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Analysis of Wounded Evacuation Methods from the Combat Zone

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Abstract:

The article reflects the results of the analysis of the means that affect the efficiency of the evacuation of the wounded from the area of direct combat. The authors use the Ishikawa diagram to establish the cause-and-effect relationships that affect the quality, speed and safety of existing means of evacuating the wounded. The combination of the identified factors makes it possible to determine the only effective way to evacuate the wounded and justify the evacuation trolley's design features.

Keywords:

means of evacuation of the wounded, combat engagement, Ishikawa diagram, evacuation trolley

1 Introduction

Values are essential for every person as they motivate one to act. People's values determine the values of an organization, region, or state and, accordingly, their culture. Therefore, studying people's values and creating conditions to support them is crucial for every organization, region, and state to ensure their development [1]. A human being, his or her life and health are the greatest value.

A military unit's performance of combat missions can lead to sanitary and irreversible losses. In such circumstances, it is important to promptly transport injured or wounded persons from the place of injury to medical facilities to provide the necessary

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medical care and treatment. Accordingly, the correct distribution of field hospitals along the front line is important [2].

Medical evacuation is a critical component of the overall medical support system for military formations, ensuring the timely delivery of medical care. In modern operational environments, the importance of effective medical evacuation continues to grow. Its efficiency depends on the availability of sufficient evacuation and transport units, adequate numbers of sanitary vehicles, and the proper organization and coordination of their operations. Experience in conducting medical evacuation has confirmed that each stage has its characteristics, which require different types of sanitary transport vehicles for implementation [3].

Regulatory and legal acts establish that the overall responsibility for preserving the lives of servicemen and organizing medical support for troops (forces) rests with commanders (commanders) of all levels of military command. Given that medical evacuation is an important component of medical evacuation measures in the system of medical support of military formations, the overall responsibility for the search, collection, and removal (evacuation) of the wounded from the battlefield and advanced medical evacuation lies with the commanders of military units, military units (formations) as the main actors on whose will and decisions the development of events on the battlefield depends [4].

From the standpoint of designing a rational open-loop mass service network, the casualty evacuation system reaches maximum efficiency when its capacity to process incoming requests is optimized, while minimizing parameters such as the number of pending service requests in the queue and the number of active service channels within the network. The use of the proposed method makes it possible to calculate the required number of evacuation units (conditional evacuation units) and the number of channels in them and to quickly identify those evacuation units that need (or may need during hostilities) to be reinforced by providing additional evacuation forces and means [5].

The evacuation of the wounded and killed from the area of combat operations is complicated by the threat of destruction of the evacuation team by the enemy. The adversary's deployment of unmanned aerial systems (UAS) affords the ability to monitor most routes used by Ukrainian units, particularly during casualty evacuation. A primary mission of enemy unmanned aerial vehicles (UAVs) is to engage personnel at points of concentration – for instance, when an evacuation team moves as a single group to extract a casualty and then returns along the same route. These conditions create favorable circumstances for a single enemy drone to neutralize three to five, or more, members of the evacuation team.

The following basic requirements apply to the evacuation of the wounded:

- use the method of evacuation that is safe for the rescuers and the wounded,
- avoid unnecessary movements of the casualty that may lead to additional injuries during evacuation,
- evacuate as quickly as possible to provide timely and qualified medical care.

As a rule, a wounded soldier needs urgent medical care during the battle, and they must receive this care as soon as possible because time is against them from the moment they are wounded. From that moment on, the rule of the so-called "golden hour" comes into play, which is a key concept in modern tactical medicine. There are 60 minutes between being wounded and receiving qualified medical care at a medical center. If help is provided within the first hour after the injury, the probability of saving the casualty's life will increase to 90 %. A two-hour delay in providing medical

care rapidly reduces the percentage of survivors to 10 % [6] Adhering to evacuation timelines increases the proportion of casualties saved; yet survival is also conditioned by wound severity, the timely delivery of pre-medical first aid, and the casualty's physical capacity. Fatalities during evacuation have occurred before the end of the "golden hour" (i.e., the first 60 minutes post-injury) owing to these factors. Conversely, many casualties have survived beyond the "golden hour", reflecting the courage, resilience, and unwavering confidence in victory demonstrated by Ukraine's defenders. Even when wounded, they display remarkable fortitude: the will to live and to prevail often outweighs pain, exhaustion, and fatigue.

