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Algorithm for the use of intelligent drone ports in emergency situations in the Republic of Kazakhstan

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ABSTRACT

A structured algorithm has been developed in this study for the application of intelligent drone ports during emergency situations in the Republic of Kazakhstan. Primary considerations for the employment of drones during emergency situations in Kazakhstan include vast territorial areas, given the geography and extreme climate conditions. Initially, comprehensive performance criteria and indicators are established to cover operational performance, cost-effectiveness, safety, social and regional dimensions for the effective employment of drones during disasters/emergencies, facilitating subsequent response management. Various available drone ports were analyzed, which include universal, user-defined, and mobile stations. Following this, an analysis and classification of drones were carried out based on their functional roles in emergency management. Based on these criteria and classification, a five-stage operational algorithm was proposed. These stages are emergency detection and notification, task planning, task execution, maintenance, data collection and analysis. The integration of artificial intelligence (AI), including machine learning (ML) and computer vision, is recommended for improving automation, responsiveness, and decision-making efficiency, thereby enhancing the effective employment of drones in disaster response management. A scalable and adaptable framework was proposed to increase the overall capacity of emergency response management in Kazakhstan, thereby reducing risk and optimizing resource utilization. This research provides not only a theoretical foundation for performance assessment but also a practical roadmap for future implementation, testing, and policy development for the employment of intelligent drones in general elsewhere in the world and in particular for Kazakhstan.

Keywords: Drone port, Docking station, Unmanned aerial vehicle (UAV), Artificial intelligence, Emergency Response

1. Introduction

The employment of unmanned aerial vehicles (UAVs) and drone ports in disaster management has gained significant interest due to their potential to enhance the overall capacity for handling a broad spectrum of situations and contingencies. Various aspects of UAVs have been studied in existing studies to explore their employment in firefighting, floor monitoring and rescue operations. However, these studies are primarily restricted to the operational efficiency and performance of UAVs in the context of disaster management, without an emphasis on integrating drone port technology with modern artificial intelligence (AI) techniques.

Although the concept of autonomous drones has been studied and developed in the literature, it’s limited to take-off and landing platforms and it doesn’t incorporate the adaptability of such autonomous drones in remote and low infrastructure areas, where diverse terrain and obstacles may limit the function of autonomous drones. This is a critical gap that poses unique limitations to the employment of existing drones in Kazakhstan's diverse geographical areas, particularly in its prevailing extreme climatic conditions.

The application of existing drones in such flight envelopes requires assessment. In terms of AI and UAVs integration, the concept of flight path optimization and task automation is underdeveloped, which restricts the real-time application during actual contingencies where a life-and-death scenario is posed and a critical decision-making path is crucial for a successful handling of the contingency.

AI has been integrated to a certain extent to enhance overall efficiency and resource management in autonomous drones [1], [2]. Still, these drones cannot function in dynamic and unpredictable conditions that arise during large-scale disasters.

The economic viability of large-scale applications of autonomous drones during large-scale disasters is also not studied in the existing literature. In short, existing literature has focused on isolated aspects related to the performance of drones in emergency handling. A comprehensive framework for their large-scale autonomous employment in disaster response management is non-existent, which may account for probabilistic, social, economic, and geographical factors to incorporate conditions specific to Kazakhstan [3].

The increasing incidence of emergency situations (accidents, disasters or catastrophes) in the Republic of Kazakhstan [4], [5], both in urbanized areas and in sparsely populated and hard-to-reach areas of the country, has revealed several problematic issues, including insufficient technical equipment of special government services in the emergency zone with modern unmanned vehicles for the detection and rescue of victims, organization of cargo delivery and communications [6], [7].

The Republic of Kazakhstan is the world’s ninth-largest country, boasting a highly diverse landscape that includes vast steppes, deserts, and significant mountain ranges [8], as well as extreme climatic conditions [9]. The frequency of natural disasters, such as earthquakes, floods, wildfires, and snowstorms, emphasizes the need for an emergency response system. The key tasks of emergency response units include providing operational support for search and rescue operations, continuous monitoring of disaster areas, cargo transportation, and coordinating communication.

Considering the current level of information technology development, the most appropriate way to solve them is to use modern intelligent technical systems. The use of UAVs with various payloads in emergency zones is also one of the most optimal solutions for several tasks [10]. At the same time, attention should be paid to the systematization of flights and the intellectualization of drones to increase the effectiveness of mitigating the consequences of accidents, disasters, and catastrophes [11].

Currently, one of the key areas of scientific research in the Republic of Kazakhstan is the complete automation of the use of UAVs in an emergency zone, including the processes of control, navigation, task identification, charging (changing) batteries, changing payloads, transmitting necessary information to the server, storing and protecting drones from external influences [12].

