RESEARCH ARTICLE

A Holistic View of Health Infrastructure Resilience before and after COVID-19

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Abstract

Background: Large-scale events such as COVID-19 show that there are situations that can lead to huge stress on health infrastructure systems (HIS). The pandemic reveals that it is very difficult to protect HIS from all kinds of possible hazards. They can be unpredictable and spread rapidly; hence, it is hard to find an effective mitigation strategy to completely protect society and its important HIS.

Methods: An often raised central question is what we should do if we cannot protect HIS from these types of hazards. To answer this question, the focus should move from HIS protection to HIS resilience. Therefore, in this paper, the Critical Infrastructure Resilience Index (CIRI) is used to estimate the resilience of health infrastructure systems.

Results: The results of the case study show that HIS resilience was enhanced significantly after the implementation of measures. The results indicate that among the resilience phases the learning phase of resilience is the weakest part. This requires a root cause analysis, which should be prioritized by HIS managers and stakeholders.

Conclusion: This paper discusses how the resilience concept will help decision- and policy-makers to have a clear view of HIS performance before, during, and after the disaster. An easy-to-use and applicable methodology for HIS assessment and evaluation was employed. It can be concluded that resilience and its identified phases can help HIS managers to allocate available resources accordingly in the phases during and post-crisis.

Level of evidence: V

Keywords: Coronavirus, COVID-19, Health infrastructure systems, Iran alumina company, Resilience

Introduction

The normal life of human beings depends on the continuous services of their critical infrastructures, including health infrastructure systems (HIS). HIS can be considered to be a live organ that can be hit by severe diseases such as COVID-19. As with any usual medical practice, protection of this system against the different types of hazards (robustness), as well as its recoverability, should be considered early in the design phase. Robustness and recoverability are defined as the resilience of a system (1). We argue that resilience should be the common language between stakeholders of HIS. Although, during recent years, the focus has moved from critical infrastructure protection to resilience, during the COVID-19 pandemic, we have found that this concept and its tools for assessment require further elaboration. The main focus among policy- and decision-makers, as well as managers of HIS, remains on the protection of HIS, and recoverability is a missing concept. This can lead to un-resilient HIS, especially in a severe case such as COVID-19. For example, one of the most cited analyses regarding the two strategies which may be adopted for COVID-19 is shown in [Figure 1]: the main assumption is

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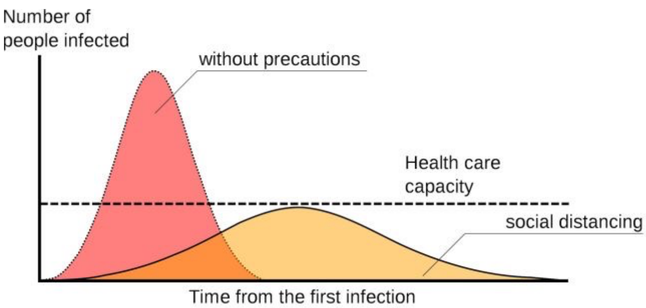

Figure 1. Impact of protection measures on COVID-19 (www. Sciencenews.org).

that the HIS is highly robust and, hence, its capacity will be constant before, during and after a disaster. However, as we saw in some hospitals, the staff became infected in the early stage of the spread of COVID-19. This led to a reduction in the healthcare capacity in the early phase of the disease. This unrealistic assumption of the HIS' robustness can lead to an overestimation of the capacity of HIS and, consequently, to short- and long-term adverse effects on HIS. Moreover, it can even lead to failure of HIS in the early stage of the disaster, causing panic in society and, finally, leading to loss of functionality in other critical infrastructures in society. This paper will discuss how the use of the resilience concept can provide a real picture of the HIS' performance in severe hazards. Thereafter, it tries to answer this critical question: "*is this practical health infrastructure resilient or not?*" For this, it employs an easy-to-use and applicable methodology for HIS assessment and evaluation. Thereafter, its application is illustrated by a case study for COVID-19.

