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MINIMIZATION OF INTEGRAL RISK OF EMERGENCY ON THE EXAMPLE OF BLYZNYUKIVSKYI DISTRICT OF KHARKIV REGION

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Optimization of fire equipment and fire departments is perhaps one of the main problems today in the State Emergency Service of Ukraine. Given the reform of the civil protection service, the redistribution of forces and resources, there is a need to create new fire and rescue units. The choice of the place of their new deployment should be scientifically substantiated and highly efficient in the operation of forces and means of civil protection. That is why there is such a task as identifying additional fire depots, taking into account the reduction of the integrated risk of emergencies or dangerous events. At the same time, the Strategy for Reforming the Civil Protection Service envisages the introduction of a man-made and fire safety management system based on a risk-oriented approach. Therefore, the urgent task is to identify parameters that affect the magnitude of integrated risk, building models and methods of risk management, forecasting the level of risk for further development of sound recommendations for the deployment of new fire and rescue units to reduce the risk of emergency (dangerous event) territory.

The purpose of the article is to minimize the risk of emergencies (dangerous events) on the example of Blyznyukivskyi district of Kharkiv region by increasing the number of fire stations.

The paper shows the inverse relationship between the coverage ratio of the region and the time of arrival to an emergency (dangerous event). the minimization of the integral risk of emergencies (dangerous events) was realized by increasing the number of fire depots on the example of Blyzniukivskyi district of Kharkiv region. Departure areas are shown on a real map in Google Maps. Departure areas of rescue units are convex polygons, the vertices of which depend on the road network. As a result of the increase from one fire station to four, the response time to the fire will be reduced by 51%, and the corresponding emergency risk will be reduced by 72%.

Keywords: Integral Risk of Emergency, Coverage Ratio, Time of Arrival, Coverage Area, Rescue Unit, Fire Depot.

Statement of problem. In connection with the reform of the State Service of Ukraine for Emergencies and in accordance with the Strategy of its reform [1], one of the ways to solve the identified problems of the service is to determine the required number of rescue units of local and voluntary fire protection in the united territorial communities and providing methodological assistance to local governments in establishing new and reforming existing rescue units (RUs). At the same time, the Strategy envisages the introduction of a man-made and fire safety management system based on a risk-oriented approach. Therefore, the urgent task is to identify parameters that affect the magnitude of integral risk, construction of models and methods of risk management, forecasting the level of risk for further development of sound recommendations for the deployment of new RUs taking into account reduction the level of integral risk of emergency for research area.

Recent research and publication analysis. In work [2] the general function for definition and management of risk of technogenic danger is given, but the given model is calculated for risk at the enterprise and does not consider integral risk as a whole. In the United States, the assessment and management of fire risk is the agency FEMA, and the results of its activities are given in [3, 4]. However, these works do not contain information about the dependence of the magnitude of fire risk on the time of the RDP to the place of emergency. A similar conclusion can be made during the analysis of risk assessment methods in different countries of the world, given in the Global Concept of Fire Safety [5–7].

Setting article objectives. The purpose of the article is to minimize the risk of emergencies (dangerous events) on the example of Blyznyukivskyi district of Kharkiv region by increasing the number of fire stations.

Main part. In our previous work [8] as a result of the correlation-regression analysis it was found that the specified integral risk of an emergency (dangerous event) depends on such factors as N_{events} – the number of emergencies (dangerous events) recorded in the region; M_{vctims} – the number of deaths due to emergencies (dangerous events) in the region; τ_{arrive} – average time of arrival of RUs to the place of occurrence of an emergency situation (dangerous event); τ_{loc} – average time of localization of emergencies (dangerous events); τ_{liq} – average time of liquidation of emergencies (dangerous events). The main parameter that RUs should focus on is the standard time of arrival of units to the place of an emergency. The normative time of arrival of RUs to the place of call [9–10] should not exceed: on the territory of cities – 10 minutes; in settlements outside the city – 20 minutes.

In [11] it was found that the time of arrival of RUs to the place of emergency (dangerous event) depends on the coverage of the area by service areas of RUs $k_{\text{cov}er}$, which is determined by the following formula:

$$k_{\text{cover}} = \frac{S\left(\bigcup_{q=1}^{N_q} P_q\right)}{S(S_0)} \quad (1)$$

where N_q – the number of existing RUs; P_q – area of departure q-th unit; S_0 – given territory; $S(.)$ – area calculation function.

