ESC204 | Praxis III

Request for Proposals

Wildland Fire Protection & Mitigation in a Canadian Context

This Request for Proposals (RFP) provides guidance towards the design and preliminary implementation of an engineering system to address challenges faced by Canadians living at the Wildland-Urban Interface (WUI), which is at particular risk of wildland fire events.

In the following sections, we provide additional information to support the Context, outline the desired Approaches teams should take to address the stated Value Proposition, and provide a preliminary set of Engineering Requirements for each approach, which any Design Concepts must address.

Contents

1 Context: Wildland Fire in Canada

This section provides key background and contextual information regarding wildland fire in Canada, organized into the following sections:

1.1: Wildland Fire Fundamentals
1.2: Prevalence and Impact of Wildland Fires in Canada
1.3: Fire Protection & Mitigation for Households & Communities
1.4: Assessing the Risk of Wildland Fire

Innovations aimed to address the ongoing environmental, social and economic effects of wildland fires in Canada (and beyond) align with the following United Nations Sustainable Development Goals (UNSDGs):

- UNSDG #11 Sustainable Cities and Communities [1]
- UNSDG #13 Climate Action [2]
- UNSDG #15 Life on Land [3]

Finally, key stakeholders within the context are discussed, and the section concludes with a statement of the Value Propositions all Design Concepts must aim to fulfill.

1.1 Wildland Fire Fundamentals

NOTE: The Wildland-Urban Interface (WUI) is any location where structures built by humans meet ("interface" with) wildland fuels (trees, shrubs or grassland) [4], [5].

Wildland fires ("wildfires") occur when an ignition source (a lightning strike, damaged power lines, industrial or recreational activities, etc.) ignites organic material such as trees, shrubs or grasses [5]. When conditions are right, such fires can grow out of control, consume forests and other vegetation, and threaten structures at the WUI. The key environmental factors contributing to the ignition and growth of wildland fires are [5]:

- **Fuels:** available flammable materials including plants/trees, branches, leaf litter, grasses, shrubs, and flammable structures.
- **Weather:** Wind conditions, precipitation, relative humidity, and temperature.
- **Topography:** slopes, ravines, and other terrain features.

Generally speaking, drier fuels pose a greater risk of ignition and subsequent spread of a wildland fire; however, how fuels are arranged (i.e., availability of oxygen, proximity and amount of fuels, etc.) may also affect fire risk [5][6]. Hot, dry weather increases fire risk by drying out fuel sources; in addition, very windy conditions can result in more extreme wildfires which spread more quickly [7][8]. All of these effects have been exacerbated by climate change [7]. In addition, topography can affect the speed at which a fire spreads: fires generally travel faster uphill [5][6].

1.2 Prevalence and Impact of Wildland Fires in Canada

Wildland fire is an increasingly prominent threat in Canada and around the world. 2023 saw the most destructive wildfire season in Canada's history, burning more than 15 million hectares of land – more than double the previous record [9]. In 2024, more than 5.3 million hectares were burned

[10][11]. Though this is much less than in the record setting 2023 season, it is still a much more destructive season than usual: prior to 2023, the 10-year average area burned was approximately 2.5 million hectares [9][11].

1.2.1 Environmental Impacts

Though wildland fire is essential to forest ecology, ongoing effects of climate change mean that wildland fires in Canada are becoming more frequent, and more severe [4]. During the 2023 wildfire season, when Canadian forests experienced the driest and hottest summer (May-September) since 1980, it is estimated that approximately 650 TgC (teragrams of Carbon) were released in the resulting fires; this is comparable to the annual fossil fuel emissions from entire nations [12]. In addition, forests offer an important means of sequestering atmospheric carbon dioxide; with increased wildfire activity due to climate change, the ability of forests to sequester CO_2 is curtailed, further contributing to atmospheric warming [12][13].

In addition to causing the loss of existing plants and wildlife, in areas with frequent or more severe wildfire activity fires can destroy not only living trees but also organic matter in soil and the seeds which would normally germinate and become new plants. This can lead to shifts in the composition of forests that do regrow, or in extreme cases, an entirely new landscape with no forest [14]. Remediating landscapes where severe burns have occurred is a laborious process: it is necessary to gather seeds from the local area (to ensure that the species planted are representative of local ecology), then spread them over the affected area, paying close attention to "micrositing", or ensuring that scattered seeds are placed in areas with appropriate conditions to promote germination and growth [15][16].