Some of these tasks can be solved by using autonomous take-off and landing platforms for UAVs (drone ports) in which automation of processes is carried out using advanced technologies, including AI [13]. Docking mechanisms are designed for precise UAV alignment during loading and payload transfer, as described for the flow-transport mechanism [14].

According to the Oxford Insights report for 2024 [15], Kazakhstan ranks 76th out of 188 countries in the government's Readiness Index for the Introduction of AI. More recently, the Concept of AI Development for 2024-2029 was approved in the Republic of Kazakhstan [16]. Therefore, an urgent issue is to identify ways to develop and apply AI in various fields, including emergency situations in the Republic of Kazakhstan, utilizing drones and UAVs [17], [18]. Due to the relatively new technologies for creating drones and integrating AI into UAVs, approaches to utilizing drones and UAVs in emergency response in Kazakhstan have not been fully explored [19]. The purpose of this study is to develop an AI-enabled drone port algorithm that addresses emergency situations in the Republic of Kazakhstan’s diverse geography and climate.

2. Method

This study employed a multi-stage methodological approach to develop an AI-enabled algorithm for utilizing intelligent drone ports in emergency situations within the Republic of Kazakhstan [20]. First, performance criteria and indicators were defined to assess the operational, economic, probabilistic, safety, social, and region-specific effectiveness of drone ports and UAVs in emergency contexts [21]. These criteria were derived from a literature review, analysis of Kazakhstan’s geographic and climatic conditions, and current UAV operational capabilities [22].

Second, existing types of drone ports (universal, user-defined, and mobile) were classified according to their functions in emergency response [23], [24]. For each type, operational functions and measures for implementation were identified, with particular attention to AI integration for automation of navigation, control, data transmission, and maintenance processes [25].

Third, the gathered criteria, functional analysis, and AI capabilities were synthesized into a five-stage operational algorithm, as shown in Figure 1, which covers: (1) emergency detection and notification, (2) task planning, (3) task execution, (4) UAV maintenance and data collection, and (5) data analysis for subsequent task planning.

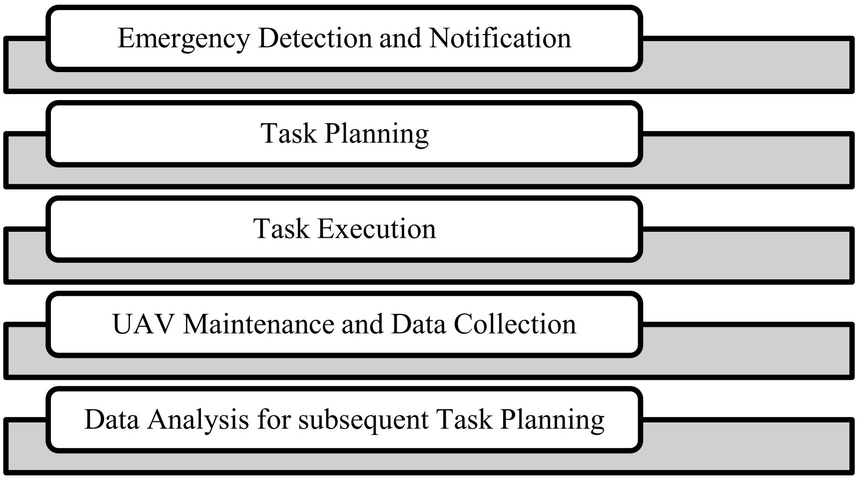

Figure 1. Five-stage operational algorithm

Finally, the proposed methodology was structured to allow comprehensive evaluation of UAV and drone port efficiency under Kazakhstan-specific conditions, providing a scalable and adaptable framework for future implementation and testing in real emergency scenarios.

3. Results and discussion

3.1. Criteria and performance indicators for the use of drones and UAVs in emergency situations in the Republic of Kazakhstan

The assessment of the effectiveness of using drone ports and their UAVs in emergency zones in Kazakhstan should be based on comprehensive criteria and indicators [26], [27], considering the specifics of the region and the purposes of their use.

Let's consider one of the options for the composition of criteria for the effectiveness of the use of drones and UAVs in Kazakhstan in an emergency zone [28]. The performance criteria and their indicators can be roughly divided into several groups below.

To consider random factors in the emergency zone in the processes of using drones and UAVs, which, among other things, include external effects on UAVs of the same type used from a particular drone port (changes in weather conditions, the appearance of obstacles in flight, interference, etc.), a probabilistic criterion can be introduced:

$$P = P\ (N_{uav}) \to max. \tag{1}$$

where P is the probability of successful completion of tasks in an emergency zone using the UAV of a specific drone port;

N_{uav} is the number of UAVs of a particular drone port performing tasks in an emergency zone.