HIS Resilance and effect of COVID-19 pandemic

The concept of resilience has spread from ecology into other fields (2). Resilience is derived from the Latin word, "*resilance*", which means to bounce back, be flexible, etc. (3). According to UNISDR (4), resilience is defined as "*the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.*"

According to this definition, he HIS' performance, as well as the pattern of restoration and recovery over time after a certain loss, in the case of the COVID-19 pandemic with one and two peaks are illustrated in [Figure 2]. At the start of the pandemic, the stress on the HIS will

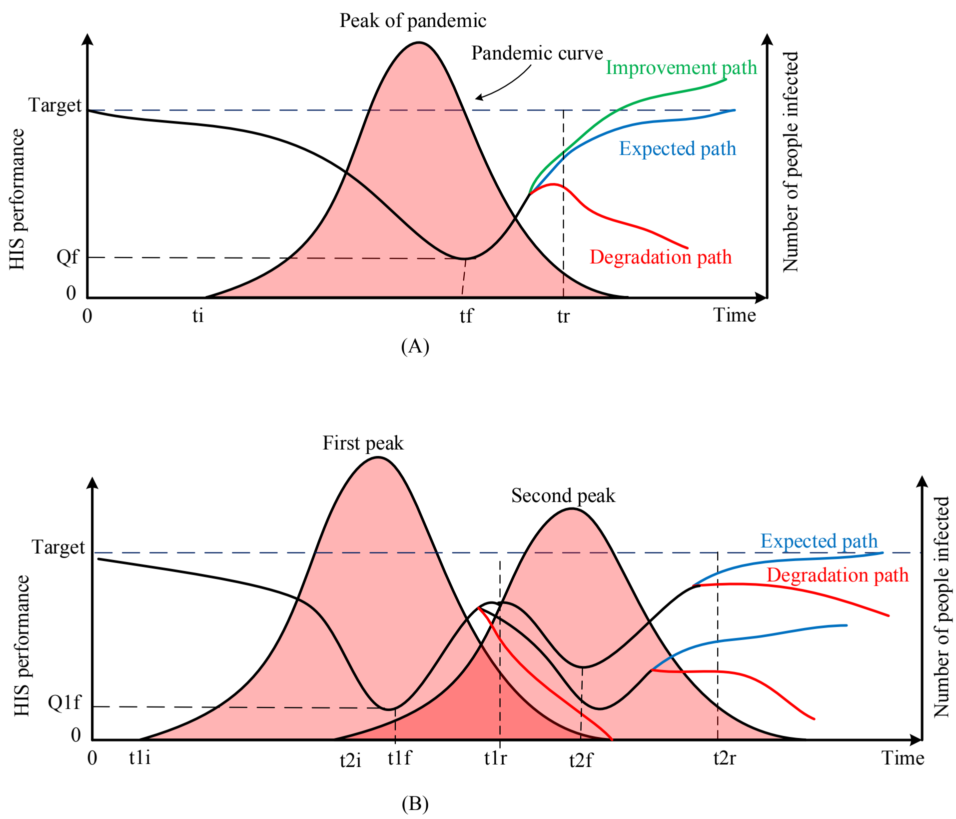

Figure 2. The HIS' resilience and the effect of the pandemic.

be increased and, consequently, their performance degraded. This could be due to the pandemic's effect on the medical crew's mental and physical health, the failure of medical tools, logistical problems, etc. At the peak of the pandemic, t_f, stress on the HIS is at its highest level, where the performance of HIS reduces to *Qf*. The *Qf* is a design characteristic of HIS, and it referes to robustness of the HIS. We argue that, the healthcare capacity should be replaced by *Qf*, which can be much less than the assumed healthcare capacity [Figure 1].

After passing the first peak of a pandemic, the HIS is going to recover. The recovery is a function of different factors, including government policy, the mental and physical health condition of the medical staff after the pandemic, and the medical equipment's performance, as well as support from society. Three different scenarios (paths) can be expected for the recovery phase: *i)* Improvement path, *ii)* Expected design path, and *iii)* Degradation path.

