The potential of emergent disruptive technologies for humanitarian supply chains: The integration of Blockchain, Artificial Intelligence and 3D Printing

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Abstract

The growing importance of humanitarian operations has created an imperative to overcome the complications currently recorded in the field. Challenges such as delays, congestion, poor communication and lack of accountability may represent opportunities to test the reported advantages of emergent disruptive technologies. Meanwhile, the literature on humanitarian supply chains looks at isolated applications of technology and lacks a framework for understanding challenges and solutions, a gap that this article aims to fill. Using a case study based on the flood of Tabasco of 2007 in Mexico, this research identifies solutions based on the use of emergent disruptive technologies. Furthermore, this article argues that the integration of different technologies is essential to deliver real benefits to the humanitarian supply chain. As a result, it proposes a framework to improve the flow of information, products and financial resources in humanitarian supply chains integrating three emergent disruptive technologies; Artificial Intelligence, Blockchain and 3D Printing. The analysis presented shows the potential of the framework to reduce congestion in the supply chain, enhance simultaneous collaboration of different stakeholders, decrease lead times, increase transparency, traceability and accountability of material and financial resources, and allow victims to get involved in the fulfilment of their own needs.

Keywords: Humanitarian logistics; disruptive technologies, blockchain; artificial intelligence; 3D printing; disaster management

Introduction

Humanitarian logistics looks at the mobilisation and management of resources (human and material) to provide support for disaster victims in uncertain conditions (Van Wassenhove 2006; Manopiniwes and Irohara 2017; Sahin, Narayanan, and Robinson 2013). The dispatch of commodities such as food, water, medicines, cleaning kits, and tents is essential to ensure the survival of the victims. However, damaged infrastructure, multiple participants, uncertain conditions, and the dynamic variation of needs hinder the provision of them. For instance, Lee and Marc (2003) argue that current disaster management systems are affected by; duplication of efforts for data input, multiple formats, lack of control of budgets, absence of accountability, lack of integrity in procurement procedures, absence of a central database, and manual reporting and tracking. These challenges engender limited coordination among multiple stakeholders, supply shortages, lack of records, and poor information management (Schultz and Søreide 2008; Whybark et al. 2010). The flood of Tabasco in 2007 represents a good example of these problems, which were amplified by the unprecedented scale of the disaster. With the advent of Industry 4.0, there is an opportunity to investigate technological applications to improve disaster management.

This paper argues that an integrated combination of emergent disruptive technologies (EDTs) can augment, trace and implement decisions capable of helping to overcome these conditions. The research questions investigated in this article are:

- What are the main challenges for the humanitarian supply chain faced by Mexican authorities during disaster management?
- How could EDTs help tackle the challenges faced during disaster management?

- What would be the benefits of a framework integrating emergent disruption technologies in the flow of information, products and financial resources in the humanitarian supply chain?

The purpose of this paper is to identify the advantages of implementing EDTs in the humanitarian supply chain (HSC) and use them to propose a framework to enhance the flow of information, products and financial resources in disaster settings through the analysis of a case in Mexico. This is the first paper looking into the value of integrating the three technologies, especially in a complex environment such as disaster response. The contribution of this article to theory includes the analysis of the use of EDTs in the HSC and the proposal of a novel conceptual framework to enhance HSCs using EDTs, tackling the current gap in the literature regarding the use of EDTs in humanitarian supply chains. Additionally, the practical contribution of this paper is the identification of their benefits in disaster management in Mexico.

The article is structured as follows. Section 2 introduces the HSC and common problems. Section 3 elaborates on the use of technology to support HSCs, Section 4 presents the methodology of this article and Section 5 introduces the case study. Section 6 discusses the potential role of EDTs in the HSC and introduces the framework for a robust HSC. Section 7 provides the research agenda and Section 8 outlines the conclusions and areas for future research.

2. The humanitarian supply chain

The purpose of HSCs is to obtain the required resources, transport them to the affected region, and deliver them to the victims. Humanitarian distribution channels present the flow of in-kind relief reaching the affected areas, flow of information and data for order transmission and control, and unilateral flow of money from donors to organisations

(Charles et al. 2016). These three flows are essential for any supply chain and are defined as logistics, information and financial flows (Wang, Jia, et al. 2019). **Error! Reference source not found.** depicts these flows in a typical HSC, beginning with financial and logistics flows from individual donors until the resources are transported to reach the beneficiaries. At the same time, information is generated at demand areas and transmitted to the stakeholders, which include donors. Traditionally, the information has been filtered by decision-makers and disseminated through mass communication channels. That dynamic is changing with the advent of social media, which is eliminating intermediaries in information management and allowing information through varied information channels.

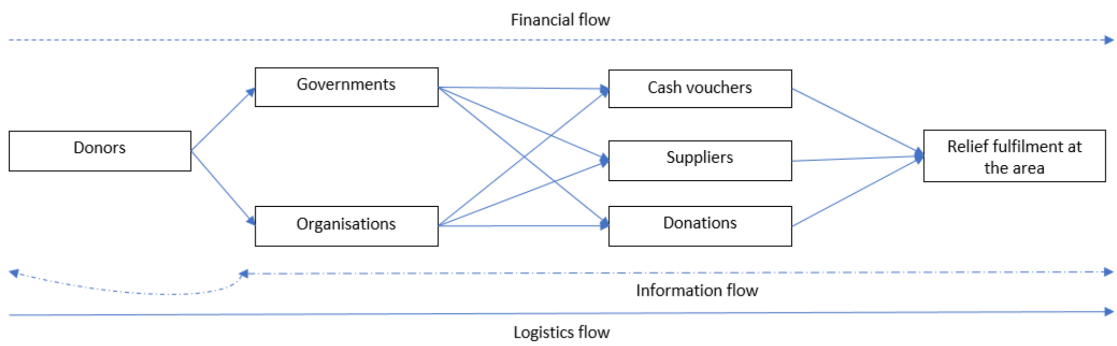


Fig. 1 Humanitarian supply chain

2.1 Logistics flow

Lead time delays, shortage of commodities and excess of low-priority products are common during disasters because of damaged transportation infrastructure and demand uncertainty (Sahin, Narayanan, and Robinson 2013). Delays are caused by poor planning, limited availability of vehicles and conditions of the disaster, whereas shortages of relief occur mostly because of limited availability of information, poor needs assessment and deficient supplier management. In other cases, however, the large number of participants can lead to the convergence of significant amounts of relief causing congestion (Holguín-Veras et al. 2014). Facilities and human resources in countries stricken by disaster can be overwhelmed by large amounts of relief. Congestion is worsened by the delivery of low-priority items among urgent relief. This creates the need to sort and manage undesired relief (Kovács and Spens 2007), which causes bottlenecks in the supply chain.

There are articles addressing these challenges by introducing formulations accounting for uncertainty in transportation, minimising time, introducing prepositioning policies for immediate deployment, and allocating human and material resources (Song, Chen, and Lei 2018; Sharifyazdi et al. 2018; Rodríguez-Espíndola, Albores, and Brewster 2018b). However, most of these articles do not look at the whole HSC nor the effect of donor independence (Whybark et al. 2010). From the HSC standpoint, Oloruntoba and Gray (2006) argue for the use of effective demand-led inventory management using postponement to allow quick responsiveness while maintaining lower costs. Saputra et al. (2015) explore the trade-off between transport modes and end-of-shelf-life policies for medicine prepositioning in cases of disaster. They present a trade-off between mode of transport and end-of-shelf-life policies affecting the pre-positioning strategy depending on the mean time between disasters. Kunz, Reiner, and Gold (2014) argue the feasibility of stock prepositioning by comparing it to investing in humanitarian logistics capabilities (e.g. training staff, pre-negotiating customs agreements, or matching import procedures with local customs). All of these solutions, however, rely on good information management and reliable decision-making, which are often missing during disaster situations.