The higher the probability of performing tasks by UAVs of the same type used from a specific drone port in an emergency zone, the higher the effectiveness of their use [29].

In the case of tasks performed by several types of UAVs of a particular drone port, provided that the number of types of UAVs $i = (\overline{1, n})$, the probability criterion will have the form:

$$P = \prod_{i=1}^{n} P\left(N_{uav_i}\right) \to max. \tag{2}$$

where N_{uav_i} is the number of type i UAVs performing tasks in an emergency zone from a specific drone port.

The higher the probability of completing the task of a type i UAV in an emergency zone, the higher the effectiveness of using a particular drone.

Minimizing the use of drone ports in an emergency zone N, involves solving problems with a minimum number of drone ports.

The criterion of economic efficiency of using drone ports can be represented as:

$$N \rightarrow min. \tag{3}$$

where N is the number of drone ports involved in performing tasks in the emergency zone.

The fewer the number of drone ports, the higher the economic efficiency.

Minimizing the use of type i UAVs in an emergency zone, which involves solving problems involving a minimum number of type *i* UAV and N_{uav_i} a specific drone port.

The criterion of economic efficiency of using type i UAVs from a specific drone port, provided that $= (\overline{1, n})$, it can be represented as:

$$N_{uav_i} = \sum_{i=1}^{n} N_{uav_i} \rightarrow min. \tag{4}$$

The fewer the number of UAVs used from a particular drone port, the higher the economic efficiency.

In addition, the criteria for the economic efficiency of a drone port can be a minimizing the cost of using drone ports in an emergency zone N_{cost}, reflecting the total cost of operating drones and UAVs, including acquisition, maintenance, repair and energy consumption (the lower the cost, the higher the efficiency), can be represented as:

$$N_{cost} \rightarrow min. \tag{5}$$

saving resources during the emergency response period through the use of drones and UAVs $N_{saving\ resources}$, this includes reducing the cost of attracting other forces and assets that perform the same tasks as UAVs, for example, the use of manned aircraft, ground-based search and rescue teams (the lower the cost of emergency response, the higher the efficiency) can be represented as:

$$N_{saving\ resources} \rightarrow min. \tag{6}$$

Duration of the cycle of using drones and UAVs in an emergency zone $T_{cycle_{ij}}$ is the time interval from the moment of receiving an emergency signal (command to complete a task) to the moment of receiving a signal (command) to complete a new task from this drone port.

The shorter the duration of the cycle of using drones and UAVs in an emergency zone, the higher the operational efficiency. This criterion can be represented as:

$$T_{cycle_{ij}} \rightarrow min. \tag{7}$$

Minimizing the cycle duration is possible provided that the drone and UAV respond promptly to an emergency and that the drone and UAV perform the task efficiently in an emergency zone:

$$T_{cycle_{ij}} = T_{resp_{ij}} + T_{compl_{ij}}. \tag{8}$$

where $T_{resp_{ij}}$ is responsiveness of drones and UAVs to emergency situations;

$T_{compl_{ij}}$ is the efficiency of performing the task by a drone and a UAV in an emergency zone.

Responsiveness of drones and UAVs to emergency situations $T_{resp_{ij}}$ is the time interval from the moment of receiving an emergency signal (a command to perform a specific task) to the start of operation of a type *i* UAV with a j payload in the emergency zone.

The criterion takes into account the preparation time of the type *i* drone and the *j* payload in the drone port for departure $t_{prep_{ij}}$ (this time is calculated for the first type *i* UAV used from a specific drone port, provided that there is a charged battery on board and the required jth payload, as well as the loading time of the first flight task; for the second and subsequent type *i* UAVs, the time is calculated taking into account charging (changing) the battery, checking (replacement) of the jth payload, removal of the received information, loading of a new flight task); UAV take-off time $t_{takeoff_{ij}}$ is the time period from the moment of completion of the drone's training at the droneport, including the UAV's launch onto the droneport's takeoff platform, turning on the engines, and taking off the drone, to the moment of reaching a safe altitude; flight time to the emergency zone

$t_{flight_{ij}}$ (includes the period from the moment the drone reaches a safe altitude, the flight time of the UAV to the emergency zone, until it is ready to start performing a specific task after the drone enters the emergency zone). The shorter the emergency response time, the shorter the duration of the drone and UAV application cycle. This criterion can be represented as:

$$T_{resp_{ij}} \to min. \tag{9}$$

Provided that the response time is expressed in terms of the amount of time elapsed from the moment of receiving an emergency signal (a command to complete a specific task) to the moment a type i UAV with a j payload is ready for operation in the emergency zone, it can be represented as:

$$T_{resp_{ij}} = t_{prep_{ij}} + t_{takeoff_{ij}} + t_{flight_{ij}}. \tag{10}$$

Efficiency of the task by drone and UAV in an emergency zone $T_{compl_{ij}}$ is the time spent on performing a specific task of a type i UAV with a j payload, for example, monitoring an emergency zone (disaster, accident or disaster), searching for missing people, relaying communications, delivering goods, etc.