Consequently, the time factor, which has a decisive impact on the survival of the wounded, must be carefully considered during evacuation operations. Vehicles used to evacuate the wounded directly from the battlefield to a safe inpatient medical facility play an important role in preserving precious minutes of the "golden hour". Moving, transferring and transporting the wounded from the site of direct combat operations to the point of transferring the casualties to the evacuation team with further assistance is the initial stage of evacuation from the area of direct threat. The next stage is the transportation of the wounded by the medical evacuation team from the point of transfer to a safe field camp location or the nearest medical facility for more qualified care [7]. Thus, the study of methods and means of evacuation is an urgent problem today and requires additional studies. The identification of an effective vehicle that is appropriate for evacuating the wounded from the area of direct combat will help save lives.

The procedure, algorithm of actions and team composition of evacuation units are described in many tactical medicine textbooks [8] and in articles by experts [7], medical professionals and volunteers [6]. However, the procedure for evacuation actions is determined based on the combat experience gained in areas of direct threat. By applying it, it becomes possible to consider the enemy's tactics, adapt to the area's peculiarities, and consider weather conditions and other factors. Studying and implementing the experience of performing combat missions will help plan and carry out evacuation operations more safely and effectively.

Evacuation is divided into non-medical and medical types. Non-medical evacuation of a casualty includes the movement of a casualty using a non-medical vehicle. In this case, the rescuer provides first aid and monitors the injured person's condition during transportation to the point of transfer to medical personnel.

The medical evacuation of a wounded person includes the movement of a casualty using a specialized ambulance. In this case, the wounded person is under the close supervision of medical personnel and receives all the necessary qualified medical care while moving to a safe place.

Thus, at different stages of evacuation, different methods and different evacuation vehicles are used. At the same time, we must not forget about the time for evacuation, which plays a crucial role in the life of the wounded. There are three types of evacuation of wounded persons [9]:

- urgent evacuation (within 2 hours),
- priority evacuation (within 4 hours),
- regular evacuation (within 24 hours).

2 Analysis of the Use of Means of Evacuating the Wounded from the Area of Direct Combat

Evacuation assets are employed solely on the commander's authority and for the specific window in which an operation is scheduled to rescue wounded personnel or recover the dead. When assigning an evacuation task, the commander considers:

- the unit's strength, capabilities, and available assets,
- the task's priority (evacuation of a wounded casualty or a deceased person),
- prevailing weather conditions,
- the time of day,
- terrain complexity,
- enemy dispositions along the axis and the likely threat.

Given the operational conditions, the unit commander then decides and specifies:

- the composition of the evacuation team and its team leader,
- movement routes (primary and contingency),
- coordination signals with adjacent units,
- the time allowed to complete the task.

The evacuation team's primary responsibility is the timely and safe extraction of the wounded from the immediate combat area, delivery of immediate pre-hospital care (initial first aid), and preservation of vital functions until definitive medical treatment can be provided in a secure location. We therefore proceed to outline the principal evacuation methods.

2.1 The Most Rapid Evacuation Method

The fastest way to evacuate and save precious minutes of the "golden hour" is to use modern models of armored personnel carriers (APCs) to transport the wounded from the area of a direct threat to inpatient medical facilities. Today, the units of the Security and Defense Forces of Ukraine use various models of sanitary evacuation armored vehicles, as shown in Fig. 1, most of which were provided by our partners from Europe [10], as well as volunteers.

