A general framework for epidemic logistics management

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Abstract. Human history is full of epidemic outbreaks that occur on a regular basis. The past epidemics have resulted in millions of deaths and economic recessions. With the increasing frequency of human-induced epidemics in recent years, effective and efficient epidemic logistics management has become vital for successfully containing the spread of the disease as well as preventing societal disruption, avoiding catastrophic human loss, and a substantial economic burden. However, there is a lack of a systematic study on this topic, let alone an in-depth understanding of logistics that are related to the epidemic. This paper aims to fill this gap by studying some co-related concepts that are relevant to epidemic logistics, i.e., humanitarian logistics, and emergency logistics. As none of these existing concepts cover the particularities of an epidemic nor they have managed to capture the characteristics of the logistics in the context of epidemics, a new definition of epidemic logistics is proposed. This definition is then followed by an analysis of the challenges and needs for effective and efficient management of epidemic logistics. This leads to our proposal for a general framework that defines all the essential elements of an epidemic logistics system with a high level of sustainability, resilience, and alignment. This framework also provides a baseline that enables systematic management of logistics operations before, during, and after epidemics. Several research directions and suggestions are provided for follow-up studies.

Keywords: Epidemic management, Logistic operations, Sustainability, Resilience, Alignment

1 Introduction

Humans have suffered from various forms of catastrophic epidemics e.g., smallpox, plague, Spanish flu (1918-1920), HIV/AIDS, SARS (2002-2003), H1N1 (2009-2010), Ebola (2014-2016), etc. Many of them still pose a great threat to humanity as they tend to return in various forms [1]. Epidemics are usually triggered by the emergence of pathogens, climatic changes, bioterrorist attacks, exploitation of the natural environment, and the consequences of natural disasters. The current outbreak of Covid-19 is considered the worst infectious disease in terms of the number of infections, deaths, and unprecedented demand for health services [2]. To date (March 26, 2022), approximately 483 million people from 225 countries (and territories) have tested positive,

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among which more than 6 million deaths have been recorded since the first reported case on December 31, 2019 [3].

While the consequence of pandemic has been increasingly severe, the inter-pandemic period has been largely shortened. Between 1700 and 1889, the average inter-pandemic period ranged from 50-60 years; since then this period has narrowed to 10-40 years [4]. According to the World Health Organization (WHO), there were a total of 1,438 epidemics outbreaks between 2010 and 2018 [5]. A previous local contained disease can easily become a global pandemic within a very short time when the disease spread is facilitated by urbanization, globalization, mass gatherings, and the mobility of humans [6] and can cause a substantial economic burden and unparalleled disruption to the global supply chain [7].

One of the possible reasons for the failure to contain the Covid-19 outbreak is the lack of a comprehensive understanding of logistics during the pandemic, i.e., what, how, and when to react. Improper understanding can lead to a delayed reaction in catching, isolating, and treating the virus [8]. This understanding should build upon and benefit from the existing research on pandemic logistics even though it is very unlikely that a coming pandemic will mimic those of past events [9]. Further, it is essential to provide methods, tools, and guidelines to the logistics stakeholders during pandemics for supporting proper and timely responses and therefore mitigating the loss. A general framework for managing logistics operations in pandemics is therefore necessary.

The study presented in this paper aims at developing a comprehensive understanding of epidemic logistics. The authors, firstly, conduct a broad review of the correlated concepts followed by a review of epidemic-related logistics activities. Challenges that are related to the epidemic logistics are identified. The paper also proposes a framework for managing logistics operations for effective and efficient handling during epidemics.

2 Epidemic as a type of natural disaster

A disaster is defined as a disruption in the functioning of society or community resulting from catastrophic events related to conditions of exposure, vulnerability, and capacity [10]. Disasters can be categorized as man-made, natural, sudden-onset, and slow-onset [11]. A natural disaster is a catastrophic event with atmospheric, geological, and hydrological origins which has a significant impact on the well-being of the affected population [12]. The International Disaster Database (EM-DAT) classifies natural disasters into 6 different types: geophysical (e.g., earthquake), metrological (e.g., storm), hydrological (e.g., flood), climatological (e.g., drought), biological (e.g., epidemic), and extraterrestrial (e.g., hazard caused by meteoroids or comets [13].

