Responsible Robotics Innovation for Disaster Response

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***Abstract*—This paper describes an evidence-based model of responsible robotics innovation for disaster response based on 36 case studies, plus an analysis of 336 instances of robot used in 48 countries in the first year of the COVID-19 pandemic. The model delineates what makes innovation for the Response Phase of a disaster different from normal responsible innovation and innovation for humanitarian relief. In addition to the model, the paper describes five unethical syndromes that have been witnessed in robotics innovation for disasters. The paper concludes with a practical checklist of questions that roboticists can internally discuss before moving forward. The paper makes three contributions to building and evaluating ethical robot systems. It provides a description of the constraints on ethical robotics innovation during a disaster response. Second, it contributes a formal, evidence-based model of responsible innovation. Third, for practitioners, it contributes an all-hazards model of ethical innovation that can guide robotics development and technology transfer before a disaster and during the Response Phase.**

***Index Terms*—Search and Rescue Robots, Robot Ethics, Field Robotics**

I. Introduction

Since 2001, ground, aerial, and marine robots have been deployed to natural and man-made disasters [1] and the recent COVID-19 pandemic [2], exemplifying the potential of beneficial AI systems. It is natural when a disaster occurs for roboticists to want to contribute to the response, the question is how to do so ethically. There are many ethical dimensions of using robots for disasters, including realistically accessing the value of the robot technology, and questioning the logistical impact of teams of roboticists competing with responders and civilians for scarce power, water, food, and housing resources. This paper will concentrate on the process of responsible robotics innovation [3], concentrating on how the robot design and technology transfer process can responsibly support disaster response.

Disasters pose significant challenges to traditional responsible innovation processes, as there is extreme time pressure, little or no access to stakeholders prior to use, and formal regulatory or institutional constraints on adoption. The life-saving and mitigation portion of a disaster response may last only from a few days (e.g., flooding, earthquakes, fires) to a few months (e.g., Fukushima Daichi nuclear accident) or, more rarely, more than a year (as in the current COVID-19 pandemic). The short time interval forces acceleration of robotics innovation, bypassing the typical months and years spent on engaging and reflecting about an innovation and its far reaching impacts. A disaster also disrupts direct engagement with the wide set of stakeholders who will ultimately be impacted by the disaster response (e.g., emergency management agencies, civilians, businesses, insurance providers, etc.) and exploring secondary and tertiary consequences.

This paper presents an evidence-based model of responsible robotics innovation for disaster response. The model is based on the "all-hazards" doctrine [4] that abstracts the common elements of natural, man-made, or technological disasters, and thus provides a generic structure for responding to all types of disasters. It assumes that emergency managers are the primary stakeholder and are knowledgeable of, and accountable to, the civilian stakeholders; thus during an emergency they can serve as a proxy for the unavailable stakeholders. The managers of a disaster, such as the incident commanders for a wildfire or the administrator for a hospital, are in the best position to understanding the impacts of innovations such as robotics. Therefore, they are empowered to make informed decisions so that the introduction of robots does not interfere with or impede the disaster management enterprise, e.g., risks harm to civilians or property, robot failures, increased work flow costs without commiserate benefit, consumption of wireless communications resources, etc. It should be noted that adoption during a disaster is typically temporary and not binding.

The model of responsible robotics innovation for disaster response not only provides an ethical design and tech transfer framework, it provides a method for analyzing the ethical implications of autonomous systems. It helps overcome the challenges of building and evaluating ethical robotic systems by specifying what emergency managers prioritize in responsible adoption. A violation of the model framework serves as an alert to unethical innovation; for example, a robot with low technical maturity, low suitability, or high risk indicates a strong potential for an ethical failure or misuse.

This paper is divided into four parts. It first describes the phases of a disaster and the unique characteristics of the Response Phase that constrains responsible innovation. It will

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then compare the differences in adoption during the Response Phase versus normative diffusion of innovation. Next it will present the model of responsible robotics innovation during disaster response that is based on evidence from the summative analysis of adoption of 36 case studies described in [1] and for the COVID-19 pandemic [3], [5]. [1], [3], [5] serve as primary sources because many articles describe the use of robots for a disaster (e.g., [6]–[9]) without detailing or explicitly discussing the adoption process or frame the use within a larger model of innovation. The paper will conclude with five unethical syndromes that roboticists may fall into during the rush to insert robots into a response.