Fig. 1 Evacuation using armored vehicles

However, the number of such vehicles is not sufficient to staff all the units in great need. As a result, the shortage is replaced by other available vehicles that will perform non-medical evacuation without providing qualified medical care. This reduces the chance to achieve the time of the "golden hour" and disappointingly reduces the

chances of saving the wounded. In addition, there is a high probability of losing the vehicle during evacuation directly from the front line due to the enemy's priority use of unmanned aerial vehicles to attack/eliminate such important targets due to rapid detection. Undertaking the rescue of one or two casualties can jeopardize the entire evacuation team, potentially leading to the loss of all personnel, the evacuation vehicle, and the evacuees themselves.

2.2 The Safest Method of Evacuation

Using the latest robotic weapons and military equipment in the combat zone changes the nature of the units' actions. The high efficiency and safety of using the latest unmanned ground vehicles (UGVs), shown in Fig. 2, is confirmed by the results on the battlefield. For military purposes, UGVs can be used to solve many tasks in which the presence of a person puts him or her in danger. UGVs are widely used to evacuate the wounded by units of the Security and Defense Forces of Ukraine.

Fig. 2 Evacuation unmanned ground vehicles on different chassis

The unmanned platform is equipped with various types of sensors and cameras that provide a 360° view of the operator at a great distance, day and night, even in adverse weather conditions which is shown in Fig. 3. They can travel over rough terrain and overcome obstacles that would be impossible for other vehicles driven by a driver.

Fig. 3 Evacuation of a wounded man with the help of an UGV

By way of illustration, we examine the principal tactical-technical capabilities of a representative unmanned platform currently fielded by Ukraine's defenders. Ukrainian manufacturers have created the Ratel-M multifunctional logistics platform [11], which is shown in Fig. 4. It can carry cargo up to 250 kg and has a battery life of 8 hours in summer and 5 hours in winter. Remote control by the operator is allowed up to 6 km. The Ratel-M platform is used to supply the military with ammunition, food,

water and other essentials on the front line. However, the main priority for the multifunctional logistics platform is to evacuate the wounded from the direct threat zone. To carry out evacuation, the logistics platform is equipped with special stretchers placed on the wheeled platform. It can also be used as a trailer, towing it behind. The payload that the UGV can handle in the towing mode allows for the evacuation of up to three wounded, provided they are sitting on the stretcher and do not exceed a total weight of 300 kg.

Fig. 4 Multifunctional logistics platforms Ratel-M and Ratel-H

Thanks to unmanned platforms, rescuing the wounded directly from the area of direct threat to the point of transferring the casualties to the evacuation team is considered the safest way to evacuate.

However, the cost of unmanned aerial vehicles for evacuation of the wounded and other logistics does not allow their use in the required quantity in units that perform combat missions every day and, unfortunately, have wounded.

2.3 The Simplest Evacuation Method

Dragging, carrying a casualty by one or more persons using equipment or hands, is considered the simplest and most common method of evacuation, as shown in Fig. 5.

The so-called "carry-on" evacuation is described in detail in tactical medicine textbooks in the sections "Evacuation of the wounded" and "Assistance in the shelling zone" [8]. Each soldier in the immediate combat zone has individual equipment (helmet, body armor, weapons, ammunition and other necessary equipment), adding another 25–35 kg to his or her weight. Accordingly, dragging and carrying the wounded becomes more difficult due to the increased weight, and the time for rescue is slowed down. If one or two soldiers were enough to move the casualty, with the increase in the weight of the combat equipment, rescuers and the casualty need to involve up to four or five soldiers for evacuation.

In the case of using evacuation equipment such as "Volokushi", no more than two evacuation team members are involved, one of whom directly pulls the casualty. At the same time, the other ensures the safety of the rescue by monitoring the tactical situation (Fig. 6). If necessary, they are ready to replace each other and provide physical assistance in dragging the wounded person over difficult terrain.

This simple method is very common among military units but dragging a wounded soldier with the help of "Volokushi" over rough terrain, in off-road conditions and difficult weather conditions, causes additional deformation, which can lead to a deterioration in the casualty's condition. The distance a soldier can be dragged is limited by

the physical capabilities of the rescuers, and the area of contact with the surface (friction area) adds to the slowdown during transportation by drag and depletes the strength of the evacuation team, which in turn affects the precious time in the fight for life.