2.2 Information flow

The flow of information involves assessment and monitoring of the situation, information sharing and coordination among organisations, and appeals to donors

(Comes 2016). The large number of stakeholders involved (e.g. Governments, NGOs, foreign governments) and the uncertain number of self-initiated participants (Whybark et al. 2010) make information management essential to foster coordination.

Disaster situations create an environment lacking communication infrastructure, standardisation, and reliable information. Hence, coordination has been identified as a major challenge. The absence of coordination can cause oversupply of resources or competition for the same resources, as exemplified by the "truck crisis" that took place on Haiti in 2010, in which the scarcity of trucks prevented the delivery of ready-to-go relief. This happened because of poor coordination among stakeholders resulting from lack of information sharing and meagre communication (Dwivedi et al. 2018).

To support disaster operations under conditions of limited information, authors have provided formulations to manage that environment using fuzzy approaches, stochastic programming, robust optimisation, network-based approaches, and hybrid approaches with optimisation (Baryannis et al. 2019) Nevertheless, the impact of unreliable information has led researchers to look for more reactive solutions for HSCs. A popular argument has been the need for agility, which allows to react to changing conditions swiftly (Oloruntoba and Gray 2006; Rasouli 2018). How to improve information across the HSC, however, remains a major challenge.

2.3 Financial flow

Disasters cause a significant flow of money towards the affected area. At times of crisis, the management of financial funds has a steep impact on the victims. Previous experience, however, has shown several shortcomings. The visibility of financial funds is often poor in these settings (Schultz and Søreide 2008). Despite the importance of procuring and tracking items during disaster response (Lee and Marc 2003), studies have identified corruption in procurement, diversion of resources, and lack of accountability stemming from the management of financial flows (Schultz and Søreide 2008). This is a problem for the aid-receivers in three ways: the resources that are not used for the intended purpose, the diminished trust from the donors, and potential bias leading to inconsistent coverage (Lentz et al. 2013).

An alternative to decentralise procurement practices has been to make the resources directly reach customers in the form of cash vouchers. Cash vouchers are coupons that can be used as money and exchanged for goods and services and are becoming an attractive alternative because these can reduce lead times and support local procurement (Lentz et al. 2013). Nevertheless, control of these cash vouchers suffers from the same challenges in terms of traceability and potential bias.

2.4 Summary

Recent experiences show challenges in the flow of relief, information and financial resources during disaster situations (Santos-Reyes, Alvarado-Corona, and Olmos-Peña 2010). The HSC requires reduced lead-times for relief delivery, improved coordination and communication, reliable accountability and transparency, real-time information, and agile practices. There are interesting proposals to achieve these, but most of them are isolated strategies to improve certain shortcomings in HSCs. There is a need to look at the whole supply chain and the three flows presented to identify the most beneficial approaches to enhance HSCs (Wang, Jia, et al. 2019). This paper argues that the integration of different EDTs can be a valuable alternative to augment, trace and implement decisions.

3. Technology in the humanitarian supply chain

A global review of disaster initiatives of the UN highlighted that the use of information, technology and applied research can be essential to tackle disaster risk reduction (Schryen and Wex 2014). Hence, different efforts have been undertaken to use information and technology in disasters. For instance, there are analysis using cooperative games to gather insights about the drivers for successful coordination (Ergun et al. 2014), ERP systems and tracking systems for humanitarian purposes (Comes 2016), RFID technology for tracking in relief distribution (Wu and Lirn 2011) and barcoded ID cards for delivery of items (Ergun et al. 2014)

More recently, technologies linked to Industry 4.0 have been seen as a potential solution to the challenges faced by HSCs. Cichosz (2018) lists 8 technologies that will be increasingly used in the forthcoming years, including; Self-Driving Vehicles (SDV), Unmanned Aerial Vehicles (UAVs), Artificial Intelligence (AI), 3D Printing (3DP), Blockchain (BC), Next-Generation Wireless (NGW), Bionic Enhancement (BE), and Virtual Reality (VR).

3.1. EDTs in the humanitarian supply chain

Damages in infrastructure and chaotic conditions in the roads have led to a lack of articles focused on SDV. Nevertheless, the need to reach the affected areas during disaster management despite these challenges has pointed at alternative vehicles, such as UAVs. There are articles looking at providing disaster assessment (Oruc and Kara 2018), developing emergency communication systems (Tuna, Nefzi, and Conte 2014), supporting search and rescue operations (Beck et al. 2018), and enhancing distribution (Chowdhury et al. 2017). Alternatively, an option to avoid having to transport commodities at all is through on-site production. Labonnote et al. (2016) suggest the use of 3DP for the construction of temporal shelters because of its capability to produce products of almost any shape (Gardan 2016). Tatham, Loy, and Peretti (2015) look at the advantages of 3DP for humanitarian logistics focusing on the ability of fused deposition modelling (FDM) to produce parts for repairing water, sanitation and hygiene equipment. More recently, Savonen et al. (2018) propose the design of a portable 3D printer for humanitarian operations using a variant of FDM.

Information and communication have been studied considering NGW and BC. NGW has been proposed for the development of new public safety communication networks (Sohul et al. 2016) and the combination of wireless with IoT to manage multiple sensors for data delivery (Al-Turjman 2019). On the other hand, BC is an enabling technology recently analysed in the context of logistics (Winkelhaus and Grosse 2019). The U.S. government explore its use to create a decentralised system through improved information sharing to exploit its traceability, transparency and immutability (Akilo 2018), and there has been an appearance of blockchain-based charity sites such as Binance and BitShares for disaster donations (Wolfson 2018).

BE has not been analysed from the perspective of HSCs, but VR has been suggested for preparedness to train disaster professionals (Farra, Miller, and Hodgson 2015), to visualise disaster scenes (Ya et al. 2018), to create disaster awareness (Suarez 2017), and to prepare disaster evacuations (Danial et al. 2019).

AI has been a prominent technology to augment decision-making. For instance, articles in the literature have focused on identifying disaster risk (Chen et al. 2013), predicting flood routing (Bagatur and Onen 2018), improving situational awareness using big data (Khare, Burel, and Alani 2019), and using big data to detect socio-economic recovery (Shibuya and Tanaka 2019) and resilience (Papadopoulos et al. 2017). Specifically looking at logistics activities, there have been contributions to enhance evacuation by analysing human behaviour (Kurdi et al. 2018), to create expert systems to simulate instances to develop operational strategies (Dong et al. 2013), and to implement agent-base techniques to manage disruptions in the supply chain (Blos, da

Silva, and Wee 2018). AI also has potential to be complemented with other technologies. For instance, Tang and Wen (2009) joined AI with GIS to inform decision-making for infrastructure management during earthquakes.

3.2. Research focus

Technology has been a major enabler for commercial operations management over time (Gershwin 2018). Winkelhaus and Grosse (2019) classified the technological building blocks into three categories; information generation, information handling and information usage. The first concept refers to gathering information to enhance visibility of the system, whereas information handling refers to managing the data and analysing it, and information usage means planning tasks, executing tasks and providing services (Winkelhaus and Grosse 2019). Different articles have studied information generation in disaster management (Alexander 2013; Lin et al. 2016; Wu and Lirn 2011). This article focuses on information handling and usage.

Among the EDTs, the lack of studies looking at BE and SDV in humanitarian logistics constraints their use. VR has been associated with training and disaster awareness, but it is more related to pre-emptive activities than the HSC at the response stage. NGW has significant value to set-up communications, but its application in relief distribution has been envisioned more as infrastructure. UAVs are an interesting alternative for relief distribution, but limitations in payload, scalability, coordination, safety and energy efficiency can limit their application (Floreano and Wood 2015; Chowdhury et al. 2017).

AI, BC and 3DP are among the most representative technologies shaping future developments in operations management (Xu, Xu, and Li 2018) and they represent suitable technologies for data handling and usage (Winkelhaus and Grosse 2019). In fact, AI as well as 3DP have been successfully combined with BC before (Dinh and

Thai 2018; Mandolla et al. 2019). Therefore, this article is focusing on the role of AI, BC and 3DP in the HSC. This article argues that the combination of these three EDTs can improve the logistics flow in the physical world at the same time as it improves processes in the virtual world for HSCs.