In the improvement path, due to the experience that the medical staff have gained during the pandemic, as well as the new equipment which has been allocated for controlling the pandemic, the performance of the HIS is improved and becomes better than the expected design performance. In the expected design performance, the performance of the HIS is as good as before the pandemic. Finally, in the degradation path, the HIS' performance is less than the expected design performance. This is due to damage inflicted by the pandemic on medical staff and equipment. However, the HIS can be hit by the second wave of a pandemic, for example sometimes immediately after the first peak [Figure 2B]. As can be seen, if the HIS' performance has been degraded, it will not be able to react properly in the second wave. Similarly to the first wave, the recovery paths will be improved, expected, or degraded. In general, the final performance of the HIS can be formulated as follows:

$$Final\ \ HIS_{performance} = Expected\ design\ performance * i$$

$$where \begin{cases} i > 1\ ;\ Improved\ path \\ i = 1;\ Expected\ path \\ i < 1\ ; Degredat\ path \end{cases} \qquad (1)$$

Here, *i* can be defined as the pandemic's permanent effect (PE). Different factors will contribute to the PE, including government policy and the learning process in the HIS, as well as the social situation after the pandemic.

In general, the reliance of the HIS can be divided into two different aspects: *i)* soft resilience and *ii)* hard resilience. The reaction of medical staff to situations that are unexpected, uncertain, often adverse, and usually unstable, can be characterized as soft resilience. Factors such as the organization's creativity, initiative and flexibility, the transparency of its functions, staff recognition, respect shown and the sense of ownership among its staff affect soft resilience (5). It should be noted that it is the medical staff who remain in the front line in the case of a hazard and execute the decisions. Hence, without the existence of the above-mentioned factors in the HIS, it is too hard to achieve an acceptable level of soft resilience. Hard reliance refers to factors such as the availability of technical equipment, location of the hospital, and number of available beds, as well as logistical effectiveness before, during and after a disaster.

Resilience assessment in the HIS

The resilience assessment tries to answer the question of whether the critical infrastructure is resilient or not, based on the established criteria. Moreover, it provides essential information for enhancing the resilience of the infrastructures. The enhancement measurements can be implemented before the disruptive event (e.g. training medical staff, establishing effective logistics for medical equipment and required medicines and PPE), during the disruptive event (e.g. self-isolation, increasing public awareness) and after the disruptive event (e.g. investment in the invention of the remedial medicine or vaccine). Pursiainen *et al.* (unpublished data) consider resilience as a process that has pre, during and post-crisis phases (6, 7). Thereafter, using the crisis management cycle, they developed a Critical infrastructure resilience index (CIRI) to estimate the resilience of critical infrastructure [Figure 3]. The HIS' resilience during COVID-19 and different phases of the crisis management are shown in [Figure 4]. Here, *Risk assessment* includes risk identification, risk analysis, and risk evaluation; *Prevention* refers to measures that enable an organization to avoid, preclude or limit the impact of a disruption; *Preparedness* defines the knowledge and capacities developed by all kinds of organizations and individuals, to effectively anticipate, respond to and recover from the impacts of likely, imminent or current hazard events or conditions; *Monitoring and Warning* include monitoring events to spot signals and indicators that predict the location, timing, and magnitude of future or immediate disruptions; *Response* means the provision of emergency services and public assistance during

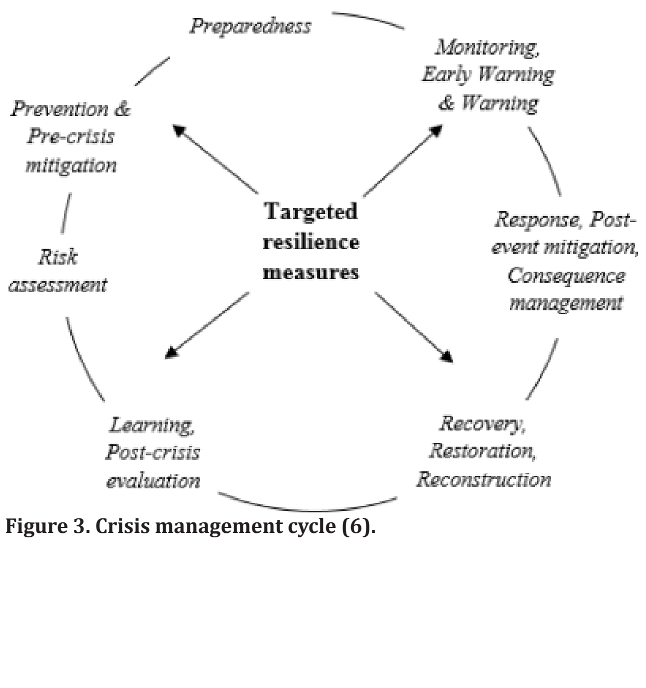

Figure 3. Crisis management cycle (6).

