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FORMALISED FORMULATION OF ROUTING TASKS AND DISTRIBUTION OF THE AVAILABLE TRANSPORT RESOURCE FOR THE EMERGENCY EVACUATION OF SPECIAL CONTINGENTS FROM SEVERAL INSTITUTIONS AT THE SAME TIME IN CASE OF A LARGE-SCALE ACCIDENT AT THE FACILITY CHEMICAL INDUSTRY

The article formalises the tasks of routing and allocation of the available transport resource to be solved by the military command of the National Guard of Ukraine in the course of developing a rational option for emergency evacuation of a special contingent simultaneously from several penal institutions in the event of a large-scale accident at a chemical industry facility.

The article formalises the general conditions for the emergency evacuation of a special contingent, the task of concentrating the necessary vehicle resources on the border of the contamination zone, the task of routing for the emergency evacuation of a special contingent from the contamination zone and the task of distributing the special contingent between penal institutions located outside the contamination zone.

Keywords: *special contingent, penitentiary institution, man-made emergency, transport resource, contamination zone, evacuation.*

Statement of the problem. For the third year Ukraine has been suffering from a full-scale invasion by the russian federation. The military operations on the territory of the country provoke a significant number of military and man-made emergencies. Given the saturation of Ukraine's territory with potentially hazardous facilities, primarily in the chemical industry, there is a great risk of the spread of chemically hazardous substances over a large part of the country as a result of accidents and disasters at such facilities.

In article [1], the authors noted the high saturation of the territory of our country with penitentiary institutions, which are located at a relatively short distance from these facilities and may be affected by the consequences of emergencies of this nature. In this regard, there is a high risk of exposure of the staff and special contingent of penitentiary institutions to chemically hazardous products and substances.

The state, in accordance with Articles 3 and 27 of the Constitution of Ukraine [2], guarantees the preservation of the life and health of all its citizens, so a prerequisite for ensuring the safety of prisoners is their prompt evacuation from the penitentiary institutions outside the contamination zone (CZ).

To respond to such emergencies and evacuate special forces, a group of forces and means of the National Guard of Ukraine (NGU) will be created, which, according to the final and transitional provisions of the Law of Ukraine [3], is the main entity involved in evacuation measures, as it has the necessary number of trained forces and means for this purpose.

Thus, there is a multi-stage process of involving the forces and means of the National Guard of Ukraine in evacuation measures, concentrating the forces and means of the NGU on the border of the contamination zone, inside it and taking the special contingent outside it. It is worth noting that evacuation measures in the contamination zone will be entrusted to the NGU military units for convoy, extradition and protection of defendants (VCHKEOP), which are deployed in the immediate vicinity of the contamination zone. However, at the same time, the military units for convoy, extradition

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and protection of defendants perform daily planned convoying tasks, which results in uncertainty for a certain period of time about the composition of forces and means (transport resources such as the CZ truck) ready to perform tasks to evacuate the special contingent from the unit. In this regard, additional ECCCs from other regions of Ukraine may be involved.

In addition, it is necessary to pay attention to the specific features of the conditions under which the military command and control bodies of the NGU will have to develop options for evacuation actions and make prompt decisions, in particular:

– impossibility to determine the size of the contamination zone in advance and accurately;

– possible changes in the structure of transport communications within the administrative units on the territory of which the penitentiary institutions are located, as well as in the capacity of these communications for a certain period of time;

– the territorial dispersion of the CFEECs in relation to the Penitentiary institutions, which requires time to march to the respective penitentiary institutions;

– the possibility of getting into the contamination zone of penitentiary institutions with different categories and conditions of detention (juveniles, women, life prisoners, etc.), which imposes additional requirements for the evacuation process.

These aspects make it impossible to prepare evacuation plans for a certain period of time in advance. Consequently, the EMB will have to solve evacuation tasks under conditions that will be relevant for a certain period of time. It should be noted here that it will be necessary to act promptly (quickly). Thus, it becomes important to develop mathematical models to justify and develop a rational version of the plan for the emergency evacuation of a special contingent from several penitentiary institutions simultaneously in the event of a large-scale accident at a chemical industry facility.