For the Kharkiv region, the following relationship was established [12] between the time of arrival to the place of call and the coverage ratio:

$$\bar{\tau}_{arrive} = -20{,}799 k_{\text{cover}} + 35{,}46 \quad (2)$$

From expression (2) it follows that with full coverage of RUs of the Kharkiv region service areas, the coverage factor is equal to one, the average time of arrival to the place of an emergency (dangerous event) will not exceed 15 minutes. This value is satisfactory, because outside the city the value of the time of the units should not exceed 20 minutes.

As an example, the coverage ratio for Blyznyukivskyi district of Kharkiv region was determined. The coverage area of the service area is equal to the area of the district 1380 km^2. The service area of the unit is equal to the sum of the service areas of all parts, taking into account their intersection. The service area of one unit will be the area of the circle with the corresponding service radius. Given the coverage of roads in rural areas, it was assumed that the speed of the bottom of the RU will be about 30 km/hour (v_{arrive}), and the time of arrival should not exceed 20 min, therefore, the service radius of one unit will be:

$$R_{service} = v_{arrive} \cdot \tau_{arrive} = 30 \cdot \frac{1}{3} = 10 \text{ km} \quad (3)$$

Calculate the area of service by one unit:

$$S_{service} = \pi \cdot R_{service}^2 = 3{,}14 \cdot 10^2 = 314 \text{ km}^2 \quad (4)$$

Having the value of the required areas, you can determine the coverage ratio of one unit in the Blyznyukivskyi district:

$$k_{\text{cover}} = \frac{314}{1380} = 0{,}2275 \quad (5)$$

From this calculation it follows that one RU covers less than 23% of the area, and the average time of arrival of the unit at the place of call will be:

$$\bar{\tau}_{прям} = -20{,}799 \cdot 0{,}2275 + 35{,}46 = 30{,}73 \text{ min.} \quad (6)$$

For one unit, the average time of arrival to the place of call exceeds the allowable value of 20 minutes, so it is necessary to increase the number of units. Calculate the coverage ratio of two RUs of Blyznyukivskyi district (Fig. 1):

$$k_{\text{cover}} = \frac{2 \cdot 314}{1380} = 0{,}4551 \quad (7)$$

From Fig. 1 we see that the unit also covers the neighboring area, so the coverage ratio should be less than 0,4551. Determine the average time of arrival

of the RUs to the place of an emergency (dangerous event):

$$\bar{\tau}_{прям} = -20{,}799 \cdot 0{,}4551 + 35{,}46 = 25{,}99 \text{ min.} \quad (8)$$

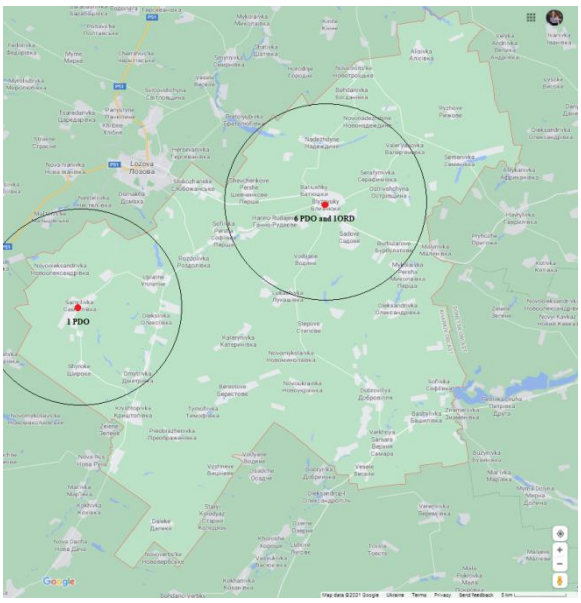

Fig. 1. Location of two fire depots in Blyzniukivskyi district of Kharkiv region

The first depot for the location of the RUs was located in the town Blyznyuky, as the level of danger there is the highest (this follows from the number of potentially dangerous objects (PDOs) and objects of increased danger (OsID)), the second depot – in the village. Samiilivka, because there is also an increased level of danger due to the presence of PDOs. Given the fact that with two RUs time of arrival still exceeds the minimum standard value of 20 minutes. Therefore, it is necessary to increase the number of depots. The third fire station should be located in the village Dobrovillya, because it is home to the maximum number of people in the united territorial community, which remained uncovered by the area of departure of the RU (Fig. 2).

