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Uncovering interrelationships between barriers to unmanned aerial vehicles in humanitarian logistics

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Abstract
Recent disasters, such as the ongoing COVID-19 pandemic, have sparked an interest in new applications for unmanned aerial vehicles (UAVs) in humanitarian aid. Nevertheless, there are still many divisive changes that need to be made in order to implement UAVs into a country's humanitarian sector successfully. Hence, this paper aims to analyze the various barriers hindering the implementation of UAVs in humanitarian logistics for both developed and developing nations. To accomplish this, the study is presented in three steps. First, previous literature and opinions from experts are analyzed to illuminate particular factors that hinder UAV implementation. Next, we propose an interval-valued intuitionistic fuzzy set (IVIFS) based graph theory and matrix approach (GTMA) to calculate a drone implementation hindrance index (DIHI). The GTMA method used in this paper utilizes the PERMAN algorithm to calculate the permanent function. Finally, the DIHI values are plotted and analyzed to compare the readiness of drone implementation between developed and developing economies. A sensitivity analysis is then performed to provide validity to the results obtained. The study has revealed that both types of countries must first improve their inadequate government regulations regarding humanitarian UAVs. Developing countries must also focus on enhancing the technological awareness of their population. The results of this study can be used by policymakers and practitioners to smoothly implement UAVs in their country's humanitarian sector. The general index defined in this paper can also be calculated for specific countries using the steps mentioned in the manuscript.

Keywords Unmanned aerial vehicles · Humanitarian logistics · IVIFS-GTMA · PERMAN algorithm

1 Introduction

Unmanned aerial vehicles (UAVs), also referred to as drones, are an emerging technology with potential applications in nearly every field. UAVs are autonomous or remotely operated vehicles and are often used for missions that are too dangerous for human-crewed aircraft (Shakhatreh et al. 2019). Their versatility in structure, function and design has created a high demand for their implementation in various sectors. They have been used extensively

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in multiple countries' military for surveillance, monitoring enemy activities and attacking military targets (Coffey and Montgomery 2002). According to a study by Keller (2014), governments worldwide spent more than $4 billion on drone technology in 2014; this figure is expected to increase to $14 billion by 2024. Drones have also been used in civil applications for policing, firefighting and infrastructure inspection (Finn and Donovan 2016). Furthermore, camera drones have been heavily utilized in the film and sports industries to capture cinematic shots that could never have been done using traditional methods (Kim et al. 2018). Many private and government organizations have used UAVs for delivering packages to remote areas and providing disaster relief. Their aerial mode of transport gives them access to move freely, unrestricted by many obstacles faced by traditional means of transportation. The multifaceted aspects of this technology regarding onboard sensors, faster transportation and lower pollution have led tech company Lux Research to project that the commercial drone market will reach $1.7 billion by 2025 (Rana et al. 2016).

Many developed countries and companies have already been seen to incorporate drone technologies into their logistics sector. As a result, in the US alone, 70,000 new drone-related jobs are projected within the coming years, with 100,000 new jobs expected by 2025 (Rana et al. 2016). UAVs' major uses in developed countries are for construction and utility inspection, aerial photography and data collection plus agricultural inspection, making up 28%, 48% and 18% of total drone usage, respectively (Aviation Administration 2016). In contrast, most developing countries have not yet fully incorporated UAV technologies into sectors other than the military. Countries such as Haiti and Peru see minimal usage of drones amongst hobbyists. The primary source of drone usage in developing countries is photography by tourists or surveying and aid offered by international organizations (Cartong 2014). Other developing countries located in Africa and Asia lack entirely the regulatory framework for drone operation (Initiative 2015). Newly industrialized countries, like India and China, have begun to see further implementation of drones in logistics and commercial sectors. In recent years, UAVs have been more frequently used in India in sectors other than the military. The Indian UAV market is expected to touch $885.7 million by 2021 (Kislay 2020). The Swamitva Yojana project aims to use drones to map over 660,000 villages across India (Thomas 2020). During the recent COVID-19 pandemic, Tamil Nadu became the first Indian state to use drones for a sanitization campaign. Over 300 UAVs were deployed to sanitize roads, metros and hospitals across the state (Kislay 2020). Meanwhile, drones have been used for disaster monitoring and relief aid in developed countries, such as the United States, since early 2010 (Kovács and Spens Karen 2011). Developing countries with many rural regions are in great need of efficiently incorporating UAVs into their logistics sector. The recent focus on UAV technology will usher in a new age of drone logistics through which regions without proper infrastructure will have access to relief aid like never before.

In order to implement UAVs in humanitarian logistics in developing countries, it is vital to study the systems in place in developed countries to gain a better knowledge of what is to be done (Banomyong et al. 2019). Many barriers currently prevent the smooth implementation of drone systems in a country's humanitarian sector (Sah et al. 2020). This paper will be using the factors identified and comparing them to one another in context to first-world and third-world countries. The study will offer a better understanding of the future needs to adopt drones in developing countries by answering the following research questions:

i. What are the various factors hindering the implementation of UAVs in humanitarian logistics in developed and developing countries?
ii. What are the inter-relationships between factors, and what is their importance in the proposed framework?
iii. To what degree have these barriers affected the implementation of UAVs for developed and developing countries?
iv. What are the practical and research implications of the study?

The following study goals are used to answer the research questions proposed in this paper:

i. To recognize the various factors affecting the implementation of UAVs in humanitarian logistics and build inter-relationships among them.
ii. To compute the drone implementation hindrance index (DIHI) of the identified factors with respect to developed and developing nations.
iii. To formulate coefficients of similarity of the main factors and propose managerial implications of this research.

This manuscript's predominant contribution is utilizing an interval-valued intuitionistic fuzzy-based graph theory and matrix approach, using the PERMAN algorithm, to analyze the impact of various barriers hindering UAV implementation in developed and developing countries' humanitarian logistics sectors. Many studies have implemented the graph theory and matrix approach in areas such as manufacturing, logistics and supply chain mitigation (Muduli et al. 2013; Muduli and Barve 2013; Wagner and Neshat 2010). However, no study has used an integrated IVIFS-GTMA approach with the addition of the PERMAN algorithm to develop an index to measure a country's reluctance towards drone implementation. This new approach allows us to deal with ambiguity in the data with remarkable accuracy (Tan et al. 2019). Based on the results presented in this paper, policymakers and practitioners will gain insight into which factors are of significant concern towards the hindrance of UAV implementation.

The remainder of the manuscript is organized as follows. Section 2 contains a literature review of the relevant works on the history of UAVs in various countries. The factors and sub-factors affecting the implementation of UAVs in humanitarian logistics and their contributions in developed and developing nations are listed in Sect. 3. The research methodology and related developments are discussed in Sect. 4. Section 5 follows the application of the proposed framework. Section 6 presents the results and contains a discussion on the same. To examine the DIHI and coefficient of similarity, Sect. 7 contains the conducted sensitivity analysis. The implications of the research are stated in Sect. 8. Finally, Sect. 9 gives the concluding remarks of the manuscript.

2 Literature review

The use of unmanned aerial vehicles has seen a rapid increase since their innovation. Their autonomous nature allows drones to perform tasks faster and at lower risk than their counterparts (Kunz and Reiner 2012). Organizations around the world are using or are planning to use commercial and do-it-yourself drones for a variety of purposes, such as humanitarian aid (Tanzi et al. 2014), precision agriculture (Tokekar et al. 2016), biological conservation (Gonzalez et al. 2016), logistics (Raj and Sah 2019), urban planning (Feng et al. 2015) and surveillance (Semsch et al. 2009). The diversity of purposes with which drones have begun to be utilized in communities reveals their enormous potential (Cummings et al. 2017).

A turning point in the popularity of UAVs was in the summer of 2003. A small UAV was tested in the United States for three possible uses: high-resolution imaging of forests, traffic monitoring using live video and power line inspection (Morris and Jones 2004). This test run provided information for further conditions and regulations needed to allow for the commercial use of UAVs in the US. The paper also discusses operational challenges, such as weather conditions, providing suitable fields for flying and the Federal Aviation Administration (FAA) restrictions. With an increase of use in developed countries, the utility of drones became recognized in the international community, which led to developments of the technology and laws relating to their implementation (Bravo and Leiras 2015, Rosser Jr et al. 2018). An upcoming field of performance for UAVs, humanitarian logistics, has also seen significant changes to its drone policies over the years. In 2008, UAVs were used in search and rescue operations after hurricanes struck Louisiana and Texas in the United States. A paper by Rana et al. (2016) explained the operations of the Predator UAV used to perform search and rescue operations and damage assessment. Similar operations, as mentioned in the same paper, were carried out in the Tohoku region of Japan after the 2011 tsunami. However, these operations were only carried out after the disaster and by government organizations in developed countries. The following year, drones were deployed by the International Organization for Migration to survey areas affected by Hurricane Sandy in Haiti (Gilman 2014). As it is a developing country, the area's locals did not have direct exposure to UAVs themselves and had to rely on aid from an international organization. This led to an inefficient rescue operation and an overreliance on organizations from outside the country. Meanwhile, as the same hurricane struck parts of Florida in the United States, the locals partnered up with nearby law enforcement to help survey the area by contributing their own drones. Simultaneously, drones were also used to deliver small aid packages to those communities affected by the disaster (Balasingam 2017).

These instances sparked the need to further the agenda of implementing UAVs in developing nations as a tool for dealing with humanitarian disasters. Multiple studies have been conducted where the application of drones was considered to combat the damages caused by a natural disaster (Bravo et al. 2019; Greenwood et al. 2020). A study by Golabi et al. (2017) developed and analyzed a model for using UAVs in humanitarian aid after the Tehran earthquake. In this model, it was considered that UAVs would reach those who could not receive help from a nearby relief station. However, the study results showed that many drones would need to be present at any given facility to increase the survival rate successfully, both for mapping the disaster region and for delivering aid. Saavedra et al. (2021) proposed a rapid mapping system based on UAVs to combat these challenges. This system would help recognize the damage at different zones and provide an optimal location for UAV hubs that should be placed pre-disaster. The paper also discusses some organizational challenges that might be faced when implementing such a system. Smaller-scale versions of these models have already seen success when used in the field. The USAID Global Health Supply Chain Program project began delivering health services to remote areas in Africa through UAVs (Triche et al. 2020). The implementation of these drones in the pre-existing supply chain significantly improved health services in remote villages. The project was able to deliver 428 flights in an hour; this would have taken over ten days for other modes of transport. Similar improved results have been recorded in other developed and developing nations when incorporating UAVs into existing supply chains (Shavarani 2019; Azmat and Kummer 2020). Even the recent COVID-19 pandemic has seen drone usage. The disinfection of popular urban areas in Chile, China, India and UAE has been done using UAVs. Other countries, such as the United States, Spain and Australia, have been using drones to deliver medical supplies and groceries to those in isolation (Sharma 2020). The recent pandemic has exemplified the range of utility provided by incorporating UAVs into humanitarian logistics and has sown the seeds for a more technologically inclusive humanitarian sector (Kumar et al. 2020).

