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DIGITAL TECHNOLOGIES FOR HUMANITARIAN SUPPLY CHAIN MANAGEMENT

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ABSTRACT

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Humanitarian supply chain management covers a large portion of humanitarian operations' costs. Thus, funding remains one of the most significant challenges and efficient supply chain management is essential. An extraordinary operating environment, distinctive characteristics of humanitarian supply chains and remarkable time pressure to mobilize the supply chains greatly challenges the humanitarian supply chain management actors.

Private sector, such as traditional industry, harnesses digital supply chain management technologies to enhance agility, transparency and efficiency. This paper investigates the possible applications of digital technologies to humanitarian operations. The aim of this paper is to conclude the best solutions for humanitarian supply chain management and explore what type of challenges the implementation faces.

This paper concludes that the digital technologies of supply chain management have numerous applications in humanitarian operations and the solutions can solve some of the traditional challenges of the humanitarian supply chain management. Yet, the area requires more funding and research to fully implement digital technologies into humanitarian supply chain management.

Keywords: Humanitarian supply chain management, humanitarian supply chain, supply chain digitalisation, digital technology, humanitarian operating environment

TIIVISTELMÄ

Amanda Lukkarinen: Digitaaliset teknologiat humanitaaristen toimitusketjujen hallinnan tueksi
Tampereen yliopisto
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Humanitaaristen toimitusketjujen hallinta kattaa suurimman osan humanitaaristen operaatioiden kustannuksista. Sillä rahoitus on humanitaaristen organisaatioiden suurimpia haasteita, nousee toimitusketjujen tehokas hallinta toiminnan keskiöön. Haasteita humanitaaristen toimitusketjujen hallintaan tuottaa humanitaaristen operaatioiden poikkeuksellinen toimintaympäristö, humanitaaristen toimitusketjujen erityispiirteet sekä suuri aikapaine toimitusketjujen mobilisoinniksi.

Yksityisellä sektorilla, kuten teollisuudessa, digitalisaation teknologioita hyödynnetään toimitusketjujen ketteryyden, läpinäkyvyyden ja tehokkuuden parantamiseen. Tässä työssä tutkitaan digitaalisten teknologioiden soveltuvuutta ja käyttökohtia humanitaariselle toimintakentälle. Työn tavoitteena on selvittää parhaita digitaalisia teknologioita humanitaaristen toimitusketjujen hallintaan ja tarkastella, mitä näiden implementointi vaatii.

Tutkimus osoittaa, että digitaalisilla teknologioilla on lukuisia käyttökohteita humanitaarisella toimintakentällä ja hyödyt auttavat ratkaisemaan humanitaaristen toimitusketjujen hallinnan perinteisiä haasteita. Kuitenkin teknologioiden käyttöönottoon liittyy merkittäviä haasteita. Toimintakenttä vaatii lisää rahoitusta ja tutkimusta teknologioiden kokonaisvaltaiseksi käyttöönotoksi.

Avainsanat: Humanitaaristen toimitusketjujen hallinta, humanitaarinen toimitusketju, toimitusketjujen digitalisaatio, digitaalinen ratkaisu, humanitaarinen toimintaympäristö

USE OF AI IN THE THESIS

I have utilised AI tools in my thesis:

- ☐ No
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The AI tools utilised in my thesis and their purposes are described below:

Names and versions of AI tools: ChatGPT-4o

Purpose of using AI tools: AI tools were used to develop ideas on how to structure the main topics in sections 2 and 3, to understand challenging terms in sections 3 and 4 and to check the citation style of the reference list.

I acknowledge that I am fully responsible for the entire content of my thesis, including the parts generated by AI, and accept accountability for any violations of ethical standards in publications.

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1. INTRODUCTION

1.1 Background and Significance of the Thesis

Humanitarian action is as relevant as ever. As Cozzolino (2012) highlights, there has been a significant increase in number, magnitude and impact of disasters with forecasts suggesting no decline in occurrence. In only the 2020s, the world has experienced a global pandemic with Covid-19, a war in Europe and in Gaza and the famine in Tigray war (JRC 2024). These are just a few examples of the turmoil of the recent years. With population growth, global warming and urbanisation, the world is getting more vulnerable to both natural and man-made disasters, making humanitarian issues as pressing as ever (UNHCR 2024).

Humanitarian operations rely heavily on logistics. It has been estimated that 80% of disaster relief consists of logistics and, more specifically, of supply chain management. (Van Wassenhove 2006) Disruptions and delays in the supply chain are a matter of life and death as they directly translate into more lives lost, a measure used in humanitarian operations. Thus, agility, adaptability, and responsiveness are prerequisites for humanitarian supply chains (Oloruntoba & Gray 2006).

The role of technology has grown exponentially in recent decades. In the 21st century, the Fourth Industrial Revolution, or Industry 4.0, has emerged and revolutionised the way organisations are recognising digitalisation as a necessity in their operations, regardless of the industry concerned (Queiroz et al. 2021). In the field of supply chain management, it offers significant advantages. Supply chain digitalisation allows for better flexibility, responsiveness, and improved productivity of the supply chain, especially when combined with blockchain technology. Moreover, it brings significant cost reductions in global supply chains and improves transparency. (Korpela et al. 2017)

Managing humanitarian supply chains is challenging due to the uncertain nature of disasters (Van Wassenhove 2006). Yet, from global pandemics to conflicts and natural disasters, just the past few years have highlighted the significance of humanitarian action. (UNHCR 2024). As a result, humanitarians have started to explore the possibilities digitalisation could have for managing humanitarian supply chains for the same reasons as the private sector. The better flow of information, improved transparency, cost reductions and adaptability could have a significant impact on the quality of disaster response while improving cost efficiency (Wakolbinger & Toyasaki 2014).

1.2 Research Objective, Research Questions, and Structure

The research aim of this thesis is to explore how digital supply chain technologies can be utilized for the benefit of humanitarian supply chain management and examine their possible applications for humanitarian supply chain management through the lens of Operations and Supply Chain Management.

The research questions are as follows:

1) How humanitarian supply chain management can benefit from digital supply chain technologies presented in the private sector?
2) What are the possible applications of these technologies in humanitarian supply chain management?

First, this bachelor's thesis presents the current state of humanitarian operations and the distinctive characteristics and management of humanitarian supply chains. Second, the thesis introduces supply chain management digitalisation of Industry 4.0 and its most significant technologies. Third, the possibilities that supply chain digitalisation technologies have on humanitarian supply chain management are further examined alongside the challenges and benefits of the applications. Lastly, the best solutions for humanitarian operations are concluded and their current limitations examined.

This topic is internationally recognized as an important research topic in the field of humanitarian operations (Marić et al. 2021, p.1003). Furthermore, use of AI, IoT, blockchain technology, and digitalised supply chains are growing trends in the supply chain management in industrial framework (Queiroz et al. 2021, pp. 1762-1763). Thus, the applications to humanitarian operations are a natural next step (Marić et al. 2021, p.1003). Improvements in the humanitarian supply chain management support all three principles of sustainability (UCLA 2024) as well as the Sustainable Development Goals (SDGs) of the United Nations' Agenda 2030 (the United Nations 2024).

1.3 Research Methodology

This bachelor's thesis is conducted as a literature review. Literature searches were conducted using primarily Tampere University's database Andor and secondarily Google Scholar. The literature research was conducted in English. The chosen articles and publications are a mixture of pioneering studies to more recent articles. They have been peer-reviewed and cited. The authors have an international audience and come from different continents, ensuring a global perspective on the global issues.

Humanitarian operations, especially humanitarian supply chain management, is a rather specific and narrow research area with a few pioneers in the field. Hence, foundational work published in the early 2000s by researchers, such as Van Wassenhove, remains highly relevant and cited. While some of the articles used in this thesis are older, their significant role in shaping the field of humanitarian research justifies their inclusion. On the contrary, the academic literature regarding the digital technologies are recent research articles and publications of the topic and hence relevant.

The objective of this thesis is to explore digital supply chain technologies from private sector and investigate their possible benefits for humanitarian supply chain management. As the operating environment of these sectors vary considerably, a significant limitation of this thesis is innate: the digital technologies in the research articles and publications are developed for industrial operating environment, not for humanitarian. However, as the challenges in the private sector, such as a need for agility, transparency and traceability, are shared with the humanitarian actors, it is justified to conclude that the solutions presented can be applied to the humanitarian sector as well.