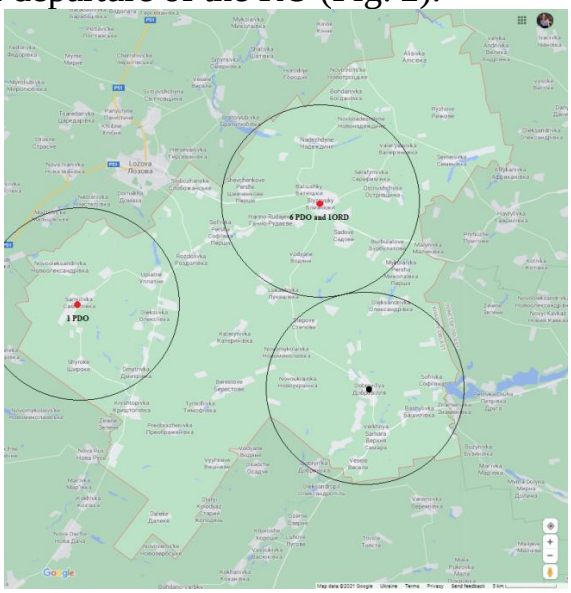

Fig. 2. Location of three fire depots in Blyzniukivskyi district of Kharkiv region

Calculate the coverage ratio and time of arrival of the unit when placing three fire depots in Blyzniukivskyi district:

$$k_{\text{cov}\,er} = \frac{3 \cdot 314}{1380} = 0{,}6826 \tag{9}$$

$$\bar{\tau}_{arrive} = -20{,}799 \cdot 0{,}6826 + 35{,}46 = 21{,}26 \text{ min.} \tag{10}$$

Since the average time of arrival of RUs to the place of call still exceeds the normative value, it would be advisable to create a fourth depot. It is most effective to place it in the village. Katerynivka (Fig. 3). Calculate the coverage ratio and time of arrival of RUs when placing four fire depots in Blyzniukivskyi district:

$$k_{\text{cov}\,er} = \frac{4 \cdot 314}{1380} = 0{,}9812; \tag{11}$$

$$\bar{\tau}_{arrive} = -20{,}799 \cdot 0{,}9812 + 35{,}46 = 15{,}05 \text{ min.} \tag{12}$$

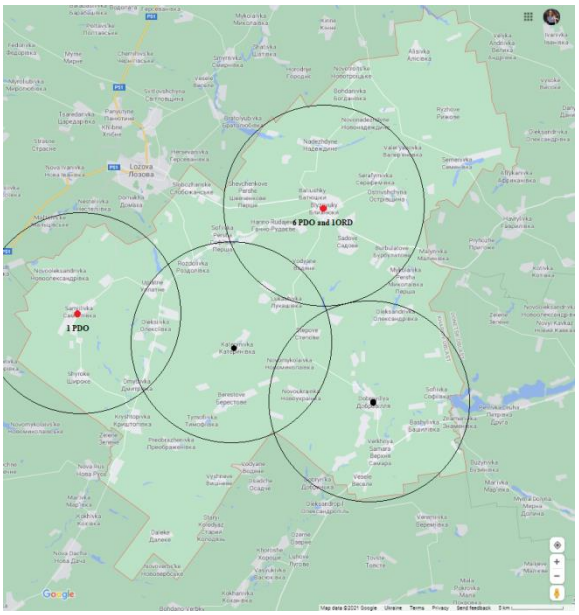

Fig. 3. Location of four fire depots in Blyzniukivskyi district of Kharkiv region

If there are four fire depots, the time of arrival will be reduced by 51%, given that in fact in this area there is one fire depot in the town Blyznyuky.

From Fig. 3 it can be seen that the service areas of fire and rescue units cover some area twice, so the actual coverage ratio will be less than the estimated. It is also necessary to take into account the following limitations of the mathematical model of emergency risk management [12] when placing these units:

1) minimum area of crossing of exit areas of RUs;

2) belonging of departure areas of RUs of given area;

3) the minimum area of crossing of the departure areas of RUs with the areas of prohibition;

4) belonging PDOs and OsID of the area of crossing of the depature areas of RUs;

5) the time of arrival of the RUs to the most remote point of the departure area, should not exceed the specified;

6) placement of RUs is carried out taking into account the limited resources.