1.2.2 Economic Impacts

Fires which take place at the WUI have the potential for significant economic impact to communities due to loss of structures and other community assets. Loss of property and impacts on resource extraction (i.e., logging, oil and gas), agriculture and tourism all contribute to economic losses, in addition to the cost of fire suppression and evacuations [4][5]. For example, a severe 2016 fire in Fort McMurray (the Horse River Fire) necessitated the evacuation of more than 88,000 people including from local hospitals and oil sites in the region. The fire burned for over a month, and it is estimated that the total cost (insured and uninsured losses of property, indirect and direct costs) were approximately $9 billion CAD [17]. In a 2017 wildfire near Williams Lake BC, insured losses of $100 million CAD were incurred due to the loss of 107 structures [17]. Suppression of wildland fires which threaten communities, structures or natural resources in Canada costs on the order of $1 billion CAD per year [17].

1.2.3 Community & Human Impacts

"The impact of wildfire is devastating and long-term. Some people never really recover from its effects. Wildfire does not recognize jurisdictional or political boundaries, does not care if you are wealthy or poor, and does not wait until you have resolved interagency differences or until your response training is completed and your equipment is ready."

– excerpt from the FireSmart guide to Protecting your Community from Wildfire [5].

Beyond economic losses incurred by communities and individuals due to wildland fire events, which may be significant, ongoing impacts of wildland fire include displacement due to the loss of dwellings, the loss of natural resources including traditional food sources and agricultural products, and impacts on air and water quality [18]. For example, smoke inhalation due to a nearby fire is strongly associated with adverse respiratory effects, while toxic chemicals released into the air can be deposited on nearby landscapes, and run off into nearby water sources (risking contaminating them). Beyond physical health, there are significant mental health impacts for communities impacted by wildland fire, particularly for those who witnessed the destruction of dwellings, lost their home, or had to evacuate [18].

These impacts are not borne equally by all members of the Canadian population. Remote, rural communities may have less infrastructure to mount a response to wildland fires than urban, more connected ones; in particular, a lack of communication infrastructure may lead to challenges in communicating between authorities and members of the public [18]. In addition, First Nations communities (many of which are also remote) are disproportionately impacted by wildfire events: they make up an estimated 42% of evacuees, while only representing 5% of the Canadian population [18]. Many First Nations communities have cultural ties to the land, and depend on hunting, gathering and/or fishing to harvest traditional food [19]; therefore, environmental devastation due to wildland fire may impact First Nations and other Indigenous communities more profoundly [18].

1.3 Fire Protection & Mitigation for Households & Communities

Fire Protection and Mitigation refers to actions that communities and individuals can take to reduce the risk to lives, structures, and the (built and/or natural) environment due to wildland fire [4]. Information about how to improve resilience of dwellings and other structures located at the WUI is disseminated by multiple federal and provincial government agencies (for example, [6],[5],[20]). Guidelines offered by these agencies focus on managing the fire risk to a particular structure (such as a home) located at the WUI by reducing the risk that the structure will catch fire during a wildland fire event (i.e., preventing fire from spreading to the structure from the surrounding wildland area).

To assess the fire risk to a dwelling or other structure, FireSmart Canada (a federal program) defines the Home Ignition Zone (HIZ), encompassing the area surrounding a home or other structure to a distance of 30m. Within the HIZ, they further define Immediate (0-1.5m from the structure), Intermediate (1.5-10m from the structure) and Extended (10-30m from the structure) Zones, within which different mitigative measures are relevant [6]. For example, in the Immediate Zone key considerations to reduce the risk that a windborne ember could ignite a structure include choosing fire retardant building materials, and regularly removing fuels such as organic debris from roofs, gutters and decks. In the Intermediate Zone, choosing landscaping elements that are resistant to ignition as well as regularly removing dry leaves, twigs and branches can further reduce the risk [5][6].

1.4 Assessing the Risk of Wildland Fire

Fire risk to a particular community is determined by both:

- The risk that a wildfire will start in the vicinity of the community; and
- Preventative and/or mitigative measures that the community has taken to reduce the risk that structures or other assets will ignite.

Preventative and Mitigative measures were discussed in Section 1.3; in addition, Reference [5] provides a comprehensive guide to understanding and mitigating fire risk to structures at the WUI. The following section provides more detail about factors which influence the risk of fires occurring in wildland areas, and how fire risk may be predicted.

