical strain. Considering this factor, the effective impact height in the calculations is expressed as:

$$h_{eff} = h_0 + \Delta h, \text{ kcal} \quad (6)$$

where  $h_0$  – the height from shoulder level to the impact zone ( $\approx 1 \text{ m}$ );

$\Delta h$  – the additional biomechanical equivalent height due to working below hatch level ( $\approx 0,2 \text{ m}$ ).

Substituting the relevant values into equation (6), we obtain:

$$h_{eff} = 1,2 \text{ m}$$

When opening the hatches of one wagon using a 6 kg crowbar, each strike is generated by lifting the tool, and the mechanical energy of one strike is determined as:

$$E_1 = m \cdot g \cdot h_{eff}, J \quad (7)$$

During the opening of one wagon's hatches, 112 strikes are delivered. The total mechanical work performed is characterized by the sum of the mechanical energies of all strikes:

$$A_{mech,open} = N_{z,tot} \cdot E_1, J \quad (8)$$

Under current conditions, 4.8 minutes are required to open the hatches of one wagon. This process involves delivering 112 high-amplitude strikes with a 6 kg crowbar, working at a position 2.8 m below the hatch level, and active engagement of the shoulder girdle, back muscles, and wrist-elbow joints during each strike.

Taking these factors into account, the actual physiological energy expenditure during the opening process is determined as:

$$E_{phys,open} = \frac{A_{mech,open}}{\mu}, J \quad (9)$$

Muscle efficiency ( $\mu$ ) is defined as the ratio of useful mechanical work performed to the total physiological energy expended by the body:

$$\mu = \frac{A_{mech}}{E_{phys}} \quad (10)$$

For a rested worker (at the beginning of the first wagon), it is typically assumed that:  $\mu_1 = 0,25$ .

This value corresponds to an optimal (non-fatigued) condition.

In practical labor physiology, it is accepted that during consecutive heavy tasks, muscle efficiency decreases linearly as the number of wagons increases. This relationship is described by the following general mathematical expression:

$$\mu_n = \mu_1 (1 - \alpha(n - 1)) \quad (11)$$

where  $\mu_n$  – muscle efficiency when working on the n-th wagon;  $\mu_1$  – efficiency for the first wagon ( $\mu_1 = 0,25$ );  $\alpha$  – fatigue coefficient.

For high-amplitude impact work, experimental studies estimate the fatigue coefficient within the range of 0.04–0.06. In the dissertation calculations, following a conservative approach, the value  $\alpha=0.05$  is adopted.

During the hatch opening process using a sledgehammer, the tool is lifted from shoulder level to the impact point with a certain amplitude, resulting in biomechanical strain on the worker. Considering this factor, the effective impact height in the calculations is expressed as:

$$h_{eff,s} = 2 \cdot h_y, \text{ kcal} \quad (12)$$

where  $h_y$  – the height from shoulder level to the impact zone when using the sledgehammer ( $\approx 0,5 \text{ m}$ ).

## ANALYSIS AND RESULTS

This study aimed to provide a comprehensive assessment of the worker's physiological workload during the process of opening the bottom hatches of gondola wagons positioned on an elevated railway trestle. The research incorporated empirical observation, time-motion study (chronometry), biomechanical analysis, and classification based on sanitary and hygienic standards.

The object of the study was the process of opening the bottom hatches of loaded gondola wagons. The process was examined under two conditions:

1. the worker standing at ground level, delivering upward-directed strikes to the hatch sectors and locking devices using a 6 kg metal crowbar;
2. the worker positioned on the trestle, delivering strikes at waist level using a 5 kg sledgehammer.

During the study, the work operations were divided into elements: lifting the tool, delivering the strike, repositioning, and monitoring the opening of the mechanism. The duration of each operation was measured using the chronometry method, and the total time spent opening one hatch was calculated. The number of repetitive strikes and the intensity per minute were recorded, and the movement frequency was assessed. The obtained indicators were compared with the labor intensity classification requirements according to the current Sanitary Rules and Norms (SanPiN) of the Republic of Uzbekistan and GOST 12.1.005-88.

A comparative analysis of working conditions for opening the bottom hatches during unloading from gondola wagons on an elevated track was conducted for both the existing and the proposed methods (Table 1).

The comparative analysis shows that the existing method is characterized by an awkward working posture and high biomechanical strain. In contrast, the proposed technology, based on the use of a trestle and working platforms, raises the worker's position to waist level, reducing the amplitude of strikes and energy expenditure. As a result, the time required to unload one wagon is reduced by 30–40% (Table 1).

