Requirements Specifications

Capstone PL-116

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Glossary

Dynamic Driving Task (DDT) This term encompasses all of the real-time operational and tactical functions required to operate a vehicle.

Extended Functional/Non-functional Requirement (EFR/ENFR) Given the broad scope of the PropBot initiative and the relevance of the requirements of the initiative to the narrowed scope of our project, functional and their non-functional requirement counterparts that are out of the scope of our contributions have been renamed to "extended" functional and non-functional requirements (abbr: EFR and ENFR).

National Highway Traffic Safety Administration (NHSTA) The National Highway Traffic Safety Administration is an agency of the U.S. federal government, part of the Department of Transportation.

Object and Event Detection and Response (OEDR) The action of detecting an object or event near the robot and responding accordingly. This specifically refers to the subtasks of the DDT that include monitoring the driving environment [1].

Operational Design Domain (ODD) Describes the operating domains in which the system is designed to function. ODD examples include speed range, lighting conditions, weather conditions, roadway types, etc. [1].

Operational Scenario The environment in which a feature is designed to function, and it is described by a set of ODDs [1].

Point Of Interest (POI) Specific location of interest. Within the context of path-planning, a POI is a waypoint that the path must include. Within the context of propagation data collection, a POI is the point where measurements are to occur.

1 Context and Background

The following document outlines the requirements, constraints, and operational conditions of the PropBot capstone project by Group 116. This project is being developed for the UBC Radio Science Lab (RSL) [2].

1.1 Background: UBC Radio Science Lab

The lab's current research is focused on next-generation wireless and radar systems with the intention of helping to transform numerous industries and systems, including but not limited to marine transportation systems, road safety systems, urban systems, the natural resources sector, and the national defence sector. Further, the UBC RSL values exploring how new technologies, like autonomous systems, can radically change the communications sector.

The UBC RSL requires extensive wireless data collection to facilitate their research endeavours. This involves an arduous and time consuming process of wheeling collection equipment on a cart and recording location data manually. There are currently no commercially available automated solutions specifically for wireless propagation measurement data collection. To address this unmet need, the UBC RSL is developing a six-wheeled autonomous robot, aptly named PropBot for "Propagation Robot".

1.2 PropBot: Propagation Robot

The final goal of the PropBot initiative is to qualify the PropBot as a Level 3 autonomous vehicle, as defined by the standards set by the Society of Automotive Engineers (SAE) [3]. Given this broad scope, the initiative is projected to be completed via multiple sequential capstones along with the continuous efforts of the UBC RSL.

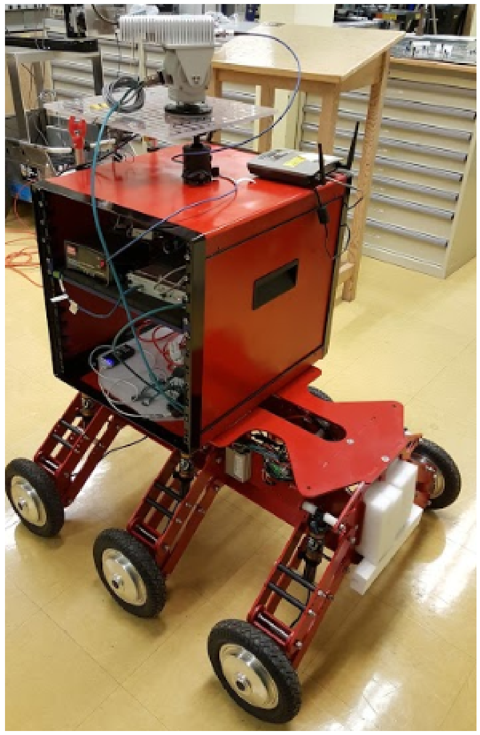

Figure 1.1: PropBot's current architecture

The final form of "PropBot" will be a fully teleoperable robot that is able to navigate through certain parts of campus autonomously, while recording highly accurate time-stamped location data to be used for research purposes. Achieving this will significantly reduce the time required for collecting propagation measurements. Further, this initiative serves as a basis for the UBC RSL to explore autonomous data collection capabilities. Specifically, PropBot's real-world driving validation methods include the use of the Aurora Connected Vehicles Testbed [4], a testing area funded by Transport Canada [5], the BC Ministry of Transportation and Infrastructure [6] and the Canada Foundation for Innovation [7]. The site was established with the purposes of advancing the use of wireless technology for freight security and efficiency and establishing best practices for use of wireless technology in Canada's Intelligent Transport Systems Architecture [8].

1.3 Our Contribution

As the first capstone involved in the PropBot initiative, our contributions will focus on the **development of an autonomy framework**, which includes the custom packages for localization, motion planning, motion control, and mission command. Along with the framework, a corresponding **autonomy sensor suite** has been selected. Finally, to facilitate future hardware improvements, we have selected **new electro-mechanical system components** to be integrated in the future.