The criterion takes into account: the time to complete the task of a type i UAV with a j-th payload in an emergency zone $t_{task_{ij}}$ (the time period from the start of a specific task by a drone in an emergency zone to the moment of its completion); the flight time of a type i UAV with a j payload to the drone port after completing the task $t_{return_{ij}}$; landing time of the type i UAV with the j-th payload $t_{landing_{ij}}$, this includes the period from the moment of hovering at a safe height above the droneport, touching its landing platform, the moment the drone lands on the droneport landing platform and turning off the engines until the UAV is captured and moved to the droneport maintenance bay to prepare for re-departure.

The less time is spent on the overall task, the shorter the duration of the cycle of using drones and UAVs. This criterion can be represented as:

$$T_{compl_{ij}} \to min. \tag{11}$$

Provided that a drone and a UAV in an emergency zone carry out the efficiency of the task. $T_{compl_{ij}}$ is expressed in terms of the amount of time spent from the beginning of a specific task by a type i UAV with a j payload in an emergency zone to the moment of its completion:

$$T_{compl_{ij}} = t_{task_{ij}} + t_{return_{ij}} + t_{landing_{ij}}. \tag{12}$$

Substituting (10) and (12) into (8), we obtain that the cycle duration of the drone and UAV applications in the emergency zone is:

$$T_{cycle_{ij}} = t_{prep_{ij}} + t_{takeoff_{ij}} + t_{flight_{ij}} + t_{task_{ij}} + t_{return_{ij}} + t_{landing_{ij}}. \tag{8 a}$$

Completeness of emergency zone coverage when using UAVs from a specific drone port $S_{coverage}$ (in percentages). First of all, the geographical coverage of the territory is taken into account. The greater the coverage of the emergency zone, the higher the efficiency. That is, it is optimal that:

$$S_{coverage} \to max. \tag{13}$$

Completeness of emergency zone coverage when using UAVs from a specific drone port $S_{coverage}$ is expressed as the ratio of the area of the surveyed territory of the emergency zone $S_{surveyed\ territory}$ using UAVs operating from a specific drone port to the total area of the emergency zone $S_{disaster\ area}$:

$$S_{coverage} = \frac{S_{surveyed\ territory}}{S_{disaster\ area}} \cdot 100\%. \tag{14}$$

The accuracy of the UAV task from a specific drone port $N_{accuracy}$, it allows you to perform tasks in an emergency zone in the shortest possible time.

For example, the accuracy of determining the coordinates of objects in an emergency zone, the accuracy of estimating the scale of the disaster, the accuracy of cargo delivery, etc. (the greater the accuracy, the higher the efficiency). The optimal value of this criterion can be represented as:

$$N_{accuracy} \to max. \tag{15}$$

The scalability of drone ports is expressed in the ability to quickly change the number of drones and UAVs involved, depending on the scale of the emergency: the less time spent on scaling $T_{scaling}$, the higher the efficiency:

$$T_{scaling} \to min. \tag{16}$$

The criteria for the safety and reliability of the drone port and UAV systems can be minimizing accidents and incidents during UAV flights from a specific drone port in an emergency zone $N_{drone\ accident}$ (the fewer the number of accidents and incidents, the higher the safety), which can be represented as:

$$N_{drone\ accident} \to min. \tag{17}$$

Reliability of the drone transport system and UAVs in the emergency zone $T_{uninterrupted\ operation}$, expressed by the ability of uninterrupted operation of drones and UAVs for a given period of time (the longer the period of uninterrupted operation, the higher the reliability), as a criterion can be represented as:

$$T_{uninterrupted\ operation} \to max. \tag{18}$$

Protection of the drone port system and UAVs from cyber-attacks in the emergency zone $T_{cyber\ defense}$, reflecting the time of stable operation of the drone port system and UAVs under the influence of cyber-attacks and unauthorized access attempts (the longer the period of protection from cyber threats, the higher the security), as a criterion can be represented as:

$$T_{cyber\ defense} \to max. \tag{19}$$

The criteria for the social effectiveness of the use of the drone port system and UAVs can be the following:

– reduction of population losses in emergency zones N_{victim}, reflecting the number of lives saved and the reduction in the number of victims due to the use of drones and UAVs (the fewer victims, the higher the social efficiency), as a criterion can be represented as:

$$N_{victim} \to min; \tag{20}$$

– acceleration of the elimination process in emergency zones, expressing a reduction in the time required to eliminate the consequences of an emergency $T_{disaster\ relief}$, due to the use of drones and UAVs (the less time for the aftermath process, the higher the social efficiency), as a criterion, it can be represented as:

$$T_{disaster\ relief} \to min; \tag{21}$$

– socialization of drone ports in emergency zones $N_{private\ facility}$, reflecting the number of drones used in an emergency zone located on the territory of private facilities (the higher the willingness of the population to deploy drones on private territories, the higher the social efficiency), as a criterion can be represented as:

$$N_{private\ facility} \to max; \tag{22}$$

– increasing the level of public confidence in emergency zones $N_{level\ of\ trust}$, expressed through the degree of public confidence in the effectiveness of the rescue services of the Republic of Kazakhstan, through the use of modern technologies (the higher the degree of trust, the higher the social efficiency), as a criterion can be represented as:

$$N_{level\ of\ trust} \to max. \tag{23}$$

The specific to the Republic of Kazakhstan criteria for a drone port and UAV system can be the following:

– adaptation to local climatic conditions, $T_{climatic\ conditions}$, the reflective ability of drones and UAVs to work effectively in the extreme climatic conditions of Kazakhstan, for example, high and low temperatures, strong winds, dust storms, snowfall, etc. (the longer the application time of the drone and UAV system in the current climatic conditions, the higher the efficiency), as a criterion can be represented as:

$$T_{climatic\ conditions} \to max; \tag{24}$$

– compliance with the geographical features of the Republic of Kazakhstan $T_{geographical\ features}$, expressing the ability of the droneport system and UAVs to work effectively in conditions of long distances, limited infrastructure, difficult terrain, etc. (the longer the application time of the droneport system and UAVs in the current geographical conditions, the higher the efficiency), as a criterion can be represented as:

$$T_{geographical\ features} \rightarrow max; \tag{25}$$

– share of the use of AI technologies, computer vision, and other advanced technologies in drone transport and UAV systems in the emergency zone $N_{new\ technologies}$, It is determined by the ratio of automation of control processes, navigation, search and identification of objects in an emergency zone (the greater the share of AI technologies, computer vision, and other advanced technologies, the higher the efficiency), as a criterion can be represented as:

$$N_{new\ technologies} \rightarrow max. \tag{26}$$

The proposed version of the performance criteria and their indicators is formulated in a general form and summarized in Table 1.

Table 1. Summary of proposed criteria and performance indicators for drones and UAVs in the emergency zone in the Republic of Kazakhstan

Criteria Group	Short Description	The value of the criterion (indicator)
Criteria of probabilistic efficiency	probability of successful completion of tasks in an emergency zone using the UAV of a specific drone port	$P = P\ (N_{uav}) \rightarrow max$ (number of completed UAV tasks)
	probability of successful completion of tasks in an emergency zone using a type I UAV of a specific drone port	$P = \prod_{i=1}^{n} P\left(N_{{uav_i}_i}\right) \rightarrow max$ (number of completed Type I UAV tasks)
Criteria of economic efficiency	minimizing the use of drone ports in an emergency zone	$N \rightarrow min$ (number of drone ports used)
	minimizing the use of type I UAVs in an emergency zone	$N_{uav} = \sum_{i=1}^{n} N_{uav_i} \rightarrow min$ (number of type I UAVs performing tasks)
	minimizing the cost of using drone ports in an emergency zone	$N_{cost} \rightarrow min$ (amount of funds spent on drone ports)
	saving resources during the emergency response period through the use of drone ports and UAVs	$N_{saving\ resources} \rightarrow min$ (the amount of expenditure on other forces and means)
Operational efficiency criteria	minimizing the duration of the cycle of using drones and UAVs in an emergency zone	$T_{cycle_{ij}} \rightarrow min$ (the time of task execution from the moment of the signal (command) to the moment of receiving a new signal)
	completeness of emergency zone coverage when using UAVs from a specific drone port	$S_{coverage} \rightarrow max$ (percentage of the emergency area serviced by UAVs)
	the accuracy of the UAV task from a specific drone port	$N_{accuracy} \rightarrow max$ (number of successful UAV sorties)
	scalability of drone port application	$T_{scaling} \rightarrow min$ (time spent using other drone ports)
Safety and reliability criteria	minimizing accidents and incidents involving UAVs from a specific drone port in an emergency zone	$N_{drone\ accident} \rightarrow min$ (number of accidents and incidents involving UAVs)
	reliability of the drone transport system and UAVs in the emergency zone	$T_{uninterrupted\ operation} \rightarrow max$ (uptime of the drone port)