3.2.1 Artificial Intelligence

AI involves determining a specific information management problem, introducing a computational formulation for it, and creating an algorithm to implement it (Marr 1977). Artificial intelligence is increasingly being utilized to make data-driven business decisions in various business and social contexts because it facilitates knowledge discovery to formulate recommendations and deep insights by employing intelligent algorithms to process (O'Leary 2013). Unlike traditional statistical and operational research techniques, it has the ability to learn from existing data and adapt with the new incoming stream of data (Kaplan and Haenlein 2019).

Employing AI-based techniques will result in: (1) reducing the information and cognitive overload posed by the huge volumes of data generated from multiple streams at any given point, i.e. automatically aggregate, process and summarise the data, thus turning it into useful information for the decision-makers; (2) reducing aggregating latency, i.e. ability to automatically aggregate historical data with new incoming data streams that will facilitate both learning from historical information and adapting outputs (recommendations) considering the newly captured information (Deparday 2019); (3) reducing analysis latency, i.e. transforming the data into usable information that will aid to quickly explore the data visually and identify interesting trends and patterns within this digital asset; (4) reducing decision latency, i.e. augmenting human decision-making supported through automated recommendations generated by employing AI techniques considering all data streams in a timely manner, which is extremely significant in the case of crisis, disaster and safety critical systems (Radianti et al. 2019).

There are a range of potential applications of AI in the supply chain. The advantages of this technology allow the design of decision-support systems for performing supplier selection, introducing agility in the HSCs, mining patterns in big data for risk identification, managing information from multiple sources, among others (Baryannis et al. 2019). Moreover, the capabilities of AI make it ideal to combine with other techniques and technologies to develop hybrid systems to augment decisions (Baryannis et al. 2019; Dinh and Thai 2018).

3.2.2. Blockchain

BC is an electronic ledger, which relevant users can view but cannot manipulate. It can record transactions in a secure, transparent, decentralized, efficient, and low-cost way (Schatsky and Muraskin 2015). BC can simplify the transmission of information to eliminate commonly conflicting layers. Information thus is more reliable, accurate, timely, highly visible and incorruptible. Having “better” information can enhance collaboration and coordination, because it can enable the implementation of decentralised systems. The key properties of this technology that makes it a valuable proposition to handle transactions are discussed below.

(1) *Immutable:* BC will record and store all transactions, and each transaction is protected from deletion, tampering and revision. Any modifications made are automatically recorded as new transactions, which are linked to the previous transaction, by the software code in the blocks.

(2) *Distributed:* All entities involved in the BC network have an identical copy of the ledger (information stored in the blocks) in their computer (often referred to

as nodes). This increases the visibility of the transactions and allows to easily identify mismanagement of the cash and the entities involved in the transaction.

(3) *Decentralised:* This property will aid in transactions between entities in the BC network without the need of any central intermediary, which leads to faster processing times and eliminates the risk of the data being held centrally.

(4) *Automated:* Every transaction is automatically recorded through the code being executed in the BC (without any human involvement) and cryptographically verified, ensuring the authenticity of the transactions. This makes the whole process incorruptible and devoid of errors. The automation leads to reduced transaction times.

(5) *Single unified ledger:* Since all the transactions are recorded in a single immutable public ledger (assuming a permission-less BC network is used), it will help to aggregate all the transactions into a single unit.

(6) *Self-reviewing:* The blockchain will automatically update after each transaction and record the information, which will ensure that every node (participating entity in the network) will store an up-to-date copy of the ledger.

BC technology will help to increase the trust among all the stakeholders involved in the financial flow and it will decrease the processing lead times, which is essential for HSCs. Additionally, analytics employed over the information stored in the blocks has the potential to better understand cash flows, which in turn will make the economic resource allocation efficient (Huckle et al. 2016).

One of the potential applications of BC is in smart contracts. BC Smart contracts are self-executing software programs encoding contractual agreements usually in the form of mathematical rules in the BC network (Saberi et al. 2018). The self-execution will depend upon the operations (actions) of the participating entities, which are the input variables to smart contract algorithm. This eliminates the reliance on the intermediaries to seek approval and thus will aid in decreasing the contract processing time. The self-executing programs in the smart contracts will help to trace and track the distribution either by collecting relevant data from sensors (IoT enabled devices) or input from organisations (Huckle et al. 2016).

3.2.3. 3D Printing

The term 3DP refers to a range of *additive* manufacturing processes that have grown from prototyping tools in the late 1980s into an ecosystem of disruptive technologies. 3DP technologies vary, but share two common characteristics:

1) They build parts in layers of material, for example metal powders that are melted by laser or liquid polymers cured with ultraviolet light. This enables complex shapes to be created, removing traditional constraints on geometry, as well as removing cost penalties traditionally associated with low volume production (Candi and Beltagui 2018; Petrovic et al. 2011).
2) They build parts directly from digital models, without the need for tooling. This enables decentralised production, removing traditional constraints on geography, as well as enabling customisation of parts (Holmström and Partanen 2014).

While unit costs and energy consumption may be higher than mass production, 3DP makes it feasible and economical to produce small batches, of parts, where and when required (Weller, Kleer, and Piller 2015; Baumers and Holweg 2019). The potential of 3DP holds appeal for environments where rapid response to uncertain demands is essential.

Supply chain research has examined a number of applications for 3DP in complex industrial contexts as well as for facilitating customer involvement. Khajavi, Partanen, and Holmström (2014) model configurations for spare parts supply chains, demonstrating the responsiveness and agility benefits from distributed 3DP compared to centralised production and transportation. Meanwhile, Beltagui, Kunz, and Gold (2019) modelled the benefits to a mobile phone company's market penetration that result from opening the design and production of accessories to customers. These studies show the advantages and potential of 3DP to be used in activities such as infrastructure repairs and production of accessories on-site, which can be highly valuable for HSCs.

3.3 Research gap

The articles reviewed in this section show that applications of EDTs in humanitarian logistics are usually isolated and still at their infancy. Despite the advances on technology, managers are still struggling to manage the financial, logistics and information flows presented in HSCs. This is partly because many advances and technologies have not been properly transferred to users in the humanitarian field, but also because the benefits from the integration of different technologies addressing the combination of three flows are currently under-investigated. It is important to look at the three flows and their integration to develop supply chain capabilities (Wang, Jia, et al. 2019).

AI, BC and 3DP have been associated with humanitarian operations before as isolated solutions, but never looking at the whole HSC. Furthermore, the integration of these three technologies has not be hinted in the literature before as a potential solution to the complications to the smooth flow of information, products and money in disaster situations. This article addresses that gap by providing an analysis of a real case study looking at the use of EDTs in the context of humanitarian logistics and proposing a conceptual framework to improve HSCs.

4. Methodology

The purpose of this paper is to analyse the role of technology in the HSC to propose a framework to improve operations. EDTs such as 3DP, BC and AI have a lot of potential to be implemented in different fields (Xu, Xu, and Li 2018). Nevertheless, several of these applications and their implications are yet to be investigated. Given the potential of case research to generate, test or elaborate on theory (Ketokivi and Choi 2014), and its value to look at instances which have been scarcely investigated before (Voss, Tsikriktsis, and Frohlich 2002), this paper uses a case study to analyse the prospective role of EDTs in disasters.

4.1. Research approach

Three types of case studies can be carried out for research purposes: exploratory, descriptive and explanatory (Yin 1981). This article is presenting an exploratory study (Yin 2018) to show the challenges faced in disaster management and the capabilities of the technologies discussed to provide solutions. An exploratory case study is suitable for this because it allows to understand dynamics existent in a defined context (Eisenhardt 1989; Burnard and Bhamra 2011). In that sense, the case presented in this article is used to analyse current issues in disaster management in Mexico to identify the value of different technologies to improve the HSC. Through a review of extant literature about technologies used in disaster situations, the case study is used to analyse potential applications of 3DP, AI and BC to improve the financial, logistics and information flow in disaster situations. The findings from the case are contrasted to different challenges in disaster management found in the literature, which supports the design and validation of a framework on the use of these technologies in disaster settings.