Analysis of recent research and publications. Domestic scientists, such as V. Beliaiev [4], D. Biriukov [5], O. Tarasenko [6] and many other scholars, have been engaged in research on the evacuation of civilians in the context of man-made emergencies.

Thus, article [4] formalises the problem of finding optimal land evacuation routes for the population in the event of the spread of the affected area as a result of natural and technological emergencies. The author notes that there are no models of evacuation of the population in the event of a threat from a dynamic area of action of disaster hazards in the literature, which emphasises the relevance of the problem of finding optimal evacuation routes for the population along a road network with a dynamic topology.

The authors of the article [5] proposed the formulation of an optimization problem, which consists in determining the plan for transporting people during the evacuation of the population by road vehicles from settlements located in the affected area in the event of an emergency.

Publication [6] presents a procedure for finding the optimal evacuation route for the population along the existing network of public roads in the event of a threat of exposure to chemically hazardous substances with the possibility of implementing such a procedure using geographic information systems (if electronic maps of the area are available).

The regulatory framework of Ukraine [7, 8, 9] defines the mechanisms of involvement and the procedure for performing escort tasks of the NGU, in particular: during the performance of planned tasks under normal conditions, in case of introduction of the legal regime of martial law and in case of threat or occurrence of emergencies of various nature. An analysis of the current legal framework leads to the conclusion that it is overly declarative, in particular in cases where an operational sequence of coordinated actions is required, interaction between several law enforcement agencies is established, and the required number of forces and means to ensure effective and emergency evacuation is determined. Thus, it can be stated that currently there are normative acts that only in general terms define the procedure for evacuation of special contingent from Penitentiary institutions that got into the lCA, and that it should be implemented according to a separate plan.

The analysis of the above and some other sources showed that considerable attention is paid to the issues of routing and distribution of transport resources during the emergency evacuation of civilians in emergency situations, in particular, accidents at chemically hazardous facilities. In view of this, it is impossible to obtain recommendations on the procedure for performing the task of evacuating special forces simultaneously from several penitentiary institutions that have been

placed in the Zone of Confinement as a result of an accident at a chemical facility.

The purpose of the article is to formalise the tasks of finding the optimal (fastest) evacuation routes and allocating the available transport resources for emergency evacuation of a special contingent simultaneously from several penal institutions in the event of a large-scale accident at a chemical industry facility.

Summary of the main material. As part of the study, a formalised formulation of the tasks of routing and distribution of the available transport resource of the ECCCPE for the emergency evacuation of special forces from the zone of hostilities was carried out. In addition, during the calculations, indicators and criteria [10] were used that meet the needs for input (initial) data and characterise the evacuation measures. In view of this, the formalisation of the process of evacuation of special forces will involve solving the following tasks.

Task 1. Formalise the general conditions for the emergency evacuation of special forces.

The essence of the task is to model the boundary of the SZ, form a set of entry (exit) points to (from) the SZ, determine the need for a transport resource such as a "AZ" vehicle for the evacuation of a special contingent and its specific distribution across all penitentiary institutions within the SZ.

Let the area Θ with a critical level of concentration of a chemically hazardous substance (CHS) has a certain area S_Θ. The level (value) of concentration Q at any point of the area Θ is described by the regression model $Q = f(x, y, t)$, where x and y are the coordinates of the point, t is the current time.

The boundary of Θ area is set according to the following criterion:

$$Q(x, y) \le Q^{cr}, \qquad (1)$$

where Q^{cr} is the critical value of a chemically hazardous substance in the air.

The intersection of the transport network (highways and dirt roads) inside and outside the Θ area defines the set of $H = \{h_i\}_{i=\overline{1,m}}$ entry (exit) points to (from) this area.