II. Innovation Opportunities during Phases of a Disaster

The disaster management lifecycle can be described in many ways but is generally thought of having four phases. There is a Preparedness Phase before the event. When the event occurs, it triggers the Response Phase, where government agencies act to serve the greatest public good by saving lives, mitigate property damage, minimize long-term health consequences, and maximize the chances for rapid economic recovery. The Response Phase is often marked by an evacuation of non-responders from the affected area, or exclusion zone. When the exclusion zone is stable, the Public is allowed to return and begin the Recovery Phase. During the Response Phase, non-governmental Humanitarian Relief organizations may be working near the exclusion zone to help individuals, and such work may expand into the affected area after the evacuation ends. The fourth phase is Mitigation where the community works to prevent future occurences.

The Response Phase often entails emergency waivers of normal modes of operation. When incident management is activated, it has temporary privileges and restrictions to enable rapid response. For example, The Federal Aviation Administration has emergency waiver processes for drones that become available to formal responders, while restricting all other aircraft through a Temporary Flight Restriction for the exclusion zone. The availability of emergency waivers may seem to be an opportunity to try robots for missions that would not normally be permitted, e.g., aerial delivery over populated areas. The ethics of opportunism are discussed later. A key restriction is that it is illegal in most states to self-deploy and one robotics team was arrested and spent the night in jail [1].

The Response Phase has other important characteristics which suggests robots will have to be tailored for specific esoteric activities and have high usability. Most of the activities during the Response Phase involve specialized expertise and familiarity with the unified incident command system. There is considerable time pressure to work quickly and effectively. In addition to that as a stressor, responders are under considerable physiological and psychological fatigue due to long work hours, disrupted sleep patterns, and the emotional toll of human suffering.

While the Response Phase is the one most receives the most attention, the Recovery Phase is another opportunity for innovation. The Response Phase may still have unaddressed needs combined with responders having more time and flexibility to accommodate de facto experimentation. Of the four phases of emergency management, mitigation and preparedness are the least likely for spontaneous innovation, as adoption would be typically follow prescribed procedures.

III. Responsible Innovation During the Response Phase

Adoption during a disaster is a subset of the general responsible innovation process [10], during which technologists design and refine innovations for high social impact applications. The process starts with a prescriptive demand analysis, where the broad set of stakeholders– end-users, regulatory agencies, and developers, etc.– are brought together before the application of a technology to determine responsible innovation. That innovation can either be in response to a clear demand from the users (demand pull) or an innovation supports new missions or new ways of doing things (innovation push) as per [11]. This wide-engagement, prescriptive process is not possible during the Response Phase due to time and access. During a disaster the primary stakeholder, that is, the emergency manager, represents the other stakeholders thus short circuiting the responsible innovation process.

While the responsible innovation process leads to more ethical designs of technology, it does not explain how end-users actually accept and integrate the technology into their enterprises. There are two other important models that capture those aspects. First, the factors for individual end-user acceptance is expressed by the Unified Theory of Acceptance and Use of Technology Model (UTAUT) (Venkatesh et al., 2003). It specifically states that adoption is primarily influenced by end-users' expectations of performance and how much effort they need to expend to integrate into work processes, also known as suitability and risk. The UTAUT factors are particularly relevant to the Response Phase because the end-user the consequences of poor performance are high and individuals will have be experiencing a higher work load and thus have a lower capacity to tolerate systems with poor usability.

Second, while whether individual end-users will actually use a technology is important, for most innovations there has to be wide-spread acceptance of the technology and acquisition processes within companies and agencies. This is generally described by models diffusion of innovation in [12], the original source for the early adopter, middle majority, etc. life cycle of adoption. Usually there are competing bottom-up and top-down acquisition and acceptance processes, many of which are captured as formal institutional procedures. The institutional innovation processes may also temporarily change during a disaster. One way is to activate formal regulations already existing for emergency adoption, such as using a waiver process to request that a robot that was not intrinsically safe to be used at the Crandall Canyone mine disaster [1]. Another example is insurance agencies waiving their business rules regulations during the initial COVID-19 pandemic, thus allowing hospitals to be paid for using telehealth robots. It

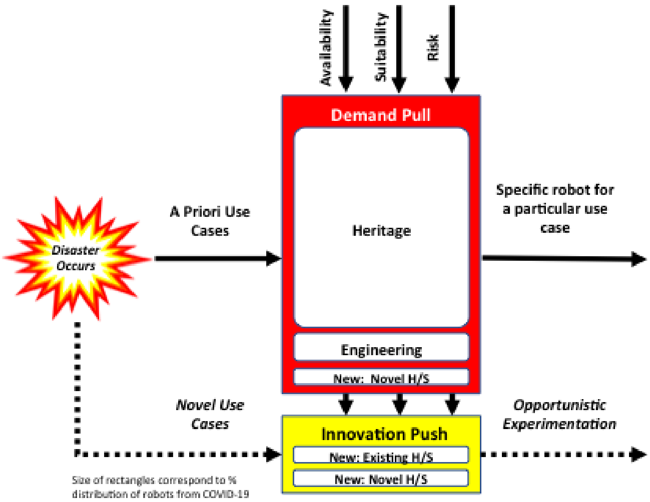

Fig. 1. Resulting model of adoption of robotics innovation.