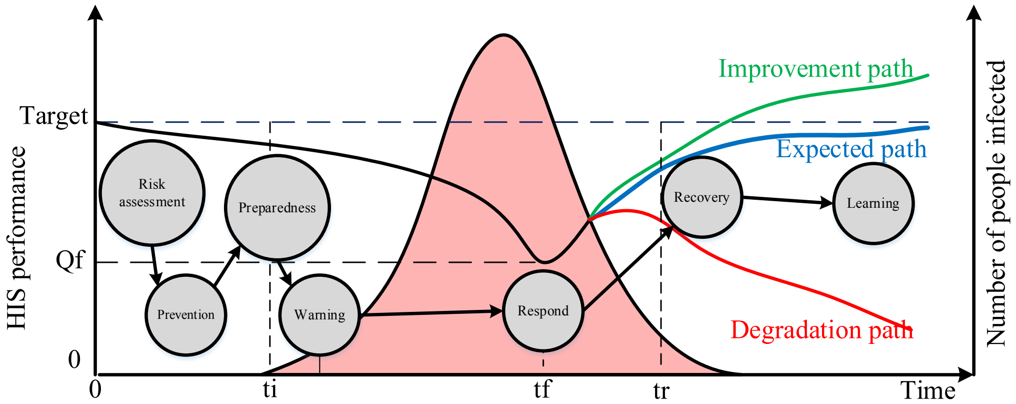

Figure 4. HIS' resilience concept and crisis management phases.

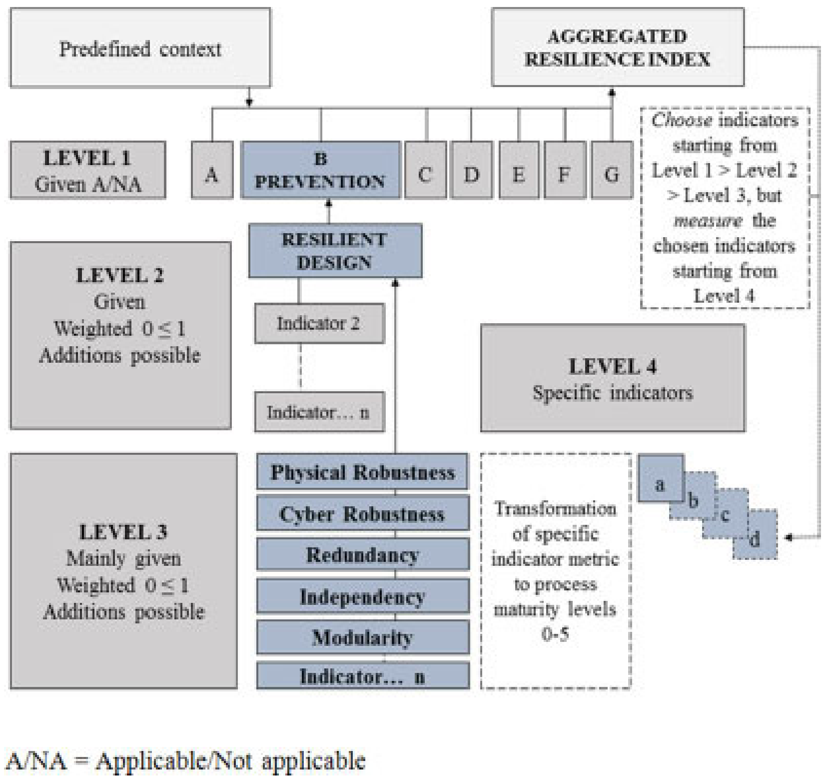

Figure 5. The Critical Infrastructure Resilience Index (7).

or immediately after a disaster, to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected; *Recovery* defines the act or process of returning to a normal state after a period of difficulty; and *Learning* covers all processes regarding the post-crisis learning and reducing long-term consequences (6).