Fig. 5 Dragging, carrying a wounded person by several persons

Fig. 6 Dragging a wounded person with the help of evacuation vehicle "*Volokushi"*

Evacuating a wounded soldier involving several soldiers is a priority task for destruction by enemy UAVs. Rescuing one wounded soldier, a combat unit may lose the entire evacuation team along with the casualty. In addition, busy hands limit the ability to use weapons for protection during extraction, and the loss of precious time decides the fate of the wounded because of the slow movement of the entire team.

2.4 The Most Practicable Evacuation Method

The wounded trolley is the best solution for the convenient and quick evacuation of the wounded from the immediate combat zone. This simple method allows a significant increase in the speed of evacuation with the wounded compared to the traditional evacuation by several people. The trolley makes it possible to take the wounded out of the danger zone by one or two soldiers and significantly speeds up the evacuation time. Carrying the wounded "on their hands" requires 4–6 soldiers and takes more time to rescue.

Many combat units use such tactical carts to help deliver ammunition, equipment, water and food to the front line and to transport the wounded on the way back. The design of the first carts was created by volunteers and introduced to the Birds of

Madyara unit of the 251st separate territorial defense battalion and other assault units of the Armed Forces of Ukraine in the summer of 2022. Very quickly, these carts gained respect among the military, so the Ukrainian manufacturer Brammer began to produce tactical carts in industrial volumes and help soldiers in the logistics of units on the front line [12]. The Brammer tactical trolley has a frame with two pneumatic wheels that are placed parallel to the axis of the loading platform, which changes the angle of inclination. The upper part of the frame is equipped with two handles, which are attached to the right and left sides of the rescuer's belt, which will relieve the load from the military during the transportation of the cargo (Fig. 7).

Fig. 7 General view of the Brammer tactical trolley and the vehicle attachment to a lifeguard

The purpose of the tactical trolley is to facilitate the evacuation of the wounded and to help deliver ammunition, food and equipment. The use of the tactical trolley in practice is shown in Fig. 8.

The disadvantage of the tactical cart is the installation of the running wheels on one axle, which makes it impossible to use it on rough terrain due to the low ground clearance, which directly affects the cart's cross-country ability and maneuverability.

Fig. 8 Application of the BRAMMER tactical trolley on the front line

The pneumatic wheels are at risk of being damaged when hitting sharp, cutting objects, and as a result, the operation of the wheelchair becomes impossible. While

moving, the serviceman cannot turn his torso to the right or left in case of a sudden threat due to the rigid attachment of the two handles of the trolley to the belt on both sides. The design of the tactical carts does not allow the rescuer to move lying down with the cart during an immediate threat from the enemy and for camouflage during movement. In the prone position, the serviceman is forced to disconnect the trolley from the belt due to the inability to crawl in different directions, pulling it along as the upper part of the frame rests on the ground on the right and left sides of the serviceman, as shown in Fig. 9.

Fig. 9 A soldier with a connected tactical cart in the supine position

But despite these shortcomings, evacuating the wounded using such carts is still the most convenient way.

3 Cause and Effect Relationships That Affect the Quality, Speed and Safety of Existing Casualty Evacuation Facilities

The purpose of the study is to determine the means of evacuating the wounded, which should be provided to units for effective work to rescue casualties from the area of direct combat and to justify the need to create an evacuation trolley, taking into account the conditions of off-road, the danger from the enemy and the capability of use by each soldier.

The variety of conditions and constraints that arise during the planning and implementation of evacuation require careful preparation and identification of appropriate ways to rescue the wounded. Based on the combat operations experience, there is a need to identify new approaches to the movement of casualties from the combat zone.

The existing problematic issues regarding effective methods and safe vehicles used during evacuation should be investigated using the Ishikawa diagram, a graphical research method; in addition, cause and effect relationships between factors should be determined [13, 14].

