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# Review on Decision Support Systems used for Resource Allocation in Health Crises

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***Abstract*—A disaster or crisis can be stated as a serious disruption occurring for a certain period of time, which could cause loss of human lives, properties, and disrupt the day-to-day life of people. Managing such situations is always a challenge due to various reasons. Especially, allocating and providing resources to manage disaster situations to restore the normal life of people is the main challenge in a disaster situation. Having a proper mechanism for resource allocation could save thousands of human lives as well as properties. Modern smart technologies play a vital role in designing and developing solutions for efficient and effective resource allocation mechanisms. For example, the COVID-19 pandemic has forced people to work from home using digital platforms. Those digital platforms have been able to support people to do their routine work while maintaining social distancing which minimizes the spread of Covid-19. On the other hand, those digital platforms provide an easy and fast way for healthcare officials to reach infected patients to provide necessary treatments and care. Present research critically reviews the past research on managing resources in health crises particularly falls under pandemics and epidemics.**

***Keywords—resource allocation systems, health crises***

## I. INTRODUCTION

Natural and man-made disasters commonly and frequently happen around the globe. Such disasters always pose threats to human life. For example, past disasters have claimed thousands of human lives and properties. In addition, the destruction they have caused to the environment is hard to recover. Especially, health disasters such as epidemics and pandemics could cause serious damages that negatively impacts human lives and the economies. For example, Cholera is responsible for 120-400 thousand deaths annually worldwide [1]. During the 2009 H1N1 flu pandemic, 203,000 deaths were reported around the globe [2]. The ongoing COVID-19 pandemic has caused 4 million deaths in 192 countries so far and declared a public health emergency by World Health Organization (WHO) [3]. Among them, a significant number of deaths have occurred due to lapses in health resources allocation. For example, in USA 15,571 deaths per month would have been prevented if the resources were effectively allocated [4], and in china it has been shown that a 10-fold per capita increase in the number of hospital beds, medical staff, and assisting staff would decrease the mortality rate by 0.393%, 0.24%, and 0.134% respectively [5]. It highlights the necessity to have a system to manage and allocate needful resources efficiently, which could save thousands of lives.

Disaster or crisis management is a broad domain that includes the phases of mitigation, preparedness, recovery, and response [6]. One of the key challenges in a disaster is that critical resources become scarce as the demand rises unexpectedly. For instance, human resources such as police, medical staff, rescue teams, and/or essential supplies like food, water, medicines/vaccines, equipment, etc. become scarce due to the high demand. A substantial number of researchers have studied and investigated this problem. However, it still remains a challenging task due to various reasons [1], [2], [6]-[18]. Resource allocation can be described as assigning resources considering various aspects of a crisis situation such as priorities, requirements (type(s) of resources and quantities needed), delivery options, and constraints such as ethical aspects [19]. For instance, in the current pandemic, the essential health resources are PCR test kits, personal protective equipment (PPE), vaccines, masks, hospital beds, ICUs equipment, medicines, etc [10]. WHO's declaration of pandemic triggered efforts to boost healthcare facilities and capacity especially in developed countries [20]. Unlike in developing countries, real-time communication technologies, control technologies, and detection technologies have been put together to provide a reliable and accurate medical resources supply system to fight against the health crisis in developed countries [8]. However, many developing countries such as Sri Lanka are suffering from lack of resources and effective resource allocation mechanisms which have made it hard to cope with the COVID-19 pandemic. The poor health infrastructures, lack of well-trained human resources, budget constraints, and poor resource management are the main contributors to this deprivation. Among those factors, poor resource management has been identified as a root cause for poor resource allocation in health crises. For example, quantifying available resources, surveilling the allocations, lack of social

awareness and the inability of taking timely decisions are the main issues with the current process. A substantial amount of research has proposed various solutions to mitigate the above problems but still optimizing resource allocation remains a challenging task due to poor resource management. It motivated us to investigate the existing systems to find their pros & cons.

## II. OBJECTIVES

Objectives of this study are as follows;

- Exploring the existing resource allocation systems in Health Crises
- Analyzing advantages and limitations of existing resource allocation systems
- Studying existing ethical frameworks and guidelines
- Identifying a necessity of a proactive resource allocation system dedicated to health crises

The rest of the paper is organized as follows. The methodology section presents the method used to select the related research followed by section IV which contains a critical review of the selected research and highlights the limitations & issues with the existing resource allocation systems. Finally, section V discusses the literature concisely and concludes this paper with the future directions of the research.