Database	Search	Filters	Results
Andor	"Supply Chain Management"	2017-2024	78 527
Andor	"Humanitarian Operations"	2020-2024	799
Andor	"Humanitarian Logistics"	2010-2024	2524
Google Scholar	"Humanitarian supply chain*" AND "digital technology"	2020-2024	649
Andor	"Global natural disasters"	2015-2014	99
Andor	“Data sharing” AND humanitarian	2020-2024	52
Andor	"Supply chain" AND digitalisation	2020-2024	3398
Andor	"Supply chain" AND digitalisation AND “Industry 4.0”	2020-2024	679
Google Scholar	UAV AND GIS AND "natural disaster"	2015-2024	4550
Andor	UAV AND GIS AND "natural disaster"	none	15

Table 1: Keywords used, and results acquired in the literature research

Table 1 presents examples of the used databases, keywords, filters and results. The first six (6) rows present how the articles were searched from different databases with different filters and keywords for more optimal results. The second two (2) rows present examples of different searches for narrowing down the results. The last two (2) rows showcase how searching different databases brought different results. The primary keywords used for literature searches were broad terms such as “supply chain management”, digitalization AND “supply chain”, “humanitarian operations” and “humanitarian logistics” to understand the research area. As the search developed further, more specific terms combining the research areas, such as “humanitarian supply chain” AND “digital technology”, were used.

Due to the scarcity of the material of the humanitarian operations and humanitarian supply chain management, the pearl growing technique for information retrieval turned out remarkably useful. As supply chain digitalisation and technologies of Industry 4.0 are currently high-interest research topics and therefore have extensive and recent research, the pearl growing method also brought good results for these topics. As a result, almost half of the articles used in this thesis were found with pearl growing method.

The twenty (21) articles for this thesis were chosen firstly for their relevance on the topic, secondly by their publication year and lastly based on the value they add for the thesis alongside the other articles and publications. In addition, the number of citations of the papers were examined and the more cited ones were used. Eleven (11) of these papers were found from the databases by the searches described in the Table 1 and the rest were found with the pearl growing technique. In addition to academic literature, thirteen (13) non-academic secondary sources were used in this thesis to verify statistics, to validate data and provide context.

2. HUMANITARIAN SUPPLY CHAIN MANAGEMENT

2.1 Humanitarian Operations in Disaster Relief

Humanitarian operations refer to an organised action taken to provide relief and support populations in crises. The objectives to humanitarian action are save lives, alleviate suffering and maintain human dignity during and after man-made crises and natural disasters. Humanitarian action should be conducted by the humanitarian principles of *humanity*, *impartiality*, *neutrality*, and *independence* to remain neutral in politically volatile environment, work as an independent actor in a complex situation with multiple stakeholders and to offer relief mid-crisis solely on the basis of need, without discrimination (European Commission, 2024)

In humanitarian action, when referring to delivering effective and efficient care and products for the victims of the event, there are two commonly used terms with slightly different meanings: humanitarian logistics and humanitarian supply chain management. According to Cozzolino (2012), logistics in a disaster context is focusing on moving something or someone from a certain point to another, whilst supply chain management is more focused on relationships among the entities that make the movement possible. Moreover, Van Wassenhove (2006) highlights, that supply chain management is at the centre of any give logistical operation. While both are crucial in disaster response, this paper focuses mostly on the disaster supply chain management or more in general, on humanitarian supply chain management.

When focusing on humanitarian disaster relief and humanitarian supply chain management, it is relevant to specify what a disaster is. According to Van Wassenhove (2006, p. 476), a disaster is “disruption that physically affects a system as a whole and threatens its priorities and goals”. Furthermore, disasters can be distinguished into different categories based on their cause, predictability and speed of occurrence. On one hand, considering the cause, the disasters can be distinguished between man-made and natural disasters. On the other hand, the predictability and speed of occurrence, the disasters can be distinguished into a slow-onset and a sudden-onset categories. (Table 2) (Van Wassenhove 2006; Cozzolino 2012) In this paper, the focus is on sudden onset disasters.

	Natural	**Man-made**
Sudden onset	Earthquake Tsunami Hurricane	Terrorist Attack Chemical leak Coup d'Etat
Slow onset	Drought Famine Poverty	Political Crisis Refugee Crisis

Table 2: Different types of disasters, adapted from Van Wassenhove (2006)

2.2 Operating Environment for Humanitarian Supply Chain Management

In humanitarian action, one of the main characteristics separating the field from commercial and industrial one is the operating environment. The operating conditions vary with every case in humanitarian operations. The disaster areas are typically vulnerable both geographically and politically, challenging the humanitarian aid providers. In addition, numerous stakeholders and scarce funding add to the equation with intense time pressure resulting from the disaster. (Van Wassenhove 2006) This creates a unique and challenging operating environment for humanitarian supply chains and will be the focus of this subchapter.

In humanitarian operations, physical and geographical factors significantly shape the operating environment. Infrastructure limitations are often a significant challenge in disaster-affected areas where essential transportation networks are usually damaged or entirely destroyed. (Van Wassenhove 2006) For instance, in the aftermath of the 2010 Haiti earthquake, damaged roads and ports rendered large portions of the country inaccessible, delaying relief efforts and complicating the delivery of supplies (IASC 2011). Without roads, bridges, and warehouses, humanitarian actors have to rely on temporary setups and alternative modes of transportation, which are less efficient and more costly. Moreover, humanitarian organizations usually have outdated technology with robust equipment which makes the rescue process even more challenging. (Van Wassenhove 2006)

Another significant geographical challenge for natural onset disasters is geographical remoteness. Geographical remoteness highlights infrastructural issues, especially in regions with limited connectivity. Many rural communities in mountainous areas or island regions are difficult to reach even under ideal conditions. (Van Wassenhove 2006) As the disaster strikes, accessing these areas require specialized transport methods, such as helicopters, small aircraft, or even donkey and foot transport. For example, during the 2005 Kashmir earthquake, landslides and mountainous terrain isolated entire communities, necessitating airlifts for aid delivery and posing significant challenges for humanitarian responders. (Van Wassenhove & Besiou 2013; NATO 2024)

Additionally, extreme weather conditions and secondary hazards add to the complexity of the operating environment of humanitarian operations. Heavy rains, cyclones, and floods not only delay transportation but can also make regions entirely inaccessible for days or even weeks. In Southeast Asia, the annual monsoon season frequently impacts humanitarian operations by flooding roadways and isolating villages. This forces aid organizations to adopt new plans quickly, often stretching the already limited budgets of humanitarian organizations. (Thomas & Kopczak 2007)

When a disaster strikes, various actors are mobilized simultaneously. The local and international governments are alarmed, international agencies and NGOs get prepared, local military organizes its efforts and international media starts reporting the events immediately. The multiple stakeholder environment is one of the defining factors of the operating environment in humanitarian action. The actors are heavily interconnected as presented in Figure 1. Coordinating the efforts of numerous stakeholders in a disaster situation creates a real challenge for humanitarian actors. (Van Wassenhove 2006; Cozzolino 2012)

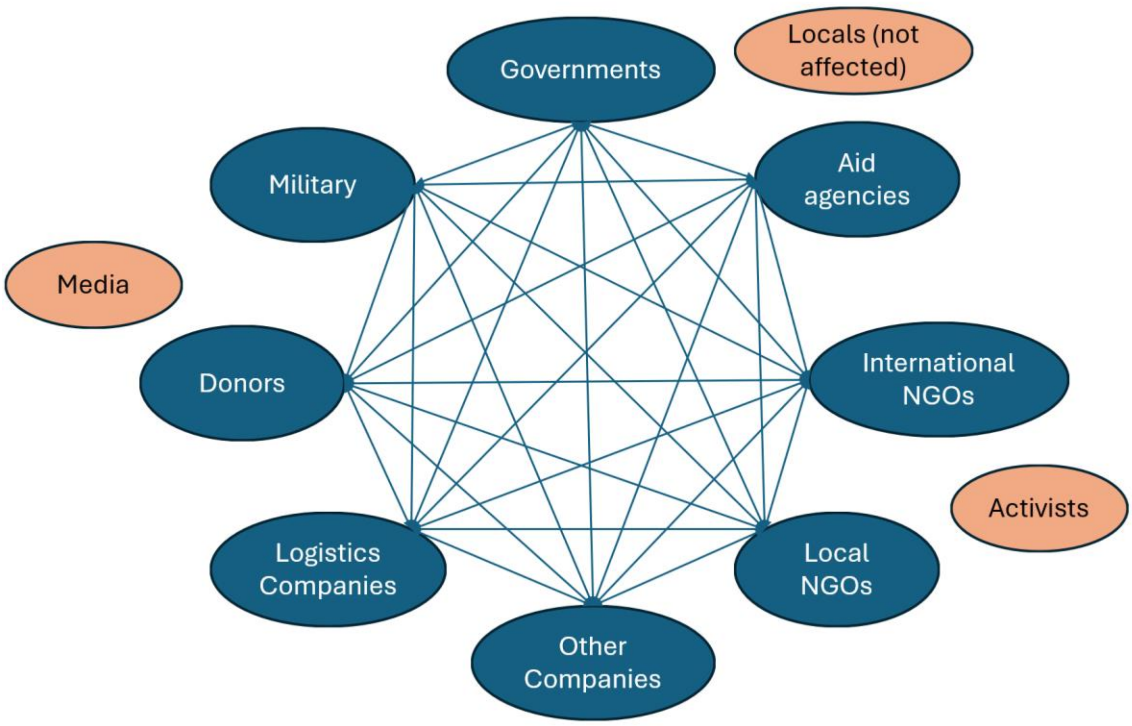

Figure 1: Actors in humanitarian action, adapted from Cozzolino (2012). Supply chain actors in blue, other important stakeholders in peach.