Given the above restrictions, as well as the existing network of roads, the exit area of the PDP will be a bunch of broken lines (Fig. 4).

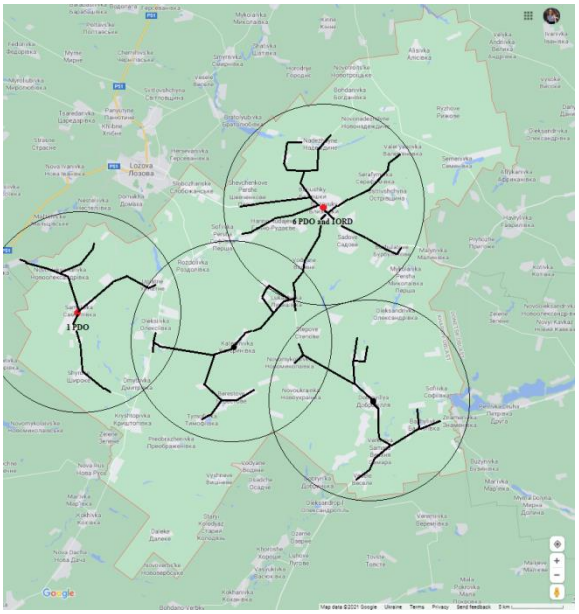

Fig. 4. Departures of fire depots according to the existing network of roads in Blyznyukivskyi district of Kharkiv region

To determine the service area, it is necessary to build a convex shell for tying broken, which allows you to get a polygon (Fig. 5), which is the actual area of departure, taking into account all the above limitations.

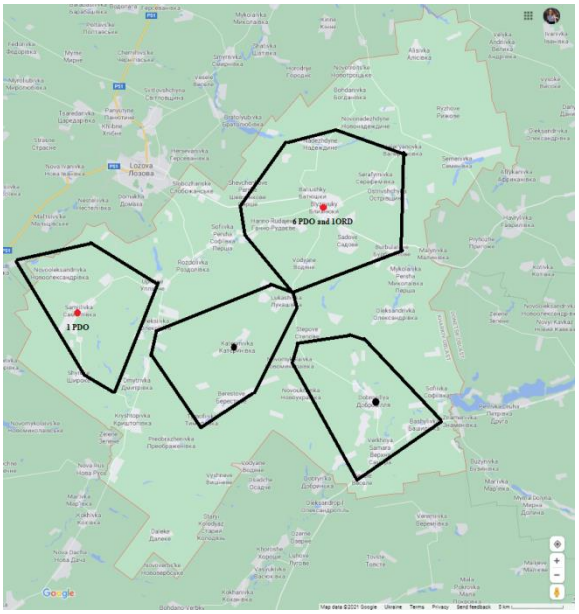

Fig. 5. Areas of departure by rescue units in Blyznyukivskyi district of Kharkiv region in the form of convex polygons

Based on Fig. 5 it can be concluded that the coverage area, as well as the coverage ratio, will decrease compared to the coverage of circles of the corresponding radius. That is why the average arrival time of the PRP to the place of occurrence of a dangerous event will exceed 15 minutes.

Since Blyzniukivskyi district is a region of Kharkiv region, which is part of the second cluster [12], we build a graph of the dependence of the integrated risk on the time of the unit to the place of call (Fig. 6).