An epidemic is a unique form of disaster for many different reasons. Firstly, unlike other disasters, an epidemic, if not contained, can easily become a global pandemic within a very short period, eventually leading to a significant societal and economic disruption. The transmission of an epidemic disease knows no borders and makes everyone in the world vulnerable [14]. Time is a critical factor in the context of an epidemic.

Another interesting characteristic of an epidemic is that it doesn't cause any physical damage to one's property nor do they destroy any means of transportation or other infrastructures [15]. Therefore, there is no need to mobilize people to the safest place or provide them with food or shelter. However, it is extremely important to identify the infected individuals and isolate them from the other susceptible. Thus, during an epidemic, the goal is not only to save lives by treating them, but also about blocking the source of infection to protect other individuals [16].

During an epidemic, saving lives through proper treatment demands a timely supply of medical equipment, food, vaccines, and other essential services and materials (such as hospital beds, facemasks, disinfectants, etc.). An efficient logistics system for secure and timely delivery to the right place is therefore critical for containing the epidemic and alleviating suffering. As an epidemic may spread quickly from one region to another, the level of demand on these suppliers can vary rapidly in a short amount of time. This can easily result in immediate regional, national, or worldwide shortage of essential supplies – whereas, in other forms of disasters, demand comes only from the affected area.

Compared to other types of disasters, the duration of an epidemic is also uncertain. It hardly goes away if containment efforts are not put in place whereas other disasters such as floods, landslides, earthquakes, etc., are not as enduring as epidemics and last ranging from few days to months. This uncertainty is especially challenging and can only be handled by a highly resilient logistics system.

3 Epidemics and logistics

An epidemic is a rapid spread of disease in a given population within a short time [17]. When an epidemic is not contained properly and timely, it develops easily in scale and scope and ends up as a pandemic. With the increasing frequency of human-induced epidemics in recent years, effective and efficient epidemic logistics management has become vital for successfully containing the spread of the disease, preventing societal disruption, and avoiding catastrophic human loss as well as a substantial economic burden.

The term "epidemic logistics" is observed to be rarely used in academia, and neither have its elements been the focus of current research. This might be because, prior to today, the term is often obfuscated with other concepts, i.e. humanitarian logistics [18–21], emergency logistics [16, 22, 23], and disaster logistics [24]. This obscurity has resulted in difficulties in other critical tasks that are related to epidemic logistics management, i.e., identifying actors and implementing logistics functions that are essential for timely and cost-effectively handling for containing an epidemic.

Among a few definitions available, Thomas and Kopczak [25] defined humanitarian logistics as "*The process of planning, implementing and controlling the efficient, cost-effective flow and storage of goods and materials, as well as related information, from the point of origin to the point of consumption for the purpose of alleviating the suffering of vulnerable people. The function encompasses a range of activities, including preparedness, planning, procurement, transport, warehousing, tracking and tracing,*

and customs clearance". To this day, this definition is the most widely used in academia while some authors have slightly modified the version of this definition [20]. This seemingly common-accepted definition focused primarily on some logistics management functions, i.e., planning, executing, and control, with clear objectives like efficiency and cost-effectiveness. However, the definition didn't cover essential aspects, i.e., the primary goal of an epidemic, an effort to block the chain of the spread of disease. The suffering of vulnerable people can be alleviated only after the epidemic is contained. In addition, his definition focuses only on the preparing and operating phases of an epidemic. By not considering the post-epidemic phase, there is a risk of recontamination or suffering of long-term infrastructural deficiency.

The study of Altay and Green [26] divided the disaster life cycle into four phases: mitigation, preparation, response, and recovery. These four phases seem reasonably relevant to epidemic logistics. While Kovács and Spens [27] mainly focused on the causes of a disaster where an epidemic is due to natural ones, the study from Altay and Green [26] stated different management goals in terms of stages of an epidemic, i.e., mitigating epidemic risks and reduce losses by proper preparation to possible epidemics (pre-epidemic), providing timely response during an epidemic (during epidemic) as well as rapid recovery after the epidemic (post-epidemic).