## III. METHODOLOGY

In a crisis situation, priority is given to save human lives. For example, at present, the whole world is racing towards finding a sustainable solution for COVID-19 to save and protect people from the deadly virus. While medical experts are working around the clock to find a medical solution, other healthcare workers are trying to mitigate the crisis with the available resources. As a consequence, the need for efficient and effective resource allocation mechanisms have been proposed based on past research. Studying and investigating the existing research provides a better insight into their advantages, effectiveness, applicability, and limitations. Therefore, the present research critically reviews some of the related research published in the recent past. This review was carried out as qualitative analysis in two stages. First, the relevant research papers were collected from different sources such as IEEE Xplore, Science Direct, ResearchGate, Google scholar, and random search on the Internet using Google search engine. In addition, the most cited papers in the reference lists were also added to the collection. We filtered papers published in the past decade, and the Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [21] standard was used as the guide for filtering papers according to its excluding and including criteria. Apart from that, the details of the community healthcare infrastructure and the resource allocation process to mitigate the COVID-19 pandemic in Sri Lanka were collected through observations and the Ministry of Health publications.

In the second stage, the selected papers were critically reviewed based on qualitative aspects to identify the features, pros & cons, and limitations of existing resource allocation systems. Prior to this, a keyword-based clustering technique was used to identify the most prominent keywords in related studies because keywords reflect the areas that have been covered in a particular study. The main reference tool used was Mendeley, and Microsoft Excel was used as a support tool for maintaining the keywords of selected papers. Out of the selected research papers, only 25 research papers included keywords. Thus, those papers were considered for keyword-based clustering that contained altogether 118 keywords as in the word cloud shown in Figure 1. After pre-processing the collected keywords, the feature extraction was performed using the Term Frequency-Inverse Document Frequency (TF-IDF) vectorizer. Then the Affinity Propagation algorithm, which is an unsupervised Machine Learning (ML) algorithm available for clustering was used for identifying inner patterns in the keywords.


Fig. 1. Keyword word cloud of selected research papers

## IV. SMART DECISION SUPPORT SYSTEMS FOR RESOURCE ALLOCATION IN HEALTHCARE

Designing health-related information systems is always challenging because critical decisions are made based on the information and analytics produced by those systems. Therefore, the accuracy of the system is a crucial factor to be considered when designing such decision support systems. Apart from that, due to the sensitivity of health data, it is required to consider the ethical aspects when allocating resources.

### *A. Decision Support Systems (DSS)*

Resource related decision-making is a complex process especially during crises but the accuracy and the effectiveness of the decisions can be improved with the use of new technologies. Recent studies have proposed promising resource allocation systems with the aims of prioritization, utilization, scheduling, and dispatching resources effectively [6], [7]. Those systems consist of data collection frameworks, databases, and resource deployment guidelines. Besides, different algorithms have been used for victims clustering, resource allocation, and dispatching resources during disaster situations. To take effective and efficient resource allocation decisions it is required to have robust mechanisms to verify data collected from various sources using different data

collection methods. Among them, IoT devices such as sensors, RFID, and Google Maps API have been used in modern systems to collect real-time data. As a smart device, mobile phones play a vital role in modern data collection, and it enables people to be aware of the current situation of the crisis [9].

As this research is narrowing the scope to the health crises, it is worth reviewing the past research that has investigated decision support systems used in the health domain. Optimizing healthcare resource allocation, and distribution has been a key topic in past research. For instance, a platform has been built based on cyber-physical systems for optimizing the city medical resource distribution [8]. It is capable of training people for medical treatment, reducing imbalance and improving utilization of resources with the help of its intelligent and real-time network. A data-driven optimization approach has also been introduced specifically for a cholera outbreak [1]. It considers only vaccines and antibiotics as resources and practices multi-period allocation based on location-specific data of a meta-population. Unlike that, both human and material healthcare resources are assigned, monitored, predicted, and coordinated by the IMPRESS system along with resource mobilization [11]. Another promising way is introducing mathematical models as an aid for resource allocation. For example, patient prioritization and smart dynamic allocation models usage are possible in a patient-driven mobile medical information system [15], [22]. In order to improve decisions, some frameworks also have been designed based on a country's Geopolitical position that is capable of locally collecting, centrally aggregating data prior to being analyzed and communicated [23].