Criteria Group	Short Description	The value of the criterion (indicator)
Criteria of social effectiveness	protection of the drone port system and UAVs from cyber-attacks in the emergency zone	$T_{cyber\ defense} \rightarrow max$ (time of protected operation of the drone port)
	reduction of population losses in emergency zones	$N_{victim} \rightarrow min$ (number of victims)
	speeding up the aftermath process in emergency zones	$T_{disaster\ relief} \rightarrow min$ (time to eliminate the consequences)
	socialization of drone ports in emergency zones	$N_{private\ facility} \rightarrow max$ (number of drone ports located at private facilities)
	increasing the level of public confidence in emergency zones	$N_{level\ of\ trust} \rightarrow max$ (number of positive reviews from victims)
Criteria specific to the Republic of Kazakhstan	adaptation to local climatic conditions	$T_{climatic\ conditions} \rightarrow max$ (time of application of the system in the current climate)
	accounting for geographical features	$T_{geographical\ features} \rightarrow max$ (time of application of the system in a specific area)
	share of AI and computer vision technologies in drone port and UAV systems	$N_{new\ technologies} \rightarrow max$ (percentage of task automation)

At the same time, an accurate mathematical expression of these criteria is possible when identifying many factors that affect a specific criterion for the effectiveness of using drones and UAVs in an emergency zone in Kazakhstan, and is the subject of further research [30], [31].

A comprehensive performance assessment should consider all of these criteria. The weighting factors for each indicator can be determined depending on the priorities and purposes of using drones and UAVs in a particular emergency [32], [33].

One of the key criteria and indicators in our study is the percentage of AI technology, computer vision, and other advanced technologies used in drone ports and UAV systems, expressed as the ratio of automated tasks to their total number in percent.

The list of tasks performed by UAVs in an emergency zone is reflected in [34], [35], and [36]. The tasks themselves are performed using various techniques.

For example, the tasks of extinguishing forest fires are presented in the studies [37], [38], [39], and [40] the tasks of relaying communication signals [41], [42] and [43], the tasks of delivering goods in an emergency zone can be performed using the techniques [44], [45], and [46].

It should be noted that the drone ports themselves in the emergency zone for various types of UAVs and their aerodynamic layouts can be classified as presented in [47] and [48]:

- universal drone ports designed for all stages of operation with UAVs from maintenance and charging to round-the-clock flight operations using, among other things, an integrated weather station, an alarm system and protection against unauthorized entry, video surveillance systems and control of the drone landing site;
- user terminals that are responsible for receiving and dispatching goods, but do not service drones;
- mobile stations that can be installed on cars and other vehicles from which drones are launched to perform monitoring and aerial photography tasks, except for cargo delivery tasks.

The presented classification of drone ports (universal, user terminals, mobile stations) makes it possible to more efficiently organize the operation of UAVs in an emergency zone, since each type of drone performs its own specific functions and tasks, providing a comprehensive solution for the use of drones at various stages of emergency response [49], [50].

3.2. Functions performed by drone ports in an emergency zone

The main functions performed by each type of drone [51] and [52] when using UAVs in an emergency zone and measures for their implementation are shown in Table 2.

Table 2. Main functions of drone ports in the emergency zone and measures for their implementation

Type of drone port	Drone Port Functions	Measures for the implementation of the drone port function
Universal	Basic maintenance and technical support for UAVs	– diagnostics and maintenance of UAVs (troubleshooting, module replacement, minor repairs); – charging of UAV batteries (using a charger or battery replacement device); – calibration of UAV sensors and sensors; – storage of spare parts and consumables.
	Preparing the UAV for flight	– uploading flight tasks and routes to the UAV; – configuring UAV operation parameters (cameras, sensors, communications); – pre-flight inspection of UAV systems.
	Mission control	– automatic launch and landing of UAVs; – UAV status monitoring during flight (telemetry, video); – UAV flight control, including redirection and dynamic route change.
	Flight safety and access control	– data processing of the built-in weather station for monitoring weather conditions; – ensuring the functioning of the protection system against unauthorized entry into the territory of the drone port; – ensuring the functioning of the video surveillance system and control of the runway.
	Data transmission and communication	– receiving and processing data collected by UAVs (video, photos, sensor data); providing communication with the control center, rescue services and other drone ports; – real-time data transmission from UAVs; – flight information capture; – data storage and archiving.
User-defined	Receiving and sending of goods	– receiving cargo delivered by UAVs (medicines, food, equipment); – sending cargo to UAVs for delivery to other points in the emergency zone; – cargo sorting and storage.
	Technical maintenance	– charging (changing) UAV batteries (optional).
	Data transmission and communication	– operation of the cargo accounting and tracking system in real time; – provision of communication with operators and other terminals.
	Ensuring cargo safety	– ensuring the safety and security of goods; – protection against unauthorized access.