As categorized in the study by Vargas-Ramírez and Paneque-Gálvez (2019), there have been several instances of UAV usage by government organizations and NGOs for humanitarian aid in the last decade. There have also been several instances of UAVs being incorporated into an existing logistics network to improve its efficiency (Azmat and Kummer 2020). Nevertheless, despite the world's vested interest in UAV operations in humanitarian logistics, there has yet to be a study comparing hindrances to their implementation in developed and developing nations. This manuscript will provide factors by which the criteria for the readiness of implementation will be judged; then, a drone implementation hindrance index will be generated to provide a comparison between the two types of countries.

3 Factors affecting UAV implementation in humanitarian logistics

The following section gives a detailed description of the various factors inhibiting the adoption of UAV technology in the humanitarian sector. Along with this, we also provide information on how these factors influence developed and developing countries. Specifically, the United States, Spain, United Kingdom, Canada and Australia were chosen to represent developed countries; Chile, China, India, Nigeria, and UAE were considered when judging developing nations. The variables for the study were established by a thorough literature analysis and consultation with selected experts, as shown in Fig. 1. The literature review included many cases of drone usage in the humanitarian and other sectors in various countries. After making a list of factors to be considered for this study, specialists were invited for interview to discuss the barriers, complete the relevant questionnaire (Sect. 12) and suggest possible amendments. As a result of the expert consultation, the factor "Obstruction Caused by Lack of Regulated Spectrum Range (L4)" was added. Finally, the identified factors were divided into four major categories based on their influence – legal, financial, operational plus knowledge and behavioral. The factors obtained through analysis of previous studies and interviews with experts are presented in this section.

3.1 Legal factors

In order to adopt a new technology in a sector, laws must be firmly set in place to allow for the innovation to succeed (Raj and Sah 2019). Government regulations regarding UAV usage vary around the globe from country to country; nevertheless, some laws must not be ignored while trying to implement a UAV system. Legal factors, such as restricted flight permissions and the unavailability of insurance, can hinder an organization's ability to take even the first few steps in implementing drones (Jones 2017). This is often due to drone laws that are too strict; thus, they cannot be abided by. Another factor, the impediment of operations due to trespass laws, hinders the ability of UAVs to quickly respond to disasters by limiting their operational area (Cracknell 2017). A similar problem is found regarding the restrictive visual line of sight laws, which require an operator to be within a certain vicinity when operating a drone (Pinkney et al. 1996). Even many developed countries have yet to allow operators to use UAVs beyond their line of sight. Furthermore, the unavailability of a dedicated spectrum range for UAVs is another barrier that has yet to be overcome in any country (Vergouw et al. 2016). These factors can lead to costly damages and conflicts when determining the responsibility of those who are responsible for an accident. A detailed description of restrictive legal factors is given in Table 1(a).

3.2 Financial factors

As sufficient funds must first back the implementation of new technology, the financial barriers faced in this scenario are more significant (Mohammed et al. 2014). Although there are many economic benefits to UAV delivery and surveillance, there are also many hindrances to implementing this new technology in a system. The main concern with drone implementation in humanitarian logistics is the costly commercial solutions available in the market (Tatham 2009). According to a study by Doole et al. (2020), an average delivery drone used in the fast-food sector will cost 4,800 USD per UAV. This is almost twice the cost of the next most efficient solution, an e-bike. Due to a lack of specialization in the humanitarian field, the exact sensors needed on a device are not available, increasing the initial and subsequent maintenance costs (Estrada and Ndoma 2019). Other reasons for variation in maintenance costs are losses in communication, poor weather conditions or destroyed infrastructure. These high initial costs make it difficult for humanitarian organizations to invest in UAVs. Another factor is the high cost of transporting many goods (Chiang et al. 2019). Although drones are more eco-friendly than other methods of transport, due to their limited payload capacity, it is harder to deliver a large number of supplies. For current systems, same-day delivery by e-vans costs 0.17 USD per delivery; however, the same delivery by drone would cost 0.70 USD per item (Sah et al. 2020).

Along with the cost of delivery, the total carrying capacity of drones is also a downside. Where it might take 22 vans to deliver 60,000 products, the same task would require 900 drones. Furthermore, the payload size of the drones is restricted. Many companies offer healthcare drone solutions that can carry 0.5 kg for 45 minutes or 1kg for 25 minutes. These restrictions on flight time and payload weight make it evident that UAVs can only be used for specific delivery cases in areas where other solutions may not be available (Shen et al. 2021). More information detailing the influence of financial factors in developed and developing countries is displayed in Table 2(b).

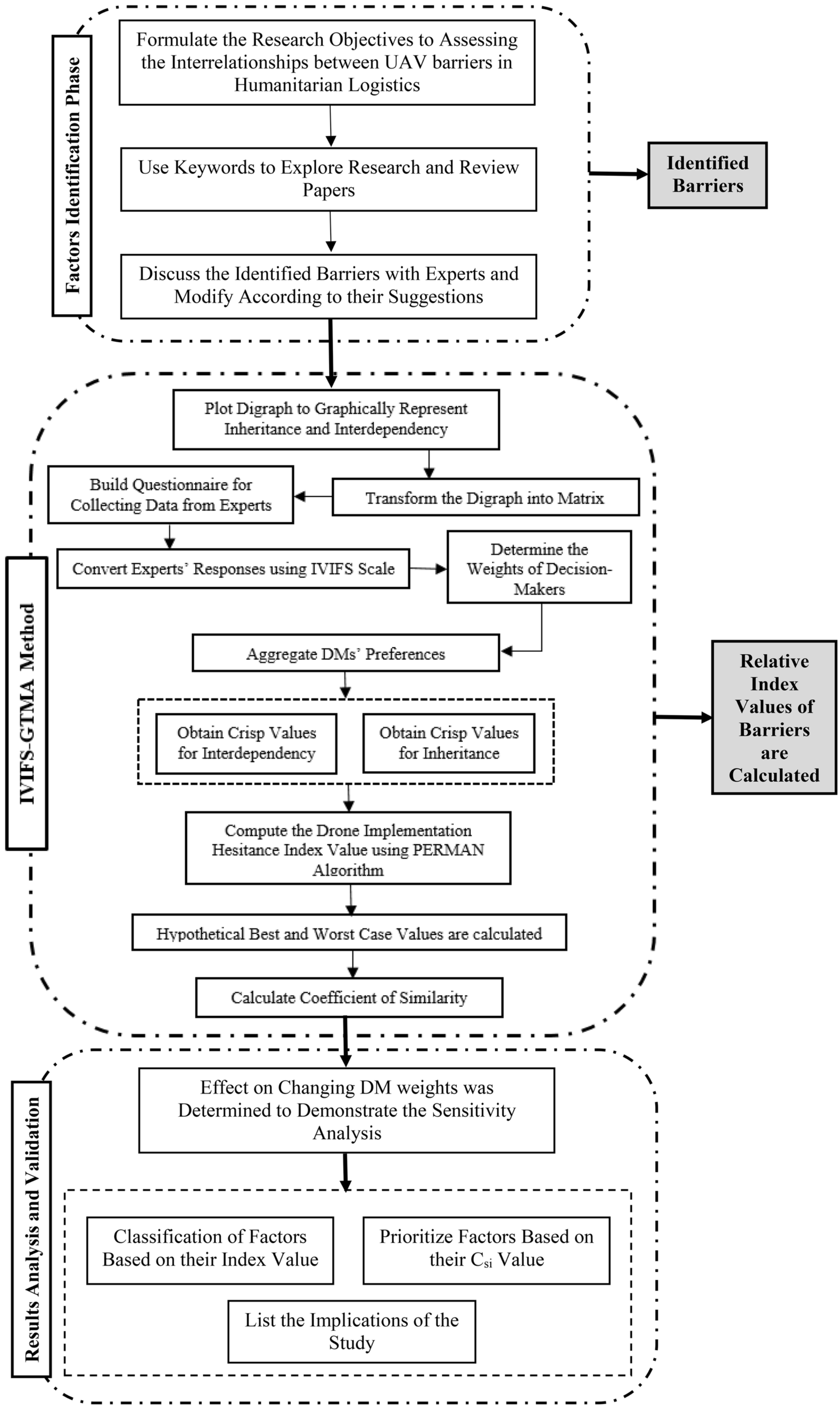

Fig. 1 Flow of Study

Table 1 (a) Legal factors affecting UAV implementation in humanitarian logistics in developed and developing countries

Serial No	*Factor*	*Authors' Contribution*	*Influence in Developed Countries*	*Influence in Developing Countries*
L1	Restricted Flight Permissions	(Flores et al. 2021; Jones 2017; Giyenko and Cho 2016)	The small size of UAVs make them difficult to integrate with traditional air traffic control (ATC) laws. The limited sight of the operator also calls into question the reach given to drones. It is estimated that most developed countries will have a properly integrated registration system that abides by ATC laws by 2025. Nevertheless, many developed countries have introduced beyond visual line of sight (BVLOS) operations and are continually conducting research on their implementation in real-world scenarios	Many developing nations don't have specific laws in place for drone regulation. This can lead to confusion with local law enforcement regarding flying permission. Regional disputes, such as the one regarding Kashmir during the 2005 Pakistan earthquake, can hinder the opportunities for UAV usage. Furthermore, many developing nations that allow for flying have yet to introduce legislature regarding BVLOS
L2	Impediment of Operations due to Trespass Laws	(Cracknell 2017; Farber 2016)	Drones used for relief missions are required to fly large distances. There are many cases in which UAVs have to detour due to restrictions around some areas. This can cause delays in a time-critical mission. There have been several cases in countries like the UK, where the hazardous operation of drones near airports has led to stricter laws regarding forbidden flight areas	Most developing nations have similar policies to developed countries. They also restrict drone airspace near airports and other areas of national importance. However, there are some countries that do not have any laws regarding drones and thus have no bans either. The trespass laws are often paired with the visual line of sight approach given to drone operators

Table 1 (continued)