The transport network within the region Θ is modelled by a weighted undirected graph $G = (P, E)$, where $P = \{p_i\}_{i=\overline{1,n}}$ is the set containing the graph nodes (modelling road intersections), and $H \subset P$ $E = \{e_{ij}\}_{i=\overline{1,n},\, j=\overline{1,n}}$ is the set containing the graph edges. Weighting $t(e_{ij})$ of some edge e_{ij} quantifies the time $t = \dfrac{l_{ij}}{v_{ij}}$ of movement along the corresponding road section.

Several penitentiary institutions, modelled by the set $\hat{U} = \{\hat{u}_j\}_{j=\overline{1,p_1}}$, are simultaneously inside the region Θ. In each $\hat{u}_j$, which differ in the contingent of detainees ($r_{\hat{u}_j} = \overline{1,3}$; 1 – juveniles; 2 – women; 3 – men), $N_{\hat{u}_j}$ persons of the special contingent serve their sentences respectively. Outside the area Θ there are penitentiary institutions modelled by the set $\check{U} = \{\check{u}_j\}_{j=\overline{1,p_2}}$, and $p_2 >> p_1$. Each of them at a certain moment of time t is characterised by the volume $\chi_{\check{u}_j}$ of the special contingent that can be additionally accommodated in this penitentiary institutions, and $\sum_j \chi_{\check{u}_j} > \sum_j N_{\hat{u}_j}$.

Military units for convoying, extraditing and guarding defendants are geographically deployed outside the region Θ and are modelled by a set of $V = \{v_i\}_{i=\overline{1,k}}$. Each v_i at a certain moment of time t can allocate λ_{v_i} vehicles of the "AZ" type (not involved in the performance of planned tasks) for the transportation of defendants and convicts with an average number of seats $\bar{\xi}$ in each of them.

The need for transport resources of the NGU to evacuate the special forces from the area Θ determines a certain distribution of resources across all penitentiary institutions by the expression:

$$R_{A,\hat{U}} = A_{\hat{u}_1} \cup A_{\hat{u}_2} \cup,\ldots,\cup A_{\hat{u}_{p_1}}, \quad \left|A_{\hat{u}_j}\right|_{j=\overline{1,p_1}} > 0, \qquad (2)$$

with restrictions:

$$\bar{\xi} \cdot \left|A_{\hat{u}_j}\right| \ge N_{\hat{u}_j}, \qquad j = \overline{1, p_1}, \qquad (3)$$

$$\Delta_{\%} = \frac{\left|A_{\hat{u}_j}\right| - \frac{N_{\hat{u}_j}}{\bar{\xi}}}{\left|A_{\hat{u}_j}\right|} \cdot 100\%, \quad j = \overline{1, p_1}, \quad (4)$$

where $\left|A_{\hat{u}_j}\right|$ is the number of "AZ" vehicles to be concentrated in $\hat{u}_j$ penitentiary institutions for evacuation from the region Θ of a special contingent of $N_{\hat{u}_j}$ people;

$\Delta_{\%}$ is the percentage of the transport resource reserve set by the policy.

Task 2. Concentrate the required vehicle resource on the border of the pollution zone.

The specificity of the task is the selection of routes that will ensure the minimum time of arrival of special vehicles from the NGU military units to the border of the EZ. The totality of such routes will constitute a route plan for the concentration of the NGU's vehicle resource on the border of the EZ. This concentration will determine a certain distribution of transport resources between the entry points to the EZ.

Due to the different remoteness of the elements of the set $V = \{v_i\}_{i=\overline{1,k}}$ from the area Θ, only those v_i for which the criterion is met will be involved in the evacuation process

$$T_{v_i \to \Theta} \le T^{dir}, \quad i = \overline{1,k}, \quad (5)$$

where $T_{v_i \to \Theta}$ is an estimate of the time of movement of a convoy of vehicles of the "AZ" type from the permanent deployment point of a certain military unit v_i to the region Θ;

T^{dir} is the time set by the policy.