2 Domain

PropBot falls under the domain of autonomous vehicles and mobile robots. It also falls under the domain of testing equipment for next generation wireless communication, e.g. 5G networks.

3 Goals

Traditional data collection for propagation measurements is a very lengthy and tedious process. Figure 3.1 is an example of a traditional collection session. Sessions differ greatly depending on the type of measurements, the number of points of interest (POI), the environment in which the measurements are being collected, and the proximity of the points of interest to each other. Often research campaigns involve collecting data for 9 hours a day.

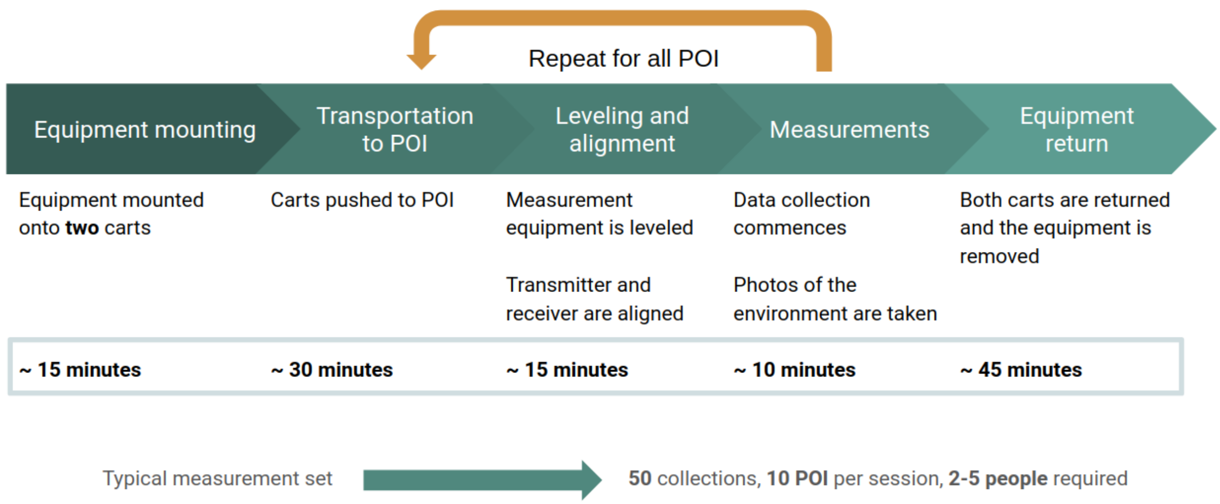

Figure 3.1: Example of traditional propagation measurement data collection

However, the repeatability of the various types of collections can be harnessed to improve the current system. Specifically, **the transportation to and from POIs**, **leveling and alignment**, and **environmental awareness**.

3.1 Goals of the PropBot Initiative

The goals of the PropBot initiative as a whole, to be achieved over multiple capstones and numerous contributions from members of the RSL, are that

- The PropBot shall help UBC RSL improve their efficiency of data collection.
- The PropBot shall help UBC RSL decrease the human power that each research requires.

characterized by

- A decrease in time required to transport equipment to/from POIs by 50%
- The limiting of the humanpower required to transport equipment to/from POIs to a maximum two people

- Improvements in environmental awareness by increasing position accuracy by 25% and providing a 3D scan of test locations

3.2 Project Goals

To optimize our contribution, the broad scope initiative was narrowed to focus on

1. Evaluating the legacy electro-mechanical system and proposing new system components.
2. Evaluating the legacy sensor suite and selecting a new autonomy sensor suite.
3. Developing an autonomy package so a robot will safely follow a programmed route throughout campus
4. Integrating sensors for situational awareness and position estimation that improve the robot's safety features.
5. Developing a vehicle interface firmware stack for interfacing with the drive system, the autonomy computer, and peripheral sensors.

4 Project Constraints

Below is an overview of the constraints of the entire initiative to develop PropBot. Although not every constraint directly affect the scope of our contributions, they were the motivating factors for the design decisions. Given the relevance, the initiative's constraints will not be separated from the project's constraints. The constraints that were addressed exist within the project requirements, each of which will be validated. The remaining requirements exist in the form of extended functional and non-functional requirements (EFR/ENFRs), which **will not be validated**.

4.1 Robot Constraints

Since this project is based on an existing product, some of the hardware components have already been decided. And according to our communication with our client, some of the components should be remained on the robot. Table 4.1 illustrates the constraints that the PropBot has due the legacy of previous process.

Tag	Constraint	Justification
C1.1	The current electronic power system (including the lithium ion batteries) must be used.	The current batteries constrain the length of the operation time depending on which power consuming modules are installed on the robot.
C1.2	Robot operates within UBC campus.	The purpose of the robot is to collect data with research equipment on campus.
C1.3	The onboard computer is limited to the already available computers including the NVIDIA Jetson TX1 and NVIDIA Jetson Nano.	These computers were already scoped and purchased for usage on this robot.
C1.4	The rack module (box-shaped body of robot that holds lab equipment) is removable and so sensors can be mounted on the structure.	The client expects to mount data collection equipment on the rack module, potentially replace it entirely, and may further extend its height in the future.
C1.5	The robot operates on near flat terrain with a maximum incline of $2°$.	The implementation of a mechanical brake system is out of our project scope.