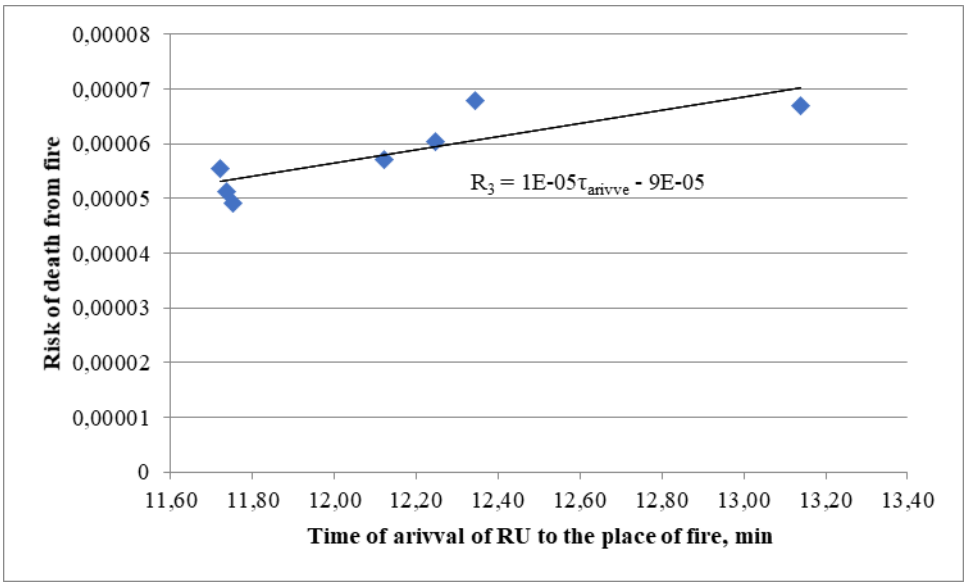

Fig. 6. Dependence of the integrated fire risk R_3 on the time of the RUs τ_{arrive}

We calculate the value of risk in Blyzniukivskyi district when placing the 1st, 2nd, 3rd and 4th fire depots:

$$R_3^1 = 10^{-5} \cdot 30{,}73 - 9 \cdot 10^{-5} = 2{,}173 \cdot 10^{-4}; \quad (13)$$

$$R_3^2 = 10^{-5} \cdot 25{,}99 - 9 \cdot 10^{-5} = 1{,}699 \cdot 10^{-4}; \quad (14)$$

$$R_3^3 = 10^{-5} \cdot 21{,}26 - 9 \cdot 10^{-5} = 1{,}226 \cdot 10^{-4}; \quad (15)$$

$$R_3^4 = 10^{-5} \cdot 15{,}05 - 9 \cdot 10^{-5} = 6{,}05 \cdot 10^{-5}. \quad (16)$$

Comparing the obtained data, we can conclude that with the increase in the number of fire depots, the integrated risk decreases. Thus, in the presence of 4 fire depots, the arrival time to the place of call is reduced by 51%, and the corresponding risk – by 72%.

Conclusion. The paper minimizes the integral risk of emergencies (dangerous events) by increasing the number of fire depots on the example of Blyzniukivskyi district of Kharkiv region. Departure areas are shown on a real map in Google Maps. Departure areas of RUs are convex polygons, the vertices of which depend on the road network. As a result of the increase from the 1st fire station to 4, the response time to the fire will be reduced by 51%, and the corresponding risk of an emergency will be reduced by 72%.

Literature

1. Про схвалення стратегії реформування системи державної служби України з надзвичайних ситуацій. Розпорядження кабінету міністрів України від 25 січня 2017 р. URL: http://zakon2.rada.gov.ua/laws/show/61-2017-%D1%80.
2. Бєгун В.В., Гречанінов В.Ф., Клименко В.П. О современных методах регулирования безопасности. *Математичні машини і системи*. 2013. № 4. С. 135-146.
3. Risk Management Practices in the Fire Service. URL: https://apps.usfa.fema.gov/publications/display?id=1071.
4. State fire death rates and relative risk. URL: https://www.usfa.fema.gov/data/statistics/fire_death_rates.html.
5. Global Concepts In Residential Fire Safety (2007): Part 1. Best Practices from England, Scotland, Sweden, and Norway, CDC, prepared by TriData Corporation.
6. Global Concepts in Residential Fire Safety (2008): Part 2. Australia, New Zealand, and Japan, CDC, prepared by TriData Corporation.
7. Global Concepts In Residential Fire Safety (2009): Part 3. Best Practices from Canada, Puerto Rico, Mexico, and Dominican Republic, CDC, prepared by TriData Corporation, 2009.
8. Kravtsiv S., Sobol O., Komyak V., Danilin O., Al'boschiy O. Mathematical Model of Management of the Integral Risk of Emergency Situation on the Example of Fires. In: Murayama Y., Velev D., Zlateva P. (eds) Information Technology in Disaster Risk Reduction. ITDRR 2019. IFIP Advances in Information and Communication Technology, vol 575. Springer, Cham. https://doi.org/10.1007/978-3-030-48939-7_16.
9. Про затвердження критеріїв утворення державних пожежно-рятувальних підрозділів (частин) оперативно-рятувальної служби цивільного захисту в адміністративно-територіальних одиницях та переліку суб'єктів господарювання, де утворюються такі підрозділи (частини). Постанова кабінету міністрів України від 27 листопада 2013 р. http://zakon0.rada.gov.ua/laws/show/874-2013-п.
10. DSTU 8767:2018 Пожежно-рятувальні частини. Вимоги до дислокації та району виїзду, комплектування пожежними автомобілями та проектування.
11. Bordiuzhenko S., Sobol O., Uvarov Y., Stelmakh O., Danilin O., Shevchenko S. Mathematical Model of Integral Fire Risk Management. In: Murayama Y., Velev D., Zlateva P. (eds) Information Technology in Disaster Risk Reduction. ITDRR 2020. IFIP Advances in Information and Communication Technology, vol 622. Springer, Cham. URL:https://doi.org/10.1007/978-3-030-81469-4_19.

