Responding with AI-planning to Disasters- RAID

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Executive summary

Disaster response involves the consideration of an abundance of time-varying information as well as the coordination of a substantial number of first responder assets as efficient as possible. The complexity of response operations can be even more accentuated according to the scale of the disaster (e.g. the size of the disaster area, the density of the population). While the deployment of unmanned vehicles in the setting of manned-unmanned teaming has been identified to be beneficial for faster and more flexible disaster response, especially in impervious areas, the exploitation of the concept is only possible if the dynamic planning can be performed with increased autonomy.
We propose a use case based on the planning for a team of a manned vehicles and multiple unmanned vehicles in a disaster response operation. Besides conceptualizing a use case for the Unified Planning Framework (UPF) of AIPlan4EU, we also intend to showcase the use of UPF in an on-field demonstration based on a Search-And-Rescue operation in an Alpine area.

1 Context

Enhancing Disaster Risk Resilience (DRR) is an important agenda for every first-class society. Large-scale disasters are more prone to happen, partly due to increasing climate-related natural hazards.
According to a study carried out by the EC's Joint Research Center (JRC) in PESETA IV[1] on the impact of climate change across Europe, floods and wildfires account for the most fatal natural disasters in Europe in the coming decades. With a global warming of 1.5°C by 2050 for example, about 100 mil Europeans yearly (tenfold of today's impact) will be exposed to heatwaves (with an expected annual fatality of 30,000), 230,000 Europeans will be exposed to river floods (with yearly losses of more than 20 €bil), and 10 mil Europeans will be exposed to wildfires for at least 10 days per year.

Climate-related natural disasters often hit a *wide area*, causing enormous difficulties for carrying out first-responder operations, although timely response is essential to avoid casualties, minimize injuries and mitigate damage to critical infrastructure. Furthermore, disaster-struck areas can become *impervious* to first responders, causes delay in the rescue operation or even danger to the first responders.
For the above reasons, many first responder organizations leverage unmanned vehicles, and especially unmanned aerial vehicles (UAVs) to explore the disaster area. These UAVs can be of more compact quadcopters, but also larger fixed-wing aerial vehicles[2]. The following scenarios depict how UAVs can assist first responders in their operations:
1. Search-And-Rescue (SAR) in coastal areas
Fixed-wing UAVs can maintain a stable flight profile despite the wind and breeze at coastal areas. With these UAVs, wider areas can be scanned quickly. In the case where damage to critical infrastructure at sea is to be mitigated, UAVs can fly closer and more quickly to this infrastructure.
2. SAR in mountain areas
Avalanche and forest fires can happen in mountain areas. Given the topology of these areas, many can quickly become impervious to first responders after the disaster strikes, thus making rescue operations extremely challenging.
3. Rescue operation in flooded urban areas
Given the increasing flood risk across the EU, many urban areas become vulnerable to floods, causing casualties and financial losses to local communities. Besides assisting with the rescue operations, UAVs can also help in reaching out early (early warning) to residents that are unaware of the flood risk and guide them to a safe evacuation.

While any of the above scenarios can be used as a use case for AIPlan4EU, Scenario 2 can be of more substantial interest as a field demonstration is also possible.

<u>Motivation for the use of AI-planning</u>
To help increase the efficiency of the deployment of UAVs, a viable solution is to encourage manned-unmanned teaming. In this setting, the unmanned vehicles (typically UAVs) will be deployed from another manned vehicle (either a manned aerial vehicle such as a helicopter or a manned ground vehicle). However, this is only possible if the coordination of the unmanned vehicles is highly automatized, as the number of human operators in the manned vehicle is limited. Therefore, an automated mission planning system will be in this setting highly beneficial.

The table below highlights the current workflow in deploying UAVs, their drawbacks, as well as the advantages that can be achieved with the innovation intended.