This research was carried out through the following process; 1) Research question definitions, 2) Case study selection looking at countries heavily affected by disasters, 3) Archival data and reports collection about the case chosen, 4) Description of the case study and identification of challenges, 5) Analysis of the challenges through the lens of 3DP, AI and BC, 6) Definition and discussion of a conceptual framework to enhance the HSC in the context of the case, 7) Conclusions and future agenda. The schematic of the methodology can be seen in Figure 2.

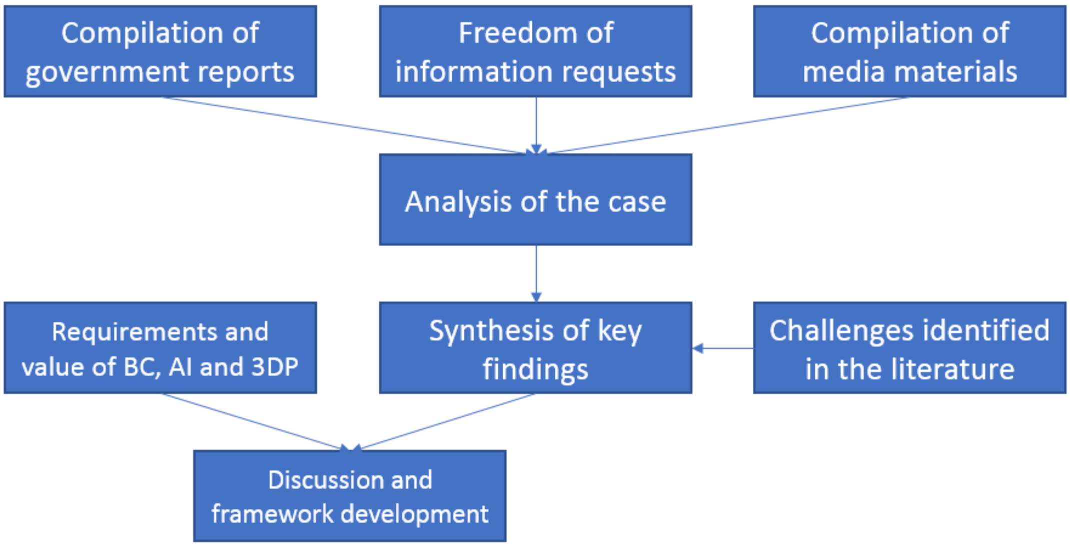


Fig 2. Methodology

4.2. Data entry and management

Freedom of information requests (FOIs) were filed to each one of the organisations involved in disaster management in Mexico. The FOIs were submitted looking for information about records including the affected areas and population, facilities used, donations, logistics activities, resources deployed, and supplier management.

A total of 128 requests to nine National authorities and 134 requests to eight regional authorities were filed. Among the seventeen agencies enquired, there were organisations only consulted about reports or international aid (i.e. CENAPRED, SRE and Universidad Juarez Autónoma de Tabasco), whereas some others declared no jurisdiction or information available (i.e. SEDESOL). Hence, thirteen agencies were included for the case, and these were Municipality, DICONSA, DIF, IMSS, ISSET, PC, SMEXICO, STABASCO, SCT, SEDENA, SEGOB, SEMAR and SSP.

The data was aggregated and combined with secondary information from governmental and non-governmental reports. The information was used to provide a description of the situation and to perform an analysis of the HSC during the disaster. The methods and tools used to systematically analyse the information obtained from the reports have been summarised in Table 1 below.

Table 1: Methods and Tools to analyse case-study

Context	Method
Similarity matching in the maps to identify difference in flood masks	Image similarity using pixel comparison and distance matching (Nguyen and Bai 2011) libraries in the R software
Quantitative data comparative analysis obtained from the reports	Exploratory and descriptive analysis (Williams 2011) of quantitative values using descriptive analytics library in the R software
Identifying co-occurring topics, i.e. inconsistencies, barriers and challenges from textual contents	Employing topic modelling (Nikolenko, Koltcov, and Koltsova 2017), i.e. textual analytics, followed by machine learning to cluster and classify keywords using text analysis libraries in the R software
Content mapping for developing the conceptual framework	Framework analysis (Ritchie and Spencer 2002) to map topics identified to the characteristics of emerging technologies discussed in this article, followed by alignment to the key components in humanitarian supply-chain.

5. Case study: Disaster management in Mexico

Mexico has been a country seriously affected by disasters (Santos-Reyes, Alvarado-

Corona, and Olmos-Peña 2010), with an average of 4 large-scale disasters per year and a total damage of over US 43 billion from 1950 to 2015 (CRED 2016). The flood of Tabasco in 2007, which represented a major catastrophe in the country, is used in this research to analyse the challenges in the HSC in Mexico and to investigate of the role of BC, 3DP and AI to alleviate them.

5.1 Conditions of the flood in Tabasco in 2007

The flood of 2007 in Tabasco has been one of the worst natural disasters experienced in Mexico in this century. This flood affected around 1.6 million people, leaving behind an estimated economic damage of 3 billion US dollars (CRED 2019) and nearly 80% of the state flooded (Santos-Reyes, Alvarado-Corona, and Olmos-Peña 2010). Despite the existence of a well-established disaster management system in Mexico, this event exceeded the capacity of authorities.

The flood affected the 17 municipalities of the State of Tabasco, which forced authorities to open 1,287 shelters to provide refuge for over 120,000 people (PCT 2014). Mexican authorities invested major resources to provide relief during the emergency, which includes up to 42 different types of products in cases of disaster (SEGOB 2012). These survival items range from food kits to mattresses, tools and cleaning kits. The number of products is estimated based on the needs of the affected areas communicated by assessment teams, which triggers relief procurement and distribution.

5.2 Supply chain challenges in disaster management in Tabasco

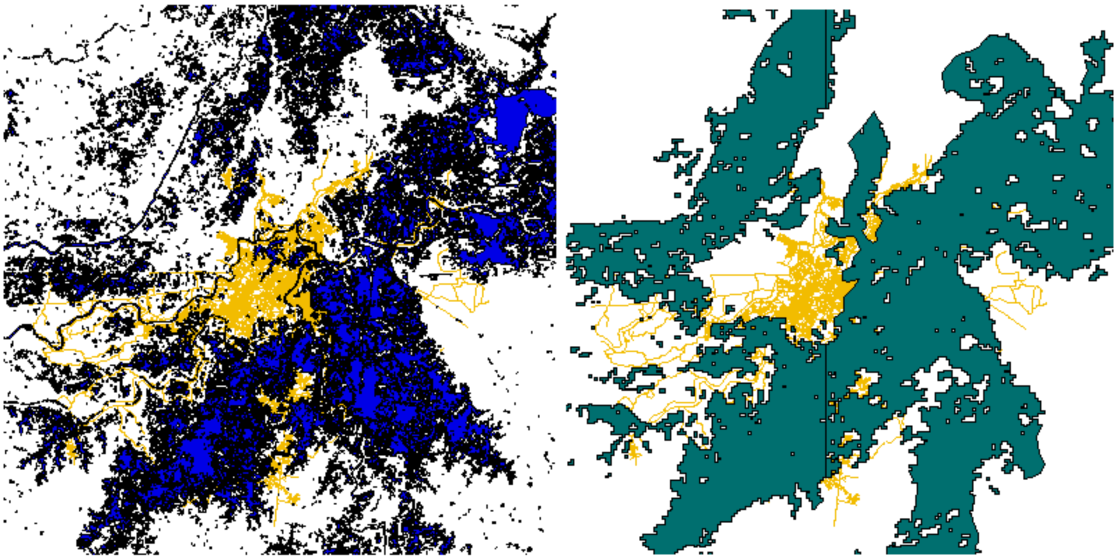
Different complications affected operations in Tabasco. Stemming from the challenges identified by Lee and Marc (2003) and the flow of products, money and information, this section investigates the application of the framework proposed to the situation in

Tabasco considering 3 themes: data entry and management, procurement processes and records, and budgets and accountability.