1.4.1 Understanding and Predicting the Risk of Wildland Fire

In Canada and internationally, the Canadian Forest Fire Danger Rating System (CFFDRS) is used to predict the likelihood of wildland fire, as well as fire behaviour and impact (collectively, "Fire Danger") [21]. This is a complex model which relies on many data inputs and subsidiary models to make informed predictions of fire risk and behaviour. One aspect influencing fire danger is the Fire Weather Index (FWI), which is calculated using the FWI System (another complex model). Weather data, in particular current and historical temperature, wind, rain and relative humidity all influence the FWI [22]. These inputs may be understood individually as important factors which influence fire danger; they in turn also influence the moisture content of fuels on the forest floor.

Reference [23] provides detailed information about how weather observations are used in the CFFDRS.

It is important to note that fire danger as well as appropriate mitigation measures and response to wildfire events can be understood both through modelling and forecasting efforts such as the CFFDRS, and through the application of local (and/or Indigenous) knowledge and experience in a particular community [24][25]. Thus, strategies for wildfire resilience should take a unified approach, involving the whole of society [4].

1.5 Stakeholder Summary

This section highlights key stakeholders in the context of this opportunity.

1.5.1 Communities & Individuals living at the WUI

Communities and individuals living at the WUI are the primary stakeholders within this opportunity space. They are at the highest risk of being impacted by wildland fire, including economic, environmental and health impacts discussed in Section 1.2. They are also largely responsible for implementing protection and mitigation strategies to improve resilience to wildland fire events (as in Section 1.3), working with local, provincial and federal agencies to achieve protection and mitigation goals. These communities and individuals are the intended users for any design concepts proposed in response to this RFP.

1.5.2 Government and Policy Makers

Local, provincial and federal government agencies are actively involved in promoting understanding of fire danger as well as appropriate prevention and mitigation strategies across Canada. They publish guidelines as described in Section 1.3 to help communities and individuals living at the WUI implement appropriate prevention and mitigation measures to reduce the risk of impact due to wildland fire. They are also actively engaged in monitoring Canadian wildland areas to determine both the fire danger (potential for a wildland fire to start and impact human activities; as in Section 1.4) and to identify active or ongoing wildland fires.

The Canadian government is also actively engaged in developing policy to address the ongoing risk to communities and individuals due to wildland fire; for example, references [4] and [24] represent recent policy agendas released to encourage ongoing engagement with these topics from many different perspectives.

1.5.3 Forests and the Natural Environment

As this opportunity falls within the mandate of UNSDG #15 (Life on Land, [3]), the natural environment is an important stakeholder within this opportunity space. Forest management practices in recent decades have left forests more vulnerable to more intense and destructive fires; at the same time, ongoing effects of climate change have caused hotter, dryer summers which further intensify burns [4][7]. Enabling communities and individuals to "live well with wildfires" (Razim Refai, Section 3) while promoting understanding of environmental factors which lead to increased wildfire risk (and how these are linked to climate change and forest ecology) may offer an avenue to create more sustainable communities at the WUI.

1.6 Value Proposition

Wildland fire is essential in the renewal of Canada's forest landscapes; however, it has the potential to cause significant damage to structures and other community assets at the Wildland-Urban Interface (WUI) in Canada. Empowering communities to improve the resilience of both community and privately owned structures to the eventuality of wildland fires can support thriving of these communities in the long term.

2 Preferred Approaches: Mechatronics and IoT

This section outlines two preferred approaches which address the Value Proposition provided in Section 1.6:

2.1 Mechatronic Approach: Combustible Materials Cleanup
2.2 Internet-of-Things (IoT) Approach: Environmental Monitoring

More details regarding these preferred approaches as well as a preliminary table of Engineering Requirements tailored to each approach are provided in the following sections.

2.1 Mechatronic Approach: Combustible Materials Cleanup

In alignment with the recommendations of FireSmart Canada, maintaining a roof and yard clear of organic debris is a key strategy to reduce the risk that a structure will catch fire [5], [6], [20]. Frequent debris removal is time consuming, and may pose a safety risk due to uneven or slippery surfaces (especially while cleaning roofs). Thus, to encourage home and business owners at the WUI to adequately maintain their yards and/or roofs free of organic debris, we solicit designs which reduce both the time burden on community members and the possibility of injury while clearing debris. Both individual and community level solutions are of interest.