One significant stakeholder in humanitarian action is the media, and its role in disaster relief action and fundraising. Humanitarian operations are mostly international and gather global interest rapidly. Therefore, the role of media is one that cannot be undermined with humanitarian operations. (Van Wassenhove 2006) How the media presents the crisis has a significant impact on the whole operation because funding is traditionally one of the most challenging factors for humanitarian operations (Oloruntoba & Gray 2006; Van Wassenhove 2006).

Media representation of the crisis straightly translates into donations of supplies and capital, especially from private donors. For slow onset disasters, the problem typically is the lack of funding as the media interest declines over the course of months and years. For natural sudden onset disasters, the media interest is typically high. Consequently, the humanitarian actors are usually better equipped with supplies. However, the sudden, rapid overflow of goods and materials might even cause bottlenecks in the supply chain and tie down personnel and resources as the overflow must be sorted out. (Van Wassenhove 2006)

Humanitarian work can also be done in a politically volatile environment. (Van Wassenhove 2006) This is more often the case for man-made disasters by the nature of the man-made disasters, but also natural disasters affect politically vulnerable areas. For example, Middle East has a been politically unstable for the last decades but is also one of the most active seismic areas on Earth. (EFEHR 2016). As a result, safety is a great issue for humanitarian workers and must be taken into account in humanitarian operations (Van Wassenhove 2006).

For humanitarian operations, the work is done under a high degree of uncertainty in terms of supply and demand, assessment and even exact time and place (Van Wassenhove 2006). As a result, uncertainty is a dominant factor for humanitarian operating environment creating fundamental problems for humanitarian supply chains and managing them (Oloruntoba & Gray 2006).

Lastly, the time pressure in humanitarian operations is one of the defining factors. Any delays and disruptions in the aid and supply chains straightly translate into more lives lost, a unit used in humanitarian operations. In addition, working in a constant crisis scene is mentally draining. This creates a high-pressure environment to work in. As a result, the staff turnover is traditionally high in humanitarian operations, making it challenging to develop processes in the long term into more effective ones and create a learning environment for upcoming operations. Moreover, this means that skilled staff are in short supply. (Van Wassenhove 2006)

2.3 Humanitarian Supply Chains

Managing supply chains effectively is a crucial part of any business. Its importance is highlighted in humanitarian context as getting the right number of resources, at the right place at the right time is a matter of life and death (Van Wassenhove 2006). But to begin with, what exactly is a supply chain and how does the humanitarian supply chain differ from an industrial one? Defining what humanitarian supply chains are and how their structure result from challenging operating environment is the focus of this subchapter.

According to Mentzer et al. (2001), a supply chain can be defined as a set of three or more entities that are directly involved in the upstream and downstream of products, services, finance, and/or information from a source to a customer. The entities can be either organizations or individuals, such as suppliers, manufacturers, distributors, retailers and customers. This network supports material, information and financial flows, both up and downstream (Van Wassenhove 2006). A traditional industrial supply chain is presented in Figure 2, showing the traditional relationships between actors in a supply chain.

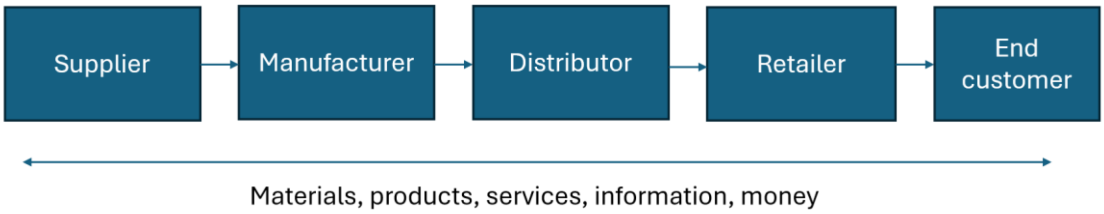

Figure 2: A traditional supply chain, adapted from Hugos (2018)

A traditional supply chain in the industrial context begins with suppliers. The suppliers provide raw materials for products. The raw material supplies are delivered to manufacturers' factories and processed into products. The finished products are distributed to different locations, such as distribution hub or distributors' facilities, for further deliveries for retailers. Retailers ensure the final transaction to end customers. In practice, this process can involve hundreds of actors and numerous transactions between them. Consequently, the process should be dynamic, systematic and predictable to ensure that supply and demand are balanced cost-effectively. (Venkataraman & Demirag 2022).

The humanitarian supply chains have distinctive characteristics and requirements compared to the traditional supply chains (Van Wassenhove 2006). The main difference to industrial supply chains is that the primary goal of humanitarian supply chains is to save lives and alleviate suffering rather than to generate profit. Due to the unique nature of humanitarian crises, there is no single form for humanitarian supply chains. There are still some characteristics found in most supply chains that can be generalized into an exemplary humanitarian supply chain as follows in Figure 3. (Oloruntoba & Gray 2006).

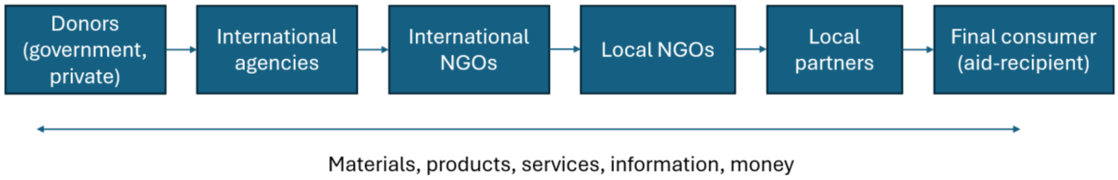

Figure 3: Humanitarian Supply Chain, adapted from Oloruntoba and Gray (2006)

The supply chain begins with governmental and private donors. The donors can be gathered prior to the crisis, but a large number of donations happen as the crisis gets media attention. (Van Wassenhove 2006) Donors purchase and distribute essential facilities, services, equipment and capital to international agencies, such as UN agencies UNICEF and WFP (Cozzolino 2012; UNICEF 2024; WFP 2024). International agencies coordinate large-scale efforts (Cozzolino 2012). They procure and mobilize resources to international NGOs, such as Doctors Without Borders (Cozzolino 2012; Doctors Without Borders 2024).

International NGOs operate on an international level. They take responsibility for mobilizing the supplies from regional hubs to local areas, preparing for distribution. Local NGOs are typically national level suborganisations of international NGOs, such as Kenya Red Cross Society (Kenya Red Cross 2024). Local NGOs handle logistics, distribution and coordination with local partners. Finally, local partners aid in the final delivery, ensuring that the essential supplies and help reach the aid recipients. As aid recipients receive help, the supply chain completes. (Cozzolino 2012)

Humanitarian supply chains are essentially global supply chains, like most industrial supply chains in 21st century. Global supply chains are global networks of interconnected organizations involved in these activities (Venkataraman & Demirag 2022). For humanitarian context, this means long logistics networks, hundreds of suppliers and a vast number of products and resources to mobilize on a short notice. Moreover, global humanitarian supply chains are unpredictable due to the nature of disasters, turbulent and require flexibility (Oloruntoba & Gray 2006).

One defining characteristic of humanitarian supply chains is their temporary nature. Due to the nature of disasters, humanitarian supply chains are often established to respond to specific disasters or crises and are therefore time-limited by nature. Paradoxically, in the age of digitalization and accelerating globalization, this applies to the private sector as much as it does to humanitarian actors even though this has historically been a distinctive quality of humanitarian supply chains. (Van Wassenhove 2006)

The uncertain nature of disasters leads to uncertainty factors in the operating environment. (Van Wassenhove 2006) Considering the uncertainty factors, it is critical for humanitarian supply chains to be able to rapidly response quick changes in demand and supply (Oloruntoba & Gray 2006). Consequently, the most distinctive characteristics of humanitarian supply chains are agility, adaptability, and responsiveness (Van Wassenhove 2006).