The Ishikawa diagram was compiled based on a survey of military personnel who were directly involved in rescuing the wounded from the contact line and expressed their opinion on the methods and means of evacuation. The respondents provided assessments of the weaknesses of the existing methods and means of evacuation, which helped to identify factors in terms of semantic and causal indicators that affect the quality, efficiency, timeliness and safety of evacuation. The Ishikawa diagram, shown schematically in Fig. 10, helps to determine the most effective way to rescue a wounded person much faster. The formation of the Ishikawa diagram begins with the

identification and collection of all factors, shortcomings and causes that in any way affect the outcome under study:

- formation of factors by semantic and causal blocks,
- prioritizing these factors within each block,
- Ignoring insignificant and unprincipled factors,
- analysis and synthesis of the results.

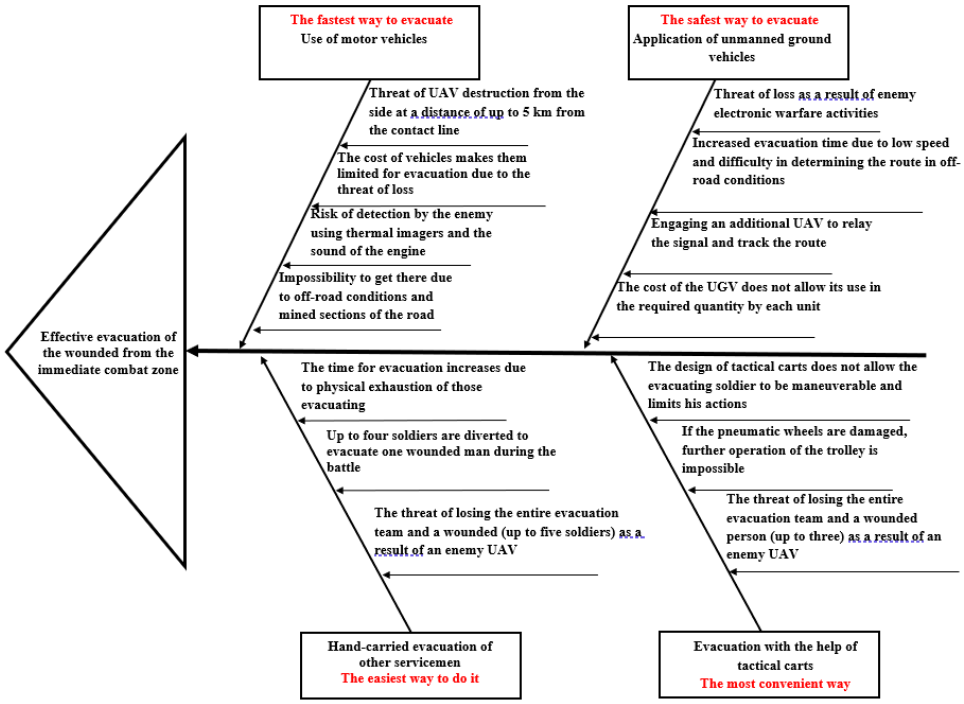

Fig. 10 Schematic overview of evacuation methods (Ishikawa diagram)

In Fig. 10, the triangle contains the goal of the graphic research method, the blocks define the main ways to realize the research goal, and the arrows depict the factors that reduce the effectiveness of the existing method. The factors that predominantly negatively impact the evacuation method are located closer to the block. The positive features of each evacuation method are indicated in red.

3.1 Limitations of the Most Rapid Evacuation Option – Employment of a Motor Vehicle

- Impassable terrain and mined road sections may prevent access,
- elevated detection risk from thermal imagers and engine noise, particularly at night,
- high cost and limited availability in units constrain use due to the risk of losing the vehicle,
- substantial vulnerability to enemy unmanned aerial vehicles (UAVs) within 5 km of the line of contact; consequently, closer approach is not feasible.

Advantage – very high evacuation speed.