Van Wassenhove [11] on the other hand, focused more on assets and organizational needs in an event by defining humanitarian logistics as "*The processes and systems involved in mobilizing people, resources, skills and knowledge*" with the goal being the same as above i.e. relieve suffering. Kovács and Spens, 2007 [27] presented a framework for humanitarian logistics that focused more on the involved actors and also distinguished the logistical activities in each stage of the disaster cycle [28]. Dasaklis et al. [6] took a similar approach but distinguished four phases of disaster: preparedness, outbreak investigation, response, and evaluation.

Jiang et al. [16] defined emergency logistics as "*a special logistics activities aimed at quickly providing necessary materials in case of natural disaster… to minimize the loss of life and property*". Zhao et al. [29] addressed emergency logistics for events including pandemics, rainstorms, and typhoons. As a more generic concept than emergency logistics, disaster logistics emphasized the importance of the quick responsiveness characteristic of logistics [30] as well as pre-and post-disaster logistics activities [24].

As seen, the existing research focused mainly on humanitarian logistics (i.e., for alleviating suffering) and emergency logistics (for quick response) which are not necessarily fitting into the scope of epidemics (contain first, alleviate second). For epidemic logistics, it is also important to consider different logistics activities in different phases of an epidemic. Further, it is essential to include different stakeholders (so as their valuable resources at hand) in management and decision-making in these phases to ensure timely, efficient, and effective logistics operations. To sum up, to provide a tailored definition of epidemic logistics, the following characteristics of epidemics should be taken into consideration:

- In the early stages, if not contained, the virus spreads so rapidly that it is very difficult to obtain information about the severity of the disease and also the demand-related information [31]
- Epidemic logistics lacks historical data [31]; it is very unlikely that the epidemiological characteristic of the disease is as same as the past ones but most likely a new variant or a novel disease which increases the uncertainty and complexity of managing an epidemic logistics system
- Even though the transportation facilities are less affected, the scarcity of items, the intervention policies, the shutdown of manufacturers, the unwillingness and absenteeism of the drivers, etc., to name a few, are the cause that forces these facilities to come to a standstill [15]
- During the epidemic, there is a surging demand for medical resources esp. medicines, or vaccine (if available) and the substitutability of these items are imperfect unlike other commodities such as food items, eventually leading to a global scarcity [31]
- Decision-makers must make decisions in uncertain environments due to the lack of predictable demand patterns, time pressure, uncertainty, and complex nature of the logistics system [32]

4 Challenges to epidemic logistics

The outbreak of an infectious disease poses an immediate threat to the public health system [31]. Logistics activities play a vital role in eliminating these threats by acting quickly and, providing all necessary needs to the epidemic-affected area at the right time and in the right quantity.

Table 1 shows the epidemic logistical challenges that have been found in our study. We classify these challenges into four categories: Operational, Management, Technological and Collaboration challenges. The majority of challenges were addressing the operational challenges of logistics activities. This is obvious given the uncertainty and unpredictability nature of an epidemic. Only after the onset of the outbreak, a rapid response is required. Further, from the management perspective, the development of a public health system and a decision-support system are central to achieving the goal of epidemic logistics. The decision-maker should consider making short and long-term decisions. In the short term, the priority may be given to rapid diagnosis and testing, transportation, and production of necessary supplies, while in the long-term, capacity building and adaptation of new technologies (e.g., digitization) should be a priority for an increased collaboration need.

Epidemic logistics has also been looked at through the eyes of sustainability and resilience but time and again, we've been hit hard by epidemics, exposing our weaknesses in our existing theories and logistics operations. Unfortunately, it seems that we have so far failed to develop a resilient system to fight against epidemics. This also reflects our negligence of not learning from the past and our inability of developing a robust logistics system to tackle supply chain disruption. Many may also observe our

unwillingness to recognize the fact that future outbreaks might be more catastrophic than the previous ones – if epidemic logistics are not managed properly.