Agility can be defined as “the ability to thrive and prosper in an environment of constant and unpredictable change” (Maskell 2001). Agility is an inherent characteristic of humanitarian supply chains creating better resilience against changing circumstances. Agility is achieved by various humanitarian supply chain methods. (Oloruntoba & Gray 2006) Yet the urgency and unpredictability drive humanitarian supply chains to be inherently agile by necessity, as the supply chains are structured to mobilize and adapt quickly to fluctuating needs. Also, humanitarian supply chains are often subject to limited resources, such as funding, and must operate in areas with damaged infrastructure. This scarcity of resources pushes humanitarian actors to find creative and flexible solutions promoting agility of the functions. (Van Wassenhove 2006)

The adaptability characteristic often relies on adaptable global networks, multiple stakeholders and flexible logistics to handle the high demand variability. (Van Wassenhove 2006) The global, multi-actor setup allows for a broader, more versatile resource pool. It also enables quick adaptation through shared resources and skills. These networks allow humanitarian supply chains to operate in varying settings and switch roles or functions as needed based on the disaster’s progression. (Tomasini & Van Wassenhove 2009)

As agility and adaptability, responsiveness is an equally significant characteristic of humanitarian supply chains. Whereas industrial supply chains often operate on forecast-driven models, humanitarian supply chains are centrally demand-driven. The demand emerges suddenly, often with little notice, based on needs of affected populations following the disaster. This demand-driven, responsive focus ensures that humanitarian supply chains are designed to react swiftly to demand, rather than sticking to pre-planned schedules or supply forecasts. (Van Wassenhove 2006; Oloruntoba 2006)

In addition, humanitarian supply chains are heavily influenced by the dependency of donors. The financial side of humanitarian supply chains is mostly relied on external funding sources, leading to resource constraints that can significantly impact operations. Humanitarian organizations often rely on donations from governments, international agencies, and private donors to finance their activities. This dependency creates challenges in ensuring a consistent flow of resources, as funding can be unpredictable and subject to donor priorities. (Thomas & Kopczak 2007) Furthermore, the need for transparency and accountability in the use of donor funds has increased and adds complexity to financial management within the humanitarian supply chains (Van Wassenhove 2006).

2.4 Managing Humanitarian Supply Chains

The complex operating environment of humanitarian operations and unique supply chains create challenging requirements for humanitarian supply chain management. This sub-chapter will dive into the specifics of humanitarian supply chain management and typical challenges humanitarian supply chain management faces.

As uncertainty and complexity are the prevalent factors in disaster relief operations, managing the humanitarian aid operations effectively and properly is crucial in implementing better responses. One tool for managing humanitarian operations efficiently is disaster management which lays foundation for humanitarian supply chain management. Disaster management has four phases that constitute the disaster management cycle: mitigation, preparation, response and reconstruction. (Cozzolino 2012) The disaster management cycle is presented in Figure 4.

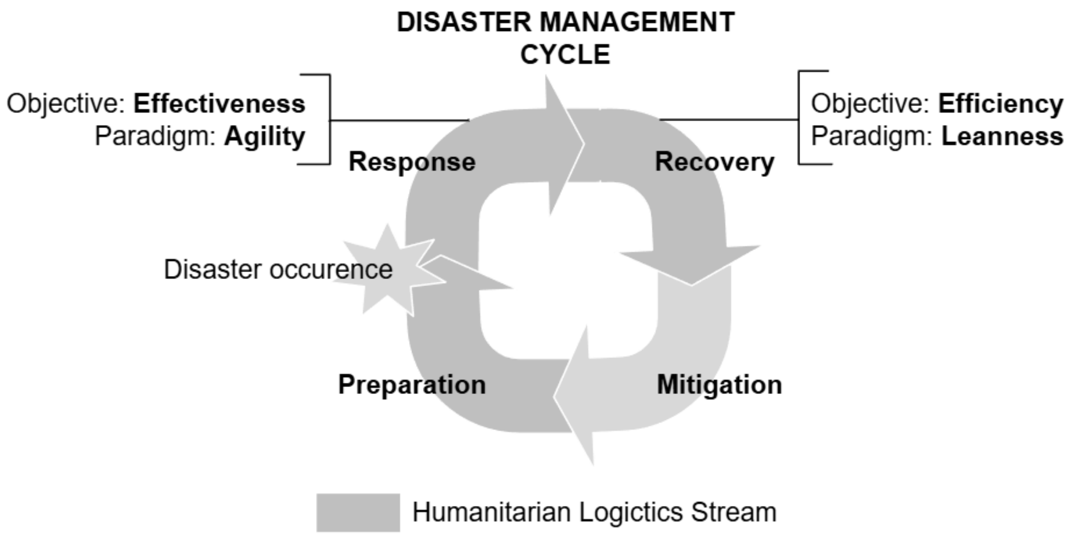

Figure 4: Disaster management cycle, adapted from Cozzolino (2012)

The mitigation phase includes social vulnerability reducing laws and mechanisms by governmental bodies. These issues do not involve direct participation of humanitarians. The preparation phase presents the operations that occur before the disaster strikes. This phase lays foundation for successful response by incorporating strategies and planning beforehand the disaster. This phase has a critical impact on the success of the disaster response. During preparation, the base of the collaboration, the physical network design, information and communication technology systems are developed. This phase should also include the critical learning process from other disasters to improve the disaster response. (Cozzolino 2012)

The response phase presents operations that implemented instantly after the disaster has occurred, consisting of two consecutive main objectives. The first is the immediate-response sub-phase: an instant respond by activating silent networks, defined by Jahre et al. (2009). The second is restore sub-phase which means restoring the basic services and delivering the goods in the shortest time possible to the highest number of beneficiaries as possible. (Cozzolino 2012)

In the response phase, collaboration between different actors is critical. (Cozzolino 2012) The objective is to operate as quickly as possible, because the first 72 hours are critical for the disaster response to succeed. Starting the process as quickly as possible at any cost is of the essence and requires rapid mobilization across the globe. (Van Wassenhove 2006) Lastly, the reconstruction phase includes operations in the aftermath of the disaster, involving rehabilitation and addressing the consequences and effects on the affected population in the long term (Cozzolino 2012). During this phase, approximately on the first 90 to 100 days, there is more of a balance between providing effective care to aid recipients and reasonable costs.

The disaster management cycle lays foundation for humanitarian logistics stream, which gives insight to main principles of humanitarian supply chain management. The humanitarian logistics stream also provides better understanding of where, when and what kind of effort to put in at different phases. It also provides guidelines for how the resources could be used in the disaster response to ensure effective managing of humanitarian supply chains. (Cozzolino 2012)

According to humanitarian logistics stream, in the response phase the objective is effectiveness which is achieved by agility in the supply chain. In the reconstruction phase, the objective is efficiency, achieved by leanness and focusing on effective and efficient work. For the response phase, the idea is to preserve life whereas in the reconstruction phase the idea is to sustain life. (Cozzolino 2012) These create the basis for humanitarian supply chain management, where “effectiveness ensures that we save time, and time saved means more lives saved; efficiency ensures that we save costs, and costs saved means more lives helped” (Cozzolino 2012).

As the disaster management cycle suggests, most decisions affecting the agility of humanitarian supply chains are done in the preparation phase. (Cozzolino 2012) For humanitarian supply chain management, this means preparedness and pre-positioning of resources and supplies globally to different hubs to reduce lead time after the occurrence of a disaster. (Van Wassenhove 2006; Cozzolino 2012)

To pre-position the supplies as accurate as possible, humanitarians must examine different risk factors for different areas. Luckily for natural, sudden onset disasters patterns can be found with geography, meteorology and physics. (Shen et al. 2018) For example, a close location to a tectonic plate boundary or to the Ring of Fire in the Pacific Ocean creates a high risk for earthquakes, volcano eruptions and tsunamis. Moreover, a short distance to the equator and ocean creates a high-risk factor for hurricanes, typhoons and tropical cyclones. (Shen et al. 2018) This gives the humanitarian some tools for forecasting the future demand. Yet, the methods are not comprehensive due to the nature of disasters.