should be noted that the adoption process during a disaster may be championed by someone who normally would not have direct adoption authority, such as a middle manager. Another important point for roboticists is that emergency adoption is temporary. The use of a robot for a disaster, no matter how successful, does not guarantee long-term institutional adoption. The failure of a robot for a disaster can set back acceptance and adoption, but the success will not necessarily translate into an immediate embrace and institutional adoption [1].

IV. Model of Responsible Robotics Innovation for Disaster Response

A analysis of the use of ground, aerial, and marine robots in 36 disasters in [1] and through the first year of the COVID-19 pandemic [5] has produced the formal model of adoption of robotic innovations during a disaster shown in Figure 1. The reader is directed to [3] for more details and evidence for the specific components of the model.

When a disaster occurs, emergency managers or health care stakeholders will look for robotic solutions for use cases that they are already aware of, sometimes called pinch points. Note that this means innovation is driven primarily by *demand pull*, not innovation push. The stakeholders are likely aware of robots from peers using robots for those functions, though roboticists working in partnership with the users may be able to direct attention to applicable robots (though hopefully not by attempting to force adoption through the Pet Project syndrome described in the next section).

The emergency managers will generally evaluate the robot based on three factors: availability, suitability, and risk. Suitability and risk are the essential metrics from the NASA Technical Readiness Assessment (TRA) method for evaluating technology [13]. The TRA method goes beyond the device-centric technology maturity ratings captured by the NASA Technical Readiness Levels to factor in the impact of insertion on workflows and the risks, both in terms of what a loss of function would do and the burden on the workforce in adopting the device. TRA formally classifies a technology into three categories:

- *Heritage*, which has high technical maturity, is in operation for the same application and workflow, and low risk of unintended physical or workload consequences;
- *Engineering*, where either a high technical maturity device is slightly modified to fit a well-established application and workflow or a high technical maturity device is being used for a different, but similar, application; and
- *New*, where a novel device is created or an existing device is applied to a new application with formative workflows.

The degree of suitability and the tolerance the responders have for performance and operational risks depends on the specific application. For example, the tolerance for a drone that might fail in flying through an interior area that cannot be reached in any other way may be higher than for a ground robot which might block all response activities. Accordingly, as seen by the scale of blocks, Heritage systems are favored for their proven platform maturity, high suitability for that application, and low risk. 78% of the robots used in the first year of the COVID-19 pandemic were Heritage systems. Note that this does not mean that the Heritage systems were perfect, only that they were sufficient for operational insertion. Some Heritage systems may need modification thus becoming Engineering systems, such as modifying the payload of the agricultural drone DJI MG-1P to support spraying of disinfectants for the COVID-19 pandemic.

In a few cases New hardware or software may have to be developed or added to meet the demand pull, such as the cloning of UVC disinfection robots to cope with the lack of availability of manufacturers, though the novelty is again constrained by the adopting stakeholder's tolerance for risk. It should also be noted that the introduction of New robots may violate intellectual property or the use for New applications may pose ethical issues such as lack of proof of efficacy. Roboticists may be able to insert New robots, but these insertions provide the opportunity for valuable opportunistic experimentation, not mainstream impact.

The model is consistent with the conservative, risk-adverse heuristics for disaster robotics from [1] and the general UTAUT model ([14]). As an example, the model provides a post hoc explanation of the adoption decision by the Mine Safety and Health Administration (MSHA) for a novel mission of sending a robot into a collapsed mine via a narrow borehole at the Crandall Canyon Mine Disaster [1]. The Crandall Canyon Mine Disaster adoption decision was a notable exception to the trend from the 36 disasters, where only commercially available robots used in similar work envelopes were adopted. In the Crandall Canyon Mine Disaster, MSHA accepted an UGV constructed from commercially available components explicitly designed for creating custom pipe inspection robots, but rejected two proposed novel robots designed specifically for the unique application by hobbyists. The adopted robot was an Engineering system, with lower risk than the two proposed New systems, both of which posed much higher risk because their technical maturity was low.