МІНІМІЗАЦІЯ ІНТЕГРАЛЬНОГО РИЗИКУ НАДЗВИЧАЙНОЇ СИТУАЦІЇ НА ПРИКЛАДІ БЛИЗНЮКІВСЬКОГО РАЙОНУ ХАРКІВСЬКОЇ ОБЛАСТІ

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Оптимізація пожежної техніки та пожежних підрозділів чи не одна із головних проблем на сьогодні в Державній службі України з надзвичайних ситуацій. Враховуючи те, що проходить реформування служби цивільного захисту, перерозподіл сил і засобів, виникає необхідність створення нових пожежно-рятувальних підрозділів. Вибір місця їх нової дислокації має бути науково обґрунтованим і нести високу ефективність по експлуатації сил та засобів служби цивільного захисту. Саме тому, виникає така задача, як визначення додаткових пожежних депо з урахуванням зниження рівня інтегрального ризику надзвичайних ситуацій чи небезпечних подій. Разом з цим, Стратегія реформування державної служби цивільного захисту передбачає запровадження системи управління техногенною та пожежною безпекою на основі ризик-орієнтованого підходу. Тому актуальною задачею є виявлення параметрів, що впливають на величину інтегрального ризику, побудова моделей та методів управління даним ризиком, прогнозування рівня ризику для подальшої розробки обґрунтованих рекомендацій стосовно розміщення нових пожежно-рятувальних підрозділів з урахуванням зменшення рівня ризику надзвичайної ситуації (небезпечної події) на досліджуваній території.

Мета статті полягає у мінімізації ризику надзвичайних ситуацій (небезпечних подій) на прикладі Близнюківського району Харківської області за рахунок збільшення кількості пожежних депо.

В роботі показано обернену залежність між коефіцієнтом покриття області і часом прямування на надзвичайну ситуацію (небезпечну подію). Реалізовано мінімізацію інтегрального ризику надзвичайних ситуацій (небезпечних подій) за рахунок збільшення кількості пожежних депо на прикладі Близнюківського району Харківської області. Продемонстровано райони виїзду на реальній карті в Google Maps. Райони виїзду пожежно-рятувальних підрозділів являють собою опуклі багатокутники, вершини яких залежать від сітки доріг. В результаті збільшення з одного пожежного депо до чотирьох, час реагування на пожежу знизиться на 51 %, а відповідних ризик надзвичайної ситуації зменшиться на 72 %.

Ключові слова: інтегральний ризик надзвичайної ситуації, коефіцієнт покриття, час прямування, область покриття, пожежно-рятувальний підрозділ, пожежне депо.

МИНИМИЗАЦИЯ ИНТЕГРАЛЬНОГО РИСКА ЧРЕДЗВЫЧАЙНЫХ СИТУАЦИЙ НА ПРИМЕРЕ БЛИЗНЮКИВСКОГО РАЙОНА ХАРЬКОВСКОЙ ОБЛАСТИ

Бордюженко С.Я., Данилин О.М., Ляшевская Е.И., Уваров Ю.В.