Thus, the basic problem of concentrating the required vehicle resource on the border of the pollution zone is written in a certain way. For all v_i find the following routes $\tilde{P}_{v_i \to h_i}$, which achieve

$$T_{v_i \to h_i} = \min_{\tilde{P}(v_i, h_i)} T_{h_i}, \quad (6)$$

where T_{h_i} is an estimate of the time to travel from a military unit v_i to some h_i entry point to the region Θ;

$\tilde{P}(v_i, h_i)$ is the set of all traffic routes from the military unit v_i to all h_i entry points on the border of the region Θ.

It should be noted here that, by virtue of expression (5), there may well be situations where condition (3) is not met. In such cases, the process of evacuation of the special forces will be carried out in conditions of lack of transport resources, which will complicate the planning and conduct of evacuation measures and affect their progress.

The total number of v_i that will participate in the evacuation, the number of λ_{v_i} vehicles of the "AZ" type allocated to each of them, and the shortest routes to the respective entry points h_i will constitute the plan for concentrating the NGU's vehicle resource on the border of the region Θ, namely:

$$PL_{conc,H} = \{\lambda_{v_i}\}_{i=\overline{1,k}} \xrightarrow[T \to \min]{} \{h_i\}_{i=\overline{1,m}}, \ \lambda_{v_i} > 0. \quad (7)$$

As a result of solving the considered basic problem, a certain distribution of the transport resource allocated from the set $V = \{v_i\}_{i=\overline{1,k}}$ of military units of the NGU CEOP is formed (determined) between the entry points from the set $H = \{h_i\}_{i=\overline{1,m}}$ located on the border of the contamination zone, according to the expression

$$R_{A,H} = A_{h_1} \cup A_{h_2} \cup, ..., \cup A_{h_m}, \ \left|A_{h_i}\right|_{i=\overline{1,m}} \ge 0, \quad (8)$$

where $\left|A_{h_i}\right|$ is the number of vehicles of the "AZ" type that will be concentrated at the h_i entry point to the Θ region;

m is the number of such points.

Task 3. Routing for the emergency evacuation of the special contingent from the contamination zone.

The essence of the task is to select an evacuation route for each penitentiary institutions that ensures the minimum evacuation time.

After the necessary transport resources are concentrated on the border of the region Θ, the question arises of the fastest possible removal (evacuation) of the entire mass of the special forces

geographically distributed in this region outside of it. Procedurally, such an operation is divided into two stages: stage 1 – concentration of the required amount of transport resources in each penitentiary institutions $\{\hat{u}_j\}_{j=\overline{1,p_1}}$ located within the region Θ; stage 2 – removal of the entire mass of the penitentiary institutions special contingent outside the region Θ.

The total time of concentration of the transport resource in the respective POCs within the Θ region will be determined (limited) by the longest time of concentration of the required resource for some $\hat{u}_j$, i.e:

$$T_{conc,\hat{U}} = \max \left\{ t_{\hat{u}_j} \right\}_{j=\overline{1,p_1}}. \quad (9)$$

Since there is a certain concentration (Q) of EDCs inside the region Θ that negatively affects the human body, and there is a certain transport network $G=(P,E)$, on which a set of paths $\tilde{P}(h_i \times \hat{u}_j)$ is defined, the following basic task arises – to find a plan for concentrating the transport resource in $\{\hat{u}_j\}_{j=\overline{1,p_1}}$ in accordance with the distribution (2), for which the total time $T_{conc,\hat{U}}$ will be minimal, that is

$$T_{conc,\hat{U}} = \max \left\{ t_{\hat{u}_j} \right\}_{j=\overline{1,p_1}} \to \min. \quad (10)$$

Taking into account the contingent of detainees, the desired plan for the concentration of transport resources is formally written in the form of the following expression:

$$PL_{conc,\hat{U}} = \left|A_{h_i}\right|_{i=\overline{1,m}} \xrightarrow[\substack{T\to\min \\ [r_{\hat{u}_j}]T\to\min}]{} \{\hat{u}_j\}_{j=\overline{1,p_1}}, \quad (11)$$

with restrictions:

$$\sum_{i=1}^{m} \left|A_{h_i}\right| = \sum_{j=1}^{p_1} \left|A_{\hat{u}_j}\right|, \quad (12)$$

$$\forall \left|A_{\hat{u}_j}\right|_{j=\overline{1,p_1}} > 0, \quad (13)$$

where $\left|A_{h_i}\right|$ and $\left|A_{\hat{u}_j}\right|$ are the amount of transport resources concentrated in the respective locations.