Table 4.1: Robot constraints

4.2 Regulatory Constraints

According to the automated vehicle regulation promulgated by Transport Canada [9], the PropBot has the following regulatory constraints

Tag	Constraint	Justification
C2.1	The robot cannot enter any construction zones, or undeveloped paths (containing cones or gravel). [9]	There are many construction zones on campus that are blocked off for public entry.
C2.2	The robot cannot enter any parkades. [9]	There are many parkades on campus, and they are only designated for cars.

Table 4.2: Regulatory constraints

5 Functional and Non-functional Requirements

The following requirements are generated based on the process recommended by the National Highway Traffic Safety Administration (NHSTA) in Appendix B.

The scope of the whole initiative only involves operation in the red bounded region on UBC campus in Figure C.1. Additional operational design domains (ODDs) are described in Appendix C and referred to in the following requirement specifications.

This section elaborates all the functional requirements and non-functional requirements related to our contributions to the PropBot initiative. But, extended requirements are outlined in section 6.

It must be noted that any requirements related to driving scenarios apply **purely to simulation**. However, they remain directly applicable to real-world driving scenarios.

Table 5.1 illustrates how all of our requirements are related to the different categories of subsystems/considerations illustrated in Figure 5.1.

Tag	Safety	Robot Control	Localization	Mission Command	Motion Planning
F 1.1	✓	✓			✓
F 1.2	✓	✓			✓
F 1.3		✓	✓	✓	✓
NF 1.1		✓	✓	✓	✓
NF 1.2					
NF 1.3		✓	✓	✓	✓
F 2.1	✓		✓	✓	✓
F 2.2	✓		✓	✓	✓
NF 2.1	✓	✓			✓
F 3.1				✓	
NF 3.1			✓		
NF 3.2				✓	
F 4.1	✓			✓	
F 4.2	✓	✓		✓	
F 4.3				✓	
NF 4.1	✓	✓		✓	✓
F 5.1	✓	✓			
F 5.2	✓	✓			
F 5.3	✓	✓			
F 5.4	✓	✓			
F 5.5	✓	✓			
NF 5.1	✓	✓			

Table 5.1: Categorized requirements

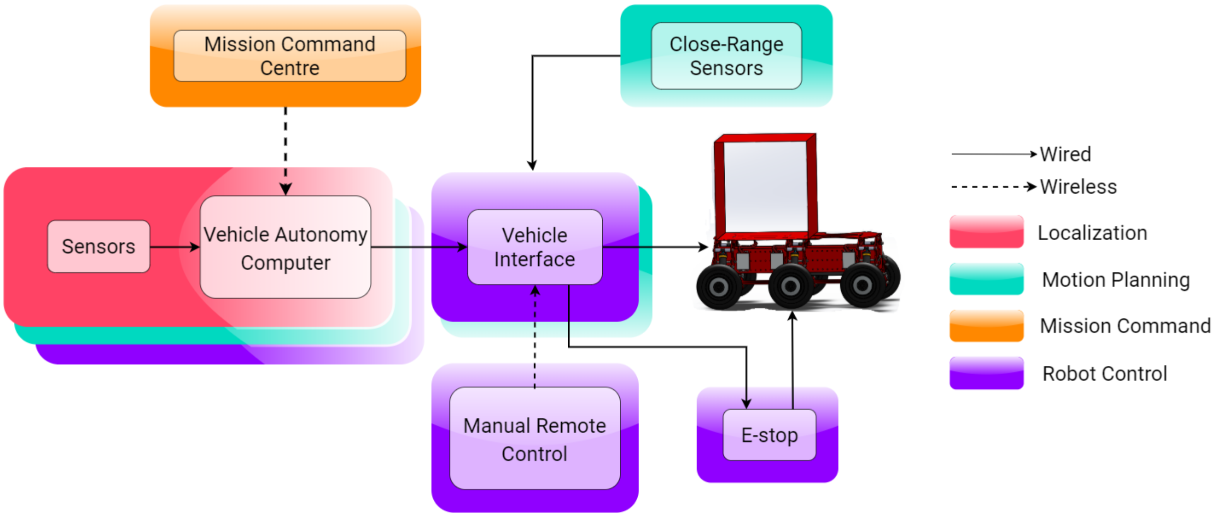

Figure 5.1: High-level system architecture

5.1 Driving Scenario Requirements

The driving scenario requirements outlined below apply **purely to simulation** in the context of our refined scope. However, these are directly applicable to real-world driving scenarios.