5.2.1. Information accuracy and reliability

The initial stage in disaster response includes an assessment of the situation and the number of victims. According to FONDEN (2012), demand in Tabasco varied based on the stage of the disaster, reaching its peak at request 294/07 on 7th of November 2018. An interesting point, however, is the inconsistency between the reports from Federal and State authorities. State authorities estimated a total of 1,120,600 people requiring support, whereas Federal authorities stated 383,000 victims (FONDEN 2007). Communication problems and obscure needs assessment forced authorities to make decisions based on the figures from Federal authorities, as seen in the official relief requests. This situation can cause over or undersupply of critical items because of the inconsistencies in different documents, which can affect the level of service provided to the victims.

The participation of multiple organisations affects the accuracy and reliability of the information handled (Kovács and Spens 2009; Tatham and Spens 2011; Whybark et al. 2010; Van Wassenhove 2006). For instance, the representation of the floods and affected areas differed from one agency to another. Figure 2 shows the comparison in the region of Centro (capital of Tabasco) between the flood mask provided by SEMAR (2014) and the image from CENAPRED (2014). Although some of the general areas are similar, SEMAR is accounting for damage in the northern part of the city and several neighbourhoods in the east and south which are not considered by CENAPRED. The absence of accurate and updated information can affect decisions related to prioritisation of relief, search and rescue activities, shelter management, and relief distribution (Apte 2009; Drabek and McEntire 2003). The lack of standardisation in practices and information sharing can deeply affect the impact of the activities carried out by different participants (Drabek and McEntire 2003; Tatham and Spens 2011)



Source: Compiled by authors with information from SEMAR (2014), CENAPRED (2014) and INEGI (2010)

Fig 3. Comparison of the flood masks of CENAPRED (left) and SEMAR(right)

It is important to have clarity and consistency in information management to avoid contradictions among organisations and deploy a coordinated and effective response. Otherwise, several command and control problems can be encountered (Van Wassenhove 2006; Whybark et al. 2010) because decisions are made based on available information. For example, SEDENA (2014) reported 26,260 people sheltered in 33 shelters in Centro, whereas PCT (2014) reported over 99,000 people sheltered in 909 refuges in the same area, and ISSET (2014) reported 1,432 people supported in 6 shelters, which were duplicated from the shelters declared by PCT but with variations in terms of the number of people held per facility. These examples of conflicting information show the need to improve data sharing across the HSC because decisions about human and material resources required are based on these figures. Nevertheless, the case shows several communication constraints among organisations, which reflect a lack of means to swiftly and effectively handle and share data (Drabek and McEntire 2003; Tatham and Spens 2011).

Another problem were the few updates in needs assessment undertaken. Timely needs assessment has been identified as a major challenge because of the quality and responsiveness in information management (Tatham and Spens 2011). For instance, after the initial Federal estimate of over 55 thousand victims, the rest of the requests in October stated 130 thousand victims, requests in November estimated 383 thousand victims and up to mid-December over 253 thousand victims were considered. Beyond the contradiction of this numbers with State estimates, information about sheltered people over time published by authorities showed a different behaviour with variations within months (García, Marín, and Méndez 2009). This is the effect of the complications to compile, manage and share information, which lead to slower processes and larger gaps between data updates. This situation affects logistics flows as decision-making is based on out-of-date information.

5.2.2. Procurement processes and records

Pre-positioning relief is the strategy employed by Mexican authorities for food kits, but most of the products are procured after the conditions of the disaster are known. After needs assessment, authorities request items from a list of authorised suppliers including details about every supplier and the prices of the different items. Despite the reported Federal expenditure in different items such as 1,104,298 food kits, 219,920 blankets or 252,130 mattresses (CEPAL 2008), in the list of 128 suppliers there is virtually no information about the items procured from any one of them (DICONSA 2017a, 2017b). Hence, it is impossible to know how procurement decisions were made, what suppliers were elicited, and track the relief. It has been acknowledged that different emergent norms and processes appear in disaster situations (Drabek and McEntire 2003), but the chaotic nature of these settings, the lack of reliable records and the absence of standardised processes among organisations (Tatham and Spens 2011) can affect the quality and impact of the decisions made. Moreover, the lack of reliable information about the decisions made prevents the possibility to learn from experience and implement improvements for future events.

Despite the different efforts and resources invested, a main issue was the shortage of critical items. Limitations of resources commonly affect disaster operations (Kovács and Spens 2009), but these can be amplified by unreliable information. For instance, at the beginning of the emergency all areas were affected by constraints in resources, as shown in the second request (October 30th) in which authorities could not cover even 60% of the needs (FONDEN 2007). That problem affected certain areas more than others. For instance, on the report from November 7th, municipalities such as Cardenas, Centro, Jalapa, Macuspan, Nacajuca, Tacotalpa and Teapa received less that the estimations from Federal authorities. Shortages can be attributed to the limited capacity of the suppliers, which are not used to steep surges in demand. The absence of reliable information combined with the uncertainty of demand prevent effective procurement management Apte 2009; Kovács and Spens 2009; Whybark et al. 2010; Van Wassenhove 2006). Additionally, there is high staff turnover affecting managing and distribution activities (Tatham and Spens 2011; Van Wassenhove 2006) along with shifting priorities of relief over time (Apte 2009; Van Wassenhove 2006; Whybark et al. 2010) which modify resource requirements. On the other hand, there can be challenging conditions preventing to reach certain areas. Infrastructure damages are common after disasters strike an area, which affect the capability to reach some of the regions affected (Kovács and Spens 2009; Tatham and Spens 2011; Van Wassenhove 2006). That was the case in Mexico, in which several parts of Tabasco were difficult to access for vehicles. For instance, Figure 3 shows several isolated areas in Centro which could not be reached by roads. The circumstances forced authorities to use different vehicles including boats and helicopters (SEMAR 2007; DICONSA 2014). The combination of these factors explains the reports of shortages found on different documents and news outlets (Santos-Reyes, Alvarado-Corona, and Olmos-Peña 2010).

5.2.3. Budgets and accountability

In major disasters, affected communities are contacted by other regions, NGOs and governments to offer support. Fuelled by the relief shortages experienced, various States, Countries and International organisations offered human and material resources in the case of Tabasco. Additionally, several self-initiated participants appear with the intention to engage in disaster operations (Drabek and McEntire 2003; Wachtendorf and Kendra 2004; Whybark et al. 2010) As a result, the large number of participants and conflicting records makes it near impossible to estimate the number of human, material and financial resources involved in operations (CEPAL 2008), which is a common problem in disaster situations (Drabek and McEntire 2003). This represents a significant challenge for accountability in order to avoid corruption in relief activities, which has been experienced in different disasters (Schultz and Søreide 2008). Also, this situation complicates the management of the disaster fund (FONDEN), which provides support for preparation, response and recovery activities in the country. It affects budget planning, as unreliable records are used as one of the few sources of information to plan budgets for future events.

Externally, there is a list of items shipped by governments and international organisations to the Mexican government, but it only accounts for the arrival to Mexican territory and the organisation in charge of managing it (SRE 2014). Tracking the benefited areas, however, is complicated because of the chaotic conditions experienced. It is difficult to provide a notion of the impact of the resources provided by FONDEN, but it becomes even more challenging to identify how private resources donated into the area were used. Donors are a relevant source of relief (Kovács and Spens 2007), but their independence can lead to having low-priority or no-priority items reaching the affected region (Holguín-Veras et al. 2014) because of the lack of information about the actual situation (Apte 2009; Kovács and Spens 2009; Tatham and Spens 2011; Whybark et al. 2010) and unpredictability of demand (Apte 2009; Kovács and Spens 2009; Whybark et al. 2010; Van Wassenhove 2006). Despite the importance of managing donations, records about the individual donors sending financial or material relief are scarce, and information tracing their use to the individual victims is non-existent. The effect is twofold: resources might not be used for the intended purpose, and there is a diminished trust from the donors (Wei and Marinova 2016).