Serial No	*Factor*	*Authors' Contribution*	*Influence in Developed Countries*	*Influence in Developing Countries*
L3	Restrictive Visual Line of Sight (VLOS) Laws	(Flores et al. 2021; Cracknell 2017; Jones 2017)	One of the largest obstacles in large distance deliveries is the requirement of drones to remain within a pilot's VLOS. Many developed nations are experimenting with a beyond visual line of sight system. Countries such as Japan, Australia, the United States and Canada allow the BVLOS rule in some restricted areas for testing	Most developing nations have implemented a visual line of sight approach, with other nations completely banning the commercial ownership of UAVs. Countries like Chile, Belarus, Argentina and Egypt have a ban on obtaining commercial licensing for drones. On the other hand, countries like Nepal, South Africa and Thailand have a VLOS system
L4	Obstruction Caused by Lack of Regulated Spectrum Range	(Vergouw et al. 2016; Marcus 2014)	Many interference problems can occur during operations due to a lack of any dedicated spectrum range for drones. UAVs used for delivery of rescue items need to travel large distances. If the spectrum range used by these drones is not regulated, then the radio equipment of the drone may be interfered with. Other people may also be using the same frequency, which can lead to conflicting inputs for the drone	
L5	Uncertainty in Determination of Liability	(Yapp et al. 2018; Rao et al. 2016)	In many developed countries, the owner of a drone is held liable for all actions performed. However, for those countries experimenting with a BVLOS system, there is an issue of how liability should be treated. A problem also arises when taking into account autonomous drones. Many countries have decided to currently place responsibility on the one who turns on the UAV	There are many conflicting views about liability in developing countries. Some countries such as China have assigned full responsibility to the operator, or in the cases of autonomous devices, to the person who turns the device on. Other countries are still sceptical about this approach and are considering assigning some responsibility to drone manufacturers for faulty systems
L6	Unavailability of Insurance	(Jones 2017; Stöcker et al. 2017)	A major issue in drone regulation is the need for some type of insurance. Most developed countries that allow drones for commercial use require the purchase of insurance. Countries such as the United Kingdom and Canada require insurance, whereas others like the United States do not have any such regulations in place	Very few developing countries require an operator to have drone insurance. In countries such as Chile, Columbia and Thailand, insurance is required; however, due to legal complications, it is near impossible to obtain. Other countries such as Argentina, Panama and Mexico have no set requirements for insurance

Table 2 (b) Financial factors affecting UAV implementation in humanitarian logistics in developed and developing countries

Serial No	*Factor*	*Authors' Contribution*	*Influence in Developed Countries*	*Influence in Developing Countries*
F1	Costly Commercial Solutions	(Rao et al. 2016; Tatham 2009)	The cost of UAVs is high no matter where they are purchased. Nevertheless, countries that are home to drone manufacturers, such as the United States, Canada and France, have an advantage when trying to implement UAVs in their various sectors. The availability of nearby manufacturers gives them more options for customizability and repair	There are very few developing countries that house drone manufacturers. China and India are such countries and thus have an advantage when it comes to implementing drone technology. Other developing nations, such as Nigeria, Haiti and Peru, must rely on international aid to bear the cost of these expensive solutions
F2	Difficult Start-up Opportunities	(Welch 2015; Tatham 2009)	Developed countries have a higher chance of being home to drone manufacturers, making it easier for purchasing. Countries like the United States, Netherlands, South Korea and Germany are home to UAV manufacturers. This gives them an advantage over developing countries when first implementing UAVs in a sector	There are very few developing countries that are able to risk the investment of implementing drones in their humanitarian logistics sector. Countries such as China and India have drone manufacturers available to purchase from, making for easier implementation; however, this is not the case for most developing countries who require aid for expensive start-up costs
F3	High Transport Costs for Larger Deliveries	(Chiang et al. 2019; Thibbotuwawa et al. 2018; Haidari et al. 2016)	The transportation infrastructure of developed countries is often sufficient to the point where most areas can be reached by roads. In these cases, a hybrid truck-drone delivery system can be used where some of the distance is covered by trucks, and the final delivery is by drones. This helps reduce transport costs for larger deliveries	When disaster strikes in rural areas of developing countries, there is insufficient transportation infrastructure in place to easily deliver relief aid. In these cases, a purely UAV delivery must be used to supply essential goods. This can increase transport costs due to the fuel consumption by drones flying large distances with heavy payloads
F4	Varying Maintenance and Repair Costs	(Estrada and Ndoma 2019; Petritoli et al. 2018)	There are many cases during field missions where UAVs can go missing or get damaged. Due to errors during operations, the maintenance of devices is not always possible. Developed countries with a better infrastructure have a higher probability of being able to successfully recover lost UAVs and keep them in use	As the recovery of drones that are lost during operations is dependent upon the infrastructure of the country, developing countries have a greater variance for repair and maintenance costs. Missing or destroyed devices will increase costs for replacement and will delay completion of a mission

3.3 Operational factors

During relief and surveillance missions to provide humanitarian aid, many problems can interfere with the objective. These problems, be it environmental changes, human error or technological limitations, are operational barriers (Loh et al. 2009; Overstreet et al. 2011). For example, a frequent effect of natural disasters is the destruction of infrastructure, hindering the usage of UAVs (Erdelj et al. 2017). Destroyed infrastructure can lead to biological and chemical changes in the area around the disaster region. Another barrier faced in the field is unstable weather conditions that cannot be accounted for due to the infancy in the technology of humanitarian-related UAVs (Morris and Jones 2004). Furthermore, there are many rural regions in countries where connectivity issues may prevent full utilization of drones (Koeva et al. 2018). More information regarding operational factors and their influence in developed and developing countries is presented in Table 3(c).

3.4 Knowledge and behavioral factors

Barriers classified in the knowledge and behavioral section describe those challenges rendered due to the population of the considered regions. The final stage of the new humanitarian relief supply chain requires interaction between drones and the public; hence, the public should accept this new technology (Aydin 2019). For example, public ignorance about UAV technologies, a significant barrier when incorporating new systems, can decrease support for implementation of drones in humanitarian logistics (Yoo et al. 2018). Another valid factor is a lack of environmental perception amongst citizens. This factor is described as the ability of a person to analyze and make decisions based on the happenings around them. As citizens during rescue are often panicked, they may not properly interact with any UAVs in their vicinity (Chowdhury et al. 2017). This greatly reduces the impact a drone can have during a humanitarian operation. Also, vandalism threats during missions often lead to damaged devices and delayed responses (Clothier et al. 2015). The extra precautions that need to be taken in order to avoid vandalism can sometimes greatly delay the operation. The UAV handlers' overall knowledge also comes into play as inexperienced operators can lead to failed missions (Chappelle et al. 2014). Further implications of these factors, along with their influences in developed and developing countries, can be found in Table 4(d).

4 Solution methodology

The methodology for this research utilizes a combination of an interval-valued intuitionistic fuzzy set (IVIFS) with a graph theory and matrix approach (GTMA) to effectively compute the various barriers restricting the implementation of UAVs in humanitarian logistics. Furthermore, the PERMAN algorithm will efficiently calculate the permanent function of matrices used in GTMA. In 1989, Atanassov and Gargov (1989) proposed the IVIFS as an extended development to the intuitionistic fuzzy set (IFS). The membership, non-membership and hesitancy degrees are categorized as intervals instead of a crisp value. Incorporating an interval of values allows IVIFS to deal with situations of a more complex nature with greater degrees of uncertainty (Abdullah et al. 2019). The ability of IFS to handle the issue of hesitancy when a decision is made by taking into account the disagreement degree, sits well with the added interval model of IVIFS. Hence, IVIFS has been utilized in many studies since its creation.

This study applies the interval scale given by IVIFS in collaboration with the interconnectivity network diagram provided by the graph theory and matrix approach. GTMA is a well-known systematic and logical decision-making approach. It has previously been used in studies across various domains such as error reduction, reverse logistics and rapid prototyping. A paper by Rao and Padmanabhan (2007) uses the GTMA technique to select a rapid prototyping method to best suit their needs. Another manuscript by Agrawal et al. (2016) utilizes GTMA to select the best disposition alternative for a manufacturing plant. Aju Kumar and Gandhi (2011) used GTMA to develop an index to measure the potential of human error of a given task. The method consists of two main elements; nodes and edges. The nodes represent the attributes, or, in the case of this study, the barriers that influence the disposition decision of any system. In contrast, the edges connecting the nodes represent their relative importance (Kulkarni 2005). Next, the diagraph is transformed into a square matrix. This allows for more critical analysis by converting complex network relations to visualize into easy-to-understand matrices (Geetha and Sekar 2017). Finally, a permanent function of the matrix is calculated and is used to express an attribute's effect through an index (Tuljak-Suban and Bajec 2020). The index can then help managers understand the weightage each factor has towards the overall system.

The calculations used in the mathematical model have been programmed in MATLAB. To ease the load of the program while calculating the permanent function, the PERMAN algorithm is used. The time complexity of the PERMAN algorithm is $O(N \times 2^{n-1})$, whereas the normally used Ryser algorithm has a time complexity of $O(N^2 \times 2^{n-1})$. The PERMAN algorithm is used as it is more efficient for larger values of N and is less susceptible to finite precision errors than the Ryser algorithm (Nijenhuis and Wilf 2014).

There are many decision-making methods other than GTMA that have been used in previous works. Pairwise Comparison, Structural Equation Modelling (Semsch et al.), TOPSIS (Abdollahnejadbarough et al. 2020), Analytic Hierarchy Process (AHP) (Ranđelović et al. 2018) and Analytic Network Process

Table 3 (c) Operational factors affecting UAV implementation in humanitarian logistics in developed and developing countries

Serial No	*Factor*	*Authors' Contribution*	*Influence in Developed Countries*	*Influence in Developing Countries*
O1	Destroyed Infrastructure from Disaster	(Jeong et al. 2020; Erdelj et al. 2017)	In the wake of natural disasters, many parts of a country's infrastructure are left in ruin. This can limit the manoeuvrability of UAVs when trying to deliver relief aid in the aftermath of disasters. Due to the proper construction of critical infrastructure in developed countries, the chances of a major collapse after a disaster is lessened	According to the 2016 World Risk Report, developing countries such as Haiti, Peru and Ecuador are at a much higher risk of destruction of infrastructure. The lack of proper infrastructure can result from insufficient construction precautions, vulnerable supply lines or lack of redundant transportation routes. These deficiencies can hinder disaster logistics
O2	Unstable Weather Conditions; Prompt Delivery Problems	(Thibbotuwawa et al. 2020; Morris and Jones 2004)	During times of disaster, relief missions cannot be delayed or cancelled due to the weather. The aid must be provided regardless of environmental conditions. In situations where there are poor weather conditions, the usage of UAVs is limited as drones cannot operate efficiently in extreme weather conditions. There are currently no advancements to allow UAVs to successfully and reliably work in unstable weather	
O3	Communication Restrictions in Rural Areas	(Ortiz et al. 2019; Koeva et al. 2018)	Many developed countries have connectivity across most regions. This helps to maintain constant information flowing between operators in the central station and the drones in action. There are very few areas in developed countries that do not have access to stable connections	Communication between the central hub and active drones must be maintained in order to keep up with operations. Many areas in developing countries do not have proper connectivity, leading to a delayed response from drones or even a loss of communication
O4	Biological and Chemical Threats	(Lai et al. 2020; Tulum et al. 2009)	A natural disaster may occur in zones where infrastructure contains biological and chemical reactants. The spread of these reagents can damage on-board electronics of UAVs, leading to malfunctions or other disruptions to the mission. These threats can also affect the payload for relief missions, effectively wasting an entire delivery run and the supplies being transported	