Tag	Functional Requirement	ODD	Test Tag
F 1.1.	Robot shall drive through user-generated waypoints on campus.	All	ST1.1
F 1.2.	Robot shall not collide with any obstacles along the route.	All	ST1.2
F 1.3.	Robot shall stop at predefined points of interest.	All	ST1.3

Table 5.2: Driving scenario functional requirements

Tag	Non Functional Requirement	ODD	Test Tag
NF 1.1.	Robot must create a path from user-generated waypoints that minimizes distance while not leaving approved operation zones.	O 2.3 O 2.4 O 6.1 O 6.2 O 6.3	ST2.2
NF 1.2.	Robot batteries must last for at least 1.5 hours during route navigation.	All	HT3.1
NF 1.3.	Robot must stop at predefined points of interest within 2m.	All	ST1.3

Table 5.3: Driving scenario non-functional requirements

5.2 Object and Event Detection and Response Requirements

As with the driving scenario requirements described in tables 5.2 and 5.3, the object and event detection and response requirements outlined below apply **purely to simulation** in the context of our refined scope. Again, these requirements can carry over to real-world driving scenarios.

The event responses discussed in the below tables are fairly general, but are described in further detail in Appendix D.

Tag	Functional Requirement	ODD	Test Tag
F 2.1.	Robot shall perform go-around maneuver when it detects the ODD static object in frontal zone.	O 3.1 O 3.6 O 3.8	ST2.1
F 2.2.	Robot shall stop if it cannot determine a feasible trajectory given the surrounding objects.	O3.*	ST2.3

Table 5.4: Robot event response functional requirements

Tag	Non Functional Requirement	ODD	Test Tag
NF 2.1.	Robot must maintain a safe minimum euclidean distance of at least 1m from objects at all times.	O3.*	ST1.4

Table 5.5: Robot event response non-functional requirements

Although not in the direct scope of our contributions, the requirement acted as a basis for our power budget and led us to all the decisions on the motor drivers, autonomy computer, and sensor suite.

5.3 Data Collection Requirements

As outlined by Transport Canada's standards for testing "Highly Automated Vehicles" in Canada, "[a]ll trial vehicles should have a data recording device that records technical information about the status and operation of the ADS." [9]. So for both research and regulator purposes, the robot is required to record position and status information.

> **Propagation Measurements vs PropBot Data Collection**
> It must be noted that the data collection referred to in the section relates to purely position and robot and mission status info. The propagation measurement equipment is considered out of the scope of the PropBot project as no interfacing will occur between the robot's systems and the measurement equipment.

Tag	Functional Requirement	ODD	Test Tag
F 3.1.	Robot shall record time-stamped position data.	All	ST1.5, HT5.1

Table 5.6: Data collection functional requirements

Tag	Non Functional Requirement	ODD	Test Tag
NF 3.1.	Robot must record position that is accurate to at least 0.5m	All	HT5.2
NF 3.2.	Robot must record time-stamped position data at 1Hz.	All	ST1.6, HT5.2

Table 5.7: Data collection non-functional requirements

5.4 Mission Command Centre Requirements

Although the core goal of the entire initiative is to achieve SAE level 3 autonomy [3], it is still necessary to have a long-range monitoring system to track the route progress and robot status.

To provide an accessible user experience, a mission command center is being integrated into our system. The back-end aggregates robot and mission status and presents it in the GUI. Further, the user will be able to plan routes using the interactive front-end waypoint setter.

The following are requirements for the system.

Tag	Functional Requirement	ODD	Test Tag
F 4.1.	Mission command centre shall receive operational status of the robot (location coordinates, and route progress)	All	ST3.1
F 4.2.	Mission command centre shall have the ability to start and stop robot mission at all times.	All	ST3.2
F 4.3.	Mission command shall communicate with the robot over a local network	All	ST1.7

Table 5.8: Mission command centre functional requirements

Tag	Non Functional Requirement	ODD	Test Tag
NF 4.1.	Speed commands must cease within 1 second of the assertion of "stop" on the mission command GUI	All	ST3.3

Table 5.9: Mission command centre non-functional requirements

5.5 Manual Control Requirements

To contribute to the goal of teleoperability, which will support the achievement of SAE level 3 autonomy (as it requires a fall-back to manual control [3]), the following requirements related to the manual control have been defined. Within the context of our contributions, the requirements apply to a placeholder device (a small RC car) as no outdoor testing of PropBot will occur during our timeline due to safety concerns related to the electro-mechanical system.