CIRI is especially suitable for soft and hard resilience evaluation and can provide a single quantitative value for the HIS' overall resilience [Figure 5]. As Figure 5 shows, in CIRI, four hierarchical levels of indicators should be evaluated:

Level 1: The crisis management cycle phases shown in [Figure 3]

Level 2: The generic indicators; these can be defined as all factors influencing the crisis management cycle

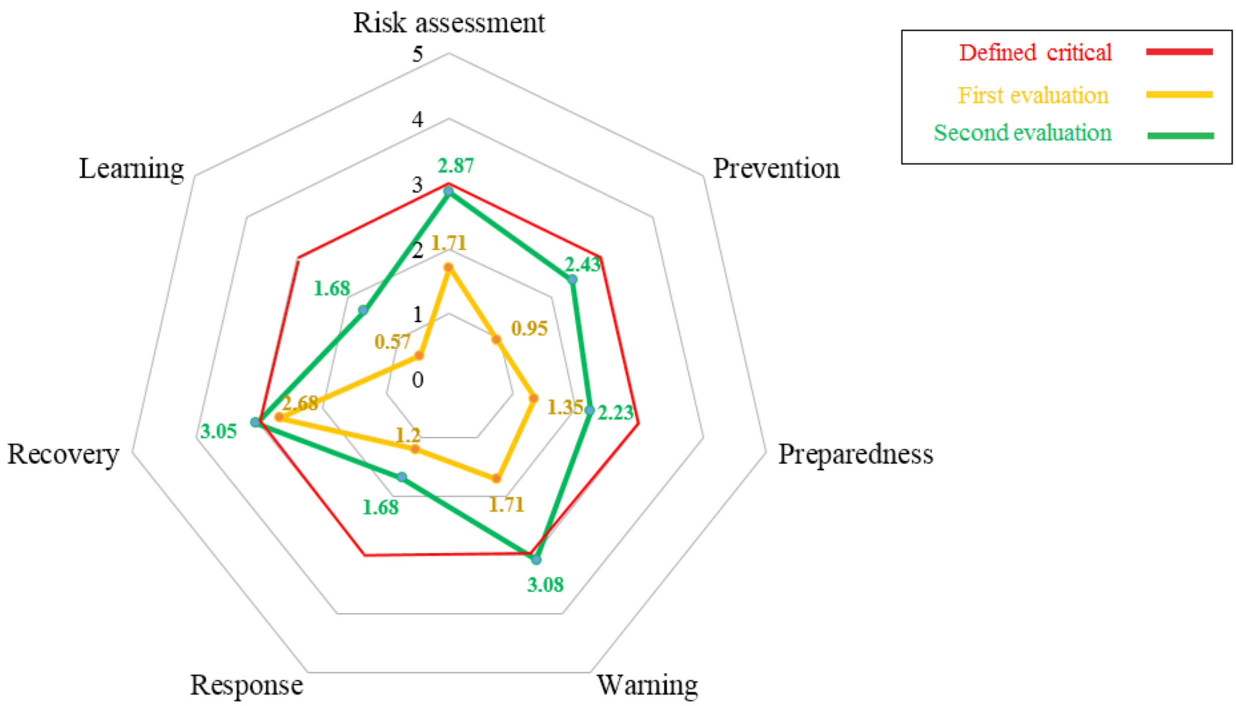

Figure 6. The radar chart of the $HIS_{J\&G}$.

phases. For example, available historical data is an important factor for the risk assessment phase of the crisis management cycle; hence, it will be considered a generic indicator for the risk assessment phases. These indicators are defined based on the operator's needs, as well as on the characteristics of infrastructures. See for further discussion (7).

Level 3: Dividing the generic indicators into parts; this level tries to divide Level 2 into smaller and more easily measurable processes or systems. For instance, the "*Resilient design*" can be further broken down into "*Physical Robustness*", "*Cyber Robustness*", "*Redundancy*", "*Modularity*", and "*Independence*" [Figure 6].

Level 4: Indicators to be measured; resilience indicators at level 4 should be detailed carefully, according to the characteristics of the concrete facility in critical infrastructures (sector-specific indicator cards). For example, regarding the redundancy in Level 3, it could be redundant reserve capacity (7).

Level 4 indicators can be process maturity levels of identified metrics, for example, from 0 to 5, where the 0 means the non-existence of the indicator, and 5 represents well-developed procedures for evaluation and continuous mentoring of the indicator in the organization. These levels can be defined by the HIS, based on their current practice. For more information see (7).