Table 4 (d) Knowledge and behavioral factors affecting UAV implementation in humanitarian logistics in developed and developing countries

Serial No	*Factor*	*Authors' Contribution*	*Influence in Developed Countries*	*Influence in Developing Countries*
KB1	Public Ignorance About UAV Technologies	(Aydin 2019; MacSween 2003)	Citizens in developed countries are well informed on technologies such as UAVs due to mainstream media or the technology's appearance in movies or television. This leads to easier implementation of drones as the general public is already aware of the technology and its basic functions	In order to properly implement a new technology, the public should first be aware of and accepting of the technology. People living in rural areas of lesser developed countries are often unaware of newer technologies. Their lack of awareness can lead to improper interaction between themselves and the device during a humanitarian operation
KB2	Lack of Environmental Perception Amongst Citizens	(Chowdhury et al. 2017; Loh et al. 2009)	Although someone in a developed country may have knowledge about drones and their functions during rescue scenarios, the panic that ensues during a disaster makes it harder for them to appreciate assistance delivered by drones. A person must first be completely aware of their surroundings before trying to make a rescue near them	During crisis scenarios, people are in a panicked state. This hinders their judgment and makes it harder for them to notice assistance delivered by UAVs. In less developed countries, where knowledge of drone operations is less, this becomes even more prevalent
KB3	Vandalism Threats during Missions	(De Campos et al. 2021; Motlagh et al. 2017; Clothier et al. 2015,)	Vandalism in developed countries can be caused by local residents whose property the UAVs fly over along with law enforcement of that area. There have been many vandalism cases in the United States where drones used for activist movements have been shot down due to privacy issues	Vandalism of drones in developing nations is often caused by lack of awareness. The public might destroy or damage these devices in self-defence. The drones damaged by vandalism in rural areas of developing nations will be harder to recover without a proper retrieval system in place
KB4	Inexperienced Operators	(Gwak et al. 2020; Chappelle et al. 2014; Ruiz et al. 2015)	In cases where a drone cannot operate autonomously, a skilled human operator is needed to pilot the UAV. Drone operators in developed countries have an easier time practising due to the increase of drone flying as a hobby. The increased practice gives them a better chance of performing well in tense situations	Operators can only gain experience for field missions when they have either the software or the technology to replicate those scenarios. These opportunities are missing in developing countries where there are little or no opportunities for handlers to learn such skills without personally owning a drone
KB5	Public Nuisance	(Shanker and Barve 2021; Kwon et al. 2017; Lyu et al. 2017)	Drones used for humanitarian aid in developed countries will likely be paired with other forms of transportation to minimize costs. Thus there is a lower chance of these humanitarian UAVs flying directly over the public. This can lead to better public acceptance as they do not have to constantly worry about this issue	Public ignorance in developing countries about UAVs can also lead to greater concerns of them being regarded as a public nuisance. If citizens of a country have no knowledge of these devices, they will be much warier of devices flying above their heads. Many people might not trust these technologies as they can be used for wider surveillance

(ANP) (Uzun et al. 2016) are all structured decision-making tools utilized in various studies. However, some major differences give GTMA the advantage over these methods. Pairwise Comparison and AHP do not consider the interdependence of variables (Zhou et al. 2018; Ho and Ma 2018). ANP, while taking into account the various inter-relationships, does not contain any hierarchical system between variables (Zhao et al. 2019). SEM derives a model for development and specification by theory instead of mining data (Scherer et al. 2018). Furthermore, the precision of SEM relies on a large sample size. In contrast, GTMA is a robust and straightforward approach with fewer limitations than mentioned above.

Graph theory and matrix approach has a clear advantage over other visual analysis tools due to its incorporation of matrices to ease mathematical calculations. This becomes apparent when comparing GTMA to classical representations such as block diagrams, cause and effect diagrams or flow charts, which cannot be converted into a mathematical form (Muduli et al. 2013). This study uses GTMA to quantify an index to rate the effect of hindrances on a country towards the implementation of UAVs into humanitarian logistics. A flowchart to illustrate the methodology used in the study, i.e. the combination of IVIFS with GTMA, is shown in Fig. 1. A detailed explanation of the procedure for the implementation of this methodology is shown in Sect. 10.

5 Application of the proposed framework

The proposed methodology has been tested and verified in the context of UAV implementation in both industrialized and developing nations' humanitarian sectors. Figure 1 presents the flowchart of the research framework that leads to the final calculation of a drone implementation hindrance index. The formulas are given in Appendix A; the detailed process of the data collection and analysis are given below.

5.1 Respondent selection, questionnaire development and data collection

The barriers to implementation of UAVs in humanitarian logistics have been identified through a thorough literature review. These factors were then confirmed by experts selected for their applicability in this study. The specialists were chosen due to their experience in fields relating to the research topic.

Initially, a pre-interview questionnaire was sent to multiple academicians and industry experts. This questionnaire asked respondents for their basic information, such as field of expertise, years of experience, and position in their company. Furthermore, they were also presented with a list of factors selected from the literature review. These respondents were then asked to go through the factors and modify existing ones or suggest more as they deemed appropriate. Finally, the questionnaire asked if the respondents would be comfortable appearing for an interview to discuss the next stage of the data gathering process.

A total of ten experts properly responded to the first questionnaire and were contacted for the subsequent interview. The interview was conducted in a semi-structured manner. Initially, all interviewees were asked about their previous responses and the factors they wanted to change or add. Then, the scoring system of the IVIFS-GTMA methodology was explained. Experts were shown an example table consisting of the factors from the pre-interview questionnaire; then, an exercise was performed where the interviewer would go through a few cells and explain how they would have personally done the ranking if they were in the expert's position. The same procedure was also performed with the table comparing the effects of barriers on developed and developing nations.

After all the interviews were concluded, an updated factor list was compiled with consideration to the suggestions given by the experts. The updated list, empty tables for rating factors, and rating scale were communicated to the respondents through a post-interview questionnaire. Out of the final ten responses, only six were included in the results, as the other four contained significant bias made evident by performing the sensitivity analysis (refer Sect. 7).

Further information about the respondents and the pre and post interview questionnaires are available in Sects. 11 and 12, respectively.

5.2 Computing the drone implementation hindrance index of identified barriers

This section details the steps taken in applying the IVIFS-GTMA methodology to compute the DIHI of developed and developing nations' humanitarian logistics sectors. The drone implementation hindrance index is a term introduced in this manuscript to measure the extent or degree to which a certain barrier hinders UAV implementation in humanitarian logistics. After all ratings have been submitted, the permanent function of the chosen matrix will produce the DIHI of the main factor or the overall system. Higher values of E_i and r_{ij} will result in an increased DIHI value. As the factors chosen for this study all have a negative impact on the overall goal, the larger the drone implementation hindrance index, the more detrimental the factor is towards UAV implementation.

5.2.1 Behavioral diagraph

A diagraph is developed to showcase the factors affecting UAV implementation in humanitarian logistics and their inter-relationships using nodes and edges (Fig. 2). Let the

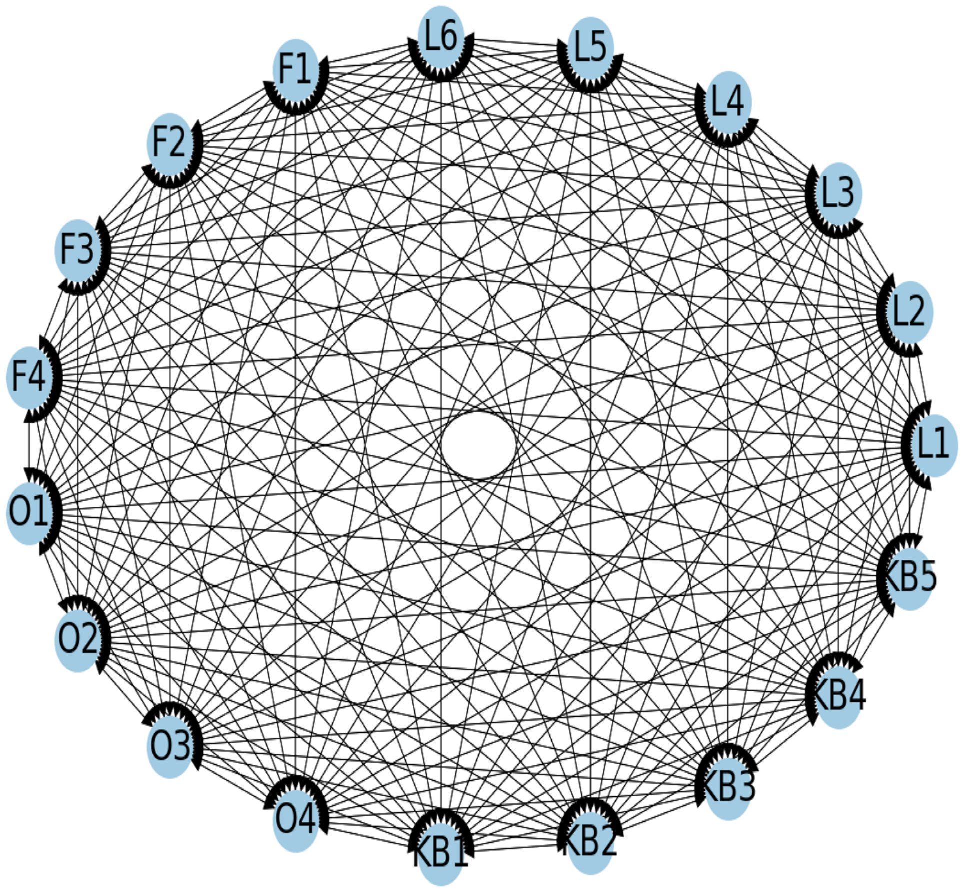

Fig. 2 Diagram of Interrelationships among UAV Implementation Barriers

nodes of the diagraph (E_i) represent the identified barriers i.e. L_1, L_2, F_1 etc. and edges (r_{ij}) represent their interactions. As there are 19 factors considered for the study, 19 nodes are present in the diagram. The nodes are connected by edges r_{ij}, which indicate the degree of dependence of the j_{th} factor on the i_{th} factor. In the diagraph, the edge r_{ij} is depicted as a line from node E_i to node E_j. Furthermore, each node has a corresponding value of E_i which depicts the value of the i^{th} factor represented by that node. To demonstrate the applicability of the diagraph, let us take an example of the relationship between factors F4 and KB4. Inexperienced operators (KB4) can often lead to the destruction of hardware during missions, which in turn leads to a variation in maintenance and repair costs for UAVs. However, due to maintenance costs, operators may not have many opportunities to practise flying their drones. Thus, the two-sided arrows indicate that the relative importance between these two factors acts in both directions.