Tag	Functional Requirement	ODD	Test Tag
F 5.1.	The fallback ready user shall be able to kill power to the system via power-off switch on robot.	All	HT1.1
F 5.2.	The fallback ready user shall be able to command 0 speed to the robot via physical e-stop button on robot.	All	HT2.1
F 5.3.	The manual control device shall allow the user to independently control the robot's longitudinal sets of wheels.	All	HT2.2
F 5.4.	The manual control device shall allow the user to send 0 speed to the robot.	All	HT2.3
F 5.5.	The manual control device shall allow the user to switch between manual and autonomous driving modes.	All	HT2.5

Table 5.10: Manual control functional requirements

Tag	Functional Requirement	ODD	Test Tag
NF 5.1.	Any changes in the robot operation must execute within 1 second of the command assertion (e-stop, mode switch)	All	HT2.4

Table 5.11: Manual control non-functional requirements

6 Extended Functional and Non-functional Requirements

As mentioned in section 5, extended requirements have been defined which fall out of the scope of our contributions, but remain within the scope of the PropBot initiative as a whole. Their exclusion from the scope of our contributions indicates that they **will not be validated**.

Contrary to the requirements defined in section 5, any item associated with driving scenarios refers to its application exclusively in real-world situations, with some opportunity with integration into simulations.

Lastly, as with all the previously identified requirements, the generation was based on the process recommended by the National Highway Traffic Safety Administration (NHSTA) in Appendix B.

6.1 Extended Legal Requirements

Our contributions do not focus directly on the regulatory implications of the initiative, but future progress may focus on areas affected by legislation and regulations. Below is an outline of the legal requirements initially identified for PropBot when outdoor testing and usage occurs.

Tag	Functional Requirement	ODD
EF 1.1.	All trial vehicles shall have a data recording device that records technical information about the status and operation of the ADS. [9]	All
EF 1.2.	The robot shall be able to transit between automated and non-automated modes. [9]	All
EF 1.3.	The robot should also have a request to intervene function alerting the driver to perform the relevant fallback action in the event of the robot encountering an out of scope ODD or cannot plan a viable path. [9]	All
EF 1.4.	The automated vehicle shall have a mechanism to alert the driver of a robot failure. [9]	All
EF 1.5.	Robot shall provide clear and effective communication with other road-users. [9]	All

Table 6.1: Extended legal functional requirements

Tag	Non Functional Requirement	ODD
ENF 1.1.	Transition between automated and non-automated modes must be “safe”. [9].We define this transition from automated to non-automated mode to be within 0.5s.	All
ENF 1.2.	The request to intervene function alerting the driver to perform the DDT fallback must occur with sufficient warning time. [9] We define the sufficient warning time in this case to be 10x the average visual and auditory reaction time (0.514 - 0.524s), which is 5 seconds. [10]	All
ENF 1.3.	Robot shall alert pathway users within a 3m radius to be aware of its presence.	All

Table 6.2: Extended legal non-functional requirements

6.2 Extended Driving Scenario Requirements

The driving scenario requirements outlined below are applicable to real-word driving situations more than simulation.

Tag	Functional Requirement	ODD
EF 2.1.	Robot shall only drive in approved zones and not enter any off-limit zones. The ODDs for this requirement specify the zones.	O 2.3 O 2.4 O 6.1 O 6.2 O 6.3
EF 2.2.	Robot shall abide by all regulations of zones it traverses.	O 6.4

Table 6.3: Extended driving scenario functional requirements

6.3 Extended Object and Event Detection and Response Requirements

Tag	Functional Requirement	ODD
EF 3.1.	Robot shall return control to the fallback-ready user when approaching ODDs	O 3.7
EF 3.2.	Robot shall perform a go-around maneuver when it detects the ODD moving object travelling towards the robot’s frontal zone.	O 3.2 O 3.3 O 3.4 O 3.5
EF 3.3.	Robot shall perform follow object maneuver when it detects the ODD moving object travelling away from the robot’s frontal zone.	O 3.2 O 3.3 O 3.4 O 3.5

Table 6.4: Extended robot event response functional requirements

6.4 Extended Mission Command Requirements

Tag	Non Functional Requirement	ODD
ENF 4.1.	Mission command centre must send and receive information to the robot within a radius of 8km as constrained by C1.2.	All

Table 6.5: Extended mission command centre non-functional requirements

6.5 Extended Manual Control Requirements

Tag	Functional Requirement	ODD
EF 5.1.	The robot shall not collide with any static or non static obstacles in manual control mode.	All

Table 6.6: Extended manual control functional requirements

Appendix A Level of Automation

The following figure specifies the definition of SAE Level 3 autonomy.

Level	Name	Narrative Definition	DDT - Sustained lateral and longitudinal vehicle motion control	DDT - OEDR	DDT fallback	ODD
Driver performs part or all of the DDT						
0	No Driving Automation	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	*n/a*
1	Driver Assistance	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver and System*	*Driver*	*Driver*	*Limited*
2	Partial Driving Automation	The *sustained* and *ODD-specific* execution by a *driving automation system* of both the *lateral* or the *longitudinal vehicle motion control* subtask of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and supervises the *driving automation system*.	***System***	*Driver*	*Driver*	*Limited*
ADS ("System") performs the entire DDT (while engaged)						
3	Conditional Driving Automation	The *sustained* and *ODD-specific* performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user is receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle systems*, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	*Limited*
4	High Driving Automation	The *sustained* and *ODD-specific* performance by an **ADS** of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	*Limited*
5	Full Driving Automation	The *sustained* and unconditional (i.e., not *ODD-specific*) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	***Unlimited***

Figure A.1: Summary of the levels of automation [1]

Appendix B Specifications Generation Process

This document refers heavily National Highway Traffic Safety Administration (NHTSA)'s *"A Framework for Automated Driving System Testable Cases and Scenarios"* [1] and Transport Canada's (TC) *"Testing Highly Automated Vehicles in Canada: Guidelines for Trial Organizations"* to guide the specifications outlining process. A NHTSA suggested process is loosely followed.