There is a surge in recent studies that focused COVID-19 pandemic as the case study for implementing resource allocation systems. For example, an optimal solution for ventilator distribution during pandemics was proposed as a mixed-integer model adapting an epidemic model called SEIAR (suspectable, exposed, infected, asymptomatic, recovered) for demand prediction [12]. The findings suggest that inter-regional pooling strategies are ensuring adequate provision of ventilators. Further, a time-varying linear optimization-based approach has been proposed for vaccine allocation during a pandemic using the same epidemic model [14]. This solution considers immunity uncertainty along with population density and infected ratio. Apart from that, it has introduced a vulnerability score for vaccine allocation along with the strategies for clustering regions for warehouse selection. A similar epidemic model is also used in the multi-criterion intelligent decision support system suggested by Aggarwal et al. [13]. Most importantly, the resource allocation systems need to be cost-effective in order to prevent extra expenses during an emergency like the COVID-19 pandemic. Thus, recent researchers have proposed a cloud-based smart resource allocation advisor which can identify low-cost high benefit allocations [10]. It has been utilized to analyze the severity of the pandemic with the help of different algorithms and also this system could detect resource demand, adjust allocation schema, learn from the knowledge about the patients as well. Moreover, it is visible that both qualitative and quantitative parameters have been considered when deciding the factors for flattening the growing curves of COVID-19 with the help of ML algorithms. There are possibilities to utilize ML models during an emergency to guide resource allocation-related decisions [24]. Those models have been used in areas like risk monitoring, analyzing disease transmission, and to find people who are less likely to complete the vaccination, etc. In order to analyze the disease, spread patterns, usage of social media platforms as the key source for ML algorithms is also noticeable. For instance, the Tweets have been used to predict influenza transmission where it provides a real-time accurate assessment and predicts the weekly percentage of patients and future influenza activities which help resource planning [2].

With the advancement of technology, researchers are focusing on simulation approaches when analyzing, developing, and testing resource allocation systems. For example, to evaluate the spread of the coronavirus pandemic a simulation-based multi-agent approach is suggested by Aboulaich et al. [25] that uses a compartmental model to identify individuals with the same behavior, and for forecasting the evolution of the disease against preventive measures. The evaluation of alternative healthcare resource allocation possibilities is also essential in emergency situations [17]. Even though a few of these approaches are not introduced particularly for public health emergencies, most of them contain the objective of levelling the resource utilization according to the severity of patients where it has a possible use case in COVID-19 pandemic. Furthermore, several studies have produced solutions through simulation by integrating optimization techniques as well. For example, in order to reduce the door-to-doctor time, an optimal approach was introduced for an emergency department that mainly focuses on allocating human resources using a meta-model-based simulation and an imperialist competitive algorithm for resource optimization within a limited budget [16]. A simulation environment is also suggested for optimal resource planning during the COVID-19 crisis [18]. In there, deep-learning and linear optimization methods have been used for making predictions in resource demand, deaths, and infected cases as well as resource exchange decisions.

With the current pandemic, public health officers face a number of difficulties when collecting close contacts' information for PCR testing. In order to mitigate those difficulties to some extent, a community-based system has been introduced that includes a risk status indication via a QR code by analyzing close contacts and virus hot zones based on GPS technology [9]. This system can also schedule and send notifications about infection testing to people while following the smart city concept and, it also has been integrated with private institutions along with the capability of continuous data visualization. Here, public agents deal

with the web UI and a dashboard and community through the mobile interface. Even though similar approaches were taken in other applications such as China's 'Health Code' and India's 'Aarogya Setu', they had effectively performed only in the initial stage of the pandemic. In most cases, attention on resource allocation is commonly shifted from individual patient-centered to population-centered during a pandemic. Therefore, visualization of the aggregated data is vital. Thus, some studies have used social media to visualize and understand how people are concern and react to the pandemic. For example, topic modelling, an unsupervised ML technique was used on the Tweets by Tao et al. [26] along with an emotion analysis. Another visualization has done on a dashboard according to the interaction with a speech interface which consists of multiple views and tested using the COVID-19 pandemic as the case study [27]. As a gist, we can say that many decision support systems have been proposed addressing health crises and especially for COVID-19 pandemic using various approaches including optimization techniques, simulation approaches, ML techniques, and IoT for allocating both specific or generic resource types.