5.2.2 Matrix representation

The large size of the diagraph makes it complicated to analyze. Thus, the diagraph given in Fig. 2 is converted into a square matrix by using the formula given in Eq. (1). For this study, the matrix has a size of 19 to represent each of the chosen factors.

5.2.3 Calculation of E_i and r_{ij} values using IVIFS

Step 1: Collect the linguistic data from decision-makers and convert them to IVIFS values using Table 5.

Table 5 Linguistic scale to IVIFS conversion

Linguistic Scale	IFS	IVIFS
No Influence	(0.10, 0.80, 0.10)	([0.050, 0.150], [0.750, 0.850], [0.000, 0.200])
Low Influence	(0.25, 0.60, 0.15)	([0.175, 0.325], [0.525, 0.675], [0.000, 0.300])
Medium Influence	(0.50, 0.40, 0.10)	([0.450, 0.550], [0.350, 0.450], [0.000, 0.200])
High Influence	(0.75, 0.20, 0.05)	([0.725, 0.775], [0.175, 0.225], [0.000, 0.100])
Very High Influence	(0.90, 0.05, 0.05)	([0.875, 0.925], [0.025, 0.075], [0.000, 0.100])

Table 6 Linguistic to IVIFS scale of DMs preference weights

Linguistic Scale	IVIFS
Very Important	([0.875, 0.925], [0.025, 0.075], [0.000, 0.100])
Important	([0.725, 0.775], [0.175, 0.225], [0.000, 0.100])
Medium	([0.450, 0.550], [0.350, 0.450], [0.000, 0.200])
Unimportant	([0.175, 0.325], [0.525, 0.675], [0.000, 0.300])

Step 2: Determine the weight associated with each decision-maker by using Table 6. The importance of a decision maker's rating is formulated using Eqs. (4), (5), (6), (7) and (8).

Step 3: Aggregate the decision-makers' ratings using Eq. (7). The IVIFS score given by the n^{th} decision-maker indicates the influence of a node E_i on node E_j.

Table 7 Crisp values for "r_{ij}

	L1	L2	L3	L4	L5	L6	F1	F2	F3	F4	O1	O2
L1	**E1**	0.046	0.635	0.046	0.634	0.047	0.637	0.105	0.637	0.046	0.026	0.085
L2	0.954	**E2**	0.105	0.047	0.046	0.198	0.637	0.105	0.105	0.022	0.105	0.022
L3	0.365	0.895	**E3**	0.046	0.047	0.105	0.198	0.105	0.105	0.105	0.105	0.105
L4	0.954	0.953	0.954	**E4**	0.047	0.046	0.83	0.634	0.637	0.2	0.849	0.4
L5	0.366	0.954	0.953	0.953	**E5**	0.047	0.4	0.2	0.046	0.105	0.924	0.371
L6	0.953	0.802	0.895	0.954	0.953	**E6**	0.046	0.047	0.4	0.047	0.371	0.371
F1	0.363	0.363	0.802	0.17	0.6	0.954	**E7**	0.022	0.047	0.2	0.546	0.333
F2	0.895	0.895	0.895	0.366	0.8	0.953	0.978	**E8**	0.2	0.047	0.435	0.4
F3	0.363	0.895	0.895	0.363	0.954	0.6	0.953	0.8	**E9**	0.4	0.924	0.371
F4	0.954	0.978	0.895	0.8	0.895	0.953	0.8	0.953	0.6	**E10**	0.105	0.022
O1	0.974	0.895	0.895	0.151	0.077	0.629	0.454	0.565	0.077	0.895	**E11**	0.924
O2	0.915	0.978	0.895	0.6	0.629	0.629	0.667	0.6	0.629	0.978	0.077	**E12**
O3	0.629	0.6	0.6	0.895	0.077	0.6	0.667	0.877	0.877	0.077	0.817	0.783
O4	0.667	0.6	0.077	0.629	0.077	0.077	0.741	0.974	0.077	0.629	0.817	0.817
KB1	0.629	0.895	0.978	0.895	0.895	0.077	0.629	0.629	0.629	0.629	0.4	0.4
KB2	0.6	0.978	0.895	0.6	0.077	0.6	0.151	0.077	0.629	0.4	0.895	0.895
KB3	0.151	0.895	0.667	0.978	0.6	0.565	0.978	0.6	0.667	0.895	0.6	0.6
KB4	0.974	0.629	0.6	0.565	0.877	0.565	0.978	0.667	0.077	0.783	0.898	0.783
KB5	0.063	0.915	0.915	0.877	0.895	0.974	0.629	0.077	0.629	0.328	0.077	0.629

	O3	O4	KB1	KB2	KB3	KB4	KB5
L1	0.371	0.333	0.371	0.4	0.849	0.026	0.937
L2	0.4	0.4	0.105	0.022	0.105	0.371	0.085
L3	0.4	0.924	0.022	0.105	0.333	0.4	0.085
L4	0.105	0.371	0.105	0.4	0.022	0.435	0.123
L5	0.924	0.924	0.105	0.924	0.4	0.123	0.105
L6	0.4	0.924	0.924	0.4	0.435	0.435	0.026
F1	0.333	0.26	0.371	0.849	0.022	0.022	0.371
F2	0.123	0.026	0.371	0.924	0.4	0.333	0.924
F3	0.123	0.924	0.371	0.371	0.333	0.924	0.371
F4	0.924	0.371	0.371	0.6	0.105	0.217	0.672
O1	0.183	0.183	0.6	0.105	0.4	0.102	0.924
O2	0.217	0.183	0.6	0.105	0.4	0.217	0.371
O3	**E13**	0.371	0.6	0.924	0.371	0.6	0.102
O4	0.629	**E14**	0.6	0.022	0.4	0.371	0.924
KB1	0.4	0.4	**E15**	0.105	0.042	0.105	0.071
KB2	0.077	0.978	0.895	**E16**	0.4	0.6	0.105
KB3	0.629	0.6	0.958	0.6	**E17**	0.6	0.022
KB4	0.4	0.629	0.895	0.4	0.4	**E18**	0.183
KB5	0.898	0.077	0.929	0.895	0.978	0.817	**E19**

Table 8 Crisp values for ε$\mathbf{E_i}$ε

	Developed	Developing
L1	0.3111	0.6118
L2	0.3111	0.6118
L3	0.6118	0.7806
L4	0.6118	0.6118
L5	0.7806	0.7806
L6	0.3111	0.6118
F1	0.6118	0.7806
F2	0.6118	0.6118
F3	0.3111	0.3111
F4	0.1632	0.3111
O1	0.1632	0.6118
O2	0.6118	0.6118
O3	0.1632	0.3111
O4	0.1632	0.1632
KB1	0.3111	0.6118
KB2	0.3111	0.3111
KB3	0.1632	0.6118
KB4	0.3111	0.6118
KB5	0.3111	0.6118

Step 4: Obtain the crisp value for r_{ij} by using Eq. (8). The crisp values are displayed in a 19 × 19 matrix, as shown in Table 7.

Step 5: Repeat steps 3 and 4 to get crisp values of E_i for developed and developing countries, as displayed in Table 8.

5.2.4 Computing the DIHI Value from the crisp relation matrices

The drone implementation hindrance index is calculated for developed and developing countries using the PERMAN algorithm given in Eqs. (9), (10), (11), (12) and (13). The values for E_i in Table 7 are changed in accordance to the case being considered. Thus, the index value for each main factor is also derived from the 19 × 19 matrix. Next, by taking the minimum and maximum values from Table 8, the indexes for the hypothetical best and worst cases are calculated. Finally, the coefficient of similarity for individual cases is calculated based on a scale for comparison. The final values are displayed in Table 9.

6 Results and discussion

The index values of the various factors for developed and developing countries are given in Table 10. The value given for a specific main factor depicts its degree of influence on the implementation of UAVs in humanitarian logistics. The higher the DIHI value of a factor, the more influence it has; whereas, the lower DIHI valued factors are not as significant. The drone implementation hindrance index can be used to determine the readiness of various nations to incorporate UAVs into their humanitarian logistics sector. The nations with higher index values are more reluctant and require greater efforts to incorporate this technology. The following section presents a detailed description of the results obtained from the IVIFS-GTMA methodology.

6.1 Overall analysis

By analyzing the results displayed in Table 9, it is clear that developing countries are not as suited to implementing UAVs in the humanitarian sector as developed countries. The DIHI value for developing countries is 9.57×10^{10}, which is closer to the worst-case value of 10.43×10^{10} than the value given for developed countries. Nevertheless, this shows that many developed countries are also not fully prepared to implement drones into

Table 9 DIHI values for the main factors of developed and developing countries

		Drone Implementation Reluctance Index	Best Value	Worst Value	C_{si}	C'_{si}
Overall Index	**Developed**	6.59×10^{10}	9.83×10^{9}	1.04×10^{11}	0.5937	0.4063
	Developing	9.57×10^{10}			0.9091	0.0909
Legal Factors	**Developed**	3.7129	0.0658	6.1825	0.5963	0.4037
	Developing	5.2440			0.8466	0.1534
Financial Factors	**Developed**	0.5574	0.0338	0.9917	0.5466	0.4534
	Developing	0.6623			0.6561	0.3439
Operational Factors	**Developed**	0.5065	0.0338	1.3077	0.3711	0.6289
	Developing	0.7310			0.5473	0.4527
Knowledge and Behavioral Factors	**Developed**	0.5618	0.0441	1.6900	0.3145	0.6855
	Developing	1.2336			0.7227	0.2773

Table 10 weights assigned to DMs during sensitivity analysis

	DM 1	*DM 2*	*DM 3*	*DM 4*	*DM 5*	*DM 6*
Case 1	*Very Important*	*Unimportant*	*Unimportant*	*Unimportant*	*Unimportant*	*Unimportant*
Case 2	*Unimportant*	*Very Important*	*Unimportant*	*Unimportant*	*Unimportant*	*Unimportant*
Case 3	*Unimportant*	*Unimportant*	*Very Important*	*Unimportant*	*Unimportant*	*Unimportant*
Case 4	*Unimportant*	*Unimportant*	*Unimportant*	*Very Important*	*Unimportant*	*Unimportant*
Case 5	*Unimportant*	*Unimportant*	*Unimportant*	*Unimportant*	*Very Important*	*Unimportant*
Case 6	*Unimportant*	*Unimportant*	*Unimportant*	*Unimportant*	*Unimportant*	*Very Important*
Normal	*Very Important*	*Important*	*Very Important*	*Medium*	*Important*	*Unimportant*

their humanitarian sectors as they have an index value of 6.59×10^{10}.

