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Preparing for the Unexpected: Needs for Emergency, Disaster, and Crisis Management Education Among Engineering Students

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Abstract

The risks of emergencies, disasters, and crises are continuously increasing and making detrimental impacts on communities, especially engineering companies. Thus, engineers are expected to possess necessary skills and knowledge for emergency, disaster, and crisis management (EDCM). However, educational efforts for engineering students, many of whom become engineers, have been lacking in institutions of higher education. As an initial effort, the current study aims to identify importance of EDCM standards and guidelines education, current assets among engineering students, and recommended learning elements for future EDCM education. Semi- structured interviews and focus group discussions were conducted with a total of 19 participants from three stakeholder groups: students, faculty members, and public safety professionals. The interviews and group discussions were audio-recorded and transcribed for a Thematic Analysis, using *Atlas.ti*, a qualitative data analysis software program. Findings indicate that all participants agreed with the importance of education on EDCM standards and guidelines among engineering students. In contrast, students received very basic safety training without having advanced understanding about EDCM standards and guidelines such as FEMA. Further, our study identified six learning elements recommended for future education and training: (i) basic drills, (ii) emergency actions, (iii) Incident Command System, (iv) engineering knowledge, (v) psychological aspect, and (vi) financial aspect. These findings will inform the design and provision of future courses and curricula to enhance EDCM skills and knowledge among engineering students.

Keywords: Emergency, Disaster, Crisis, Standards, Educational Needs

1. Introduction

There are growing threats of emergencies, disasters, and crises (EDCs) to humanity. According to US National Center for Health Statistics, 21.7% of adults (i.e., 18 years old or above) in the US visited emergency department more than one time in 2019 [1]. With respect to large-scale disasters, there have been 400 weather-related disasters in the US since 19080 that caused at least one billion US dollars with a total cost estimated to be 2.8 trillion US dollars [2]. For example, Hurricane Helene that struck the Southeastern US in September 2024, left catastrophic damages resulting in economic losses of at least seven billion US dollars [3]. In addition to daily emergencies and large- scale disasters, public health crisis such as the COVID-19 pandemic caused unprecedented damages and disruptions to the entire world.

While EDCs cause disruptions to households and local communities, they also bring serious impacts on business operations. EDCs bring damages to physical facilities, infrastructure, supply chains, demands on goods and services, and even governmental mandates [4]. For example, Hurricane Harvey in 2017 significantly impacted the energy sector, disrupting oil and gas processing facilities in the US [5]. The 2018 Camp Fire that occurred in California, the deadliest and most costly wildfire in the State history, was caused by Pacific Gas & Electric (PG&E) company, which ultimately filed for bankruptcy later due to the colossal damage from the fire [6], [7].

As demonstrated in previous major cases, engineering companies are heavily impacted by EDCs as well as play crucial roles in managing EDCs. Also, it is common that a large portion of managers in engineering companies start their career as an engineer. According to the US Bureau of Labor Statistics, over 80% of engineering manager positions required an engineering degree [8]. Therefore, it is necessary for managers in engineering companies to possess skills and knowledge required for preparing for and responding to EDCs.

Despite increasing risks of EDCs worldwide, educational efforts embodied in either curriculum of a college degree or related courses remain very limited. According to FEMA Higher Education College List [20], of over 5,300 colleges and universities in the US, only 346 (6.5%) offer emergency management programs. It is worth noting that previous work [21], [22] attempted to fill this gap by incorporating some standards such as ISO 14001 (environmental management system) and ISO 45001 (occupational health and safety) into engineering classes. However, education on EDCM standards and guidelines established by FEMA, NFPA, and CDC is still limited for engineering students, many of whom are expected to assume managerial roles of engineering companies in different sectors. Especially, there is a clear gap in engineering education with respect to fundamental terms, concepts, and principles required for EDCM. As the first step towards promoting engineering students' enhanced understandings of EDCM standards, guidelines, and practices, this study aims to investigate current educational needs related to EDCM standards and identify areas for improvement to better prepare engineering students for future professional careers.