Coordinating the efforts between different actors and stakeholders is one of the main challenges in humanitarian supply chain management. In the crisis scene, there are hundreds of actors with different agendas trying to provide aid for their own cause. For successful disaster response, coordinating the action is crucial. The different strategies for coordination are coordination by command, where a central coordination is presented by one actor; coordination by consensus, where organizations have access to compatible or shared communications equipment; and coordination by default, which includes routine contact between desk officers and civil military operations centres. (Van Wassenhove 2006)

Coordination by command is presented usually in the immediate response phase to get the humanitarians to the scene of the disaster as quickly as possible and to prevent bottlenecks from emerging. Coordination by consensus is useful strategy when the bottlenecks are cleared, and the humanitarian actors are operating on their specific mandates. Coordination by default is used in the reconstruction phase when the humanitarian organizations start to pull out from the crisis scene. (Van Wassenhove 2006)

These strategies help organize the multi-stakeholder environment from creating bottlenecks in the supply chains. Yet, the humanitarian actors face problems in information sharing (Van Wassenhove 2006). Lacking common databases to organise the efforts creates significant challenges for efficient communication between different stakeholders. Some of this happens naturally as, for example, the military is traditionally rather reluctant to share their information systems with other actors. This creates overlapping of resources and makes the humanitarian supply chain less effective. (Shalash et al. 2022)

The lack of coordination creates a chaotic disaster relief operation which was seen in the aftermath of the Indian Ocean Tsunami in 2004. There were too many actors, too much money and an overwhelmed government playing the coordinating role with the UN arriving too late to offer resources and help in coordination. (Van Wassenhove 2006) The chaotic response showed how crucial the coordination is in the humanitarian supply chain management was, resulting in more research in the area. Additionally, this demonstrates how crucial it is to plan the coordination efforts beforehand in the preparation phase.

One factor challenging the humanitarian supply chain management is the funding. As presented, natural sudden onset disasters usually get funding – but after the disaster has struck (Wakolbinger & Toyasaki 2014). This uncertainty of funding does not only create little incentive to learn from the past, but also challenges the learning curve of the organizations (Van Wassenhove 2006). Moreover, the implementation of new technological solutions for humanitarian supply chain management is problematic without proper resources (Besiou & Van Wassenhove, 2020). This is unfortunate because the technological advantages of 21st century have an enormous potential for improving the disaster responses and advancing humanitarian supply chain management. A consistent flow of funding could offer significant advantages for humanitarian supply chain management (Wakolbinger & Toyasaki 2014).

3. SUPPLY CHAIN MANAGEMENT DIGITALISATION

3.1 Digitalisation of Supply Chains

The digitalization of supply chains has significantly reshaped the landscape of supply chain management over recent decades. The Fourth Industrial Revolution, or Industry 4.0, has made organisations recognise digitalisation as a necessity in all their operations. As a result, there are fundamental changes in how organizations coordinate, optimize, and operate their activities, including managing supply chains. (Queiroz et al. 2021) This change has been driven by technological advancements that enable real-time data integration, automation, and enhanced transparency across the supply chain. This subchapter examines the key aspects and background of digitalization, its impacts on supply chains, influence on industries and lastly, its associated challenges, and emerging opportunities.

The digitalization of supply chains began in the late 20th century with the introduction of electronic data interchange (EDI) and enterprise resource planning (ERP) systems. These allowed companies to manage their supply chain processes more effectively as the transactions digitalized and separate business functions integrated. For example, ERP systems centralized and automated inventory management, procurement, and logistics, improving both accuracy and efficiency (Venkataraman & Demirag 2022). These early systems laid the groundwork for more advanced digital tools that enabled real-time data sharing and collaboration, which are the foundation for today’s digital supply chain ecosystems (Queiroz et al. 2019).

Since the 2000s, new technologies such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain technology have transformed supply chains, allowing for real-time tracking, predictive analytics, and enhanced security across the supply chain (Korpela et al., 2017; Queiroz et al. 2019). This shift from linear supply chains to interconnected and agile supply networks has enabled businesses to respond more quickly and effectively to market changes and disruptions (Queiroz et al. 2019).

Currently, digitalization has significantly impacted on how supply chains operate. Digitalisation has effective tools for information flow control. Information technology brings cost savings to the supply chain management, improves accuracy and enables more frequent information transfer and processing with more entities around the globe (Neubert et al. 2004, according to Korpela et al. 2017) Efficiency, transparency and resilience have significantly improved by the application of digitalization in the supply chains. At present, IoT-enabled sensors allow for real-time tracking of products and goods and offer visibility across the supply chain while reducing the risk of theft or damage. (Korpela et al. 2017) In logistics, digital tools enable real-time monitoring of transport routes and environmental conditions, ensuring products are maintained under optimal conditions (Queiroz et al. 2019).

Data from these systems provides critical insights into demand patterns, production needs, and logistics optimization. Consequently, this enables companies to forecast demand with higher accuracy. (Venkataraman & Demirag, 2022) Moreover, using analytics enhances decision-making, helping companies optimize resources and reduce waste across the whole supply chain, from procurement to last-mile delivery (Queiroz et al. 2019).

The integration of digitalization in supply chains has been a catalyst for significant changes across entire industries. In sectors such as manufacturing and healthcare, digital supply chains provide companies with competitive advantage by enabling quick responses to changes in demand. (Venkataraman & Demirag 2022) For example, in the healthcare industry, blockchain technology ensures traceability and visibility in the distribution of sensitive medical products, preventing malfunctioning products from entering the market (Korpela et al. 2017).

Furthermore, industries are moving towards interconnected digital ecosystems at an increasing rate. In these interconnected ecosystems, multiple stakeholders collaborate through shared data platforms. (Queiroz et al. 2019) This interconnectivity supports the emergence of new business models for supply chain management, such as subscription-based supply chain services and predictive maintenance in manufacturing (Venkataraman & Demirag 2022).

Despite its benefits, digitalization of the supply chains introduces significant challenges. One central issue is data security and privacy. Digital supply chains involve extensive data sharing across multiple stakeholders. Blockchain, although secure, requires consensus and integration among all parties, which can be difficult to achieve in complex, multi-stakeholder environments. (Korpela et al. 2017) Additionally, the initial costs of implementing digital technologies such as AI and IoT can be insurmountable, especially for smaller companies lacking the resources of large organisations (Venkataraman & Demirag 2022).

Moreover, reliance on digital infrastructure exposes supply chains to cybersecurity risks, which can disrupt operations and cause significant financial loss if data is compromised (Queiroz et al. 2019). As more companies adopt digital supply chains, they face the ongoing challenge of protecting their systems from cyberattacks. This requires investment in heavy cybersecurity measures and continuous monitoring, adding once again costs to implementing these technologies. (Venkataraman & Demirag 2022)

However, digitalization opens new opportunities by enhancing supply chain sustainability, resilience, agility and responsiveness. For example, the usage of AI-driven analytics can help companies optimize energy usage in production and logistics and reduce their environmental impact. (Venkataraman & Demirag 2022) Moreover, IoT sensors allow for real-time monitoring of energy consumption and emissions, helping companies achieve sustainability standards and reduce waste (Queiroz et al. 2019).

Digitalisation of the supply chains can increase resilience by providing the companies forecasting tools that help identify potential disruptions and, as a result, respond proactively. Blockchain technology, for instance, enhances transparency and accountability, which is particularly valuable in sectors where traceability and supply chain transparency are critical. (Korpela et al. 2017). Overall, the digitalisation of the supply chains enables organisations to shift from reactive to more proactive strategies increasing supply chain agility, adaptability and responsiveness in today’s volatile global market (Queiroz et al. 2019).

3.2 Digitalisation Tools for Supply Chain Management

The digitalisation of supply chains has been possible through various technological breakthroughs and has enabled new levels of transparency, integration, efficiency and responsiveness in supply chain management. This subchapter presents the most important digitalisation tools that are central in the advancing supply chain management operations, such as blockchain technology, artificial intelligence (AI), geographic information systems (GIS), unmanned aerial vehicles (UAVs, or drones), Big Data Analytics, the Internet of Things (IoT), and robotics. These digitalisation tools have transformed the supply chain management in recent years (Venkataraman & Demirag 2022).

Blockchain technology has emerged as a powerful tool in supply chain management due to its ability to provide transparency and traceability in the most complex, multi-stakeholder environments (Korpela et al. 2017). Blockchain technology creates an immutable ledger, where the data entered can't be altered, tampered with, or deleted. Thus, blockchain technology ensures the secure tracking of transactions and goods, from raw materials to finished products. Furthermore, it ensures that all parties have access to reliable, shared data. (Queiroz et al. 2019) This traceability is particularly valuable in industries where verification of product origins is crucial, such as medical products and food, where safety and authenticity are priorities (Venkataraman & Demirag 2022).