[1] Feyen L., Ciscar J.C., Gosling S., Ibarreta D., Soria A. (editors) (2020). *Climate change impacts and adaptation in Europe*. JRC PESETA IV final report. EUR 30180EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-18123-1, doi:10.2760/171121, JRC119178.
[2] https://larus-pro.de/index.html

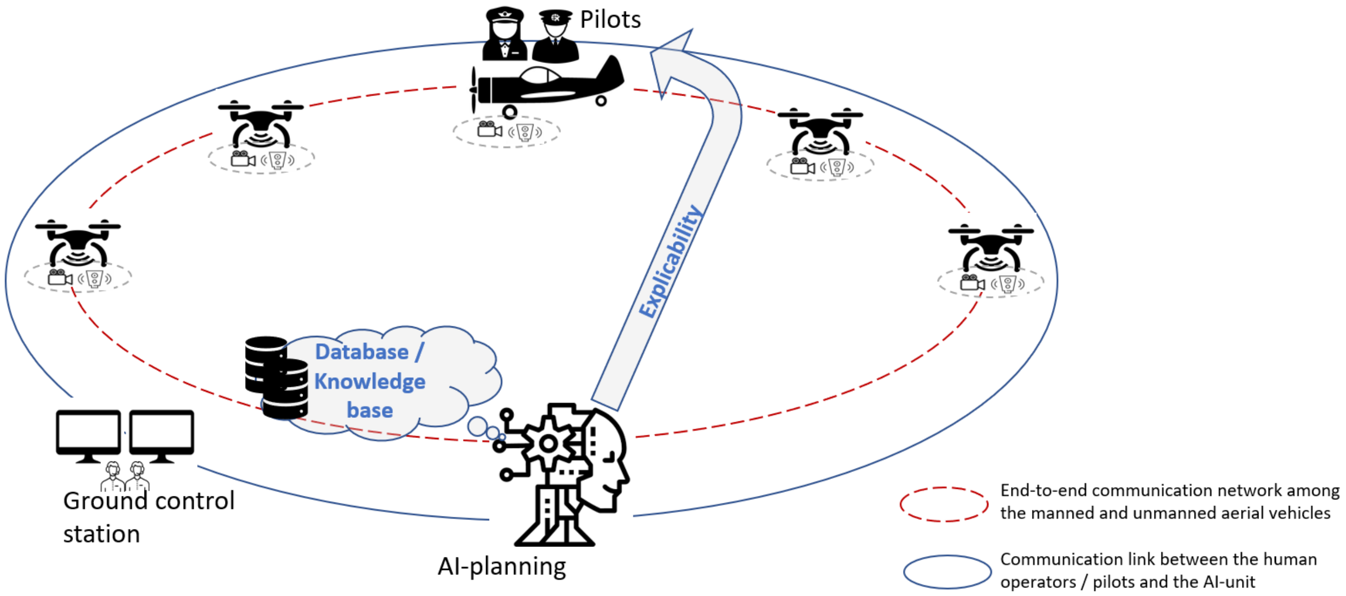

Figure 1. Manned-unmanned teaming supported by AI-planning

Current workflow	Drawbacks	Intended innovation
Each UAV is operated by at least one remote pilot.	It is costly to continuously operate many UAVs for rescue operations that can take days or even weeks (e.g. forest fire).	With automated planning, the coordination of many UAVs can be performed without increasing the operating costs.
(Non-routine) Operations are planned mostly by hand and on black board in a command-and-control center.	Besides being highly inefficient, manual planning is also incapable of leveraging the increasing abundance of digital information (e.g. automatically recognised objects with computer vision).	With automated planning, more information can be considered without increasing planning time, therefore reducing delay to response actions.
The UAV must maintain line-of-sight (LoS) communication with its command point (i.e. usually a remote pilot nearby the command-and-control center).	This will limit the deployment of the UAVs only within areas that have LoS-communication with the remote pilots that are often positioned close to the command-and-control center.	By enabling the operation of multiple UAVs from onboard a manned vehicle, the deployment of these becomes more flexible and can reach more areas which are otherwise impervious to remote pilots on the ground. Since the manned vehicles is unlikely to be able to accommodate many remote pilots, automated planning is necessary.

2 Planning Application

Several components are essential in the mission planning aimed at manned-unmanned teaming to enhance response in disaster areas. These are i) a planning system, ii) a human-machine interface as well as iii) a communication network and interface that allow for interoperability among different agents. With this open call for use cases, we intend to

experiment and work with scientists from the automated planning community to co-develop an automated planning system.
The expected plan output from the automated planning system must comprise of *a sequence of time-stamped actions* to be carried out by the different agents in the mission environment. Ideally, if possible, *several plans must be provided*, so that the plans serve as suggestions to the human operator(s), respecting thereby also human autonomy in decision making to comply with the EC's guidelines on the uptake of AI in the EU.
Some minimal information to explain the plan must be provided for *explicability*, so that human operators understand the reasoning behind the automated planning system, and can, in some cases, also intervene, i.e. by modifying the plan partially.