### *B. Ethical Frameworks and Guidelines for Resource Allocation*

This section focuses on the proposed guidelines and frameworks that have been related to resource allocation morality during health crises. Legal and ethical issues are possible to raise during a health emergency [28]. Therefore, it is a must to have proper principles for resource allocation procedures that help to draw conclusions about transparency, sharing, balance, and communication under the influence of community obligations, community well-being, and good preparedness practice. It is worthwhile to have a rapid response core guidance list to ensure clear, collaborative, consistent, and context-sensitive decisions during a health emergency [29]. Likewise, for the COVID-19 health emergency, a set of recommendations was made considering ethical values such as maximum benefit, equality, and prioritization [30].

The prioritization is solely focused on a few studies. For example, a resource allocation based on multi-criteria dimensions of priorities is suggested by Angelis et al [31]. Most importantly, WHO has introduced ethics and priority settings for resource allocation during the pandemic [32]. In a health crisis, assigning equity weights on vulnerable groups for triaging people such as dementia patients could be considered as a fairer approach [33], [34]. It also argues that the cost-effective analysis is better on resource allocation. Moreover, indicators such as counts, ratios, percentages, proportions are very important in the surveillance of communicable disease [35]. For instance, a field model has been proposed with a set of potential indicators [36] which are community-based and focused on ensuring basic services are reached to the local. The percentages and ratios of elders, smokers, asthma/diabetes patients, medical officers are some of those indicators which help to make decisions. Aside from those, several studies have suggested resource-specific guidelines. For example, a study has recommended steps for allocating ICU equipment according to community engagement while considering moral reference [20]. In addition, a rapid review was also conducted for ICU resources during an infectious disease outbreak [37] along with the evaluation of the validity of the already existing triage tools and ethical frameworks. From the studies that are discussed in this section, ethical value considerations, guidelines & frameworks could be commonly seen with the main objective of maximizing the community benefit.

### *C. Limitations of Existing Resource Allocation Systems*

Despite their benefits, existing resource allocation systems have their own limitations. For example, some of these systems are specifically developed for a particular type of disaster and health crisis. Thus, the existing resource allocation systems proposed by previous researchers are difficult to customize for the COVID-19 pandemic situation in developing countries like Sri Lanka due to the following reasons.

- Healthcare budget constraints lead to extreme material resource limitations
- Poor healthcare infrastructure and differences in procedures
- A separate body for social status tracking and visualization
- Lack of hospital capacities and maintaining quarantine centers
- Secondary difficulties such as resource transportation to remote areas delay resource accessibility
- The inability to store and dispatch resources by establishing temporary facilities
- The limited availability of staff
- The community-dependent systems are not suitable because people of remote areas don't have smart devices or the technology literacy

The above conclusions are drawn by analyzing the existing literature where only a few have explicitly stated the difficulties [38] but in contrast, many have proposed systems for countries that have a high quality of life, stable economies, and technological advancements. Therefore, most of the systems have been proposed, while considering the continuous budget increases, rich healthcare infrastructures, multiple warehouse & emergency center establishments, transportation facilities, smart cities, high availability of healthcare resources [2], [6]-[9], [11], [12], [14], [16], [17], [23], [24], [30], [33]. Hence these systems would not be very much suitable for Sri Lanka.

According to statistics, as of the second week of November 2021, more than 549,500 reported cases, 13,972 deaths and, 523,503 recovered cases have been identified in Sri Lanka. In order to mitigate the further damages of this health crisis, a preparedness and response plan for COVID-

19 has been introduced by the Ministry of Health [39]. It includes resource management and priority measures such as contact tracing, quarantine, and isolation guidelines. Apart from that, a set of provisional guidelines on COVID-19 patients has also been introduced [40] which includes procedures about patient identification, monitoring, admissions, and treatments are stated especially for the health practitioners. Moreover, the way of assessing the severity of patients, level of risk by exposure, conducting PCR tests or rapid Antigen tests, taking the history of patients, usage of essential resources have been emphasized.