2. Methods

Semi-structured interviews and focus group discussions were conducted to collect data from three stakeholder groups: engineering students, faculty members, and public safety professionals. A total of 19 participants were recruited for individual interviews and focus group discussion. A total of 13 engineering students from a large public university in Texas were split in five group discussions and two faculty members and four public safety professionals such as firefighter and emergency medical service (EMS) professionals participated in one-on-one interviews. Engineering students were selected if they are 18 years old or above and no prior EDCM experience was required. Public safety professionals were recruited via convenient sampling and snowball sampling techniques based on the authors' existing network. For faculty members, the authors searched for departmental websites and personal websites to see if they teach any EDCM-related courses, or if their research areas are relevant to EDCM.

The first author of the current paper, who is experienced with qualitative studies in disaster research [9], [10], [11], conducted all the interviews and group discussions. Individual interviews were conducted via teleconference platforms such as *Zoom* or *Microsoft Teams*. Group discussions occurred in the first author's research lab. The current study followed a research protocol approved by the authors' Institutional Review Board (No. IRB2024-16). Engineering students were recruited via a campuswide bulk emailing system. Faculty members and public safety professionals were recruited with convenience sampling [12] and snowball sampling [13]. Informed consent was obtained prior to the interviews and group discussions. Participants were compensated $25 for their participation.

Participants were asked questions related to three dimensions of educational needs: (i) importance, (ii) assets, and (iii) needs [14], [15], [16]. Table 1 presents questions asked during the interviews and group discussions. Questions regarding importance were concerned with perceived importance of skills and knowledge about EDCM standards and guidelines. Questions related to assets were intended to identify existing knowledge and any learning activities about EDCM standards and guidelines. Questions regarding needs were focused on eliciting specific learning elements and instructional methods to enhance engineering students' skills and knowledge of EDCM standards and guidelines.

Table 1. Questions regarding importance, assets, and needs for EDCM standards and guidelines education

Dimension	**Questions**
Importance	• How important do you think it is to have an ability to manage emergency, disaster, and crisis as an engineer? • Why do you think it is important? • What emergency, disaster, or crisis made you think so?
Assets	• How much knowledge do you have of emergency, disaster, and crisis management (EDCM)? • What skills and knowledge of EDCM do you think you (engineering students, engineers) are lacking? • Can you tell me any EDCM standards and guidelines you know in your field of study? • What courses you took (taught) provided any of EDCM standards and guidelines? • What EDCM standards and guidelines did you learn (teach)?
Needs	• What future courses do you want to take (teach) to enhance students' skills and knowledge about EDCM? • What specific learning elements do you want to see from the future courses? • What learning methods or learning environments do you think would be the best for the courses? • What skills and knowledge do you expect of engineering students when they graduate?

All interviews and group discussions were audio-recorded and transcribed either by built-in automatic transcription of the teleconference platform or AI-based transcription service such as

Rev [17]. Average duration of interviews and group discussions was 41.1 minutes (SD=9.9, min=20, max=54). Table 2 provides participant codes, number of participants, and duration of interviews and group discussions. Authors used a Thematic Analysis method [18] to identify major themes and categories of findings from the interviews and group discussions. Using *Altas.ti* [19], a web-based qualitative data analysis software, authors read transcripts, assigned codes to phrases, sentences, and paragraphs, and grouped codes into themes that emerged, in relation to categories of importance, assets, and needs.

Table 2. List of individual interviews and group discussions

Participant code	Type	Number of participants	Duration (in minutes)
FG#01	Focus group discussion	4	43
FG#02	Focus group discussion	2	31
FG#03	Focus group discussion	2	34
FG#04	Focus group discussion	4	38
FG#05	Focus group discussion	1	20
S002	Individual interview, public safety professional	1	51
S003	Individual interview, public safety professional	1	46
S004	Individual interview, public safety professional	1	44
S005	Individual interview, public safety professional	1	54
S006	Individual interview, faculty member	1	50
S007	Individual interview, faculty member	1	41

3. Results

3.1. Importance of EDCM Standards and Guidelines Education

All the participants (19/19) expressed the importance of education on EDCM standards and guidelines for engineering students. One engineering student (FG#03-A) imagined oneself being a manager of a company and thought his/her ability to make decisions during EDCs to be crucial. Also, another student (FG#4-D) argued that its everyone's responsibility to manage EDCs by following adequate EDCM standards and guidelines. One engineering PhD student (FG#4-A) pointed out his role for protecting critical infrastructure and thus providing essential goods and services to communities.