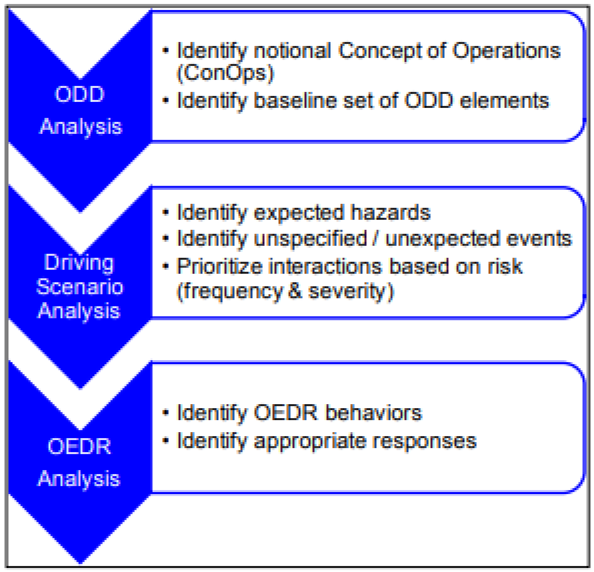

Figure B.1: OEDR capability identification process [1]

In order to specify the scope of this project, we first identify a set of ODDs that determine the DDTs that are maintained by the system, and the DDTs that will be maintained by the fallback ready user. Then, different sets of functional and non-functional requirements are generated based on these ODDs, constraints, and legal requirements.

The ODDs for this project are especially important, because TC states *"Specifying the ODD of the trail vehicle and confirming that the vehicle is able to perform all the necessary DDT within its ODD and will only be tested within its ODD"* [9].

Appendix C Operational Design Domains

The following operational design domains are based on the conditions of operations present within the UBC Campus Border.

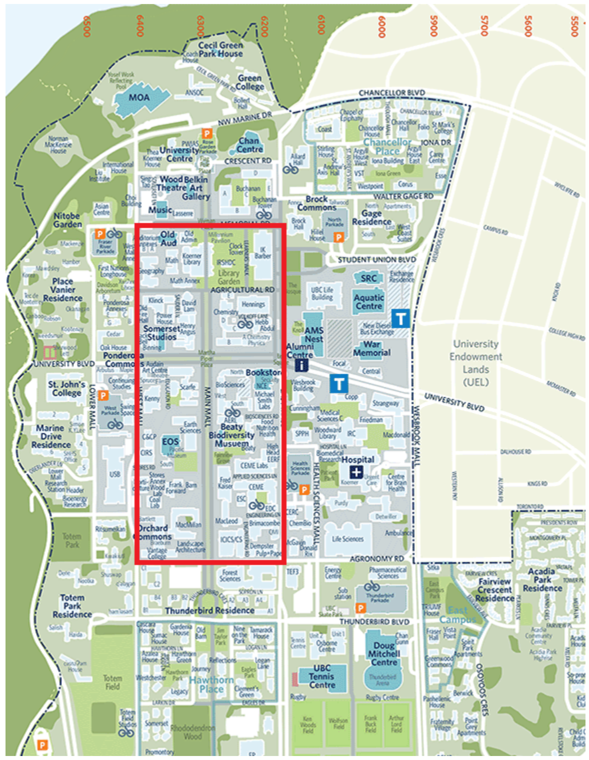

Figure C.1: PropBot's operation domain at UBC [11]

C.1 Physical Infrastructure

Physical infrastructure refers to structures present in operational areas. This includes roadways, bridges, tunnels, fountains, etc. [1]

The following ODDs relevant to physical infrastructure are declared by referring to a satellite image of UBC from Google Maps. Gravel roads, grating, and cones are not included due to C2.1.

The following categories are summarized by [1]:

- **Roadway Types**: Divided highway, undivided highway, arterial, urban, rural, parking, multi-lane, single lane, high-occupancy vehicle (HOV) lane, on/off ramps, emergency evacuation routes, one-way, turn-only lanes, private roads, reversible lanes, intersections (signaled, U Turns, 4-way/2-way stop, roundabout, merge lanes, turn-only lanes, crosswalk, toll, plaza, railroad crossing). **In addition, for the UBC campus context, we add sidewalks (pathways beside a single or multi-lane road), campus walking/bike paths to this definition.**
- **Roadway Edges**: Line markers, temporary line markers, shoulder (paved or gravel), shoulder (grass), concrete barriers, grating, rails, curb, cones.
- **Roadway Geometry**: Straightaways, curves, hills, lateral crests, corners (regular, blind corners), negative obstacles, lane width. **In addition, for the UBC campus context, we add diagonal pathways to this definition.**

There are multiple single and multi-lane roads on campus. However, due to O2.1, it is not feasible for the robot to drive on these roads.