In this methodology, choosing and developing the indicators starts at the top and words down, while calculating and measuring the indicator starts at the bottom and works up, using Eq. (2):

$$Indicator\ of\ Level\ j = \frac{1}{\sum_{i=1}^{m} w_i} \sum_{i=1}^{m} w_i I_{ji} \qquad (2)$$

where m is the number of indicators in Level j, and w_i represents the weighting coefficients for the ith individual indicators at level j, with a value between *0* and *1*, corresponding to the relevance of indicators.

Case study: HIS performance estimation and enhancement in the case of the COVID-19 outbreak

Iran Alumina Company (IAC) is located in North Khorasan province at the city of Jajarm. Currently, around 3000 employees work at the company, the majority of whom live in two small cities, named Jajarm and Garme, located almost 12 kilometers away from the factory. The total population of these cities is around 80,000 people. At the time of the COVID-19 outbreak, a hospital with 64 beds, and four small clinics constituted the main parts of the HIS.

While news about COVID-19 and its outbreak had spread around the globe, available information, such as its infection mechanism, spread pattern and rate, mortality rate etc., were collected for further risk assessment at IAC, in November 2019. There were some foreign employees, and this was an urgent need regarding the continuation of their work. Hence, the first meeting was arranged at the request of the second author, to discuss and perform a preliminary assessment of the risks associated with the spread of COVID-19 in the company, as well as the

Table 1. The primary risk assessment of COVID-19 for the IAC and $HIS_{J\&G.}$

Risk	Safety	Health	Environment	Economic	Reputation
IAC	Very High	Very High	Low	Very High	High
$HI_{SJ\&}G$	Very High	Very High	Low	Medium	Low

risks associated with the HIS in Jajarm and Garme cities ($HIS_{J\&G}$). The primary risk assessment was conducted using the brainstorming method. The results of the risk assessment are presented in [Table 1]. As shown, the risk of the spread of COVID-19 is very high, for both the company and $HIS_{J\&G}$, which entailed that some risk-reducing measures should be implemented as soon as possible. It was decided to use the CIRI to estimate the $HIS_{J\&G}$ resilience and thus to identify the key areas that needed further improvement, in order to allocate the available limited resources accordingly. Considering the available time and resources, the expert judgment process was selected as the main data collection approach. To this aim, six experts from the medical community were asked about the scores of the $HIS_{J\&G}$ resilience phases on a scale of zero to five: the higher the score, the better the status. After expert judgment elicitation, the judgments about each phase were aggregated, using the weighted arithmetic averaging technique, given by Eq. (3):

$$S_i = \sum_{j=1}^{n} w_j s_{ij};\quad i = 1,2,3,\dots,m;\ 0 \le w_j \le 1;\ and\ \sum_{j=1}^{n} w_j = 1 \qquad (3)$$

where represents the aggregated score of the ith resilience phase, is the *j*th expert's normalized weighting, is the score of the *i*th resilience phase given by the *j*th expert, is the number of phases, and is the number of experts. To calculate the values of, each expert was appointed a weighting factor, based on his or her traits, and then the normalized weighting were considered as the final experts' weighting [Table 2; 3]. By considering the weighting of each expert, and by using Eq. (3) and the interview results, the scores for each phase of crisis management were calculated and are depicted in [Figure 6]. Based on the obtained scores for different crisis management phases, the overall resilience score of the $HIS_{J\&G}$ was estimated to be 1.45. The obtained score for each phase is shown in [Figure 6] in yellow: the greater the score, the better the status. Considering a score of 3 as the acceptance criterion, all terms of $HIS_{J\&G}$ needed urgent enhancement.

Based on the fact that the employees of the company and their families constitute 15% of the total population of Jajarm and Garme, IAC- Jajarm Alumina Complex-can act as an important player in enhancing $HIS_{J\&G}$ resilience. To achieve this aim, the following actions were performed:

Risk Assessment*:* Several meetings were arranged with the $HIS_{J\&G}$ managers and other stakeholders, wherein the risk assessment results were communicated. The need to establish a data collection system regarding the COVID-19 outbreak and national or international best practices was discussed. The high-risk group of people (e.g. people with heart problems, diabetes, etc.) in both cities, as well as those among the employees at the company, were identified for future planning. At the company, daily meetings were arranged to monitor the development of the disease and to enhance cooperation with the $HIS_{J\&G}$ managers and active NGOs in the area, enabling all key players to have a common understanding regarding this threat and its potential consequences.