In addition to the transparency benefits, blockchain can make administrative processes smoother by automating contract executions through smart contracts, which trigger transactions or shipments once certain conditions are met. This reduces paperwork and potential delays, making supply chains more efficient. (Korpela et al. 2017) However, implementing blockchain requires high levels of coordination and collaboration among stakeholders. Furthermore, it can be challenging due to varying technology standards and regulatory requirements across countries. (Queiroz et al. 2019)

The advantages of using artificial intelligence in supply chain management are indisputable. Artificial intelligence enables advanced data analytics and predictive modelling for forecasting allowing companies to respond to changes more effectively. AI applications include demand forecasting, route optimization, and quality control, all of which enhance decision-making and efficiency. AI also plays a key role in process automation, where machine learning models can identify patterns in production and logistics data to optimize scheduling and resource allocation. (Venkataraman & Demirag 2022) However, AI implementation is extremely resource-intensive and requires high-quality data and technical expertise, which challenges smaller organizations (Queiroz et al. 2019).

Geographic information systems (GIS) are crucial for optimizing logistics and planning facility locations in supply chain management, especially in challenging areas. By providing spatial data analysis and real-time mapping, GIS allows companies to visualize supply chain networks better and identify optimal routes based on different factors like traffic, distance and environmental conditions. In humanitarian logistics, GIS can be utilized for mapping affected areas and allocating resources effectively, making it valuable for rapid response planning and efficient distribution in post-disaster scenarios (Besiou & Van Wassenhove, 2020). GIS supports facility location decisions by providing insights into geographic and demographic factors, helping organizations identify strategic locations for warehouses or distribution centres. (Silva et al. 2019)

Unmanned aerial vehicles (UAVs), or drones, are increasingly applied in logistics, especially for reaching inaccessible areas during disaster response. In post-disaster situation, UAVs can rapidly transport essential supplies, such as medical aid, to affected populations when ground transport is temporarily unavailable (Silva et al. 2019; Venkataraman

& Demirag 2022). This makes UAVs suited for last-mile deliveries in humanitarian supply chains, where time-sensitive and high-priority goods must reach the aid recipients in remote locations. UAVs are also used in warehouse operations in industrial settings, where they monitor inventory by scanning and tracking stock levels, which helps reduce the need for manual checks while improving accuracy. (Venkataraman & Demirag 2022) However, the UAVs are limited with load capacity, regulatory restrictions, and the need for skilled operators. These challenges increase the cost and complexity of integrating UAVs into regular operations (Silva et al. 2019).

Big Data Analytics is central to digital supply chain management, enabling companies to analyse large volumes of data from diverse sources for more informed decision-making. By analysing patterns and trends, Big Data can improve, for example, demand forecasting, inventory management, and market adaptation, allowing companies to adapt quickly to market changes. (Queiroz et al. 2019) Big data analytics can help to pinpoint inefficiencies and cost-saving opportunities, such as optimize transportation routes and identify production bottlenecks (Venkataraman & Demirag 2022). However, Big Data requires significant data storage and processing capabilities, which may be challenging for smaller organisations with limited resources. (Korpela et al. 2017)

The Internet of Things (IoT) connects physical devices, such as sensors, vehicles, and machinery, to digital networks. This enables real-time data collection and monitoring across the whole supply chain. IoT sensors provide data on the location, temperature, and condition of products in transit, resulting in more precise tracking and quality control. This real-time visibility does not only enhance transparency, but also reduces risks associated with product damage, theft, or loss. (Venkataraman & Demirag 2022) In addition, IoT supports predictive maintenance, where sensors monitor the condition of machinery and equipment in manufacturing or logistics, alerting operators to potential issues before they cause downtime (Queiroz et al. 2019). The primary challenge with IoT is ensuring interoperability among different devices and systems, as well as addressing cybersecurity risks that rise from increased connectivity (Korpela et al. 2017).

Lastly, robotics are increasingly used in supply chains for automating repetitive tasks, such as sorting, packing, and transporting goods in warehouses. Autonomous mobile robots can navigate warehouse floors to move products to different stations, reducing labour costs and increasing throughput (Queiroz et al. 2019). In addition to warehouse automation, robotics are being explored for use in transportation and delivery. Autonomous vehicles have the potential to transform logistics operations by reducing dependency on human drivers reducing human error and operating costs. (Venkataraman &

Demirag 2022) However, implementing robotics into supply chain management is significantly capital-intensive as it requires investments in technology, infrastructure, and specialized training. (Korpela et al. 2017).

Due to the scarce resources of humanitarian sector, the robotic technology is mostly unattainable for humanitarians. As the technology develops in the upcoming decades and costs are reduced, robotics could be used for pre-stocking of goods in the preparation phase and warehousing in the recovery phase. However, at this stage the costs of robotics are not aligned with benefits in the humanitarian sector and will not be discussed further in this paper.

4. DIGITAL SOLUTIONS FOR HUMANITARIAN SUPPLY CHAIN MANAGEMENT

4.1 Supply Chain Digitalisation Solutions for Humanitarian Supply Chain Management

After outlining the challenges commonly encountered in humanitarian supply chain management and examining the digital solutions adopted by the private sector, these insights are integrated to propose potential solutions. This sub-chapter explores the possible applications of supply chain digitalisation solutions for humanitarian supply chain management.

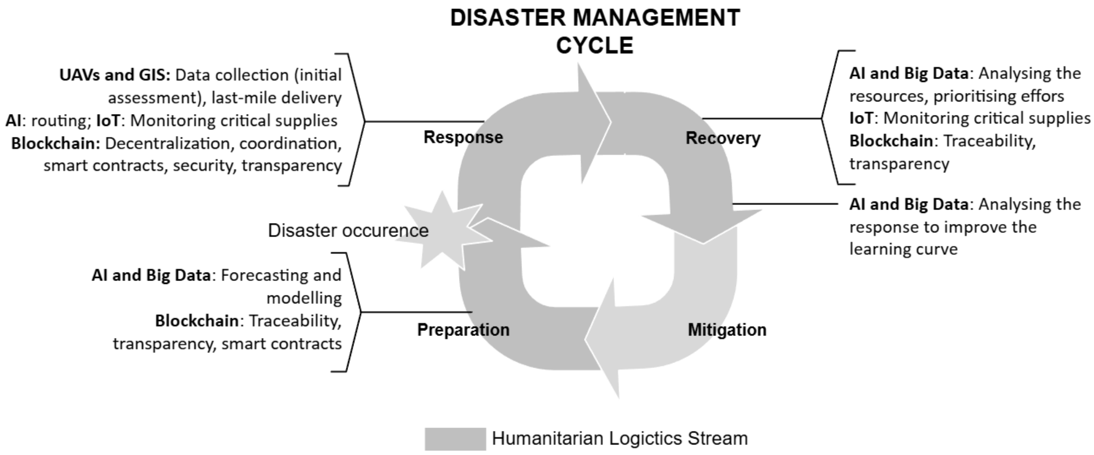

Figure 5: Applications of supply chain digitalisation solutions for humanitarian supply chain management by the phases of disaster management cycle

The possible applications of supply chain digitalisation solution for the benefit of humanitarian supply chain management are presented in the Figure 5, categorised by the phases of disaster management cycle. For preparation phase, implementation of AI and Big Data can give improved tools for forecasting and modelling (Besiou & Van Wassenhove 2020). Forecasting and modelling are critical processes for successful supply chain management and essential to the strategic, tactical, and operational planning for organizations' supply chain activities (Venkataraman et al. 2022). Analysing hazardous areas' historic disaster data and geographic phenomena with AI and Big Data could give an insight to humanitarians on where to pre-positions resources in order to mobilize them rapidly and effectively in the event of a disaster (Besiou & Van Wassenhove 2020). With AI, the humanitarians could also model possible disaster scenarios to better understand the impacts of different approaches on the aid operation.

For humanitarian supply chain management, the implementation of blockchain technology could bring significant advantages in all supply chain management activities (Ozdemir et al. 2021). For preparation phase and pre-disaster stocking of goods, the immutable record technology and real-time tracking possibility with IoT devices both improves coordination of the supply chains, but also increases trust between the donors and humanitarian actors. By creating immutable tracks of all the movements of goods, the risk of corruption decreases and donors can even track themselves how their donations are utilized (Ozdemir et al. 2021). This high-level transparency and traceability are essential for building trust between donors and actors (Korpela et al. 2017), hence increasing the funding of humanitarian operations.

In the response phase, when the disaster has just strook, the use of advanced technologies can make a difference in the pace of mobilization of the resources and hence the effectiveness of the response (Besiou & Van Wassenhove, 2020). As time is of essence, this can make a difference between life and death for thousands in the occurrence of a sudden onset natural disaster (Van Wassenhove 2006).