2.1.1 Engineering Requirements

Design Concepts developed in response to this RFP, and in particular, the Mechatronic approach described in Section 2.1 should address the Engineering Requirements given in Tables 1 and 2.

Table 1: Functional Objectives for any Design Concepts which take the Mechatronic Approach to addressing the Value Proposition.

	Objectives	Metrics	Constraints	Criteria
Functional Objectives: Mechatronic Design Concepts will...				
FO-1	Remove organic debris from surfaces near to a structure (i.e., roof(s) and/or yard(s)).	Structure and Site Hazard Rating assessed for Factor 2 (Roof Cleanliness) and/or Factor 10 (Surface Vegetation) as in the FireSmart Guide, pgs. 2-6 & 2-16 [5].	Designs must reduce the Hazard Rating in one or more indicated categories by removing accumulated organic debris.	More significant reduction is preferred.
FO-2	Reduce the active time required for a user to remove organic debris near to a structure.	Active time [h] required for a user to reduce the Hazard Rating as above in one or more of the indicated categories.	Must reduce active time relative to manual debris removal.	Less active time is preferred.
FO-3	Reduce the potential for injury to a user due to slips, trips and falls while removing organic debris near to a structure.	Mitigation of hazards related to Slips, Trips and Falls (e.g., see [26]) using a Hierarchy of Controls methodology [27].		Designs prioritizing more effective hazard control (as in [27]) are preferred.

2.2 IoT Approach: Environmental Monitoring

One commitment made by the authoring agencies of the Canadian Wildland Fire Prevention and Mitigation Strategy is to “[d]evelop and make available wildland fire risk assessment and risk planning resources and promote their adoption and integration across all sectors of society” [4]. In alignment with these goals, we solicit designs which put information regarding the fire risk to a local community directly in the hands of community members. By enabling local collection and/or interpretation of environmental data with respect to government and/or traditional guidance around wildland fire prevention and mitigation, designs should aim to improve awareness of wildland fire risk (and how it is determined), as well as providing local information to support community-based prevention and mitigation efforts.

2.2.1 Engineering Requirements

Any Design Concepts developed in response to this RFP, and in particular, the IoT approach described in Section 2.2 should address the Engineering Requirements given in Tables 3, 4 and 5.

Table 2: Performance Objectives for any Design Concepts which take the Mechatronic Approach to addressing the Value Proposition

	Objectives	Metrics	Constraints	Criteria
Performance Objectives: Mechatronic Design Concepts should...				
PO-1	Improve fire resistance of the structure from which debris is removed.	Structure & Site Hazard Rating assessed using the Structure and Site Hazard Assessment Form provided in the FireSmart Guide, pg. 2-29 [5].	Debris removal must not increase Hazard Rating for the structure overall.	More improvement in fire resistance (i.e., lower Hazard Rating) after debris removal is preferred.
PO-2	Prevent environmental contamination during or after operation.	Volume of release of materials considered "Hazardous and Special Products" (HSPs) under O.Reg. 449/21 or related regulations [28] or "Batteries" under O.Reg. 30/20 or related regulations [29].	Must not release any HSPs or Batteries into the environment.	No release is permissible.
PO-3	Minimize power required for operation.	Average power [W] consumed by the design while operating.		Less power consumed is preferred.
PO-4	Minimize use of materials consumed (e.g., fuel, disposable parts, etc.) during operation.	Consumption per square meter of surface from which debris is removed [kg/m^2].		Less consumables used is preferred.
PO-5	Operate quietly.	Sound Power (dBA) produced by the design while in operation.		Lower sound power is preferred.
PO-6	Be easy to use.	Consideration of factors leading to users 1) understanding and 2) effectively handling the design (as in Chapter 3.7 of [30], for example)		User-facing elements of the design (if any) should clearly indicate how a user can/should interact with the design.
PO-7	Be safe for the user.	Mitigation of Hazards and Risks associated with operation following a Hierarchy of Controls methodology (e.g., [27]).		Designs prioritizing more effective hazard control (as in [27]) are preferred.