Mobile	Mobile UAV Launch	– moving a UAV to an emergency zone by car or another high-terrain vehicle; – operational launch of the UAV from a mobile platform; – operational control of the UAV during flight; – ensuring autonomy from stationary infrastructure; – moving the mobile platform to hard-to-reach areas in an emergency zone.
	Technical maintenance	– charging (changing) UAV batteries (if available).
	Data transmission and communication	– real-time data reception from UAVs.

To ensure maximum efficiency, all three types of drone ports must interact with each other, forming a single network. Universal drone ports serve as the central nodes, providing technical support and flight control. User terminals are responsible for logistics, while mobile stations offer flexibility and responsiveness in emergency situations for hard-to-reach areas.

The placement and relocation of drone ports in the Republic of Kazakhstan should take into account geographical features, population density, transport infrastructure, potential emergency risks and economic feasibility. It is necessary to combine stationary and mobile solutions to ensure maximum efficiency and flexibility of the drone port system and UAVs in the emergency zone.

It should be noted that AI, machine learning, and computer vision technologies are applicable in almost all the main functions of drones, which can increase the percentage of automation of tasks, and hence the efficiency of using drones and UAVs in an emergency zone.

Based on the criteria and performance indicators discussed above, the main functions and measures for their implementation, we will formulate a step-by-step algorithm that describes the sequence of actions performed when using intelligent drones and UAVs for rapid emergency response in Kazakhstan.

3.3. The algorithm for using intelligent drone ports in emergency situations in the Republic of Kazakhstan

Conventionally, the process of using intelligent drones and UAVs can be divided into five main stages:

- Emergency detection and notification;
- Emergency response task planning;
- Performing emergency response tasks;
- Collecting data on the performance of tasks in the emergency zone, UAV maintenance;
- Data analysis for planning new tasks in an emergency zone.

3.4. Comparison between the proposed algorithm and existing algorithm in the literature

A comprehensive and structured framework has been proposed for the application of intelligent drone ports in disaster management. This five-stage framework addresses limitations identified in existing studies. Existing studies have focused primarily on isolated applications of UAVs, such as firefighting, flood monitoring, and search and rescue tasks, without considering drone port infrastructure, scalable UAV coordination and AI-driven decision-making.

In contrast, the proposed algorithm integrates UAV operational efficiency with a dynamic functional interplay among multiple UAV types, drone ports, and AI technologies, enabling the generation of a dynamic and adaptive emergency response in diverse environments, such as Kazakhstan. The benefits of the algorithm stage-wise in comparison with traditional deployments of UAVs are presented in subsequent paragraphs.

The proposed algorithm consists of the following five main stages: emergency detection and notification (Stage 1) -> task planning (Stage 2) -> task execution (Stage 3) -> UAV maintenance and data collection (Stage 4) -> data analysis and planning for subsequent tasks (Stage 5).

In Stage 1, emergency signals are validated using AI to identify the type and scale of the incident that has occurred. Following this, a signal is generated to trigger the suitable response protocol. In comparison with traditional UAV employment, which relies on manual or semi-automated notification mechanisms, this stage ensures accurate and swift detection, thus reducing net response time and human errors.

Allocation of UAVs, drone ports and resources to multiple tasks is determined at Stage 2 of the algorithm. In comparison to conventional/existing UAVs, task planning is static, which is predefined.

In contrast, the proposed algorithm's stage involves dynamic task assignment based on real-time information regarding terrain complexity, obstacles within the flight envelope and resource availability. Thus, as a benefit, this adaptive task allocation optimized UAV utilization to minimize redundancies, thereby allowing the simultaneous execution of multiple tasks and improving net efficiency.

Execution of assigned tasks is managed at Stage 3, which includes continuous monitoring and coordination through drone ports. Communication, relay and delivery of essential supplies are ensured proactively within minimal time.

In comparison with existing UAVs, this stage provides integrated networking across all UAVs and drone ports, enabling real-time coordination, collision avoidance and route optimization. This provides benefits in the form of improved speed and reliability, particularly in challenging weather and terrain conditions.

UAVs' maintenance is a limiting factor in effective employment of UAVs in response management during disasters because UAVs need battery replacement, payload management and performance monitoring continuously. Thus, such downtime of UAVs needs to be optimized to enhance the overall capacity of UAV operations during disaster management.

While conventional UAV and drone applications often neglect continuous data-driven maintenance strategies, ours ensures sustained operational readiness of UAVs and drone ports through systematic data collection and real-time monitoring of maintenance-related constraints, thereby providing benefits to reduce downtime incurred due to maintenance at Stage 4.