Table 1. Epidemic logistics challenges

Epidemic logistics challenges	**Challenges criteria**
	OPERATIONAL CHALLENGES
Logistics activities	Vehicle routing [33], [34]
	Inventory management [35]
	Resource allocation [36],[31]
	Facility location [37], [38]
Forecasting	Unpredictable demand [36], [31]
Reverse logistics	Managing funeral system [39] Waste management [40]
	MANAGEMENT CHALLENGES
Public health systems	Awareness policies, isolation, social distance/hygiene [41], [42]
Decision making	Operational, tactical, strategic [37], [43]
Sustainability & Resilience	Waste management [38] Reverse logistics [40]
Equitable services	Equity and fairness factor [37], [44]
	TECHNOLOGICAL CHALLENGES
Adaptation	Dynamic changes and technologies [45], [46]
Digitalization	Digital technologies [45]
Standardization	Items, methods and process [47]
	COLLABORATION CHALLENGES
Coordination	Quick response-ability, coordination control capacity [16],
Collaborate	Public and private sector partnerships [48], [47]

5 Epidemic logistics

As discussed in the early section, alleviating the suffering of vulnerable people is not enough during an epidemic because it will not stop the transmission of the disease. Thus, epidemics, if not controlled, can easily take the form of a pandemic which eventually will lead to a significant disruption of the global supply chain, resulting in a worldwide crisis of essential supplies and therefore humanity suffers on a global scale. The challenges it brings are also scalable if prompt containment and management are in place. Therefore, effective and efficient logistics management is critical for early containment (to immediately break/block the chain of transmission of the disease), timely treatment of infected populations, as well as fulfilling demand on responsive logistics systems in terms of suppliers.

Based on our findings, we noticed that epidemics logistics are distinguishable from other existing forms of logistics. The goal of epidemic logistics is not only limited to

alleviating the suffering of vulnerable people but, above all, stopping the further spreading of the disease. The latter measure is more critical than the first as, unless the spreading of the disease is stopped, more people will be suffering from it. In that sense, it is also important to define the actors/stakeholders (i.e., government, municipalities, public health services, NGOs, logistics service organizations, and so on) that are involved in the management. The epidemic can only be contained through a joint effort from a community (i.e., at the national and /or global levels). Epidemic logistics is defined as follows in our study:

A series of coordinated logistics activities - conducted by all stakeholders involved, aiming at effectively limiting and curbing the spread of a disease and therefore reducing the risk of further spreading. These coordinated logistics activities also purpose to effectively alleviate the suffering of the infected and their related communities. Epidemic logistics includes logistics activities in planning, implementing, mobilizing, operating, and coordinating community and organizational resources in all phases of an epidemic.

6 A general framework of epidemic logistics management

When the epidemic comes, in addition to isolating infected people and supplying essential resources, eliminating people's panic and enacting appropriate laws and policies are highly critical [14]. An effective epidemic logistics management (ELM) system for predicting, preventing, preparing, detecting, responding to, and controlling epidemics to minimize their impact on public health and the economy is therefore necessary. This is a comprehensive term that encompasses all the activities that must be done prior to, during, and after an epidemic [49].

Further, with the increase in the tendency of the occurrence of an epidemic and the severity it brings along, a need for a sustainable ELM system with a high level of resilience is highly desired. A prevail classification of stages in the epidemic life cycle are mitigation, preparedness, response, and recovery. However, as mitigation is more like a goal for epidemic logistics in its entire life cycle, we consider the framework for managing epidemic logistics to be built on three main pillars – Before Epidemic, During Epidemic, and After Epidemic – each presents a distinct phase of the life cycle of an epidemic. Sustainability and resilience are two cornerstones of this framework to ensure the long-term survivability and robustness of an ELM system (shown in **Fig. 1**).