Оптимизация пожарной техники и пожарных подразделений одна из главных проблем сегодня в Государственной службе Украины по чрезвычайным ситуациям. Учитывая, что проходит реформирование службы гражданской защиты, перераспределение сил и средств, возникает необходимость создания новых пожарно-спасательных подразделений. Выбор места их новой дислокации должен быть научно обоснован и нести высокую эффективность по эксплуатации сил и средств службы гражданской защиты. Именно поэтому возникает такая задача, как определение дополнительных пожарных депо с учетом снижения уровня интегрального риска чрезвычайных ситуаций или опасных событий. Вместе с тем, Стратегия реформирования государственной службы гражданской защиты предполагает внедрение системы управления техногенной и пожарной безопасностью на основе риск-ориентированного подхода. Поэтому актуальной задачей является выявление параметров, влияющих на величину интегрального риска, построение моделей и методов управления данным риском, прогнозирование уровня риска для дальнейшей разработки обоснованных рекомендаций по размещению новых пожарно-спасательных подразделений с учетом уменьшения уровня риска чрезвычайной ситуации (опасного события) на исследуемой территории.

Цель статьи состоит в минимизации риска чрезвычайных ситуаций (опасных происшествий) на примере Близнюковского района Харьковской области за счет увеличения количества пожарных депо.

В работе показана обратная зависимость между коэффициентом покрытия области и временем следования на чрезвычайную ситуацию (опасное событие). Реализована минимизация интегрального риска чрезвычайных ситуаций (опасных событий) за счет увеличения количества пожарных депо на примере Близнюковского района Харьковской области. Продемонстрированы районы выезда на реальной карте в Google Maps. Районы выезда пожарно-спасательных подразделений представляют выпуклые многоугольники, вершины которых зависят от сетки дорог. В результате увеличения с одного пожарного депо до четырех время реагирования на пожар снизится на 51%, а соответствующих риск чрезвычайной ситуации уменьшится на 72%.

Ключевые слова: интегральный риск чрезвычайной ситуации, коэффициент покрытия, время следования, область покрытия, пожарно-спасательное подразделение, пожарное депо.

References

1. On approval of the strategy of reforming the system of the State Emergency Service of Ukraine. (2017). Retrieved from: http://zakon2.rada.gov.ua/laws/show/61-2017-%D1%80. *[in Ukrainian]*.
2. Biehun V.V., Hrechaninov V.F., Klymenko V.P. (2013) On modern methods of safety regulation. *Matematychni mashyny i systemy*, 4, 135–146. [in Russian]
3. Risk Management Practices in the Fire Service. Retrieved from: https://apps.usfa.fema.gov/publications/display?id=1071.
4. State fire death rates and relative risk. Retrieved from: https://www.usfa.fema.gov/data/statistics/fire_death_rates.html.
5. Global Concepts In Residential Fire Safety (2007): Part 1. Best Practices from England, Scotland, Sweden, and Norway, CDC, prepared by TriData Corporation.
6. Global Concepts in Residential Fire Safety (2008): Part 2. Australia, New Zealand, and Japan, CDC, prepared by TriData Corporation.
7. Global Concepts In Residential Fire Safety (2009): Part 3. Best Practices from Canada, Puerto Rico, Mexico, and Dominican Republic, CDC, prepared by TriData Corporation, 2009.
8. Kravtsiv S., Sobol O., Komyak V., Danilin O., Al'boschiy O. (2020) Mathematical Model of Management of the Integral Risk of Emergency Situation on the Example of Fires. In: Murayama Y., Velev D., Zlateva P. (eds) Information Technology in Disaster Risk Reduction. ITDRR 2019. IFIP Advances in Information and Communication Technology, vol 575. Springer, Cham. Retrieved from: https://doi.org/10.1007/978-3-030-48939-7_16.
9. On approval of the criteria for the formation of state fire and rescue units (units) of the operational and rescue service of civil protection in administrative-territorial units and the list of business entities where such units (units) are formed. Retrieved from: http://zakon0.rada.gov.ua/laws/show/874-2013-п. [in Ukrainian].
10. DSTU 8767:2018 Fire and rescue units. Requirements for dislocation and departure area, manning with fire trucks and design. [in Ukrainian].
11. Bordiuzhenko S., Sobol O., Uvarov Y., Stelmakh O., Danilin O., Shevchenko S. (2021). Mathematical Model of Integral Fire Risk Management. In: Murayama Y., Velev D., Zlateva P. (eds) Information Technology in Disaster Risk Reduction. ITDRR 2020. IFIP Advances in Information and Communication Technology, vol 622. Springer, Cham. Retrieved from: https://doi.org/10.1007/978-3-030-81469-4_19.