> "So as engineer, I know that essential services that we provide to the whole society can't be interrupted. Basically, if your activity is so important, energy production for example, you need to be able to manage the crisis in an overall way." (FG#04- A)

Public safety professionals also agreed with the importance of equipping engineering students with EDCM skills and knowledge. An assistant chief in a fire department in Texas (S#003) viewed engineers as subject matter experts (SMEs) who can provide crucial information that helps emergency responders to assess situations and build action plans. In addition, the professionals highlighted importance roles of engineers during EDCS, being designers of safe industrial processes and facilities (S#002) and the first line of defense (S#003).

> "For us, engineers play a critical role as subject matter experts per se, and we rely heavily on them when we're in situations that we're unsure of the outcome because of either a structure or a chemical or something along those lines that would impact the safety of us doing our job." (S#003)

Participants also cited major incidents that made them find it important to understand EDCM standards and guidelines. Students instanced COVID-19 pandemic, Chernobyl nuclear meltdown, and Bhopal chemical release disaster. Professionals provided common examples of vehicle accidents, chemical release, medical emergencies, and fire events.

3.2. Existing Assets of EDCM Standards and Guidelines Education

Our study found that engineering students received no or little education on EDCM standards and guidelines during their undergraduate and graduate courses. Participants stated that they received basic departmental training or campuswide drills such as fire extinguisher drill (FG#04-D), fire evacuation and hurricane evacuation drill (FG#02-A), and active shooter training (FG#01-C, FG#04-C). Graduate students (FG#01-B, FG#01-D), indicated that they received basic lab safety training as a requirement for their research activities. Besides drills and training sessions, participants viewed safety seminar series in campus and *TechAlert*, a campuswide safety alert system as additional sources of EDCM information.

No student, except one, took courses relevant to EDCM standards and guidelines in the university. One student (FG#01-A) said he was taking a renewable energy course and learned about safety tips for maintenance of wind turbines and hydropower plants. However, the course did not deliver any particular EDCM standards and guidelines. Further, all students, except one who received training from a fire academy, showed little understandings about EDCM standards and guidelines such as FEMA and NFPA.

3.3. Needs for Enhancing EDCM Skills and Knowledge among Engineering Students

Participants recommended several learning elements that would improve engineering students' skills and knowledge about EDCM standards and guidelines. Figure 1 shows themes and categories of the learning elements derived from the Thematic Analysis. Main themes were (i)

basic drills, (ii) emergency actions, (iii) Incident Command System, (iv) engineering knowledge, (v) psychological aspect, and (vi) financial aspect.

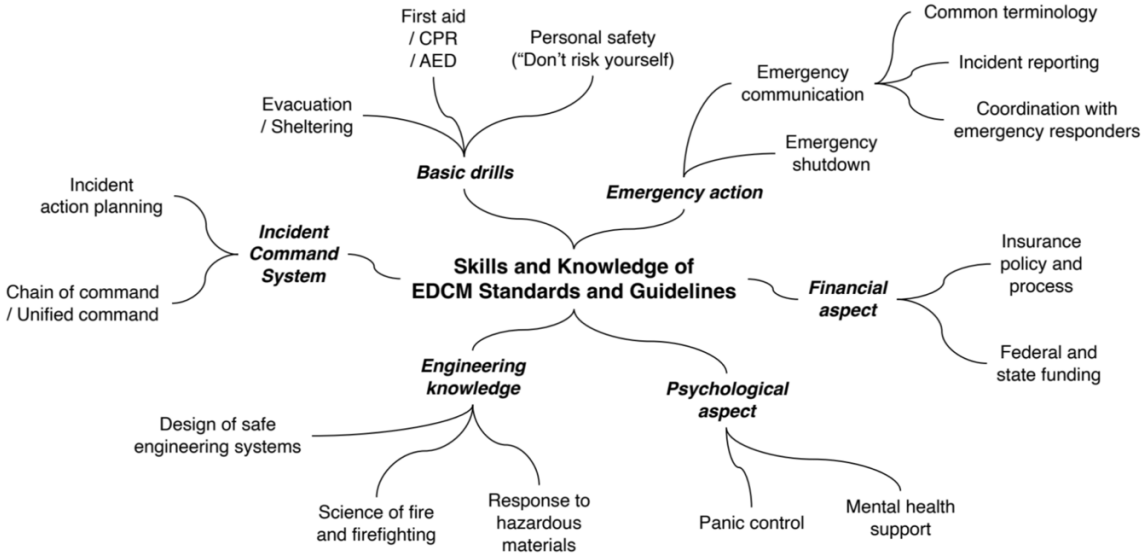

Figure 1. Themes and categories of learning elements for engineering students to enhance skills and knowledge of EDCM standards and guidelines.