3.2 Limitations of the Safest Evacuation Option – Employment of Unmanned Ground Vehicles (UGVs)

- Acquisition cost precludes fielding UGVs in the necessary quantities across all Defense Force units,
- often requires an additional unmanned aerial vehicle (UAV) for signal relay and route-tracking support,
- longer evacuation timelines owing to low transit speed and route selection in off-road conditions, including the need to identify the safest, most practicable segments,
- susceptibility to loss from enemy electronic warfare (EW).

Advantage – maximizes the safety of the evacuation team's personnel.

3.3 Limitations of the Lowest-Cost Evacuation Option – Manual Evacuation by Fellow Servicemembers

- Evacuation time increases as rescuers become physically exhausted,
- at least four servicemembers are diverted to evacuate a single casualty under fire,
- heightened risk of losing the entire team and the casualty (up to five personnel) due to prioritized targeting by enemy UAVs,
- potential for additional injury when using drag stretchers (sleds).

Advantage – universally executable by units with minimal financial outlay.

3.4 Limitations of the Most Practicable Evacuation Option – Evacuation Using Tactical Carts

- Cart design reduces the rescuer's maneuverability and constrains actions,
- damage to pneumatic tires renders the cart unusable,
- risk of losing the team and the casualty (up to three personnel) owing to enemy UAV action.

Advantage – requires few rescuers and, given the low unit cost, allows widespread cart provision across units.

4 Discussion of Results

Taking into account all factors, limitations, and causes that may influence the outcome under study, it becomes possible to determine the most effective evacuation method based on the specific conditions. The following key aspects should be considered:

- experience gained from combat operations,
- the critical time required to provide qualified medical assistance,
- the safety of the evacuation team members,
- the ability to approach as close as possible to the line of direct combat,
- the reliability of evacuation equipment design,
- ease of operation and deployment,
- the cost of evacuation equipment,
- the availability of sufficient evacuation means for the units of the Security and Defense Forces of Ukraine.

Based on the conditions and experience of combat operations, it has been determined that the use of evacuation equipment at distances closer than five kilometers from the line of contact is inappropriate, as evacuation in this zone must be conducted quietly and without detection. As a result, the wounded must be carried manually or transported by evacuation vehicles over long distances, which presents a major challenge. Accordingly, the preference in choosing a method and means of evacuation from the shelling sector is given to the one in which the number of soldiers in the evacuation group who may be targeted is small, and the speed of movement is high enough. Hand-carried casualty evacuation does not allow for rapid movement and exposes the entire evacuation team to the risk of casualties. The use of unmanned ground vehicles (UGVs) is considered a safer method; however, their cost limits the ability to procure platforms for all units that require them. One rescuer is enough to use the tactical trolley evacuation method. The speed of movement of a rescuer with a wounded person on a trolley will be much faster than carrying him or her in his or her arms or dragging him or her along the entire route, causing additional injuries.

Thus, using tactical evacuation carts to transport the wounded from the immediate combat zone is considered the most convenient way.

The advantages of choosing this method of evacuation are as follows:

- involvement of a minimum number of rescuers (one or two),
- absence of demasking factors (engine noise, large size),
- sufficient speed of movement,
- easy to operate and manage,
- affordable price to provide the required quantity to most military units,
- relatively lightweight (up to 25 kg).

The existing shortcomings faced by our military in the use of tactical carts prompted the creation of a new design of the cart, which would be used to evacuate the wounded and meet various logistical needs in the immediate combat zone.

The requirements for the new design of the evacuation trolley were created considering the shortcomings of existing models and suggestions of the military involved in the evacuation of the wounded from the area of direct combat.

To create a new design for the evacuation trolley, the following should be taken into account:

- off-road conditions and the ability to overcome difficult terrain (no axle between the wheels to increase ground clearance),
- danger from the enemy (involvement of one soldier),
- accessibility by every serviceman (lightweight cart (up to 20 kg) and easy attachment to the belt),
- protection of wheels from punctures and cuts by debris,
- the ability to quickly disconnect the trolley from the rescuer (quick reset),
- the ability to move with the connected wheelchair in the supine position (crawl),
- comfortable transportation of the wounded (avoiding additional damage during transportation),
- availability of means of securing equipment, provisions, and ammunition during transportation,
- affordable price of the trolley.