Firstly, as the affected area might be remote or the infrastructure greatly damaged, UAVs and GIS offer a tool for assessing the affected area. With UAV and GIS, the humanitarians can collect data of the scope and intensity of the disaster airborne by comparing the data before and after the disaster (Silva et al. 2019; Besiou & Van Wassenhove 2020). This provides vital data for the humanitarians to plan the aid distribution routes for humanitarian personnel and assess which areas are in most critical need of aid. Additionally, AI can be of usage to analyse the data collected by the UAVs to further identify concerning factors in the affected area (Besiou & Van Wassenhove 2020). The clear advantage of UAV and GIS usage is that the analysis can be done quickly, cost-effectively and without risking the personnel's safety nor further creating damage to the areas (Venkataraman & Demirag 2022). This also supports the objective of effectiveness of the immediate response phase.

Secondly, multiple features of blockchain technology can be of essence in the response phase. Blockchain technology is highly beneficial for coordination of multi-stakeholder environments (Korpela et al. 2017). First and foremost, blockchain technology could enable decentralised collaboration between multiple stakeholders and different humanitarian actors (Ozdemir et al. 2021). With blockchain technology, trust and coordination are achieved through the blockchain's immutable ledger where all the transactions and activities are recorded on a shared ledger that is visible to all authorized participants (Korpela et al. 2017). This ensures transparency and security (Venkataraman & Demirag 2022). With blockchain technology, actors can trust the system rather than each other, securing the collaboration even with numerous partners in a disaster setting and the operations are effective. (Ozdemir et al. 2021)

Additionally, blockchain technology's role-based permissions for data access advanced bring security to the system (Korpela et al. 2017). Therefore, blockchain technology can further enhance data sharing and trust between different actors, even the traditionally reluctant ones such as military (Ozdemir et al. 2021). Another important feature could be the smart contracts of blockchain technology (Korpela et al. 2017). When predefined conditions are met, smart contracts automatically execute actions. In the event of a disaster, this could significantly reduce time to mobilize the supply chains whilst further increasing donors' trust (Ozdemir et al. 2021). Furthermore, smart contracts interacting with IoT devices could verify and record the movement and condition of the supplies and automatedly give updates along the supply chain, resulting in better control and visibility of the movement of the goods. Blockchain technology equipped with IoT can also bring real-time data on the movement of supplies for all the actors (Korpela et al. 2017). This could make the efforts more efficient by reducing duplication of supplies by different actors.

Later in the response phase, after the assessment of the situation and the mobilization of the first resources is done, UAVs and GIS can be utilized to provide help to aid recipients (Silva et al. 2019). UAVs can carry small loads of food, water and medical supplies to access remote areas with destroyed infrastructure (Besiou & Van Wassenhove 2020). These last mile delivery challenges are common in earthquakes and in mountainous regions and UAVs could bring quick relief before the humanitarian actors get access to the region.

After the response phase, the efficiency of the aid operations is highlighted in the recovery phase (Cozzolino 2012). As the focus shifts from rapid aid delivery to more long-term rebuilding, resource allocation, and infrastructure development, the digital tools of supply chain management can play a critical role in building more efficient systems. Big Data and AI can be utilized in analysing data to identify where resources are needed most and conclude predictive analytics to help prioritise rebuilding efforts and allocate funds (Besiou & Van Wassenhove 2020). This could ensure optimal use of limited resources of humanitarians, reduce wastage and focus efforts on where they are most effective. IoT can be utilized for monitoring certain parameters of the supplies in the supply chain (Venkataraman & Demirag 2022), such as the temperature of the vaccines and blood, to ensure the medical supplies stay intact and functionable during the delivery.

In the recovery phase, blockchain technology is yet again a key technology in increasing supply chain transparency to improve the efficiency of operation and reduce waste. Blockchain technology can also play a key role in increasing donor trust whilst the operations prolong from rapid response phase to profound humanitarian aid (Ozdemir et al. 2021). After the event, Big Data and AI can be used to analyse the response (Besiou & Van Wassenhove 2020) and improve the learning curve.

4.2 Analysis of the Solutions and Best Practices

The supply chain digitalisation technology of the 21st century has undisputable benefits to all sectors. Yet, challenges lie in the implementation of these practices especially in the humanitarian sector. As humanitarians work with remarkable limited resources, the costs affect the equation even more greatly than in traditional industries (Besiou & Van Wassenhove 2020). Even though some technologies could have potential for enhancing humanitarian supply chain management significantly, only a few advancements can be implemented. This sub-chapter explores the limitations of implementing the solutions presented in the sub-chapter 4.1 and examines the costs and benefits of the introduced technologies concluding the best solutions for humanitarian actors.

Technology	**Benefits**	**Limitations**
Blockchain technology	- decentralization - transparency - traceability - transaction security - smart contracts	- resource-intensive - technical expertise - initial collaboration - data security risks - reliance on the internet
Artificial Intelligence	- tools for forecasting, modelling and routing - advanced analytics for performance	- resource-intensive - high-quality data required - technical expertise - cost
UAVs and GIS	- improved data collection - assessing the impact - last-mile delivery capabilities	- load capacity - weather dependency - regulatory restrictions - skilled operators
Big Data	- forecasting and modelling - advanced analytics for performance	- resource-intensive - high-quality data required - possible cost
Internet of Things	- monitoring critical supplies	- resource-intensive - reliance on the internet

Table 3: Limitations and benefits of the digital supply chain technologies presented in the paper

The limitations and benefits of the presented solutions are presented in the table 3, which compiles observations of this thesis from the sources used in this thesis. Some of these applications have data-related limitations. Artificial intelligence is highly data dependant, requiring large, high-quality data sets to function properly and technical expertise to maintain the data. Additionally for Big Data, the data availability might be challenging in the disaster situation. Data might also be biased, leading to inaccurate analytics or decision-making in both cases (Besiou & Van Wassenhove 2020). For IoT, data overload might challenge humanitarian organisations if they lack adequate processing and analysis capabilities. IoT devices are also prone to damage in harsh environments which are typically present in natural sudden onset disasters. Moreover, most IoT devices rely on the internet access (Venkataraman & Demirag 2022) which might be challenging to achieve in some disaster conditions.

For most solutions, such as blockchain technology, AI, IoT and Big Data, the main limitation is the initial cost of implementing a new system (Besiou & Van Wassenhove, 2020). Setting up and maintaining complex systems required specialized knowledge and skills that humanitarians rarely have, especially in sufficient volumes. Moreover, the system itself has an initial cost, but also the training of the personnel, transition period of switching the systems and implementing new processes takes up resources (Besiou & Van Wassenhove, 2020). Furthermore, implementing new digital networks and systems exposes humanitarians to more cyber risks as the attack surface increases. Reliance on internet connection might also become a problem for most remote areas. Thus, some type of hybrid approach should be proposed to ensure reliability even in the most remote settings.

A connecting limitation to all the solutions comes down to funding. Especially for sudden onset disasters, the donations start flowing in as the disaster strikes (Wakolbinger & Toyasaki 2014). Yet, the infrastructures, systems and processes must be implemented well in advance. The core challenge of humanitarian operations arises: how to get continuous flow of sufficient funding with which advancements are enabled? As highlighted in the sub-chapter 2.4, the preparation phase lays foundation to a successful response by creating a base for the collaboration, the network designs and information and communication systems are implemented (Cozzolino 2012). But finance-wise, this creates a challenge as this is the phase with least resources to operate with.

Bar the initial investment, blockchain technology requires significant investments resource-wise. Implementation of blockchain technology requires high levels of collaboration and coordination among different stakeholders (Korpela et al. 2017). This collaboration might be challenging to achieve without a connecting disaster to work on, especially as the process is time consuming. Moreover, varying technologies of different stakeholders and regulatory requirements in different countries add to the challenge (Queiroz et al. 2019) and might become insurmountable at least to the smaller organisations. In addition, many features of the blockchain technology, such as smart contracts, require complex coding which might be challenging for humanitarians.

For UAVs, the initial cost is not as significant as for large-scale systems. Yet, modernising the equipment is still capital consuming (Van Wassenhove 2006). Limitations to UAVs come down to the innate shortcomings of the equipment itself. For last mile deliveries, the limited load capacity of the equipment narrows its usage for deliveries and only lighter supplies can be carried with it (Venkataraman & Demirag 2022). Furthermore, UAVs are weather dependant which is challenging in the events of natural disasters. Poor visibility due to weather conditions such as fog, mist, or heavy rain can limit the operational capabilities of UAVs (Climavision 2024). Moreover, the use of UAVs is regulated, and violations may occur due to poor visibility. The UAVs require skilled operators and hence require either more training or recruiting new personnel to operate them, adding to costs.

After analysing the limitations and benefits of the introduced technologies, the different solutions can be assessed with Cost-Benefit matrix. The matrix is presented in the Figure 6, and it complies observations from the sources of this thesis. The Cost-Benefit matrix showcases the possible advantages and costs of the introduced digital supply chain management tools for humanitarian supply chain management. With the matrix and evaluated benefits and limitations of each solution, best practices for humanitarian supply chain management can be concluded.