V. Five Unethical Syndromes

The above model of responsible robotics innovation for disaster response highlights that adoption during a disaster is generally a rational decision-making process driven by an emergency manager, not the roboticist. If roboticists truly respect the emergency management enterprise, then robots cannot be aggressively promoted independently of a true understanding of needed missions and the constraints of the work domain. Likewise, a decision by a manager to not adopt a robot should be respected regardless of reason. The decision may not be a reflection on the technology; responders may simply be too stressed to accommodate anything new to them. The best course of action in that case is to create a positive relationship for insertion of technology into future disasters.

A. Disaster Tourism

The Disaster Tourism syndrome is when a roboticist wants to participate in disaster in order to generally learn about disasters or just be part of a disaster. A disaster is not the time to learn or to treat a disaster as a high fidelity staged world experiment. Often roboticists take the attitude that if they are there for science, it does not matter that anyone not directly involved in incident command are evacuated. The presence of extra personnel places a burden on responders who have to maintain the safety of everyone in the affected area. It also places a burden on the local infrastructure in supporting an influx of people who need electricity, food, water, housing, and transportation. After the Tohoku earthquake (2011), the Japanese government asked the National Science Foundation to stop all funded scientists from coming to Japan. In particular, civil engineers from all over the world were inundating affected areas, draining resources and adding more people for authorities to account for if a major secondary earthquakes happened; the Japanese government pointed out that their scientists were already collecting structural data and sharing with the world wide community. The moratorium delayed the Center for Robot-Assisted Search and Rescue for two weeks in bringing marine robots to assist a Japanese team in reopening shipping channels and ports, despite having written invitations from two Japanese cities. As another example, during Hurricane Harvey (2017), drone pilots arrived in the metro Houston area in the hopes of being able to find an agency that would ask them to fly or flying then offering the data to response agencies only to discover that they had duplicated efforts or the data was not of high value areas. Meanwhile, county response workers and their families were sleeping on the floor in the emergency operations center because their houses were flooded and no hotel rooms were available.

B. Pet Project

The Pet Project syndrome is when a roboticist promotes their technology for the response. It is natural to want to help and to think of ways that their talents, expertise, and creativity could help. However, this often enters unethical territory if the technology does not be high value for the responders' true goals, priorities, and activities. Just because a robot can perform a task, does not mean that roboticizing that task is worth the time, effort, additional logistical demands, and risk to insert it. Another unethical aspect of the Pet Project syndrome is when roboticists work independently of responders or circumvent their chain of command in order to insert robots, for example, putting political or media pressure on an incident commander to accept the introduction of a technology.

C. Something is Better Than Nothing

"Something is better than nothing" is a common phrase espoused during a disaster by roboticists and as a justification for why a roboticist is promoting their pet project. Unfortunately this is not true, as shown at the Pike River mine disaster, robots can make things worse. In that instance a robot failed, blocking access to the mine for all other robots and people; the response was shut down until the robot could be remotely restarted many hours later [1]. The development mantra "fail often, fail fast" is dangerous when applied to disasters. Robot failures have real consequences to saving lives and mitigating the disaster plus there is rarely an opportunity for iteration due to the short duration.

D. Fear of Missing Out (FOMO)

This syndrome captures a "everyone else is doing it, so it must be safe (or ethical)" attitude. Unfortunately as seen with the use of drones for COVID-19, what is acceptable use in one culture is not acceptable in another. For example, the use of drones for quarantine enforcement and population surveillance in China during the initial COVID-19 pandemic was not acceptable for Western countries and generated public backlash [15]. Roboticists who argue for use of robots based on what other agencies, states, or countries are doing should be aware of legal and cultural differences.

E. Hidden Agenda

The Hidden Agenda syndrome is similar to surveillance capitalism: the robot is offering a visible benefit but the real purpose is to collect data or some other effect. This is similar to the Disaster Tourism syndrome, where the insertion of the robot has high value to roboticist but unclear value to the response. Manifestations of the Hidden Agenda syndrome are often press coverage, which should be regulated by the incident command's Public Information Officer, and bending the rules. On a private forum, a UAS team announced that they were applying for an emergency waiver for a particular type of flight even though the missions did not require it. The intent was to force the FAA, which was unlikely to realize that the mission did not really need that authorization, to grant the waiver. Then the team would be able to argue that since the FAA had authorized it during an emergency, they should start authorizing it for normal conditions.