In order to reduce the time of exposure of prisoners chemically hazardous substances, the removal (evacuation) of the special contingent from the penitentiary institutions (from the region Θ) will be carried out by the shortest route. Thus, the following basic task arises for each $\hat{u}_j \in \hat{U}$ to find such routes $\tilde{P}_{\hat{u}_j \to h_i}$, that achieve

$$T_{\hat{u}_j \to h_i} = \min_{\tilde{P}(\hat{u}_j, h_i)} T_{h_i}, \quad (14)$$

where T_{h_i} is an estimate of the time required to travel from $\hat{u}_j$ penitentiary institutions to some h_i exit point from the Θ region;

$\tilde{P}(\hat{u}_j, h_i)$ is the set of all traffic routes from $\hat{u}_j$ penitentiary institutions to all h_i exit points from the Θ area.

As a rule, it is necessary to plan (allocate) such a volume of transport resources that the evacuation of the special contingent from each $\hat{u}_j$ penitentiary institutions is carried out in one flight. If condition (3) is not met for some $\hat{u}_j$ penitentiary institutions, its special contingent will be evacuated in groups of $\bar{\xi} \cdot \left|A_{\hat{u}_j}\right|$ persons in a certain number of flights, which is determined by the following expression:

$$\rho_{\hat{u}_j} = \left\lceil \frac{N_{\hat{u}_j}}{\bar{\xi} \cdot \left|A_{\hat{u}_j}\right|} \right\rceil. \quad (15)$$

Each flight will take place within $2T_{\hat{u}_j \to h_i}$ units of time (actually $T_{\hat{u}_j \to h_i}$ units of time for the removal of the special contingent outside the region Θ, and the same time for the return to $\hat{u}_j$ penitentiary institutions for the next group of prisoners). Taking into account the limitation that the speed v_{ij} of convoys in the region Θ during evacuation will remain constant, it becomes clear that it will take time equal to

$$\overline{T}_{\hat{u}_j} = 2T_{\hat{u}_j \to h_i} \cdot \rho_{\hat{u}_j} - T_{\hat{u}_j \to h_i}. \quad (16)$$

The plan to withdraw the special forces from the region Θ will take shape

$$PL_{wd,H} = \{N_{\hat{u}_j}\}_{j=\overline{1,p_1}} \xrightarrow[T\to\min]{} \{h_i\}_{i=\overline{1,m}}. \quad (17)$$

The implementation of the mentioned plan will result in a certain distribution of the special contingent of all Penitentiary institutions by h_i exit points from the area Θ in the following form:

$$R_{N,H} = N_{h_1} \cup N_{h_2} \cup,...,\cup N_{h_m}, \ \left|N_{h_i}\right|_{i=\overline{1,m}} \geq 0, \quad (18)$$

for restrictions:

$$\sum_{j=1}^{p_1} N_{\hat{u}_j} = \sum_{i=1}^{m} \left|N_{h_i}\right|, \quad (19)$$

where $\left|N_{h_i}\right|$ is the number of prisoners being transported (evacuated) from the region Θ through h_i exit point from this region.

Task 4. Distribute the special contingent between penal institutions located outside the contamination zone.

The problem is reduced to solving the classical Monge-Kontarovich transport problem [11], which will determine the distribution of prisoners to penitentiary institutions located outside the SZ.