In countries like Sri Lanka, the Public Health Inspectors (PHI) and (Medical Officer of Health) MOH are directly dealing with society and, handle all the community-based procedures manually. There are about 60,000 people who live in a particular MOH area, and they receive resources from the regional medical supply division under the coordination of the PHIs. With the accelerated growth of the pandemic, there are a large number of problems occurred in the area of health resource allocation. As the result of extreme demands, there is a possibility that coronavirus disease would overwhelm the healthcare infrastructure in Sri Lanka. It has come to the level where the infected patients are also isolated at homes while only the severe cases are transferred to a hospital. With the skyrocketing COVID infected cases, the admissions of severe patients are also getting late day by day. In the current procedure, when there is a delay in conducting PCR tests and getting the test results, one should contact the PHI officer directly which is very difficult with the current rush. On the other hand, the vaccination campaigns are overcrowded without any prioritization. When a limited number of vaccines are received for a certain MOH area, insufficient vaccine utilization and improper tracking of people for the second dosage could be clearly observed. The disease-related indicators such as asymptomatic and symptomatic rates, case fatality rate, infected percentages by age that are important for MOH officers & high authorities in surveillance and for allocating resources are irregularly traced for each area. In addition, transporting patients, distributing food, and case monitoring are also not handled effectively. These unnecessary delays of healthcare resources may put the patient in a dangerous position and the community in hardships. Therefore, a decision support system for resource allocation is a necessity that combines data and decision logic to assist decision-makers to overcome the above difficulties. Providing timely and accurate decisions regarding resource controlling/coordinating, distributing and monitoring as well as building community awareness should be the main objectives of a system along with automating the tasks handled by the PHI officers in each MOH area from the patient identification to conducting PCR tests for close contacts. In such system, data visualization could be used to visualize the current resource allocations in that particular area which helps to increase social awareness as well. Likewise, the external parties who receive updates would be able to make decisions easily with the use of resource allocation systems.

## V. RESULTS AND DISCUSSION

The analysis of relevant existing systems in support of making resource-related decisions during a pandemic like health crisis have been discussed throughout this study. The keyword-based clustering provided greater insights into the literature during the analysis and, it supported the analysis process by showing up the key areas that previous researchers have focused on. It generated 14 clusters highlighting the recurrent areas as shown in Table I. Some of the dominant keywords identified were related to the scope such as COVID-19, coronavirus, resource allocation, disaster planning, pandemic, critical care, public health, and healthcare. As per the remaining categories of the keywords, several reasoning can be made by analyzing relevant literature. The resource allocation guidelines, policies, legal and medical frameworks are generally established as common components or proactive plans of disaster management [29]-[31], [33], [36]. The resource-related decisions should be taken by considering the maximum community benefit, ethics, and vulnerable groups. In several studies, triage has been considered when allocating resources according to the severity levels of the patients during an emergency [20], [28], [37]. The selection, adaption of these frameworks, and dealing with uncertainties of situations must be more focused based on the health crisis. The simulation and optimization can be also identified as prominent keywords [8], [12], [14], [16]-[18], [25]. The simulation approaches were commonly used in the areas of pandemic spread analysis, events generation & representation, and resource allocation with the help of GIS (Geographic Information System) where some are embedded with allocation optimization techniques as well.

Moreover, the use of ML techniques for the predictions of required resources, pandemic transmission, contact tracing, infected and suspected cases can be commonly seen [7], [13], [18]. When studying the literature, one could identify that the resource allocation is hugely addressed in the response phase of a disaster and there were several interrelated problems attached such as transportation, scheduling, and facility locations. The resource allocation-related decision support systems, health information, and healthcare systems were proposed in numerous studies [9]-[14]. Both disaster-specific and resource-specific systems are mostly focusing on the COVID-19 pandemic. However, the technology has enabled the community to collaborate with public agents during a crisis. Emerging technologies such as Big Data, IoT, facial/voice recognition, and Artificial intelligence have a dominant role in those smart systems.

Table 1. Clustered keywords

| Label | Keyword | Label | Keyword |
|---|---|---|---|
| 0 | COVID-19 | 7 | Pandemic |
| 1 | Medical ethics | 8 | Triage |
| 2 | Resource allocation | 9 | Critical care |
| 3 | Machine learning | 10 | Decision support |

| | | | |
|---|---|---|---|
| 4 | Optimization | 11 | Healthcare systems |
| 5 | Coronavirus | 12 | Public health |
| 6 | Disaster planning | 13 | Simulation |

In this study, different kinds of resource allocation systems were discussed pertaining to the health crises. A detailed overview of the current stand of resource allocation systems was explicitly presented as the main objective of this study. The keyword clustering and PRISMA standard were used to investigate and filter previous studies, in a systematic manner. The allocation of both the critical/non-critical and human/material resources was considered in this study.

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