In the case of Tabasco, it is difficult to identify the mechanism for allocation of resources and the impact and benefit of each donation or fund. This can be problematic because in developing countries there is a politically volatile climate (Van Wassenhove 2006), which can lead to social unrest. The result were complaints about financial donations not reaching the intended areas (Morales and Barboza 2007) and political interference in resource allocation (Dudley 2007) because of the lack of certainty about the use of resources and the subsequent trust loss in authorities.

6. The role of AI, BC and 3DP in the humanitarian supply chain

Technology plays a crucial role for information handling and usage in disaster management. Current advances, however, are obscured by the complications find on the field. The case study presented has shown several shortcomings that need to be addressed by technology, such as;

- Inaccurate needs assessment (5.2.1)
- Inconsistent information among participants (5.2.1)
- Out-of-date information (5.2.1)
- Lack accountability of financial resources (5.2.2)
- Poor control of budgets (5.2.2)
- Uncertainty about the areas reached by the organisations involved (5.2.2)
- Inability to track resources and requests to different suppliers (5.2.3)
- Isolated areas difficult to reach (5.2.3)

It is interesting to note how these challenges show the intrinsic link between the logistics, financial and information flows. It is essential to look at those links to propose alternatives to strengthen supply chains (Wang, Jia, et al. 2019). This article argues that the combination of AI, 3DP and BC can provide suitable answers for these challenges.

6.1. Artificial Intelligence

Needs assessment is the foundation of response operations, because it triggers relief activities by providing details about the conditions in the area and the potential number of victims. The case provide evidence of inaccurate and infrequent needs assessment, which aligns with findings in previous disasters (Tatham and Spens 2011). Shifting priorities and uncertainty of demand are inherent aspects of disaster situations which have a significant effect on the volume and type of resources required (Whybark et al. 2010; Kovács and Spens 2009). The result can lead to an excess of low-priority products causing congestion and the need for extra resources (Kovács and Spens 2007), or shortages of high-priority items leading to complaints and poor levels of service for the victims. Considering the shortcomings in needs assessment and the independence from donors, AI represents an opportunity to improve decision-making. Initially, AI can be used in combination with historical information to predict initial patterns of demand to complement information from the field (Mohammadi, Fatemi Ghomi, and Zeinali 2014), and once more information is known it can prioritise the items in order to augment decisions from relief organisations and donors.

Supervised machine learning (SML) can use real-time information obtained from the varied data sources (Ragini, Anand, and Bhaskar 2018) at the source (e.g. location information from tracking sensors, extent of impact in the disaster location from satellite imagery and social media, estimated number of victims from shelter reports, repair and medical aid requirements from needs assessment), to prioritise resource allocation by employing clustering and classification. The clustering aggregates related resources (e.g. medical, food, shelter aid) into a single unit, and the classification aids in prioritising the units (i.e. each cluster) for a given location. SML uses historical information and decisions made as a baseline denominated the target exemplary set to learn and propose priorities for deployment of resources. In that way, the decision mechanisms are transparent, input data is more reliable through the combination of different sources, and the decisions about relief allocation and distribution are augmented by truly considering the impact of the disaster on the different areas and looking at all the resources available in the system.

The output of the AI can be visualised in dashboards in the form of recommendations to the organisations and relevant decision makers (such as governmental organisations, budget holders and donors) using web and mobile-based platforms. The visualisation can provide a deeper and broader understanding of the recommendations by showing the rationale behind them, the data sources used, and a summary of the training set used by the learning algorithms. This allow decision makers to allocate and deploy resources in an effective and efficient manner. This transparency helps to increase the trust of the decision-makers on the recommendations and drives the adoption of such technologies to develop dynamic expert systems to augment human decision-making in HSCs. Hence, the potential of AI can be employed to manage resources more efficiently to enhance logistics flows and make more efficient use of financial flows.

6.2 Blockchain

Decisions, especially in urgent settings, must be made based on an accurate and updated flow of information (Tatham and Spens 2011). The case revealed that information management is one of the major challenges faced in Mexico. This was expected as information and communication are challenges commonly found in disaster situations (Kovács and Spens 2009). The case showed duplication of efforts, inconsistent information among different organisations, absence of information sharing, the use of out-of-date information for decision-making, the existence of unreliable information, and lack of records. Improving needs assessment processes involves to communicate information timely and improve reliability (Tatham and Spens 2011). BC can dramatically reduce the number of decisions made with out-of-date information and to increase the overall credibility of the operations.

BC also has enormous potential to improve information sharing among the participants and enhance their collaboration, which stemmed as a problem in the case of Tabasco and it has been noted as a complication in previous disasters (Rodríguez-Espíndola, Albores, and Brewster 2018a). Introducing BC can serve to create a decentralised system accessible to the different participants can reduce the number of inconsistencies and provide near real-time information to support decision-making. Because of the characteristics of BC, data would be secure, transparent and available in a single source, thereby minimising the chance for inconsistencies or corruption.

The case also showed a major need for visibility of the financial resources sent to the area to ensure the adequate use of them. Complaints about political bias and deviation of funds align with findings arguing that corruption and lack of trust are a major barrier in disaster operations in developing countries (Schultz and Søreide 2008). BC can allow donors and external organisations to trace their contributions and make sure they are used for disaster relief, as it introduces visibility, traceability and transparency for all types of transactions, which will lead to better accountability. Using BC to track transactions allow participant organisations to keep track of the resources invested, give clarity about other resources available and control budgets with increased accountability.

The physical distribution of products can also be greatly benefited by using BC. Governments are often seen as liable to incur in corruption during procurement (Schultz and Søreide 2008), creating the need to reassure the public of the legitimacy of HSCs. BC would allow to track the path of each relief product individually from the supplier to the beneficiary. There is a strong focus on what is supplied to the area, but it is also important to look at when and from whom. The outcome of using BC would be reliable information about the use of procurement budgets and accurate records and control of suppliers, thereby providing visibility and legitimacy to relief distribution. Additionally, it allows to identify the benefited areas to prevent the duplication of activities.

Past experiences in the field have motivated the development of different measures to reduce response time (Kunz, Reiner, and Gold 2014). Nevertheless, lead-time reduction is still a major challenge. Expediting procurement can be vital to reduce lead times. The use of BC-enabled smart contracts can allow to speed up the procurement process by triggering the immediate request of items once the needs assessment is in place (Dolgui et al. 2019). These contracts can be used by governments and other organisations, thereby reducing the complexity of their interactions with suppliers and decreasing procurement lead times, also contributing to more transparent supply chains (Kamble, Gunasekaran, and Arha 2018).

6.3. 3D Printing for on-site production

The case exhibits a situation in which shortage of supplies stemmed from different reasons. A major cause were requests below the actual requirements. In that instance, suppliers may struggle to react swiftly to the steep variation in requests from authorities from one period to the next, and the absence of alternative suppliers found in different countries can delay relief (Van Wassenhove 2006). Additionally, roads to different areas were found unusable, constraining transportation because of damages to infrastructure (Sahin, Narayanan, and Robinson 2013). Despite the focus on lead-time reduction (Kunz, Reiner, and Gold 2014), the inherent disruption of supply found on disaster situations makes on-site production a very impactful alternative. It allows products or components to be produced as and when needed, without waiting for deliveries. For example, in earthquake-hit Nepal, 3DP has been used to repair damaged water pipes (Jones 2015) and produce medical equipment in field hospitals (Parkin 2017).

The use of 3DP to produce some of the items in the affected areas can be beneficial to reduce lead times for distribution and to mitigate the congestion in the supply chain by reducing the number of items being requested, sorted and managed. This would be important to reduce the burden on suppliers, reduce the convergence of items towards the affected areas (Holguín-Veras et al. 2014), allow to direct activities in distribution centres towards specific urgent items, reduce the number of material and human resources used for relief distribution, and satisfying the needs of isolated areas more effectively. This way relevant items can be produced on-site to solve immediate problems, to reinstate services and to aid reconstruction efforts (Delgado Camacho et al. 2018).