Having received the distribution (18) of the special contingent by exit points from the region Θ, the question arises of its distribution among penitentiary institutions located outside this region, with further delivery of the special contingent to their destinations. Since the prisoners at this stage are out of reach of chemically hazardous substances, it is advisable to carry out their further evacuation according to a certain option that will ensure the lowest total expenditure of public funds. This leads to the following task. For the entire population of special forces evacuated from the region Θ and distributed to h_i exit points from this region, find a plan of transportation to $\{\check{u}_j\}_{j=\overline{1,p_2}}$ penitentiary institutions that will satisfy the objective function:

$$F(x) = \sum_{i=1}^{m}\sum_{j=1}^{p_2} c_{ij} \cdot x_{ij} \to \min, \quad (20)$$

with restrictions:

$$\sum_{j=1}^{p_2} x_{ij} = \left|N_{h_i}\right|, i = 1,...,m, \quad (21)$$

$$\sum_{i=1}^{m} x_{ij} = \chi_{\check{u}_j}, \ j = 1,...,p_2, \ x_{ij} \geq 0, \quad (22)$$

$$\sum_{i=1}^{m} \left|N_{h_i}\right| = \sum_{j=1}^{p_2} \chi_{\check{u}_j}, \quad (23)$$

where c_{ij} is the transport costs (tariff) for the transportation of one prisoner by a certain type of transport from the *i*-th point of departure (exit point from the oblast Θ) to the *j*-th destination (penitentiary institutions outside the oblast Θ);

x_{ij} is the number of prisoners transferred from the *i*-th point of departure (exit point from the region Θ) to the *j*-th destination (penitentiary institutions outside the region Θ);

$\left|N_{h_i}\right|$ is the number of prisoners being transported (evacuated) from the region Θ through h_i exit point from this region.

Task (20)–(23) is a classical transport problem [11], which is an optimisation problem. Based on the results of its solution, the expedient distribution of prisoners to penitentiary institutions located outside the region Θ is determined (obtained) by the expression:

$$R_{N,\check{U}} = N_{\check{u}_1} \cup N_{\check{u}_2} \cup,...,\cup N_{\check{u}_j}, \ \left|N_{\check{u}_j}\right|_{j=\overline{1,p_2}} \geq 0, \quad (24)$$

where $\left|N_{\check{u}_j}\right|$ is the number of special forces planned to be relocated to $\check{u}_j$ penitentiary institutions located outside Θ.

The desired plan for the delivery of prisoners to the relevant (designated) penitentiary institutions will be formally written in the form of the following expression:

$$PL_{del,\check{U}} = \left|N_{h_i}\right|_{i=\overline{1,m}} \xrightarrow[W\to\min]{} \{\check{u}_j\}_{j=\overline{1,p_2}}, \quad (25)$$

where W is the total expenditure of state funds on the delivery of prisoners to their designated penitentiary institutions.

Therefore, the set of plans represented by expressions (7), (11), (17), (25) will constitute the content of the general plan for the evacuation of the penitentiary institutions special contingent from the contamination zone Θ , which in formal form will look like this:

$$PL_{evac} = \left(PL_{conc,H}; PL_{conc,\hat{U}}; PL_{wd,H}; PL_{\partial el,\check{U}} \right). \quad (26)$$

Based on the results of solving the above tasks, the officials of the NGU's MDU draw up a rational (expedient) version of the plan for the evacuation of the special forces.

Conclusions

The formalisation of the tasks of evacuating special forces from penitentiary institutions allows the military command and control bodies of the National Guard of Ukraine to determine, in the course of planning activities the optimal (fastest) evacuation routes, the boundaries and perimeter of the contamination zone, the set of entry (exit) points to (from) the contamination zone, the need for transport resources for the evacuation of the special contingent and its rational distribution between the entry points to the contamination zone, all penal institutions within the zone, the exit points from the contamination zone, and then between penal institutions located outside the contamination zone.

The proposed approach makes it possible to obtain a general plan for the evacuation of the special contingent of penitentiary institutions from the contamination zone in a formalised form in the conditions of limited time for decision-making.

Areas for further research should include the development of a methodology for developenitentiary institutionsng an evacuation plan for special contingent from several penal institutions that have fallen into a chemical contamination zone with a non-stationary transport network.