Table 3: Functional Objectives for any Design Concepts which take the IoT Approach to addressing the Value Proposition

	Objectives	Metrics	Constraints	Criteria
Functional Objectives: IoT Design Concepts will...				
FO-1	Collect data regarding key indicators of local wildland fire risk.	Collection of data relevant to assessing fire risk in a local area (e.g., factors which influence Fire Weather Index (FWI) [22]).	Must collect data relevant to assessing fire risk.	More distinct data type(s) are preferred.
FO-2	Communicate data to community members.	Availability of data to the user [uptime for communication].	Must communicate data.	Designs which enable on-demand communication are preferred.
FO-3	Promote understanding of wildland fire risk in a local area.	Consideration of principles of Universal Design for Learning (e.g. see [31]) to promote understanding.		Designs prioritizing UDL principles (as in [31]) are preferred.

Table 4: Performance Objectives for any Design Concepts which take the IoT Approach to addressing the Value Proposition, Part 1

	Objectives	Metrics	Constraints	Criteria
Performance Objectives: IoT Design Concepts should...				
PO-1	Provide information regarding a large coverage area.	Coverage area [km^2] over which accurate information is provided.		Larger coverage area is preferred.
PO-2	Provide information on multiple aspects of wildland fire risk.	Aspects of wildland fire risk addressed.		More aspects addressed is preferred.
PO-3	Be maintainable within the operational context.	Consideration of characteristics of maintainability such as Mean Time To Repair (MTTR), Health Status Monitoring (HSM), etc. [32].		More maintainable designs are preferred.
PO-4	Minimize use of materials consumed (e.g., fuel) during operation.	Consumption per day in use [g/day].		Less consumables used is preferred.

Table 5: Performance Objectives for any Design Concepts which take the IoT Approach to addressing the Value Proposition, Part 2

	Objectives	Metrics	Constraints	Criteria
Performance Objectives: IoT Design Concepts should...				
PO-5	Prevent environmental contamination during or after operation.	Volume of release of materials considered “Hazardous and Special Products” (HSPs) under O.Reg. 449/21 or related regulations [28] or “Batteries” under O.Reg. 30/20 or related regulations [29].	Must not release any HSPs or Batteries into the environment.	No release is permissible.
PO-6	Be easy to use.	Consideration of factors leading to users 1) understanding and 2) effectively handling the design (as in Chapter 3.7 of [30], for example)		User-facing elements of the design (if any) should clearly indicate how a user can/should interact with the design.
PO-7	Be safe for the user.	Mitigation of Hazards and Risks associated with operation following a Hierarchy of Controls methodology (e.g., [27]).		Designs prioritizing more effective hazard control (as in [27]) are preferred.

3 Opportunity Champions

Hassan Tahir

Hassan is an Engineering Science (Aerospace) 2T6+PEY student at the University of Toronto and a dedicated advocate for addressing global challenges through technological innovation. Having completed Praxis III last year, Hassan proposed the topic of wildfire mitigation and prevention as a vital design challenge after his interest was sparked by the devastating Khyber Pakhtunkhwa wildfires in Pakistan and the record-breaking North American/Australian bushfires of 2022.

As a 4-year Avionics Engineering member of the University of Toronto Aerospace Team’s UAS division, Hassan has worked on developing autonomous aircraft for wildland aerial firefighting missions as part of the SAE competition. Through this work, he has seen firsthand the potential of mechatronics and autonomous technologies to revolutionize wildfire prevention and response, which have the potential to save millions of hectares of land, human settlements, and ecosystems globally each year.

Hassan is driven by a commitment to sustainability and believes wildfire mitigation is a critical frontier in the fight against climate change. By championing this opportunity, he hopes to inspire innovative solutions that empower future engineers to address one of the world's most urgent environmental challenges.

Razim Refai

Razim is a Mechanical Engineer who works at FPInnovations, a not-for-profit research and development (R&D) company in the forestry sector. He is currently the Research Lead for the Wildfire Operations Research program that focuses on aviation, community protection, fire behaviour, wildfire detection, and equipment evaluation.

In early days of graduate school, Razim found that viewing wildfires from an engineering lens offered a non-traditional approach to problem-solving issues in wildfire operations. Fundamental engineering concepts of heat transfer, fluid dynamics, and product design all found real-world applications in the wildfire industry. With aviation in wildfires being the largest cost-driver in suppression operations, Razim chose to explore the effectiveness of aviation suppression chemicals as the topic of his graduate thesis. This approach soon stretched to other facets of wildfire operations that are now core pillars of research in the Wildfire Operations Research program.

Razim currently works with wildfire agencies across Canada, USA, and Australia to improve wildfire operations in the domains of preparedness, risk mitigation, response, and recovery. His goal is to ensure that research in this space has a meaningful impact on our efforts to live well with wildfires.

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