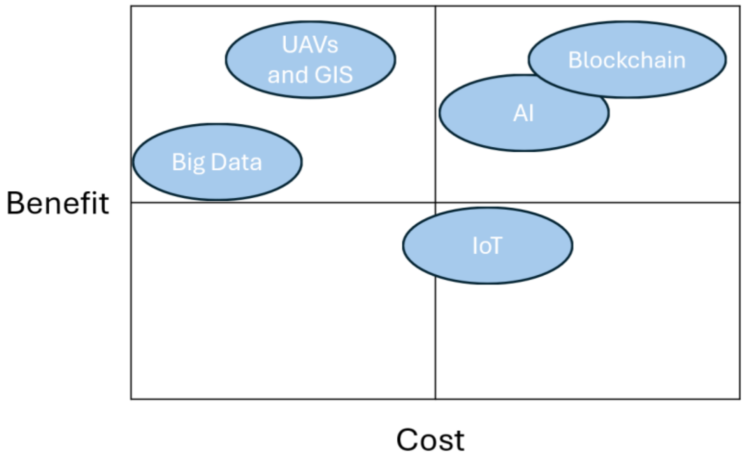

Figure 6: Cost-Benefit Matrix of digital supply chain technologies for humanitarian supply chain management

As the figure suggests, the highest value with lowest costs is gotten with UAVs and GIS and Big Data. The initial cost of UAVs is not as remarkable as with large system implementation and benefits are evident in the quick data collection and assessment in the immediate-response phase (Besiou & Van Wassenhove 2020). Moreover, the delivery capabilities could become lifesaving (Venkataraman & Demirag 2022) in a disaster scene. To tackle the need for skilled operators, humanitarians could investigate the possibility to create subcontract-partnerships with local professionals, alarmed when a disaster occurs. The weather dependency creates significant limitations (Climavision 2024) for certain natural sudden onset disasters, such as volcanic eruptions, but for the others, such as earthquakes and landslides, UAVs bring remarkable benefits for quick results with low costs.

Big Data Analytics might seem contradictory in the high-benefit, low-cost as the analytics requires high expertise and significant investments. However, as data collection and storage might be expensive, the most beneficial option for humanitarian would be to use low-cost or free data sources for analytics (Besiou & Van Wassenhove 2020). Satellite imagery and crowdsourced data could bring advantages for response analytics with lower costs. With these assumptions, it is justified to consider Big Data as a low-cost, high-benefit solution for humanitarians. Big Data analytics with AI applications can bring advancements for forecasting and modelling (Venkataraman & Demirag 2022) and further improve response analytics for learning purposes (Besiou & Van Wassenhove 2020).

Blockchain technology provides great applications for humanitarian supply chain management. With blockchain technology, different stakeholders and humanitarian actors can ensure trust and improve collaboration and coordination in a multi-stakeholder environment (Ozdemir et al. 2021). Implementation of blockchain technology enhances security of transactions (Korpela et al. 2017) and makes humanitarian supply chain management more efficient by increasing automation via smart contracts. Furthermore, improved transparency of management practices enhances donor trust which is crucial for continuity of humanitarian action (Ozdemir et al. 2021). Therefore, it is justified to put blockchain technology to the high-benefit quadrant. Yet, the high initial investment costs and required expertise for system management are challenging. To tackle challenges, building partnerships between humanitarian actors would be beneficial to share costs and expertise and should be strongly considered.

AI brings improvements for forecasting and modelling to help humanitarians better prepare for upcoming disasters, analyse the responses and improve the learning curve (Besiou & Van Wassenhove 2020). AI can be utilized for routing optimization and analysing and prioritising resources (Venkataraman & Demirag 2022). Like blockchain technology, AI requires significant investments and technical expertise to implement properly (Besiou & Van Wassenhove 2020). Thus, building partnerships between larger organisations could help to get the required resources.

Implementation of IoT would be valuable for critical humanitarian supply chains. For temperature sensitive supplies, such as medical supplies and food, IoT devices could help monitor and ensure optimal conditions (Venkataraman & Demirag 2022) during response and recovery phase. However, due to the limitations in funding (Besiou & Van Wassenhove 2020), IoT might be too capital consuming for large scale implementation in humanitarian supply chain management. Therefore, the technology should be targeted only for critical supply chains.

5. CONCLUSION

The significance of humanitarian action is estimated to increase in the upcoming decades due to the global warming and population growth (Cozzolino 2012; UNHCR 2024). As the number of humanitarian crises, especially natural onset disasters, increases, and funding remains insufficient and declining, the efficiency of humanitarian supply chain management is highlighted (Besiou & Van Wassenhove 2020). In the private sector, these challenges have been approached by implementation of digital technologies of Industry 4.0 to bring agility, transparency and efficiency to the global supply chain networks. (Quieroz et al. 2019) Furthermore, these technologies improve trust and collaboration between entities in a global B2B market (Korpela et al. 2017). Thus, the digital supply chain technologies have potential for humanitarian supply chain management (Besiou & Van Wassenhove 2020).

The research questions investigated how humanitarian supply chain management could benefit from digital technologies of private sector and what type of applications they could have in the humanitarian supply chain management. The thesis concludes that the digital supply chain technologies are adaptable for humanitarian supply chain management, and they can bring significant advancements. Firstly, blockchain technology can bring cost-savings to the supply chain management addressing the challenge of scarce funding. Furthermore, applying blockchain technology to humanitarian supply chain management can bring security to the transactions easing the collaboration between different stakeholders and increase donor trust through improved transparency (Ozdemir et al. 2021).

Secondly, artificial intelligence and Big Data can play a key role in all phases of disaster management cycle improving the learning curve with advanced analytics of the disaster response. Applying these technologies in forecasting, modelling and routing brings humanitarians more tools for analysing the disaster situation and best practices to advance the response (Besiou & Van Wassenhove 2020). Using low-cost Big Data sources and sharing the expertise and costs of artificial intelligence between different actors, humanitarians can improve their level of their supply chain management performance.

Thirdly, UAVs and GIS can benefit humanitarian supply chain management with fast data assessment and collection in the immediate response phase to quickly mobilise the efforts (Besiou & Van Wassenhove 2020). In addition, they can be applied to perform vital last-mile deliveries for medical supplies and food in challenging territories or conditions (Venkataraman & Demirag 2022).

Lastly, IoT can be applied for monitoring the critical supply chains, such as medical supplies and food, to ensure the supplies stay intact and in optimal conditions throughout the supply chain (Queiroz et al. 2019; Venkataraman & Demirag 2022). Moreover, connecting IoT devices to blockchain technology enables real-time tracking allowing humanitarians to trace and react to bottlenecks in real time. This allows for more efficient and agile supply chain management benefitting the humanitarian supply chain management. Due to the limitations in funding, IoT should be targeted only for critical supply chains.

The most significant limitations for applying these technologies to humanitarian sector lie in funding, required technical expertise and in the challenging operating environment of the humanitarian operations (Besiou & Van Wassenhove 2020). The initial investment for new systems is significant and, without existing technical expertise, the training of the personnel, transition period of switching the systems and implementing new processes takes up resources considerably. Additionally, the multi-stakeholder environment challenges the humanitarians as motives vary and comprehensive collaboration prior to the disaster is difficult to achieve.

To overcome the challenges and benefit from digital technologies, humanitarians should consider partnerships to share the costs and expertise. Collaboration between private and humanitarian sectors should also be considered as it would benefit both parties: Humanitarians could help the private sector navigate unpredictability and enhance the agility of the supply chains. On the other hand, the private sector could offer the technical expertise required for digital supply chain technologies. All in all, the thesis concludes that the humanitarian supply chain management can significantly benefit from the digital technologies of the private sector and the application possibilities enhance the disaster response remarkably. Therefore, the implementation of these technologies should be studied further to be applied to humanitarian sector.

Overall, more research, both academic and applied, is required to implement digital technologies into humanitarian supply chain management. Most research done in this area is primarily theoretical and hasn’t been verified by real case studies (Ozdemir et al. 2021). This also limits the findings of this thesis. Hence, piloting the applications of digital technologies to humanitarian supply chain management should be firstly concluded in small scale operations before implementing to humanitarian supply chains worldwide. Moreover, as each humanitarian supply chain is unique, the digital technologies might not be appliable to every supply chain. The barriers to application should be studied and identified so that the resources can be targeted toward the most feasible and impactful solutions.

Despite humanitarians’ efforts, the industry requires consistent flow of capital to fully implement new processes and systems which eventually are lifesaving. As natural disasters become more prominent, these advancements are crucial and should be implemented well in advance to address the trend.

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