If these requirements are integrated into a single evacuation-cart design, a schematic can be produced to convey the cart's overall form and functional capabilities in

military employment. Fig. 11 depicts the cart in its deployed configuration, ready for operation.

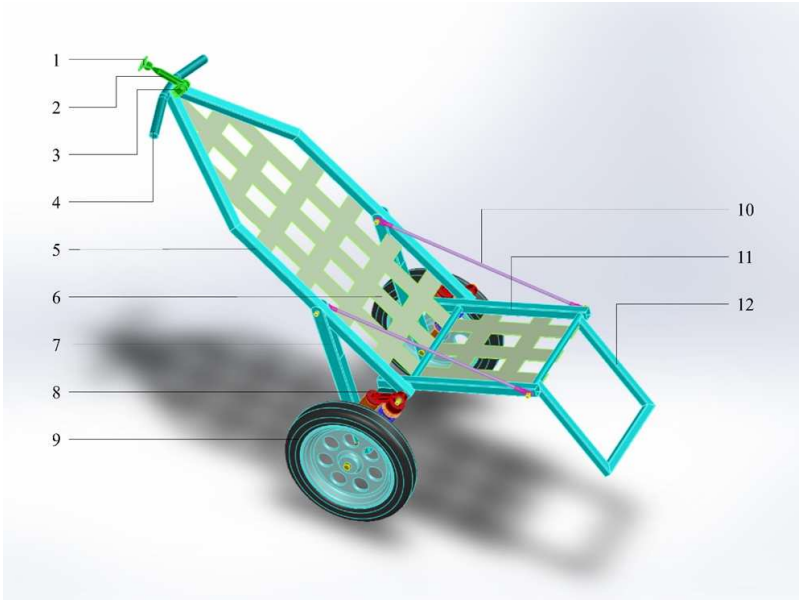

Fig. 11 Schematic of the evacuation cart: 1 – articulated, quick-release belt interface; 2 – lever terminating in a ring-shaped end; 3 – adjustment mechanism to set the lever's pitch to the rescuer's belt height (by stature); 4 – auxiliary handles allowing additional personnel to assist over difficult terrain; 5 – primary frame (chassis); 6 – webbing straps to secure the casualty and attenuate shocks during movement; 7 – independent-suspension arm; 8 – shock absorber; 9 – solid rubber (non-pneumatic) wheel; 10 – steel cable supporting the seat frame;11 – seat frame; 12 – auxiliary footrest frame

The upper assembly incorporates an articulated joint with a quick-release connection to the rescuer's belt, allowing immediate disconnection should circumstances suddenly require it.

Fielding this evacuation-cart design in serial production and issuing it to military units would enhance the effectiveness of casualty extraction from the immediate combat area and materially increase the likelihood of timely, qualified medical care. The analysis identifying the most practicable evacuation method – the "Evacuation Cart" – motivates further, more detailed research. The next phase is fabrication of a prototype and subsequent trials.

5 Conclusions

The article reflects the results of the analysis of the means that affect the efficiency of the evacuation of the wounded from the area of direct combat. With the help of the Ishikawa diagram, the author establishes the cause-and-effect relationships that affect the quality, speed and safety of existing means of evacuating the wounded. The combination of the identified factors makes it possible to determine the only effective way to evacuate the wounded and justify the evacuation trolley's design features.

Further design refinements can be determined during manufacturing and validated through combat-zone trials of the evacuation trolley. Wider fielding of these vehicles would enable units to conduct other logistics tasks – moving ammunition, rations, and critical supplies to the forward line of contact and, on the return route, evacuating wounded personnel and recovering fallen personnel ("on the shield").

It should be remembered that the most powerful weapon is a soldier. Without ensuring the reliable operation of the logistics system and all its components, this weapon will not be able to operate properly.

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