Tag	ODD	Justification
O 1.1.	Parking Lot Test Area	This is the designated testing area for the robot.
O 1.2.	Sidewalk (pathways beside a single or multi-lane road)	The campus contains many sidewalks.
O 1.3.	On campus walking/bike paths	The campus contains walking/bike paths.
O 1.4.	Paths with grass shoulders	The campus contains grass shoulders.
O 1.5.	Straight roads	The campus contains straight roads.
O 1.6.	Corners	The campus contains corners.
O 1.7.	Diagonal pathways	The campus contains diagonal pathways.

Table C.1: Physical infrastructure ODDs

C.2 Operational Constraints

Operational constraints include dynamic changes in speed limits, traffic characteristics, construction, etc [1].

The following categories are summarized by [1]:

- **Speed Limit**: Minimum and maximum speed limit (absolute, relative to speed limit, relative to surrounding traffic).
- **Traffic Conditions**: Minimal traffic, normal traffic, bumper-to-bumper/rush-hour traffic, altered (accident, emergency vehicle, construction, closed road, special event). For campus purposes, we add minimal foot traffic, normal foot traffic, and rush-hour foot traffic.

Tag	ODD	Justification
O 2.1.	Speed Limit: 10km/h	As this robot is in initial stages, the speed is limited to 10km/h to ensure the safety of robot and other road users.This speed will allow for the robot user to achieve a small stopping distance during manual control, and easily hit the onboard E-stop if needed.
O 2.2.	Traffic Density: Minimal	Foot and bike traffic on the campus will likely be at a minimum before 8am, after 7:30pm due to class start and end times. In addition, foot traffic will likely be low in between class blocks (every 30 minutes).
O 2.3.	Construction zone	The campus contains many construction zones and nearby areas with cones/gravel roads.
O 2.4.	Closed roads and special events	There are often closed roads and special events on campus.

Table C.2: Operational constraints

C.3 Objects

In order for the robot to behave as intended, it must be capable of OEDR for relevant objects.

The following categories are summarized by [1]:

- **Signage**: Signs (e.g., stop, yield, pedestrian, railroad, school zone, etc.), traffic signals (flashing, school zone, fire department zone, etc.), crosswalks, railroad crossing, stopped buses, construction signage, first responder signals, distress signals, roadway user signals, hand signals.
- **Roadway Users**: Vehicle types (cars, light trucks, large trucks, buses, motorcycles, wide-load, emergency vehicles, construction equipment, horse-drawn carriages/buggies), stopped vehicles, moving vehicles (manual, autonomous), pedestrians, cyclists.
- **Non-Roadway User Obstacles**: Animals (e.g., dogs, deer, etc.), shopping carts, debris (e.g., pieces of tires, trash, ladders), construction equipment, pedestrians, cyclists. In the campus context, these objects also apply to **Pathway User Obstacles**.

Due to O1 only including sidewalks and pathways, we can omit signs that are found on roads. In addition, moving vehicles do not need to be considered unless they are at points of crossing, as the robot will not be driving on the road.

Tag	ODD	Justification
O 3.1.	Parked vehicles	The robot drives on sidewalks and needs to exit off of and enter onto sidewalks while performing street crossings. Thus, the robot encounters parked vehicles.
O 3.2.	Pedestrians	The campus contains pedestrians on walking paths and street crossings.
O 3.3.	Dogs	The campus contains dogs on walking paths and street crossings.
O 3.4.	Cyclists	The campus contains cyclists on walking paths and street crossings.
O 3.5.	Skateboarders	The campus contains skateboarders on walking paths and street crossings.
O 3.6.	Construction Equipment	The campus sometimes contains construction equipment on walking paths and street crossings.
O 3.7.	Crosswalks and crossing points	The campus contains crosswalks and crossing points on single and multi-lane roads.
O 3.8.	Static structure	The campus contains many static structures such as fountains, statues, etc.

Table C.3: Object definitions

C.4 Environmental Conditions

Environmental conditions play an important role in the safe operation of the robot. They can affect the robot's maneuverability, its wheel friction, and increase crash risk.