6.2 Comparison of the main factors

The final index values for the main factors shown in Table 10 tell us that legal factors i.e. government rules and regulations, are the most crucial barrier in the implementation of UAVs in the humanitarian logistics sector. Developing nations have an index value of 5.24, whereas developed nations have a value of 3.71. The next main factor is the knowledge and behavior of citizens. The index value of developing countries for this factor is 1.23, but is only 0.56 for developed countries. For operational factors, both developed and developing nations have similar index values of 0.51 and 0.73, respectively. Finally, financial factors have a DIHI value of 0.66 for developing countries and 0.56 for developed countries.

A graphical representation of the coefficient of similarity of the main factors for developed and developing nations is displayed in Fig. 3. The figure can be used to compare the relative difference between factors more easily. According to the results shown in Table 10 and Fig. 3, legal factors, i.e. government regulations and laws, are the barriers that have greatest weightage in hindering implementation. The C_{si} value for legal factors is 0.5963 for developed countries and 0.8466 for developing ones, the highest valued factor for both categories of nations. The next factor with greatest impact for developing nations was knowledge and behavioral factors with a C_{si} value of 0.7227, followed by financial factors at 0.6561. Finally, the least impacting barriers for developing countries were operational factors with a score of 0.5473. In developed nations, the second highest were financial factors with a C_{si} of 0.5466. The final two factor types of operational plus knowledge and behavioral factors had less impact with C_{si} values of 0.3711 and 0.3145, respectively.

7 Sensitivity analysis

Using human-provided variables to calculate a decision-making index never yields an accurate result. When analyzing the findings of this study, several questions arise: To what extent is the index value influenced by the weighting of DM preferences? Is there any difference in the statistics

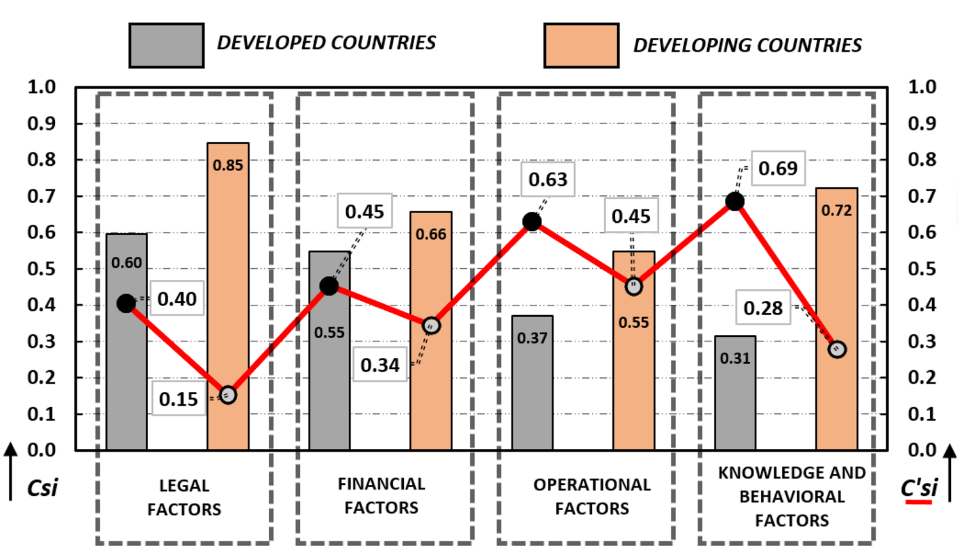

Fig. 3 Graphical Representation of the Coefficient of Similarity

Table 11 DIHI and coefficient of similarity for factors during sensitivity analysis case

	CASE 1				***CASE 2***				***CASE 3***			
	Developed Countries		***Developing Countries***		***Developed Countries***		***Developing Countries***		***Developed Countries***		***Developing Countries***	
	DIHI	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}
Overall Analysis	3.00×10^{10}	0.214	3.85×10^{10}	0.303	2.69×10^{10}	0.180	3.44×10^{10}	0.260	2.82×10^{10}	0.195	3.63×10^{10}	0.280
Legal Factors	3.5496	0.570	4.1165	0.662	3.5532	0.570	4.0499	0.651	3.5496	0.570	4.1165	0.662
Financial Factors	0.349	0.329	0.278	0.255	0.3099	0.288	0.2404	0.216	0.349	0.329	0.278	0.255
Operational Factors	0.3613	0.257	0.6722	0.501	0.3312	0.233	0.6322	0.470	0.3312	0.233	0.6322	0.470
Knowledge and Behavioural Factors	0.3339	0.176	0.9328	0.540	0.2175	0.105	0.6965	0.396	0.2175	0.105	0.6965	0.396
	CASE 4				***CASE 5***				***CASE 6***			
	Developed Countries		***Developing Countries***		***Developed Countries***		***Developing Countries***		***Developed Countries***		***Developing Countries***	
	DIHI	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}	***DIHI***	C_{si}
Overall Analysis	*2.86 x 10^{10}*	*0.199*	*3.67 x 10^{10}*	*0.285*	*2.86 x 10^{10}*	*0.199*	*3.64 x 10^{10}*	*0.282*	*1.16 x 10^{10}*	*0.018*	*1.34 x 10^{10}*	*0.038*
Legal Factors	*3.5496*	*0.57*	*4.1165*	*0.662*	*3.5532*	*0.57*	*4.0499*	*0.651*	*0.7669*	*0.115*	*0.9894*	*0.151*
Financial Factors	*0.349*	*0.329*	*0.278*	*0.255*	*0.3099*	*0.288*	*0.2404*	*0.216*	*0.0632*	*0.031*	*0.0716*	*0.039*
Operational Factors	*0.3312*	*0.233*	*0.6322*	*0.47*	*0.3613*	*0.257*	*0.6722*	*0.501*	*0.1549*	*0.095*	*0.1727*	*0.109*
Knowledge and Behavioural Factors	*0.2175*	*0.105*	*0.6965*	*0.396*	*0.3339*	*0.176*	*0.9328*	*0.54*	*0.0673*	*0.014*	*0.0907*	*0.028*

	NORMAL			
	Developed Countries		***Developing Countries***	
	DIHI	C_{si}	***DIHI***	C_{si}
Overall Analysis	*5.08×10^{10}*	*0.434*	*6.59 x 10^{10}*	*0.584*
Legal Factors	*5.4073*	*0.873*	*5.9731*	*0.966*
Financial Factors	*0.4823*	*0.468*	*0.3851*	*0.367*
Operational Factors	*0.5064*	*0.371*	*0.8852*	*0.668*
Knowledge and Behavioural Factors	*0.5701*	*0.32*	*1.3635*	*0.802*

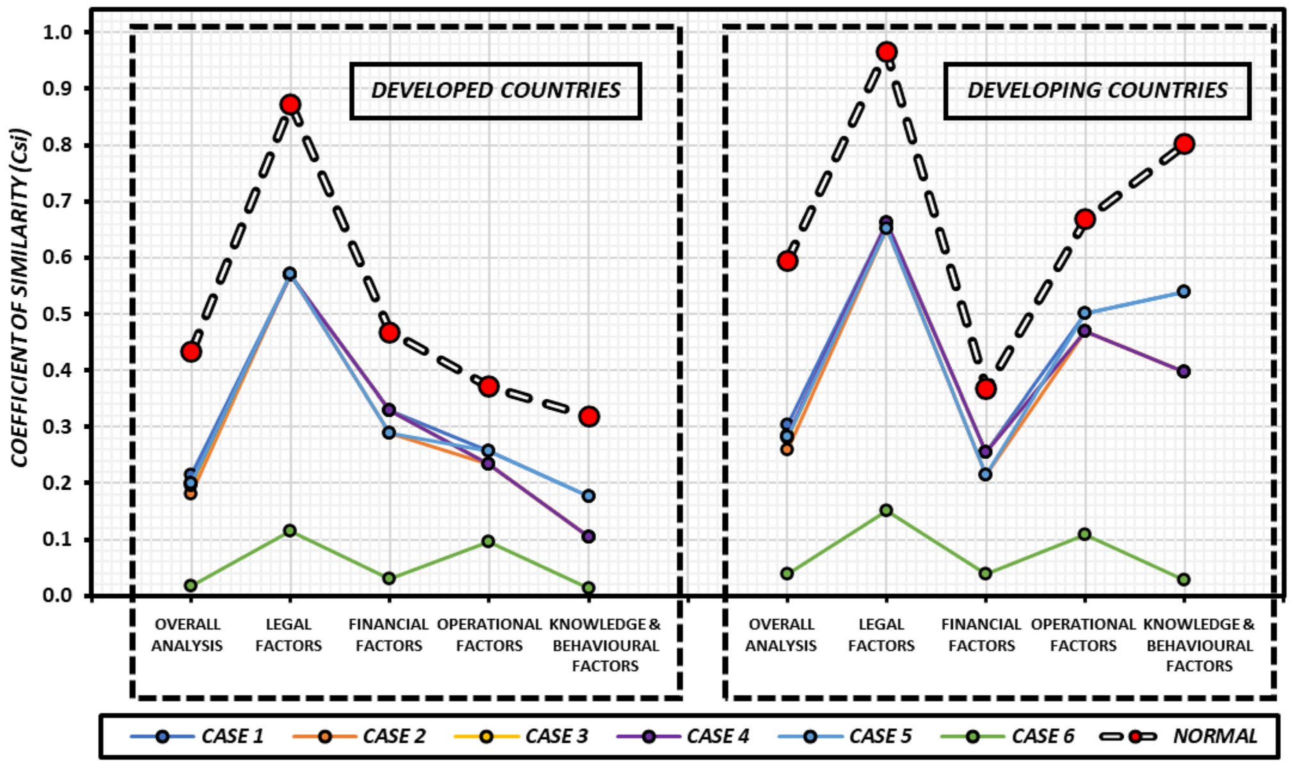

Fig. 4 Coefficient of Similarity (C_{si}) for Factors when Changing DM's Weight via Sensitivity Analysis

because of personal bias? What is the consistency of the findings when these weights are changed? A sensitivity analysis was carried out to combat unpredictability and offer answers to these issues. Sensitivity analysis is a prominent analytic approach for determining how much the stability of a solution is affected by tiny changes in input values. (Mukhametzyanov and Pamucar 2018; Shanker et al. 2021). Chang et al. (2007) demonstrated how small differences in relative weights might lead to substantial differences in the final structure of components. Because human input is the major source of decisions in this study, it is critical to perform a sensitivity analysis to evaluate the findings. This fact is especially relevant to the results obtained in the study. As mentioned previously, out of the ten responses to the post-interview questionnaire, only six were considered for the final results. This was due to significant variations in data from the other four respondents when a sensitivity analysis was performed. In the case of those four experts, a change in DM weights drastically altered the study's final results. Thus, the biased data was omitted from the analysis.