**Table 1. Comparative Analysis Results of Working Conditions for Opening Bottom Hatches During Unloading of Gondola Railway Wagons on an Elevated Track (Existing vs. Proposed Method)**

| No. | Analytical Indicators            | Existing Method (opening hatch from below) | Proposed Method (opening hatch on trestle) |
|-----|----------------------------------|--|--|
| 1   | Worker position                  | Below wagon level, ≈2.8 m lower            | On elevated track, at waist level          |
| 2   | Working posture                  | Awkward, bent posture                      | Ergonomic, upright posture                 |
| 3   | Hatch opening method             | Manual, high-amplitude upward strikes      | Striking from working platform             |
| 4   | Tool type                        | 6 kg crowbar                               | 5 kg sledgehammer                          |
| 5   | Number of strikes per hatch      | 8  | 8  |
| 6   | Time per strike                  | 2.2 h                                      | 1.5 h                                      |
| 7   | Transition time                  | 3.15 h                                     | 3.15 h                                     |
| 8   | Total time per hatch             | 20.75 h                                    | 15.15 h                                    |
| 9   | Time per wagon                   | 4.8 minutes                                | 3.5 minutes                                |
| 10  | Time saving                      | –  | ≈30–40%                                    |
| 11  | Effective impact height          | ≈1.2 m                                     | ≈1.0 m                                     |
| 12  | Mechanical work (1 wagon)        | ≈7.9 kJ                                    | ≈5.5 kJ                                    |
| 13  | Physiological energy expenditure | ≈7.6 kcal                                  | ≈5.3 kcal                                  |
| 14  | Muscle strain                    | High (lower back, shoulders, elbows)       | Moderate                                   |
| 15  | Fatigue rate                     | Fast                                       | Slow                                       |
| 16  | Occupational safety              | Low  | High                                       |
| 17  | Labor category (SanPiN)          | Light work (with high strain)              | Light work (within standard limits)        |
| 18  | Overall assessment               | Inefficient and hazardous                  | Technically and ergonomically efficient    |

The reduction in mechanical and physiological energy expenditure decreases the worker's fatigue rate. At the same time, positioning workers farther from the unloading zone significantly improves occupational safety. Overall, the proposed technological solution is scientifically justified as an effective and safe method that improves working conditions compared to the existing practice.

## CONCLUSIONS AND SUGGESTIONS

The manual process of opening the bottom hatches of gondola wagons on an elevated track is characterized by a high physiological workload. Calculations show that opening 14 hatches on one wagon requires 112 high-amplitude strikes, approximately 4.8 minutes, and 7.6 kcal of energy. Repetitive upward strikes with a 6 kg crowbar cause significant strain on the shoulder girdle, wrist-elbow joints, and back muscles. The worker's position 2.8 m below the hatches further increases biomechanical discomfort. During consecutive servicing of multiple wagons, muscle efficiency decreases, resulting in higher physiological energy expenditure for each subsequent wagon. This leads to local fatigue, decreased movement accuracy, and reduced work productivity. Repetitive striking movements increase the risk of strain and injury in the wrist-elbow joints, disrupting the workflow and reducing occupational safety. The results indicate that this operation is ergonomically and physiologically inefficient. Therefore, the need to mechanize or ergonomically improve the hatch-opening process is scientifically justified.

The proposed technical solution for opening gondola wagon bottom hatches using an elevated trestle significantly improves working conditions. In the trestle setup, the worker operates at waist level relative to the wagon hatches, reducing biomechanical discomfort. Strikes are delivered to the sectors and locking devices with a 5 kg sledgehammer, requiring a total of 8 strikes per hatch. The time per strike in the proposed method is 1.5 seconds, shorter than in the existing method. As a result, the time to open one hatch decreases to 12 seconds, achieving up to 40% time savings. Including the transition time, the total time per hatch is 15.15 seconds, which is 30% less than the current method. Opening all 14 bottom hatches of a wagon takes 3.5 minutes, showing a significant advantage compared to the existing 4.8 minutes. Experimental results showed that the difference between calculated and actual times does not exceed 3%. The reduction in strike height in the trestle setup reduces the mechanical energy per strike to 49.5 J. Consequently, the total mechanical work and physiological energy expenditure for opening one wagon's hatches decrease by 42–43%, with physiological energy expenditure calculated at 5.3 kcal per wagon. These results scientifically confirm that opening hatches using an elevated trestle improves occupational safety, reduces physical strain, and allows the process to be classified as "light work."

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