The first pillar consists of three elements: i. Lesson learned from the past, ii. Mitigation and iii. Preparedness. "Lesson learned from the past" helps in building all the mitigation and preparedness plans based on past experiences. The second element "Mitigation" focuses on activities that will help in identifying the potential source of the disease through a real-time surveillance system to prevent a possible outbreak while the third element "preparedness" contains preparedness plans to respond promptly if the outbreak happens. It must take into account several factors, including the expected demand, logistic infrastructure, existing capacity, reverse logistics planning, etc. Some of the logistics activities that support this pillar are resources assessment, stock

prepositioning, sourcing, procurement, facility location, warehousing, transportation & distribution planning, and so on.

The second pillar consists of an emergency response system and a warning system that are active only after the onset of an epidemic. The goal here is to quickly control and contain the epidemic through a rapid emergency response system which includes activities such as quickly identifying the vulnerable group, rapid testing and diagnosing of disease, supply of critical items (including vaccines if available), expanding of facilities, building temporary service center, etc. A quick response always relies on a well-built preparedness plan esp. during the initial phase of an epidemic. The warning system will inform the beneficiaries about the severity of the disease and assist them to follow the appropriate precautions and protocols to avoid contracting the disease and treat those who have already contracted it. The use of simulation models, forecasting, contact tracing tools, etc. are of core importance during this stage. This helps the decision-maker to decide on logistics activities such as ramping up/down the production, out/in-sourcing, closing/opening of facilities, resource allocation, procurement, handling, vehicle routing, distribution, delivery centers, etc.

The last pillar includes a recovery and reconstruction phase. After the epidemic is contained, it is vital to evaluate and reassess the bottlenecks as well as the problems that are incurred during the response phase and based on the discoveries, modify or rebuilt the current capacity, close or repurpose the temporary facilities, adaptation of new methods, systems or technologies, etc.

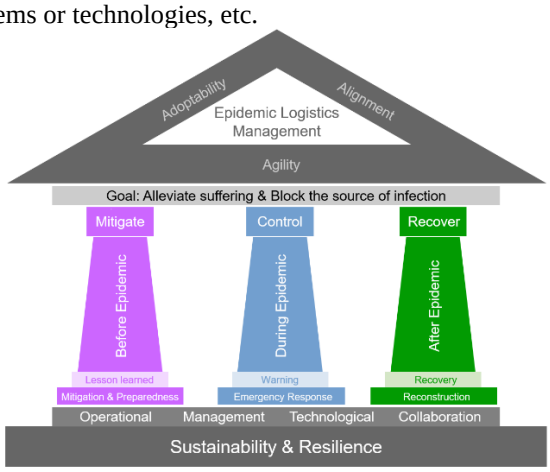

Fig. 1. A general framework for epidemic logistics management

Furthermore, all forms of epidemic logistics functions including operational, management, technological, and collaboration should be carried out to enhance the responsiveness and effectiveness of this framework (refer to **Table 1**). This framework should always be on a stand-by mode with a sustainable solution by constantly reinventing its plan and activities because old issues may be resolved but new challenges appear all the time [50]. A sustainable ELM can be achieved by continuously improving itself through a holistic approach by being agile (responding quickly), adaptive (ability to

change, scale & re-purpose), and align (with the stakeholders through cooperation and coordination).

7 Conclusion and future work

In this paper, we first distinguished an epidemic and its related logistics activities from other types of disaster and then identified the challenges faced during the time of an epidemic outbreak. Despite the frequent occurrence of the high virulent epidemic disease, there is no unified understanding of the term epidemic logistics, and the focus is rather shifted toward humanitarian logistics as well as other related concepts. However, epidemic logistics differ from other types of logistics because of their uncertain and unpredictable nature. To provide a clear understanding and bring more attention to this topic, we propose a definition of epidemic logistics and develop a general framework for sustainable and resilient epidemic logistics management. The framework provided in this paper has been constructed based on our review of the articles that are gradually collected while searching for literature related to epidemic logistics. More extant and systematic literature reviews need to be carried out to improve the quality of the definition as well as the elements of the framework. More precisely, each pillar of the framework can be further studied for a complete understanding of the provided framework.

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