The sensitivity analysis was carried out by changing the weights allocated to the decision-makers' preferences. One decision-maker's weight is set to "Very Important" in each scenario, while the remaining five are set to "Unimportant."

Table 13 Initial List of Factors

Factor ID	Factor Name	Factor ID	Factor Name
L1	Restricted Allowable Flight Range	**O1**	Damaged Surroundings
L2	Impediment of Operations due to Trespass Laws	**O2**	Unstable Weather Conditions; Prompt Delivery Problems
L3	Restrictive Visual Line of Sight Laws	**O3**	Communication Restrictions in Rural Areas
L4	Uncertainty in Determination of Liability	**O4**	Biological and Chemical Threats
L5	Improper Insurance System	**KB1**	Public Ignorance About UAV Technologies
F1	Costly Commercial Solutions	**KB2**	Lack of Environmental Perception Amongst Citizens
F2	Difficult Start-up Opportunities	**KB3**	Vandalism of Drones
F3	High Transport Costs for Larger Deliveries	**KB4**	Inexperienced Operators
F4	Varying Maintenance and Repair Costs	**KB5**	Disturbance for the Public

Table 14 Finalized List of Factors

Factor ID	Factor Name	Factor ID	Factor Name
L1	Restricted Flight Permissions	**O1**	Destroyed Infrastructure from Disaster
L2	Impediment of Operations due to Trespass Laws	**O2**	Unstable Weather Conditions; Prompt Delivery Problems
L3	Restrictive Visual Line of Sight (VLOS) Laws	**O3**	Communication Restrictions in Rural Areas
L4	Obstruction Caused by Lack of Regulated Spectrum Range	**O4**	Biological and Chemical Threats
L5	Uncertainty in Determination of Liability	**KB1**	Public Ignorance About UAV Technologies
L6	Unavailability of Insurance	**KB2**	Lack of Environmental Perception Amongst Citizens
F1	Costly Commercial Solutions	**KB3**	Vandalism Threats during Missions
F2	Difficult Start-up Opportunities	**KB4**	Inexperienced Operators
F3	High Transport Costs for Larger Deliveries	**KB5**	Public Nuisance
F4	Varying Maintenance and Repair Costs		

Table 10 provides more details on the weightage distribution used in the sensitivity analysis. The DIHI and C_{si} values for the key factors in each instance were computed and compared to the typical case. The weightage variations were also used to calculate the overall index value for developed and developing countries. Table 11 summarizes the findings of the sensitivity study. The results closely follow trends in the normal case. In most cases, the ranking order remained the same. Legal factors remained the chief factor in both types of countries as rated by all decision-makers. The next prominent factor for developed countries was financial, which had DIHI values less than 0.35. Meanwhile, for developing countries, some cases showed that operational factors were the next prominent, while another gave this position to knowledge and behavioral factors. Finally, for developed countries, operational factors and knowledge and behavioral factors were less of a hindrance, as shown by their C_{si} values in Fig. 4. In developing countries, the smallest hindrance is provided by financial factors. This may be attributed to the lesser developed infrastructure in developing nations, giving operational factors greater precedence when considering what to improve Tables 12 and 13.

As displayed in Fig. 4, despite variations in the index values over the six cases, the trend for the factors remained nearly constant. The largest variations were observed in Sect. 7 for both types of nations. Factors classified in knowledge and behavioral, such as threats to vandalism, inexperienced operators and unawareness amongst the populace, cannot be easily ranked without a thorough understanding of an individual country's system; this means a greater amount of variation in results. The greatest contrast between C_{si} values for developed and developing countries were in Sect. 7. This indicates that educational levels and awareness of the general public in this area are much lower in developing countries. Contrary to this, the most stable C_{si} value across all cases was legal factors. All decision-makers agreed that inappropriate government regulations were the greatest hindrance when implementing UAVs in any country. Despite attaining a lower DIHI value, developed countries are not fully ready to implement UAVs in their humanitarian sectors. The results of the sensitivity analysis complemented previous results, confirming the importance of creating better policies for UAVs. Incorporating drones in humanitarian logistics will first require a thorough review by policymakers of the regulations relating to the operation of the technology. The sensitivity analysis performed has provided many benefits for the authenticity of this study. By proving that the trends observed in the distribution of main factors remain constant regardless of DM weightage, we can claim that observer bias has not greatly influenced our results.

8 Implications for practice and research

This study aimed to propose an IVIFS-GTMA evaluation framework to determine the readiness of a country to implement UAVs in their humanitarian logistics sector. The combination of opinions provided by experts and the integration of IVIFS into GTMA was used to determine the inter-relationships between identified factors and evaluate them with a drone implementation hindrance index. Managerial and research implications can be drawn from the methodology used to arrive at the results in Table 9 and Fig. 3. The insights presented by this study are:

i. If a country aims to integrate UAVs into their humanitarian logistics sector, it is recommended that they focus on legal factors along with the knowledge and

Table 15 Rating Scale

Linguistic Scale	Input Data
No Influence	N
Low Influence	L
Medium Influence	M
High Influence	H
Very High Influence	V

Table 16 Criteria vs. Criteria Table

	L1	L2	L3	L4	L5	L6	F1	F2	F3	F4	O1	O2
L1	**E1**											
L2		**E2**										
L3			**E3**									
L4				**E4**								
L5					**E5**							
L6						**E6**						
F1							**E7**					
F2								**E8**				
F3									**E9**			
F4										**E10**		
O1											**E11**	
O2												**E12**
O3												
O4												
KB1												
KB2												
KB3												
KB4												
KB5												

	O3	O4	KB1	KB2	KB3	KB4	KB5
L1							
L2							
L3							
L4							
L5							
L6							
F1							
F2							
F3							
F4							
O1							
O2							
O3	**E13**						
O4		**E14**					
KB1			**E15**				
KB2				**E16**			
KB3					**E17**		
KB4						**E18**	
KB5							**E19**

behavioral factors affecting implementation. Policymakers should focus on improving laws regarding drones in humanitarian operations; the public should be better informed about the new technology.

ii. The research findings suggest that government rules and regulations are the major factors preventing smooth implementation of UAVs in humanitarian logistics for both developed and developing nations.

iii. The findings of this study provide a list of coefficients of similarity, normalized with the best and worst values. Policymakers and humanitarian organizations can use this list when developing a plan for implementation of UAVs.

iv. This paper presents a unique methodology, i.e. IVIFS-GTMA using the PERMAN algorithm, to analyze barriers preventing implementation of UAVs in

Table 17 Influence of Criteria on Alternatives

	Developed	Developing
L1		
L2		
L3		
L4		
L5		
L6		
F1		
F2		
F3		
F4		
O1		
O2		
O3		
O4		
KB1		
KB2		
KB3		
KB4		
KB5		

humanitarian logistics for developed and developing countries.

v. For the methodology used in this study, the linguistic scale for GTMA was reclassified utilizing IVIFS. The membership, non-membership and hesitancy functions are defined with intervals rather than a crisp number. This change provides an improved method to handle imprecise and vague data.

vi. The proposed methodology is reliable as the response of each decision-maker is weighted. Inaccurate, dubious or ambiguous data from respondents was dealt with using interval-valued intuitionistic fuzzy numbers. This investigation also used IVIF weighted averaging to total the decision-makers' assessments. Furthermore, the IVIF entropy measure was utilized as a magnitude to measure information in IVIFS. This method has been presented in an easy-to-understand manner for use in future studies.

vii. As mentioned previously, no similar study has analyzed the potential of developed and developing countries to implement UAVs in their humanitarian logistics sectors. The technique used in this study is a general case that can be modified to find the DIHI value of any country.

viii. According to the sensitivity analysis, inadequate government laws are the most significant impediment to UAV adoption in humanitarian logistics, independent of decision-makers' preferences or a country's economic status.

ix. The largest difference in C_{si} values for the case of developed and developing countries was in Sect. 7. Practitioners must note that to implement UAVs in developing countries, technological awareness in those countries must be improved.

x. The countries considered when making decisions for developing nations ranged from those on the higher side of the scale, such as China and India, to those on the lower end of the scale, such as Chile and Nigeria. The variation in nations considered for developing countries has led to a more generalized index that can be refined by considering the cases of individual nations.

xi. Similarly, the nations chosen to judge the hindrances affecting developed countries are those that permit or are currently introducing legislation for BVLOS testing and operations. The index values for developed countries may vary if a specific case is taken for a developed country that has not yet introduced BVLOS.

9 Concluding remarks

The utilization of unmanned aerial vehicles for humanitarian relief and surveillance operations is a rapidly growing research area. The scope of UAVs in humanitarian logistics has been internationally recognized due to their role in recent disasters. Thus, to successfully implement drones into the humanitarian logistics sector, an analysis of barriers preventing their implementation is needed. To better understand the factors hindering UAV implementation, this study answers the research questions proposed in the Introduction. *"What are the various factors hindering the implementation of UAVs in humanitarian logistics in developed and developing countries?"*; this question was addressed in the Factors Affecting UAV Implementation in the Humanitarian Logistics section, where four main factors along with their subfactors were listed and discussed in relation to developed and developing countries. The methodology applied in this study, as discussed in the Solution Methodology section, is used to answer the question, *"What are the inter-relationships between factors and what is their importance in the total framework?"* This issue is answered utilizing IVIFS-GTMA, a sophisticated multi-criteria decision-making method in which we evaluate the inter-relationships between specified elements and give a weightage to their importance priority. *"To what degree have these barriers affected the implementation of UAVs for developed and developing countries?"* The Application of the Proposed Framework section validates the methodology by using a weighted average of values given by decision-makers. In addition, a sensitivity analysis was conducted to examine the stability of DIHI values for the identified factors. The final result of the IVIFS-GTMA structure was the generation of a drone implementation hindrance index showing how much each main factor affected UAV implementation in developed and developing nations. Finally, *"What are the practical and research implications of the study"* was answered in the Implications for Practice and Research section, where the implications of this study were listed. The results can help policymakers and practitioners improve their decision-making processes when trying to implement UAVs into a humanitarian organization for a specific country.

Many situations in this study could be amended or developed for future works. The weighted consideration of each decision-maker could be improved by taking into consideration a new aggregating method. Also, the definition of a developed and developing country is not exact; thus, as several countries for all aspects of the spectrum were taking into consideration, the results have become generalized. Further works can be conducted by analyzing specific scenarios in a country by using the proposed framework and changing the values received from decision-makers.