The following categories are summarized by [1]:

- **Weather**: Wind, rain, snow, sleet, temperature
- **Weather-induced Roadway Conditions**:Standing water, flooded roadways, icy roads, snow on road
- **Particulate Matter**:Fog, smoke, smog, dust/dirt, mud
- **Illumination**:Day, dawn, dusk, night, street lights

Tag	ODD	Justification
O 4.1.	Light rain during daytime hours (1 hour after sunrise to 1 hour before sunset)	Vancouver has a long-term rainy season each year. Only light rain is included because during development, the perception system will not be robust enough for OEDR in non-clear weather conditions. In addition, there is no mechanism to shield the lab equipment from heavy rain.
O 4.2.	Normal weather (sunny, cloudy) during daytime hours (1 hour after sunrise to 1 hour before sunset)	In Vancouver, besides rainy days, most days are either sunny or cloudy. This is the ideal environment for developing initial OEDR capabilities of the robot.

Table C.4: Environmental conditions

C.5 Connectivity Conditions

Connectivity and automation are increasingly being integrated into vehicles with the objective of improving safety, mobility, and providing a better driving experience. As such, connectivity may define where and how well ADS features can operate. [1]:

The following connectivity categories are summarized by [1]:

- **Vehicles**: vehicle to vehicle communication, WiFi, DSRC
- **Traffic density information**:crowdfunded (e.b. Google Maps and Waze) and vehicle-to-interface
- **Remote fleet management system**:remote operation centers
- **Infrastructure sensors and communications**:work zone alerts, incident reporting management, GPS, 3-D high-definition maps, pothole locations, weather data, data on the cloud, etc.

Tag	ODD	Justification
O 5.1.	Access to static maps from Mission command centre	These maps would provide a layout of campus, and pre-marked construction areas.
O 5.2.	GPS signal	Most areas on campus have GPS access.

Table C.5: Connectivity conditions

C.6 Zones

OEDR capabilities of the robot may be limited or inhibited spatially by zones. Differ from typical conditions

The following zone categories are summarized by [1]:

- **Geo-fencing**:central business districts, school campuses, and retirement communities. For example, the speed limit in B.C. cities is 50km/h.closure
- **Traffic Management Zones**:may include temporary lane closures, dynamic traffic signs, variable speed limits, temporary or non-existent lane markings, human-directed traffic, loading/unloading zones
- **School/Construction Zones**:Dynamic speed limit, erratic pedestrian and vehicular behaviors
- **Regions/States**: any legal, regulatory, enforcement, tort, or other considerations (e.g., following distance, licensing, etc.)
- **Interference Zones**:tunnels, parking garages, dense foliage, limited GPS due to tall buildings, atmospheric conditions

Tag	ODD	Justification
O 6.1.	School campus geo-fence	The robot will be driving around the campus and the school campus will have a geo-fence.
O 6.2.	Construction zones	The campus has a large presence of construction sites is expected. These zones can affect sidewalk and crosswalk areas where the robot may travel, and maps with geofences with these construction zones can be generated.
O 6.3.	Parking zones	The campus has many parking zones and entries, and these can be geo-fenced.
O 6.4.	Regulatory zones	The robot must abide by all regulations of the zones it traverses.
O 6.5.	Interference zone	Some buildings on campus are fairly tall and could affect the integrity of GPS data.

Table C.6: Zone definitions

Appendix D Robot Object and Event Responses

The ODDs identified important objects and events that the robot could encounter within its operating conditions. The diagram below describes how these objects and events will be described when in the vicinity of the robot.

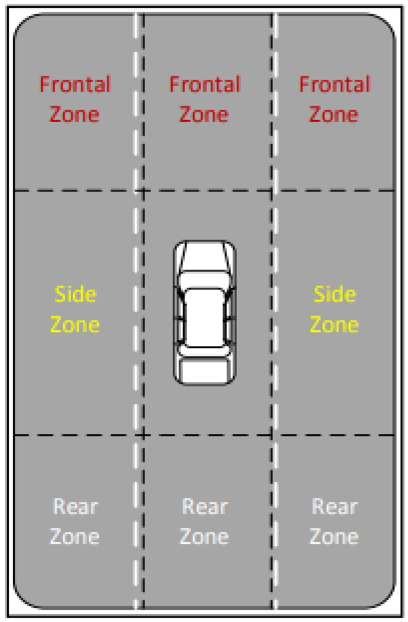

Figure D.1: Detection zones [1]

The summary of L3 traffic jam roadway user events and L3 traffic jam non-roadway user events drive the following OEDR requirements [1].

These are the following relevant response actions defined by [1]:

- **Follow object**:Implement later and/or longitudinal control actions to maintain a safe following distance from an immediate lead object. This safe distance is as defined by **NF3.1**.
- **Decelerate**:Implement longitudinal control actions to decrease speed.
- **Stop**:Implement longitudinal control actions to decelerate in a safe and stable manner to a complete stop.
- **Return control to fallback-ready user (Manual Control)**: Return longitudinal and lateral control to human occupant/driver (while providing sufficient warning), as defined by **NF1.1**.

In addition to these actions, we add:

- **Go-around maneuver**:Implement longitudinal and latitude control actions to go around object with a safe minimum distance, as defined by **NF3.1**, if feasible

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