VI. Checklist for Ethical Deployment of Robots to a Disaster

Given that is easy for any roboticists to be overly enthusiastic about their innovations and unintentionally fall into one of the five unethical syndromes, we have created a checklist of questions for roboticists to ask themselves. The questions highlight how important it is for roboticists to place the needs of the response first, and to be truly familiar with the emergency response work domain before trying to insert new technology into it. Though the intended audience of this paper and checklist is roboticists, incident command may wish use to the questions to help establish the suitability and risk of the robots.

The first question is:

- *Is this use of robotics in response to an explicit demand pull or is it an innovation push?* Did an emergency response or government agency initiate a request? For example, was there a direct invitation due to an existing partnership with an agency or relationship or did it stem from a general call for assets as seen at Fukushima? Is the request a result of a Pet Project or Hidden Agenda being forwarded through political channels?

If the robot is not being provided in response to a request, the application is effectively an innovation push. If a roboticist contacts an agency involved in the management of the incident, the roboticist should be confident that their system is appropriate, otherwise they are distracting the agency by even offering the robot. Here are some questions that a roboticist should ask internally before contacting responders:

- *Why is a good fit with high technical maturity, high suitability and low risk?* Is it a Heritage robot or one that is Engineered or New. If New, then the robot is extremely unlikely to be viewed as having sufficient value to be worth adopting during the disaster. Is the basis for a Heritage or Engineering that assessment an empirical guess or is it the result of a principled assessment of the technical maturity, suitability, and risk?
- *What is expected benefit over existing methods? Is the benefit for primary, secondary, or tertiary activity?* This is a question that agencies will ask, but roboticists should ask themselves first before pushing their technology. If the roboticist does not know, versus assume, the existing methods, then that suggests that the team does not understand the work domain and thus the robot poses a risk.
- *Is the robot reliable enough and are there sufficient resources to keep it in service for multiple days? If something breaks, are replacements immediately available?* If a response integrates robots into their workflow, the robot is expected to be part of the response for the duration. A rubric is that a team needs three robots to keep one in operation in the field at all times.
- *What is the experience of the team?* Is the robotics team trained for field work in often austere conditions with little sleep and the lack of typical amenities? Are they trained for disaster response? Do they know the incident command system or agency operation structures?
- *What is the logistics footprint?* Responders focus on minimizing the number of people engaged in the exclusion zone of the response for safety reasons. Responders will need to know that an extra dedicated generator is needed for recharging batteries or the team needs sleeping arrangements and meals. Many times, there will not be an extra generator and thus the robotics team cannot be deployed.
- *Have the roboticists considered the public accountability issues that the robot poses?* Are they familiar with implicit and explicit expectations or policies, e.g., such as responders expect all imagery to be handled with a chain of custody and preservation of civilian privacy?
- *Can delays (or never) on publishing be accepted?* All imagery from robots belong to the agency holding jurisdiction. As publicly accountable agencies, they strive to release the imagery as soon as possible but they have to screen for privacy or legal issues. For example, imagery from the recent Surfside building collapse in Miami taken by the NIST Construction Safety Team will remain sequestered as evidence until their final report is released, which could take over a year. Some imagery taken by the tactical and strategic operations UAS teams may never become available if it contains recognizable human remains. Note that asking this question about publications helps roboticists determine if they subconsciously are experiencing a Hidden Agenda syndrome.
- *Can a prohibition on posting on social media and a requirement for all press releases coming through an agency Public Information Officer be honored?* In one disaster, a robotics company agreed in writing to only go through the PIO, but immediately posted favorable press reports. The defense was that it was all just a miscommunication and the overzealousness of the company's media team should not be held against the roboticists. Given that the robot team lead who had signed the agreement was interviewed and quoted in the article, the agency interpreted the "miscommunication" as a deliberate deception and put the relationship of all the CRASAR robotics teams in danger.

VII. Conclusions

Disaster response is challenging and requires teamwork by all involved. Likewise, innovation during a disaster response ultimately means that the emergency management agency or institution is innovating their response operations by temporarily adopting existing, highly suitable, low risk robots, not that roboticists are rapidly innovating unique and novel platforms. The model of responsible robotics innovation for disaster response suggests that it is critical for roboticists who want to ethically insert technology in disaster response to have already engaged in responsible robot design with stakeholders for their known use cases before a disaster. If roboticists find themselves wishing to insert their technology into a disaster as an innovation push, the ethical checklist poses a series of questions that can help determine if there are clear benefits of robotics innovation to the response and those benefits are likely to exceed the logistics, workforce disruption, and other costs. The point is not to dissuade roboticists from contributing to disaster response, but rather to set realistic expectations and encourage roboticists to work with local emergency response professionals beforehand.

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