10 Appendix A: Interval-valued intuitionistic fuzzy-based graph theory and matrix approach using the PERMAN algorithm

Step I: Identification of the factors affecting the implementation of UAVs in humanitarian logistics of developed and developing nations while considering relative interdependencies among those factors.

Step II: Development of the diagraph, taking into account the variables recognized and their interdependencies.

Step III: Transformation of the diagraphs into matrices as shown in Eq. (1).

$$G = \begin{pmatrix} E_1 & r_{12} & r_{13} & \cdots & r_{1n} \\ r_{21} & E_2 & r_{23} & \cdots & r_{2n} \\ r_{31} & r_{32} & E_3 & \cdots & r_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & r_{n3} & \dots & E_n \end{pmatrix} \tag{1}$$

where E_i is the value of the factor represented by node i on the diagraph and r_{ij} is the relative importance of i^{th} factor over j^{th} represented by the edge r_{ij}.

Step IV: Take inputs from IVIFS linguistic terms and transform them into crisp numbers using the next steps:

- **Definition 1** Let X be an ordinary finite non-empty set. An IFS A in X is described as

$$A = \left\{ \langle x, \mu_A(x), v_A(x) \rangle | x \in X \right\}, \tag{2}$$

where $\mu_A(x) : X \to [0,1]$ and $v_A(x) : X \to [0,1]$ are represented in the following way: $0 \le \mu_A(x) + v_A(X) \le 1, x \in X$. The denotation $\mu_A(x)$ represents the degree of membership, whereas $v_A(x)$ represents the degree of non-membership of the element $x \in X$ to the set A. $\pi_A(x)$ is the hesitance level of $x \in X$ to the set A and is described as $0 \le \pi_A(x) \le 1, x \in X$. It is influences by.

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x), x \,\epsilon\, X \tag{3}$$

- **Definition 2** be a regular finite non-empty set. An IVIFS A in X is given by $\tilde{A} = \left\{ \langle x, \tilde{\mu}_{\tilde{A}}(x), \tilde{v}_{\tilde{A}}(x), \tilde{\pi}_{\tilde{A}}(x) \rangle | x \in X \right\}$, where $\tilde{\mu}_{\tilde{A}}(x) \subset [0,1], \tilde{v}_{\tilde{A}}(x) \subset [0,1], \tilde{\pi}_{\tilde{A}}(x) \subset [0,1]$ are intervals representing the degree of membership, degree of non-membership and degree of hesitation of the element x in the set A, respectively. $\pi^L_{\tilde{A}}(x) = 1 - \mu^U_{\tilde{A}}(x) - v^U_{\tilde{A}}(x), \pi^U_{\tilde{A}}(x) = 1 - \mu^L_{\tilde{A}}(x) - v^L_{\tilde{A}}(x)$ for all $x \in X$.
- **Definition 3** The IVIFS is developed based on IFS with the condition $\alpha + \beta \in [0,1]$, where $\alpha x = 0.5$ and $\beta x = 0.5$ are the fuzzification parameters. Then, the intervals are expressed as

$$\left[\mu^L_{(A)}(x), \mu^U_{(A)}(x)\right] = \left[\left|\mu_A(x) - \alpha_x \pi_A(x)\right|, \left|\mu_A(x) + \alpha_x \pi_A(x)\right|\right] \tag{4}$$

$$\left[v^L_{(A)}(x), v^U_{(A)}(x)\right] = \left[\left|v_A(x) - \beta_x \pi_A(x)\right|, \left|v_A(x) + \beta_x \pi_A(x)\right|\right] \tag{5}$$

$$\left[\pi^L_{(A)}(x), \pi^U_{(A)}(x)\right] = \left[1 - \mu^U_{(A)}(x) - v^U_{(A)}(x), 1 - \mu^L_{(A)}(x) - v^L_{(A)}(x)\right] \tag{6}$$

- **Definition 4** The aggregated value of $\alpha_j = \left(\left[\mu^L_j, \mu^U_j\right], \left[v^L_j, v^U_j\right], \left[\pi^L_j, \pi^U_j\right]\right)$ utilizing the IVIFWA operator is described as

$$\left(\left[1 - \prod_{j=1}^{n}\left(1 - \mu^L_j\right)^{\lambda_j}, 1 - \prod_{j=1}^{n}\left(1 - \mu^U_j\right)^{\lambda_j}\right], \left[\prod_{j=1}^{n}\left(v^L_j\right)^{\lambda_j}, \prod_{j=1}^{n}\left(v^U_j\right)^{\lambda_j}\right]\right) \tag{7}$$

$$\left(\prod_{j=1}^{n}\left(1 - \mu^U_j\right)^{\lambda_j} - \prod_{j=1}^{n}\left(v^U_j\right)^{\lambda_j}, \prod_{j=1}^{n}\left(1 - \mu^L_j\right)^{\lambda_j} - \prod_{j=1}^{n}\left(v^L_j\right)^{\lambda_j}\right)$$

where λ_j represents the weight of α_j.

From a suggestion by Wei et al. (2011), the fuzzy entropy of the IVIFS is also calculated by taking into consideration all components of the IVIFS.

- **Definition 5** The fuzzy entropy measure of an IVIFS $\left(\left[\mu^L_i(x), \mu^U_i(x)\right], \left[v^L_i(x), v^U_i(x)\right], \left[\pi^L_i(x), \pi^U_i(x)\right]\right)$ is described as

$$a_{ij} = E(A) = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{2 - \left|\mu^L_i(x) - v^L_i(x)\right| - \left|\mu^U_i(x) - v^U_i(x)\right| + \pi^L_i(x) + \pi^U_i(x)}{2 + \left|\mu^L_i(x) - v^L_i(x)\right| + \left|\mu^U_i(x) - v^U_i(x)\right| + \pi^L_i(x) + \pi^U_i(x)}\right] \tag{8}$$

where n is the number of elements in the IVIFS.

Step V: Transformation of these matrices into the permanent function is performed by using the equation given; this has also been used in the PERMAN algorithm.

$$x_i = a_{i,n} - \frac{1}{2}\sum_{j=1}^{n} a_{ij}(i = 1, \dots, n) \tag{9}$$

$$f(S) = \prod_{i=1}^{n} \lambda_i(S) \tag{10}$$

$$per(G) = (-1)^{n-1}2\sum\nolimits_{S}^{''}(-1)^{|S|}\prod_{i=1}^{n}\left\{x_i + \sum_{j\in S} a_{ij}\right\} \tag{11}$$

where S runs only over subsets of $1, 2, \dots, n-1$. To reduce the amount of processing required by a factor of n/2 for each subset $S \subseteq \{1, 2, \dots, n-1\}$, the following has to be computed.

$$\lambda_i(S) = x_i + \sum_{j\in S} a_{ij}(i = 1, ..., n) \tag{12}$$

Suppose the current subset S differs from its predecessor S' by a single element, j. Then,

$$\lambda_i(S) = \lambda_i\left(S'\right) \pm a_{ij}(i = 1, ..., n) \tag{13}$$

These equations are coded in MATLAB to execute the PERMAN algorithm.

Step VI: Calculation of Drone Implementation Hindrance Index utilizing PERMAN algorithm.

Step VII: The theoretical best value and theoretical worst value are calculated.

Step VIII: If their diagraphs are isomorphic or their drone implementation factors' matrices are similar, any two instances chosen for comparison will be comparable from the perspective of the implementation impediment. In general, two situations are never similar from a humanitarian standpoint; a factor that impacts one scenario may not have an impact on behaviours in other situations. As a result, measuring the co-efficient of their similarity or dissimilarity allows for a more accurate comparison of two circumstances.

$$C_{si} = \frac{\left(C_{ij} - B_{ij}\right)}{W_{ij} - B_{ij}} \tag{14}$$

where.

C_{si} = The coefficient of similarity between the i^{th} and the best factor.

B_{ij} = The best value of component i in the j^{th} scenario.

$C_{ij=}$ Current value of i^{th} factor of j^{th} situation.

The following formula is used to compute the coefficient of similarity of the i^{th} factor with the worst value.

$$C'_{si} = \frac{\left(W_{ij} - C_{ij}\right)}{W_{ij} - B_{ij}} \tag{15}$$

where

C'_{si} = The coefficient of similarity between the i^{th} and the worst factor.

W_{ij} = The worst value of comp in the j^{th} scenario.

C_{si} value implies more similarity with the best value. Alternatively, the smaller the value of C_{si}, the less is the intensity of a factor influencing drone implementation in humanitarian logistics. Similarly, the lower the value of C'_{si} the greater the effect of the factor in influencing drone implementation.

11 Appendix B: Detailed information about experts

Table 12 Detailed information about experts

Expert Domain	S.No	Years of Experience	Qualification	Designation and Job Description	
Humanitarian Supply Chain Academician	1	12	PhD	Associate Professor	Optimizing humanitarian aid
	2	13	PhD	Associate Professor	Developing UAV network platform
	3	14	PhD	Associate Professor	Logistics and transport planning
UAV Developing and Manufacturing Company Experts	4	12	Master's Degree in Engineering	Aircraft Maintenance Engineer	Ensure safe and proper operation of working aircrafts
	5	10	Bachelor's Degree in Engineering	Quality Control Officer	Assessing and verifying products meet organization standard
	6	8	MBA	Project Manager	Develop and execute plans to identify and drive productivity

12 Appendix C: Questionnaire

12.1 Background Information

The information gathered from the questionnaire will enable the research to identify and analyze the barriers preventing implementation of unmanned aerial vehicles in developed and developing nations. Along with answering the qualitative questions below, we would also ask the respondents to attend a short interview where your answers may be further explained. Furthermore, we shall be providing you with a detailed explanation of the rating scale and how the final questionnaire must be completed.

1. Please provide some basic information about yourself:

   Educational Qualification: ____________________ ____________.
   Designation: ________________________________ ____________.
   Job Description: _____________________________ ____________.
   Years of Experience: __________________________ ____________.

2. The following table contains the factors that have been considered for this study after an extensive literature review.

Are there any factors that you deem to be inappropriate for the study? If yes, please list the factor and give a brief explanation.

____
____
____
____
____
___________.

____
____

Are there any factors that should be added to the study?

i. ____
ii. ____
iii. ____

Would you prefer to be contacted through other means for the interview and second questionnaire? If yes, provide the alternative contact information below.

13 Post-Interview Questionnaire

The final list of factors is presented below in Table 14. Please rate the inter-relationships between the factors as indicated in Table 15. As explained in the interview, the cells of Table 16. must be filled with the level of influence you believe the row factor has on the column factor. For this table the diagonal values will remain empty. Next, Table 17. will indicate the level of influence a certain factor has on a developed or developing nation. We ask the respondents to take their time filling out these tables and to make decisions free of bias.

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