Prevention and Preparedness: Here, the aim was to build and to improve barriers, in order to reduce the negative consequences and the likelihood of virus spread in $HIS_{J\&G}$. To reduce the likelihood of the infection of medical staff, they were provided with some PPE by the company.

Table 2. Weighting score according to the experts' trait.

Conditions	Classification	Score
Profession	Sub-specialist	5
	Specialist	4
	General practitioner, Dentist	3
	Nurse	2
	Assistant nurse	1
Job experience	More than 30	5
	20-29	4
	10-19	3
	6-9	2
	Less than 5	1
Education	PhD	4
	Doctor of Medicine	3
	Bachelor of Medicine	2
	Diploma	1
Age	More than 50	4
	40-49	3
	30-39	2
	Less than 30	1

Table 3. Calculated weight of each expert

Expert	Expert No.1	Expert No.2	Expert No.3	Expert No.4	Expert No.5	Expert No.6
Weight of experts	0.177	0.177	0.203	0.101	0.165	0.177

Moreover, the hospital area was disinfected regularly. The IAC played an important role in exchanging knowledge regarding the prevention and preparedness practices in other regions. For example, on receiving advice from experts in the COVID-19 outbreak, a preliminary screening procedure was proposed, so that the first-round check on suspected patients could take place outside the hospital, in a clinic in the city center. This reduced both stress on hospital staff and the likelihood of the virus spreading at the hospital. This, on the other hand, increased the community's trust in $HIS_{J\&G}$ that an active contingency plan was being put in place in the city. The authors initiated an NGO to act as a bridge between the community and governmental organizations and other active NGOs. Social media played an important role in shaping the community's knowledge, beliefs and, consequently, their reaction to the COVID-19 outbreak. At the time of the COVID-19 outbreak, in these two cities, there were four groups that were mainly active on social media, such as Instagram and Telegram. We estimated that these four groups provide knowledge and present information to at least 70% of the population. To reduce the stress on $HIS_{G\&J}$, the community knowledge about COVID-19 should be increased, to reduce unnecessary appointments. Hence, several meetings took place between the authors and the social media group managers, where the upcoming risks, the resilience of MIRR&G, especially regarding soft resilience and the need for self-isolation, were discussed. Moreover, with the help of established NGOs, an expert committee was selected to check the published material about COVID-19 and its spread in these two cities. Moreover, as everywhere there were certain unbelievers in the streets and shops, a group of volunteers was formed to communicate the risks associated with COVID-19 and its spread, as well as mitigation measures, to such groups of people.

Warning: To identify the starting point for crisis response, a thermography plan was started at the company, and some equipment and logistics were provided for other organizations involved in monitoring the situation. This could provide extra room for developing preparatory or mitigating measures.

Response: To increase the response capacity of $HIS_{J\&G}$, reduce the damage to $HIS_{J\&G}$ and enhance the process of crisis decision-making, the behavior of the community needed to be predicted and necessary information disseminated. Established NGO and social media managers planned to monitor the community behavior and try to provide necessary information for decision-makers at the time of response to the crisis. Moreover, IAC logistics were used to build a field hospital near the main hospital.

Finally, after performing these activities, another interview was conducted with the same experts, to re-evaluate their scores regarding the crisis management phases. The new estimation is shown by by the green line presented in [Figure 6]. As can be concluded, the resilience of the $HIS_{J\&G}$ has improved significantly.

A lack of knowledge regarding crisis management and HIS resilience can lead to ineffective decisions. Still, there is an ongoing threat in the community and, hence, there is an urgent need for more cooperation between all HIS mangers and different parts of the community. The resilience concept has the capacity to provide a common language in such communications. Resilience and its identified phases help HIS managers to allocate available resources accordingly in the phases during and post-crisis. The results of the case study show that $HIS_{J\&G}$ resilience was enhanced significantly after the measures implemented by IAC, and the established NGOs and social media. The results of the study show that the learning phase of resilience is the weakest part of this loop. This requires a root cause analysis, which should be prioritized by HIS managers and stakeholders.

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