References

1. Kosiak O. H., Batsamut V. M. (2020). *Problemni pytannia evakuatsii spetskontynhentu iz ustanov vykonannia pokaran, shcho opynylys u zoni zarazhennia unaslidok masshtabnoi avarii na obiekti khimichnoi promyslovosti* [The problematic issues of evacuation of the special continent from penal institutions that found themselves in the zone of infection as a result of a large-scale accident at a chemical industry facility]. *Chest i zakon*, no. 2, pp. 52–60 [in Ukrainian].

2. *Konstytutsiia Ukrainy* [Constitution of Ukraine]. (1996, June 28). Retrieved from: https://surl.li/oixrqp (accessed 23 January 2025) [in Ukrainian].

3. *Zakon Ukrainy "Pro Natsionalnu hvardiiu Ukrainy" № 876-VII* [Law of Ukraine about the National Guard activity № 876-VII]. (2014, March 13). Retrieved from: https://surl.li/mzyjbr (accessed 23 January 2025) [in Ukrainian].

4. Bieliaiev V. Yu. (2010). *Shliakhy pidvyshchennia efektyvnosti nazemnoi evakuatsii naselennia pry nadzvychainykh sytuatsiiakh* [Ways to improve the efficiency of ground evacuation of the population in emergency situations]. *Problemy nadzvychainykh sytuatsii*, no. 12, pp. 37–43 [in Ukrainian].

5. Biriukov D. S., Zaslavskyi V. A., Sidliarenko A. I. (2012). *Krytychna infrastruktura v umovakh nadzvychainykh sytuatsii: na prykladi merezhi avtomobilnykh dorih* [Critical infrastructure in emergency situations: an example of a network of roads]. *Zbirnyk naukovykh prats.* Khariv : NTU KhPI, vol. 62, pp. 3–7 [in Ukrainian].

6. Tarasenko O. A., Bieliaiev V. Yu., Turkin I. B. (2011). *Znakhodzhennia optymalnykh marshrutiv evakuatsii naselennia po isnuiuchii merezhi avtoshliakhiv* [Finding optimal routes of population evacuation along the existing network of roads]. *Problemy nadzvychainykh sytuatsii*, no. 13, pp. 39–46 [in Ukrainian].

7. *Nakaz Ministerstva vnutrishnikh sprav "Pro zatverdzhennia Polozhennia z orhanizatsii z konvoiuvannia viiskovymy chastynamy (pidrozdilamy) Natsionalnoi hvardii Ukrainy" № 1090* [Order of the Ministry of Internal Affairs "On the approval of the Position on the organization of convoys of military units (subdivisions) of the National Guard of Ukraine" activity no. 1090]. (2019, December 24). Retrieved from: https://surl.li/wbwhpu (accessed 23 January 2025) [in Ukrainian].

8. *Postanova Kabinetu Ministriv Ukrainy "Pro zatverdzhennia Poriadku provedennia oboviazkovoi evakuatsii okremykh katehorii naselennia v razi vvedennia pravovoho rezhymu voiennoho stanu" № 934* [Resolution of the Cabinet of Ministers of Ukraine "On the approval of the Procedure for the mandatory evacuation of certain categories of the population in the event of the

introduction of a legal regime of martial law" activity no. 934]. (2018, November 7). Retrieved from: https://surl.li/zhtgpz (accessed 23 January 2025) [in Ukrainian].

9. *Postanova Kabinetu Ministriv Ukrainy "Pro zatverdzhennia Poriadku provedennia evakuatsii u razi zahrozy vynyknennia abo vynyknennia nadzvychainykh sytuatsii" № 84* [Resolution of the Cabinet of Ministers of Ukraine "On approval of the Procedure for evacuation in case of threat or occurrence of emergency situations" activity no. 841]. (2013, October 30). Retrieved from: https://surl.li/djlwwp (accessed 23 January 2025) [in Ukrainian].