3.3.1. Basic Drills for EDCs

Participants emphasized the needs for possessing basic skills required for EDCs. Such skills include how to evacuate during fire, hurricane, or wildfire; how to conduct first aid and CPR (cardiopulmonary resuscitation) and how to use AED (automated electronic defibrillator); and how to keep one's personal safety.

> "First and foremost, I am a CPR instructor. So, I feel it is very important for everyone to at least get CPR certified. You never know when somebody could have a cardiac event and go into cardiac arrest." (S#007)

Additionally, students emphasized the role of their existing experiences in EDCM as creating knowledge and preparation. For example, one noted, "I think my level of confidence depends on what kind of emergency situation is it. If it's safe, for instance, like a fire incident simply because I've gone through a lot of fire drills" (FG#01-A). Practice and drills were seen as preparing students with the requisite knowledge in their previous educational settings as noted here, "Knowledge I do have comes from stuff we did in high school, like fire drills, hurricane drills, there's a fire, you go pull the fire alarm, you get out the building, hurricane or tornado, you protect your head" (FG#02-A).

3.3.2. Emergency Actions

Public safety professionals viewed engineers as the first line of defense who are responsible for taking emergency actions to mitigate consequences of incidents. They maintained that engineers should know how to shut down hazardous processes that may cause harms to people and

environment. Also, we found that engineers often lack abilities to adequately communicate emergency responders during EDCs. Specific communication skills expected of engineers included the use of common terminology, how to report an incident to public safety authorities, and how to coordinate with emergency responders when they enter company premises and assess situations.

> "That's definitely a good thing to be able to do because they show up and you're not exactly sure how to explain the situation. It might cause the responders to take longer to assess the situation and they may not be knowing exactly what to look for." (FG#02-A)

3.3.3. Incident Command System

Many public safety professionals participated in our study stressed the importance of engineers' understanding of Incident Command System (ICS), one of the main pillars of National Incident Management System (NIMS), established by FEMA. Among the elements of the ICS, participants pointed out incident action planning process, chain of command, and unified command as most appropriate elements for engineers.

> "I hope they have a plan. But if they don't incident action planning and how to implement it, it is probably one of the biggest needs I could think of." (S#007)

3.3.4. Engineering Knowledge

Public safety professionals considered engineers as subject matter experts (SMEs) of the products, processes, and facilities they design and operate. In line with this view, we found that it is important for engineers to possess relevant engineering knowledge to prevent EDCs and reduce impacts from the EDCs. Such engineering knowledge includes how to design safe engineering processes and systems (e.g., emergency shutdown system, ventilation system), understanding science of firefighting (e.g., fire triangle - heat, fuel, and ignition source), and response to hazardous materials release.

> "I think a basic engineering student coming in a basic fire class, doesn't know the fire triangle: heat, fuel, and oxygen. Some of them might have an idea, but they don't know. And you have to teach that. That's a fundamental part of how we fight fire. We take away one of those sides of the fire triangle." (S#002)

> “Engineers are taught how to design things, but they're not taught to think about failure, whether that's from a disaster or whether that's an accident, or whether that bad design. And so, he said, where's the science of failure?” (S#009).

3.3.5. Psychological Aspect

Many students who participated in the group discussion expressed their concerns about psychological problems that may occur during EDCs. In other words, they thought they would be panicking once an incident takes place. In addition, students also desired to take benefits

from mental health programs if they or their friends suffer from disasters and crises.

> "I think the skills and knowledge that they should have been how to manage their workplace when disaster strikes and how to tailor that plan when unexpected things happen and when someone gets hurt while trying to evacuate or while trying to shelter. They should understand how to be calm as well." (FG#05-A)

> "You don't hear that Control. Panic control. Panic control. Yeah. Makes sense. It is just apprehension of sorts that things are going terribly wrong, but the situation may be a little bit better than it just perceived. So, to regain your own strength and conscience that okay, I can manage this situation. I've been trained for it. Gotcha." (FG#04-B).