6.4. Framework for the Integration of AI, BC and 3DP

Each one of the technologies presented have the potential to make significant strides towards successful operations. However, each one of them relies on a set of conditions that can be difficult to achieve in chaotic situations.

AI can sort through different alternatives and provide transparent decision mechanisms for demand forecasting and prioritisation using information from multiple sources, thereby enhancing logistics and financial flows. Nevertheless, it requires accurate, reliable and timely information. The case presented highlights the complications to find these characteristics during disasters, thereby constraining its use. 3DP is an invaluable technology for on-site production during and after the disasters to improve logistics flows, but it lacks efficient decision-making mechanisms to maximise the benefits from production. At the same time, it requires accurate information about the needs, which can be obscured during the disaster (Van Wassenhove 2006), as shown in the case of Mexico. Therefore, both AI and 3DP require significant improvement in information flows to achieve real impact on operations. The solution can be their integration with BC. BC can be a major player in enhancing communication, managing information from multiple sources, sharing data, enabling immediate response, and introducing accountability and traceability. Hence, it can improve information flows and become a key component on financial and logistics flows, which complements nicely the potential and requirements from AI and 3DP.

The analysis of the case combined with the independent revision of the technologies provides a picture about the current needs to improve the three flows:

financial, information and logistics. This article argues that the combination of AI, BC and 3DP can allow to reap the benefits of the different technologies whilst satisfying each other's needs. **Error! Reference source not found.**4 provides a representation of the framework proposed in this paper. Combining these technologies, while not solving all challenges, can provide substantial improvements to augmenting, tracing and implementing decisions in HSCs. BC is the corner stone of the framework proposed because it allows control over the type of information provided by external sources and offers a bridge between the AI and 3DP layers (Dinh and Thai 2018; Mandolla et al. 2019), because improvement on the information flow is the basis for enhancing logistics and financial flows (Wang, Jia, et al. 2019).

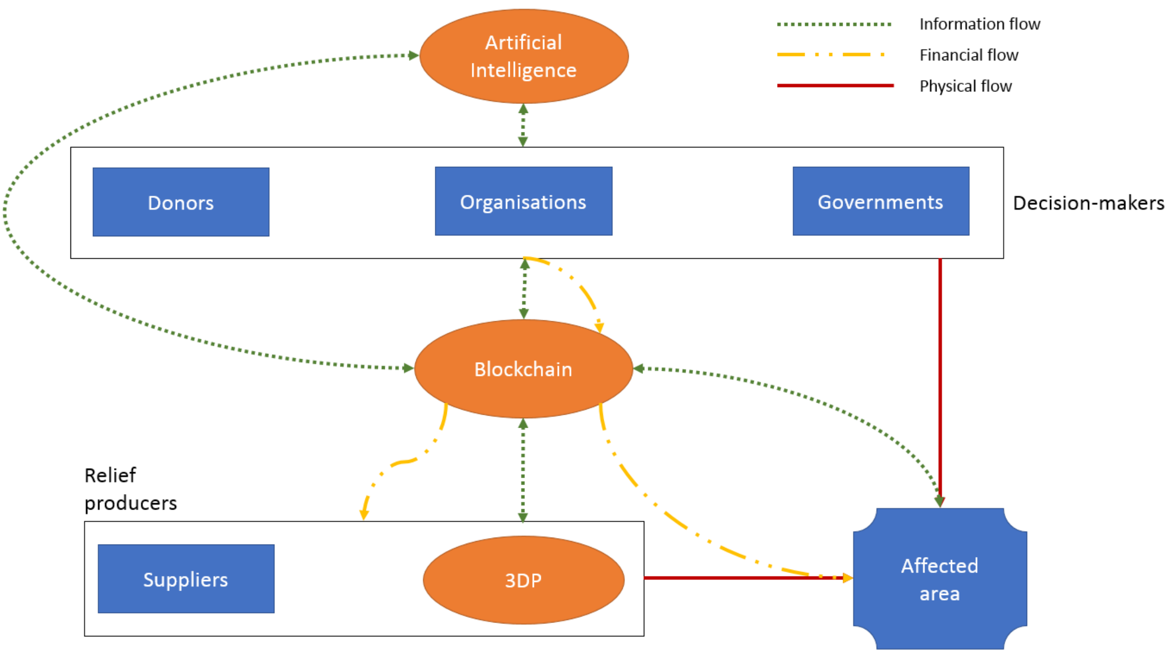


Fig. 4 Integration of innovative technology in the HSC

AI and 3DP have been successfully integrated with BC before (Dinh and Thai 2018; Mandolla et al. 2019; Wang, Jia, et al. 2019). The integration of BC provides advantages for AI such as security in data sharing, transparency, decentralised computing and the potential to coordinate untrusted devices; whereas AI provides BC with automated referee and governance, privacy enhancement, and secure and scalable blockchains. (Dinh and Thai 2018).

The integration of BC and AI into the framework presented can contribute to reduce problems in financial, information and logistics flows. This combination can introduce a two-way information flow, allowing governments, organisations and donors to understand what is needed, as well as predicting what might be next, based on appropriate analytics. From the operational perspective, the information transmitted through BC can be used by AI to contextualise and augment decisions. AI can provide reliable forecasts and a near real-time prioritisation of the items required, and it can be updated to allow collaboration among stakeholders through the use of BC. Furthermore, the combination of BC and AI would not only allow the use of smart contracts, but it would also enable the possibility of automated arbitration to reduce disruption (Dinh and Thai 2018). The overall effect would be reduction of unwanted relief items, increased possibility of the wanted items reaching the area and a reduction in transport bottlenecks.

Regarding on-site production, despite the advantages of 3DP, concerns about reimbursement and liability (Srai et al. 2016) prevent its use in HSCs. BC offers a potential route to solving both of these issues because it mitigates trustless environments (Mandolla et al. 2019). Firstly, to avoid leakage of IP, BC can be used to trace who receives and shares designs and ensure an appropriate payment has been received for the right to print (Savelyev 2018). Secondly, to control liability, BC can be used to control the authenticity and originality of designs. Incorporating BC would allow the information and financial flows to be managed near real-time (Mandolla et al. 2019), allowing the affected area to produce needed parts and allowing the manufacturer to maintain control over their IP and liability. At the same time, 3DP can benefit from integration with other platforms through BC to support product design, planning and printing (Wang, Lin, et al. 2019).

The combination of the three components can help change the paradigm from government-led to citizen-led disaster response supported by the willingness of people to help (Gunessee et al. 2018). Logistics and financial flows can be supported by the production of items on-site (Tatham, Loy, and Peretti 2015), thereby allowing victims to take part in their own recovery and support areas difficult to reach through traditional channels. Through prioritisation, which involves accounting for which items are most needed, and considering which items can be efficiently made rather than transported, AI can enable the appropriate use of 3DP in near-real time through the use of BC. This way AI can guide the decision about what is procured and what is produced, and BC can coordinate 3DP facilities to reduce the number of items that need to be transported. Additionally, controlling the digital files, sharing the information from the AI, triggering smart contracts, keeping traceability of the relief items, maintaining acceptable quality, and ensuring intellectual property is protected and paid for can be contributions from BC. Hence, the implementation of the framework proposed would reduce congestion in the supply chain by reducing the flow of unwanted items (AI), reducing duplication of efforts and procurement (BC) and allowing the production of items on-site (3DP). The impact would be reduction of delays, fewer resources needed to sort and manage products, and a more streamlined distribution, thereby reducing potential congestion by offering secure and traceable options for the flow of products, money and on-site production. Table 2 provides a summary of the impact of the different technologies on the three flows based on the findings from the analysis. The combination of technologies shows the capability to provide holistic support for the information, financial and logistics flows.