The final Stage 5 involves comprehensive data analysis to inform future emergency operations. The approach doesn’t frequently utilize feedback loops like conventional methods do. In this phase, however, information provided by AI helps in optimal task planning, resource allocation, and UAV deployment in subsequent phases.

The algorithm becomes more efficient through learning from previous operations, enabling the progressive improvement of daily operations and the adaptive scaling of emergency responses.

The combination of these five steps will create a comprehensive emergency management system that is speedy, accurate and reliable, even when employed on a large scale. Key benefits include.

- AI-driven detection and task allocation help to identify incidents and subsequent response generation in no time;
- Better use of resources: Better use of UAVs and drone ports eliminates redundancies and cuts down costs;
- The framework can fit many kinds of UAVs and drone ports so that these can be used in incidents of any scale;
- With such monitoring, predictive failure and coordinated operation of the UAVs, the risk of failure of the system would be less;
- Learning and making operations better: Because of feedback loops, the feedback loops are changed according to data, not gut feeling.

The new algorithm significantly overcomes the existing constraints of utilizing UAVs for emergency management, leveraging infrastructure, artificial intelligence, and key operational feedback, much more effectively than earlier studies.

This is particularly helpful for Kazakhstan, as the country experiences both high and low (extreme) climatic conditions, as well as geographical particularities, which necessitate a reliable, scalable, and thoughtful emergency response.

3.5. Limitations of research

This study makes significant contributions but also has several limitations. The AI-enabled drone port algorithm was not tested in the field during real-life emergency situations. Thus, it is not yet known how effective and adaptable it is in various geographies and climates. Furthermore, while the paper presents a theory for coupling UAV systems, it does not examine the cost impact of large-scale deployment or the operational costs of these systems in the long run. Another limitation is that it has been tested only in Kazakhstan. More tests are needed to determine how effective it is in regions with different environmental, socio-political or infrastructural conditions. Not further considered, the implemented system may suffer from social acceptance of UAV technologies and AI, as well as addressing privacy issues and local cultural meditations regarding Emergency Response work. Due to these restrictions, any future work is essential to making real-world testing, economic assessment, and regional generalization possible.

4. Conclusions

The proposed algorithm for utilizing intelligent drone ports in emergency situations in the Republic of Kazakhstan, based on comprehensive criteria for the effectiveness and functionality of various types of drone ports, can significantly enhance the efficiency and effectiveness of emergency response. The use of AI enables the system of drones and UAVs to adapt dynamically to changing conditions, optimize resource utilization, and make informed decisions within limited time and information constraints. However, for the successful implementation of the proposed algorithm, further research and development in the fields of AI, sensor technologies, communication systems, and the regulation of drone and UAV use in Kazakhstan are needed.

Special attention should be paid to cybersecurity and data protection issues, as well as the development of a personnel training system for the effective management of intelligent drones. Further research should focus on the practical verification of the proposed algorithm in real-world conditions and its adaptation to specific types of emergency situations common in Kazakhstan. This will create an effective and sustainable emergency response system that protects the public and minimizes damage.

Theoretically, the drone applications explored in this study can be incorporated into helicopter and drone emergency management research for a practical study. The proposed algorithm for an AI-enabled drone port contributes to the literature on UAVs, drone ports, and AI by taking the first step in integrating them into a unified approach to tackling the problems experienced in remote and disaster zones, such as Kazakhstan. This paper addresses significant gaps in the literature by proposing a dynamic, scalable, and adaptable emergency response model with real-time task planning, predictive maintenance, and continuous improvement based on data analysis.

In practice, it demonstrates that AI-integrated intelligent UAV systems can enhance the operational efficiency, resource utilization, and decision-making capacity of disaster management processes. In addition, with further development, the five-stage algorithm could be easily scaled up for future deployments in other disaster-prone areas of the world [53, 54]. Policymakers, emergency responders, and technology developers could use them to establish or improve drone-based emergency systems. This study also provides a context for the economic and social feasibility of using drones in large-scale disaster responses, offering insights for future developments in technology related to this issue.

Further studies could explore the real-world application and field testing of the proposed algorithm in various settings, including different landscapes and weather conditions, particularly in areas with limited infrastructure. Evaluating how economically sustainable and scalable drone port systems are in emergency situations would be an interesting topic for research [55].

The use of UAVs and AI in disaster response operations would provide opportunities for furthering the science through research. Research conducted in a specific rural region or culturally diverse area may provide valuable insights. More advanced AI technologies, such as deep learning [56], could be added for improved task automation and decision-making. Further studies could investigate the coordination of different governmental and non-governmental organizations as well as their system interoperability.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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Author contribution

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