10. Batsamut V. M., Kosiak O. H. (2022). *Sukupnist pokaznykiv ta kryteriiv otsiniuvannia riznykh variantiv planu ekstrenoi ta uperedzhuvalnoi evakuatsii spetskontynhentu z kilkokh ustanov vykonannia pokaran pry vynyknenni avarii na obiekti khimichnoi promyslovosti* [A set of indicators and criteria for evaluating various options for the emergency and preventive evacuation plan of the special continent from several penal institutions in the event of an accident at a chemical industry facility.] *Chest i zakon*, no. 4, pp. 45–54 [in Ukrainian].

11. Nakonechnyi S. I., Savina S. S. (2003). *Matematychne prohramuvannia* [Mathematical Programming]. Kyiv : KNEU [in Ukrainian].

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ФОРМАЛІЗОВАНА ПОСТАНОВКА ЗАДАЧ МАРШРУТИЗАЦІЇ ТА РОЗПОДІЛУ НАЯВНОГО ТРАНСПОРТНОГО РЕСУРСУ ДЛЯ ПРОВЕДЕННЯ ЕКСТРЕНОЇ ЕВАКУАЦІЇ СПЕЦКОНТИНГЕНТУ ОДНОЧАСНО З КІЛЬКОХ УСТАНОВ ВИКОНАННЯ ПОКАРАНЬ У РАЗІ ВИНИКНЕННЯ МАСШТАБНОЇ АВАРІЇ НА ОБ'ЄКТІ ХІМІЧНОЇ ПРОМИСЛОВОСТІ

Формалізовано задачі маршрутизації та розподілу наявних транспортних ресурсів, які розв'язуються органами військового управління Національної гвардії України у процесі розроблення раціонального варіанта екстреної евакуації спецконтингенту з багатодітних виправних колоній у разі масштабної аварії на об'єкті хімічної промисловості.

У статті формалізовано загальні умови екстреної евакуації спецконтингенту, задачу зосередження необхідних автотранспортних засобів на межі зони радіоактивного ураження, задачу маршруту екстреної евакуації спецконтингенту із зони радіоактивного ураження та задачу розподілу спецконтингенту по виправних установах, розташованих за межами зони радіоактивного ураження.

Формалізація завдань з евакуації спецконтингентів з установ виконання покарань дає можливість органам військового управління Національної гвардії України під час планування заходів визначати: оптимальні (найшвидші) шляхи евакуації, межі та периметр зони забруднення, набір пунктів входу (виходу) до (з) цієї зони, потребу в транспортних ресурсах для евакуації спецконтингенту та їх раціональний розподіл між пунктами входу в зону забруднення, по всіх установах виконання покарань у межах цієї зони, в місцях виходу із зони забруднення, а далі між установами виконання покарань, розташованих поза зоною забруднення.

Для вирішення поставленого завдання та досягнення зазначеної у статті мети застосовано комплекс наукових методів дослідження, серед яких:

– аналіз та узагальнення для вивчення законодавчої бази й відомчих нормативно-правових актів, що регламентують участь частин і з'єднань Національної гвардії України в заходах з реагування на надзвичайні ситуації техногенного та природного характеру, а також для аналізу наукових публікацій з предмета дослідження;

– алгоритм Дейкстри (на основі критерію мінімального часу) для визначення найкоротших маршрутів руху від військових частин до пунктів входу в зону забруднення, маршрутів руху в межах цієї зони, а також від пунктів виходу із зони забруднення до інших місць ув'язнення, розташованих у безпечних районах країни;

– метод подвійної переваги та метод заборонених комірок для визначення ресурсів посадки та транспортних засобів.

Запропонований підхід дає змогу в умовах обмеженого часу прийняття рішення розробити комплексний план евакуації спецконтингенту установ виконання покарань із зони радіоактивного забруднення у формалізованому порядку.

Ключові слова: *спецконтингент, установа виконання покарань, надзвичайна ситуація техногенного характеру, транспортний ресурс, зона забруднення, евакуація.*

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