3.3.6. Financial Aspect

One faculty member, who has taught disaster recovery modeling, shed some light on financial aspect of EDCM. In particular, the faculty member insisted that students have little knowledge of insurance policies and reimbursement processes after disasters struck. He took an example of major hurricanes and floods, such as Hurricane Harvey. He pinpointed that many insurance policies do not cover flood damages and thus it would be beneficial if students know other ways to receive financial supports from federal and state government such as the National Flood Insurance Program (NFIP) and Community Development Block Grant-Disaster Recovery (CDBG-DR), offered by the Department of Housing and Urban Development (HUD).

> "A couple of things that comes to mind. [...] I was telling you about the NFIP program, the National Flood Insurance Program. this program is mandatory for properties that are located in special flood hazard areas." (S#006)

4. Discussion

Our study showed that all participants from three stakeholder groups, students, faculty members, and public safety professionals, agreed with the importance of educating EDCM standards and guidelines for engineering students, many of whom will grow into engineers and engineering managers. Despite the consensus shown among our participants toward the importance of the EDCM standards and guidelines education, existing skills and knowledge among engineering students were of little depth and breadth. They received rudimentary training (e.g., fire evacuation drills) and revealed shallow understanding of EDCM standards and guidelines relevant to their areas of study. This finding corroborates survey results of Altababakh et al. [23] that engineering students received little training on safety and response to hazardous situations nor possessed proactive attitude towards possible incidents. Our study further highlights the needs for providing adequate education and training for engineering students for incidents that could happen in their future career.

As an essential foundation for future educational efforts related to EDCM, our study identified six learning elements: basic drills, emergency actions, Incident Command System,

engineering knowledge, psychological aspect, and financial aspect. While basic emergency drills like evacuation drills are commonly conducted in colleges and universities, students lack necessary skills for medical emergencies. Indeed, Bogle et al. [24] found that nearly 90% of 267 survey respondents who were students in a university in the US, were afraid of performing CPR in a real emergency. In line with this finding, we urge that educational efforts to improve medical emergency response skills such as CPR and AED need to be promoted more intensively for students in all major.

Furthermore, an immersive education and training setting can help engineering students acquire safety and emergency response skills. Extended reality (XR) such as augmented reality (AR) and virtual reality (VR) has been suggested as a useful tool to increase cognitive and decision-making skills under non-hazardous environments [25]. The application of these XR technologies is recommended for future engineering students' EDCM training and drills.

Another noteworthy finding from the current study was the need for learning about the Incident Command System (ICS), especially stressed by public safety professionals. The ICS [26] has been a common template for all kinds of EDCs in the US, dating back to frequent wildfires in 1980s. The ICS provides universal EDCM approaches regarding incident communication, unified command, incident action planning, logistics, finance and administration. While the ICS has been adopted by healthcare sectors [27], [28], [29], other industry domains, including engineering sectors, have seldom incorporated it into their risk management process. Thus, our finding supports the needs for education on the ICS among engineering students.

Furthermore, the current paper identified unmet educational needs for psychological and financial aspects of EDCs. Although these areas are not core elements of engineering education in general, benefits of equipping with mental health and financial knowledge of EDCM were quite apparent. As a matter of fact, a large portion of college students experienced a severe level of mental health problems during COVID-19 pandemic [10], [30]. Therefore, future efforts are needed to help students manage psychological challenges as well as financial issues as they undergo undesirable events in the future.

Despite interesting findings of the current study, some limitations should be acknowledged. First, our findings were based upon a small sample size (n=19) from one public university in Texas. While it should be noted that EDCM standards and guidelines are not a common topic engineering students are exposed to, future studies need a larger sample size from a broader pool of engineering student via multi-institutional data collection (e.g., online surveys). Second, the current study was largely focused on US-based EDCM standards and guidelines such as FEMA and NFPA. Considering that commonality exists between US-based guidelines and foreign counterparts [31], [32], our findings would be applicable to educational settings in other countries.

5. Conclusions

The current paper highlighted perceived importance of EDCM standards and guidelines education for engineering students yet insufficient efforts to enhance their skills and knowledge.

Engineering students, many of whom will become engineers and then engineering managers of essential business entities in the society, are in great needs for equipping themselves with capabilities to protect themselves, mitigate damages to engineering processes and products, and ultimately reduce impacts to surrounding communities. To foster such capabilities, continuous learning for basic skills, emergency actions, engineering knowledge, ICS principles, psychological readiness, and financial aspect needs to occur among engineering students.

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