Table 2. Relevance of technology to aid logistics, financial and information flows

Flow	*BC*	*AI*	*3DP*
Information	Introducing an accurate, transparent and immutable decentralised system that can be consulted and updated by relevant stakeholders. Creating a single record that can be updated in near real-time y participants on the field		
Information + Financial	Providing visibility of financial resources and their use to enhance accountability	Introducing transparent decision-making through the inclusion of the rationale, data sources used, and a summary of the training set used by the learning algorithms	
Information + Logistics	Feeding updated information to the AI and making its suggested recommendations available to decision-makers in near real time. Creating a unified record of activities that can be shared among participants and allowing to record transactions to avoid duplication of efforts and identifying regions supported	Undertaking the prioritisation of items to provide assistance for decision-makers. Providing support for decisions about the deployment of resources	Introducing on-site production to reduce the congestion in the supply chain by creating an alternative source of fulfilment
Information + Financial + Logistics	Including traceability of financial resources, allowing to track transactions to keep track of resources invested for budgetary purposes. Providing reliable information about the use of procurement budgets and accurate records and control of suppliers, introducing visibility across the supply chain, and allowing the use of BC-enabled smart contracts. Mitigating the challenges of IP for disaster relief	Supporting transparent and enhanced decision-making for the use of resources. Introducing an analysis to support supplier selection and procurement decisions and allowing automated arbitration to reduce disruption. Providing an assessment of the requirements to sort through different alternatives including on-site production to complement relief distribution	Reducing supply disruption by allowing on-site production for disaster response and recovery. Presenting a cost-effective alternative to reduce the flow of items to the affected area. Reaching isolated areas and allowing local suppliers to support the economic recovery of the region.

In brief, the integration of the three technologies can;

- Improve simultaneous collaboration of different stakeholders through the enhanced decision-making capabilities provided by automated AI recommendations and communicated using BC to facilitate information updates.
- Decrease lead times through on-site production enabled by 3D printing, the use of BC-enabled smart contracts with suppliers and selective procurement through the prioritisation of products through AI.
- Increase transparency and traceability of products with the implementation of BC for information sharing, management, and BC-enabled smart contracts and arbitration along with more controlled request from suppliers advised using AI.
- Manage current, forecast and plan future budgets as well as having a systematic record on the individual investments and their benefits.
- Enhance operations by providing more accurate needs assessment through the coordination of different stakeholders in an accessible BC ledger and facilitating prioritisation of needs and resource allocation using AI.
- Empower victims in disaster response and recovery even in the isolated areas through on-site production with 3DP led by AI for the selection of products and BC to coordinate with other stakeholders.

6.5. Framework Comparison

This is the first article in the field of humanitarian logistics, which has systematically developed a conceptual framework integrating three emerging technologies, considering information, financial and logistics flow, employing exploratory case-study based approach and analytical methods to examine the case-study and derive constructs to develop the conceptual framework. A comparison with similar conceptual frameworks

(Singh, Shukla, and Mishra 2018; Holsapple, Hsiao, and Pakath 2018; Zhou et al. 2017) reveals that most analytical frameworks facilitate data-driven decision making considering only the information flow and employing a single technology i.e. AI and analytics. The economic and logistical flows in these frameworks are not aggregated and investigated. The information flow is often investigated using data obtained from multiple sources such as social media, survey, interviews, case-studies, given the nature of the study, i.e. focusing on a single technology - data analytics and AI recommendations facilitating data-driven decision making.

Furthermore, articles combining two technologies, blockchain and 3DP (Mandolla et al. 2019), and blockchain and AI (Dinh and Thai 2018), do not report a conceptual framework that will facilitate decision-makers and managers to develop expert systems. The former article employs a hypothetical case-study to demonstrate the application of blockchain within additive manufacturing to secure and organise data within the aircraft industry using a case-study. The study clearly presents the drivers of the blockchain technology in the given context of developing a digital twin and focuses on the information flow in the aircraft manufacturing industry. However, our framework focuses on multiple flows within the supply chain, employing a similar methodology and with a real-life case-study, and can be extended for use within the manufacturing industry, especially facilitating data-driven decision making, automated prioritisation, and finance management using smart contracts. Dinh and Thai (2018) employs a brief review of literature, followed by research-focussed discussion demonstrating advantages of combining the technology, to facilitate data security, data management and increasing trust in AI techniques through explainability. The article can help the decision-makers and managers to understand the technology, its characteristics, advantages and impact on information organisation. However, the absence of a conceptual framework and suitable exemplary evidence, provides limited knowledge on combining these technologies to create business and societal value, strategies to combine the technologies effectively, and focussing beyond information organisation. In summary, our paper provides a pathway for decision-makers, and various stakeholders involved in disaster management, to effectively integrate multiple emerging technologies, that will facilitate timely and agile management of humanitarian supply chain, and increasing collaboration, coordination and trust among the stakeholders and intended beneficiaries.

7. Research agenda

The integration of the framework presented can indeed make a difference in the HSC. However, it is important to look at the next steps to reap the benefits of the implementation from these technologies. The research agenda stemming from the analysis includes;

- Development of expert systems for humanitarian logistics using BC and AI - The purpose would be the development of a context-aware expert systems suited for managing the dynamic and chaotic conditions presented in disasters which are currently unavailable (Baryannis et al. 2019).
- Investigation of the best BC platform for humanitarian logistics - Exploring the characteristics and implications of using public or private ledgers can lead to more successful implementation of BC, which would include studies about what kind of access is required and by whom.
- Platform selection for coordinating multiple stakeholders using BC – Studies examining potential platforms for implementation of BC considering critical infrastructure and long-term benefits to achieve standardisation.

- Analysis of BC-enabled smart contracts and implications for stakeholders - Smart contract applications self-executing over a BC network will require a dialogue and agreement between all the participating organisations explore protocols that will help in developing standard rules, embedded in the software.
- Exploring the use of BC for fundraising - The social aspects and legal aspects of technology adoption from users and organisations must be explored closely to support implementation.
- Linking 3DP to recovery and social programmes - Research on the suitability of pooling resources among companies and the local government support required needs to be undertaken to find the best alternatives to enable the use of 3DP.
- Analysing the use of BC to manage intellectual property and liability - There is an opportunity to investigate the potential of BC to protect the rights of designers and explore how to determine clear lines of responsibility and limited liability for the use of 3DP in HSCs.

8. Conclusions

This paper has looked at the potential benefits of the use of recent technology in the HSC. The advent of Industry 4.0 and has created several opportunities to improve operations in different fields. In HSCs, there are some isolated examples of the use of technology, but there is still a lot of potential to introduce EDTs in this context.

This is the first article in the literature looking at the potential of the integration of BC, AI and 3DP so as to propose a platform to solve several challenges currently found in the HSC. The article has investigated current challenges in disaster management in Mexico based on the flood of 2007 in Tabasco, identified potential solutions and proposed a conceptual framework for achieving successful operations.

HSCs are hampered by several problems in the flow of information, products and financial resources. The case in Tabasco highlighted poor needs assessment, inconsistent information among organisations, out-of-date information, lack of accountability and transparency, poor budget control, inability to track resources and requests, uncertainty about the areas reached by the organisations involved, and the unreachability of some areas as the main barriers for efficient and effective operations. This article argues that the combination of EDTs such as AI, BC and 3DP have significant potential to overcome these challenges.

These technologies can lead to leaner and swifter operations. AI can augment decision-making; BC enhance information management and 3DP allow on-site production as an alternative. Furthermore, the combination of the three can have a steep effect in HSCs. AI can enable efficient use of 3DP and boost the potential of BC, 3DP can allow AI to introduce suitable alternatives for isolated areas, and BC can introduce near-real time information, visibility, traceability and accountability to support AI and 3DP. The result can be less congestion in the supply chain, more alternatives for relief fulfilment and better collaboration among stakeholders.

There are several areas for future work. The development of the platform proposed is a very interesting research venue. To exploit the potential of the combination of the three technologies, the development of new optimisation models looking at the different relief distribution channels would be valuable. Additionally, more research is required in the area of 3D printing to strengthen its suitability to produce items beyond shelter, non-food items, and water, sanitation and hygiene items.

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