The following provides more detailed information on the key problems to address, the method to measure plan quality, the relevant data / model necessary for planning, as well as the planning procedure, i.e. how often planning has to be invoked.

Key problems to address	Quality measurement	Necessary data to tackle this problem
Time dependency: The goals and actions / tasks of the mission are time-dependent. Therefore, the planning problem considered is temporal and the solution to the problem must contain temporal information.	The duration of some tasks can only be estimated at planning time. The estimation of task duration can be probabilistic (following a uniform or Gaussian distribution). Ideally, these probabilistic estimations of the task durations can be considered in the computation of plans.	<u>Constant data:</u> The duration of each task / action is given (in a parametrized model) and is scaled accordingly (for example according to the size of the area to scan).
Higher-level tasks and motion controls: Planning for high-level tasks is necessary for both manned and unmanned vehicles. These tasks can be for instance communicate with UAVx, communicate with the manned vehicles, communicate with the ground control station, record image, scan area, fly pattern, gather information, drop first-aid assistance, extinguish fire, etc. However, unmanned vehicles must operate at higher autonomy, as they cannot be continuously remote piloted. Therefore, motion planning is also required by unmanned vehicles.	The status quo consists often in only planning for tasks of higher abstraction levels, while more detailed tactical planning such as motion planning is only considered during execution. This causes often the plans to be invalid, and only realized during plan execution. The quality of a plan also lies on the degree of refinement, thereby enhancing also *the executability of the plan*. However, the planner is also evaluated based on the *planning time*, which can be more substantial if plans have to be computed in a more refined manned.	<u>Constant data:</u> The hierarchical task network can be provided, so that hierarchical planning can be leveraged. <u>Contingent data:</u> The environment is dynamic and the observation data on the environment is updated constantly during plan execution. Therefore, subsequent decision making or planning will also need to take the validity of information into account.
Goals and objectives: To be achieved by the plan solutions can be classical goals, e.g. a state to reach, but can also be tasks that must be performed within given time	Current workflow adopted by first responders cannot cope with so many objectives. Many planning algorithms also only focus on	<u>Constant data:</u> The costs and rewards of the effects of tasks / actions can be fixed prior to planning.

windows, e.g. scan crowd between xx hour to yy hour, etc. Furthermore, the effects of actions / tasks will be associated with rewards and costs, which are expressed as objective functions to be optimized, e.g. each image recorded is rewarded with xx, each victim found is rewarded with yy, each UAV damaged cost zz, etc.	minimizing time, i.e. minimizing temporal cost. A plan is of high quality if it can simultaneously *optimize many objectives*.	Contingent data: While there can be many objectives associated to a planning problem, depending on needs, some objectives are of higher importance than others, which are often decided strategically by the first responders during the operation. For example, the objective of searching for victims in the first hours after a flood is more important than scanning buildings for damage, as the survival rate sinks exponentially over time.
Continuous plan monitoring and re-planning / plan repair: Due to the dynamic environment and the continuous update of observation on the disaster areas, computed plans may no longer be valid during execution. Therefore, a continuous plan monitoring (with plan validation) is essential. Whenever necessary, a replanning must be triggered automatically. A local plan repair instead of a replanning is preferred, so that the first responders do not always have to reorganize all their assets with each replanning. Besides, a replanning / local plan repair can also be triggered at constant intervals to check for better plan alternatives.	Continuous plan validation is often not possible or very inefficient if planning is not performed in an automated manner (as plans are not available in a digital form). A quality planner will be able to replan or repair plan efficiently within an acceptable time so that no delay is caused.	Contingent data: Each occurrence of events at disaster areas must be considered for plan validation and eventually for replanning / plan repair, if necessary.

Storyboard of planning within the workflow

Due to the large amount of assets involved, as well as the standard operating procedure among first responders, an initial plan is always necessary for the first responders to organize themselves. The initial plan can consist only of tasks of very high-abstraction level (without plan refinement), while the plan refinement is performed in a bootstrapped manned during the plan execution.

Observations of the environment will be used to monitor the validity of plans as well as the need for a replanning / plan execution. This will be performed continuously, and for as long as observation data of the environment does not remain constant.

Operators who are in charge of mission planning can also invoke a replanning or intervene with a plan repair (i.e. manual modification of plan) at any moment during plan execution.

3 Impact

3.1 Business Impacts

Type	Impacts	Target groups
Reduce operating cost on assets of first responders		
Business	- While manned aerial vehicles are more robust and flexible to operate, they are usually costly to repair or acquire (e.g. a helicopter is at least 10 times more costly to operate than a team of three UAVs). - Helicopters are often used for search and rescue services, which can take hours or days. The running costs (hourly pilot fee, fuel consumption and maintenance) are higher than the running costs of multiple UAVs.	- *Practitioners*
Reduce risks for citizens		
Business	- With more efficient and faster disaster response, casualties and injuries can be reduced or even avoided. This will also be reflected on the costs incurred on life and health insurances. - The availability of faster disaster response will increase the life quality of the residents, promising therefore prosperity in the communities.	- *Insurance companies / social security* - *Municipalities*
Reduce damage on critical infrastructure		
Business / economic	- When a disaster strikes in an area where critical infrastructure is located (e.g. power plant, data center, etc.), damages on the infrastructure can be devastating to the economy. It is therefore essential to conduct quick inspection on the infrastructure to secure prompt mitigation strategies. - The availability of fast disaster response within a community that is capable of preventing devastating damage on infrastructure and will also attract more investors to set up their businesses.	- *Operators of critical infrastructure* - *Municipalities / government*
To get first responders to go beyond digitization, by familiarizing with AI-powered automation		
Business / economic	- Market for first responders is rather user pull, as the technologies must fit into the standard operating procedures adopted by the first responders, as well as be acceptable for first responders, which can be challenging when the technology involved is meant for decision making support. Therefore, it is essential to first familiarize first responders with AI techniques, in order to incite the product development of solution providers.	- *Private sectors / solution providers for first responder technologies* - *First responders*

3.2 Other Impacts

Type	Other Impacts
Reduce emission related to disaster response	
Environmental	Conventional vehicles used for scanning disaster areas (in view of increasing situation awareness) or for SAR are high on fuel consumption, such as helicopter or trucks. By enabling the deployment of multiple UAVs in a robust manner by leveraging automated AI planning, fuel consumption resulting for disaster response can be reduced.
Protect first responders and enhance first responders' capabilities	
Societal	Some first responder' organizations relay mainly on the voluntary participation of citizens. Enhancing their capabilities with smart technology and protecting them by using unmanned vehicles as front liners in an unknown impervious area will help citizens to be more confident in their participation as volunteers in first responder organizations.

Make scientific development truly valuable to the European society	
Scientific & Societal	By showcasing the application of AI planning in disaster response to improve disaster risk resilience, it will increase awareness among European citizens/residents on the importance of AI-related developments, which goes beyond being an economy booster or being an instrument of modern industries.
Encourage dialogues between first responders and scientists in AI planning	
Scientific	By adopting use cases from disaster response, a co-development can be fostered to gear AI-planning more ready for use in complex dynamic environments to be deployed by first responders.

4 Measures of Success

KPI	Expected performance	Measure of success
1	Increase amount of information to be exploited in the planning of rescue operations without causing a drop in efficiency (i.e. longer planning time must not be the consequence of the consideration of more information)	Consideration of at least 10 types of information (e.g. automatically recognized objects, duration of tasks, number of victims and first responder assets, weather, scanned areas, etc.) in the planning of rescue mission, which otherwise are overwhelming for the current workflow
2	Reduce response time for impervious disaster areas	Identification of at least 3 scenarios where the deployment of UAVs using AI planning methods can reduce response time
3	Increase explicability for first responders	Identification of how AI planning (through an easier validation method and digitalized display of results) can increase explicability of plans compared to current workflow
4	Increase awareness among first responders about the use of AI planning, as well as among technology providers for first responder services about the new product features	- Participation of at least 3 first responder organization and at least 1 first responder technology provider at the co-development workshops/demonstrations organized by AIPlan4EU - At least 2 publications/presentations of the results from the co-development at conferences targeted at first-responders, e.g. “security research event”, events organized by CERIS or PSCE, etc.
5	Establish a set of standard benchmarking problems for future developments of AI planners	At least 3 benchmarking problems will be designed, defined and published.