Tallinn University of Technology
School of Information Technologies
Department of Computer Systems

IAF0320 Computer Systems Engineering

Course Project Report

for a system entitled:

AUTONOMOUS UNMANNED GROUND VEHICLE

Team number:	**1**	**Date started:**	**Date ended:**
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EVALUATION	**Max points**	**Points**
Project implementation and report	25	
Presentation	10	
Prototype	5	

Tallinn 2017

1 Purpose of the document

The purpose of this document is to provide an overview of the concept development stage of an **Autonomous Unmanned Ground Vehicle System (AUGV)**. This AUGV system is primarily designed for military use. However, it can also be appropriated for domestic law enforcement use as well. Topics covered include: stakeholder, needs and requirements analysis, context exploration, suggested design aspects, development, testing, maintenance descriptions and costs and also risk assessment.

2 General project description

Autonomous Unmanned Ground Vehicle (AUGV) for military applications – small, ½ or ¾ of an ordinary car sized tracked or wheeled electric vehicle able to navigate autonomously in combat situations during which it able to provide fire support using RWS (remote weapon system) and/or carrying equipment and ammunition for the troops.

Similar systems already exist today but they have limitations in operation. For example, nearly all the UGVs used today are manually controlled, are not self-aware of the combat situation and mostly they use internal combustion engines which are problematic in extreme temperature situations.

This project aims to address all the aforementioned issues to provide more cost-effective and functionally superior system compared to existing ones. A rendering of the proposed system prototype is depicted on the following figure.

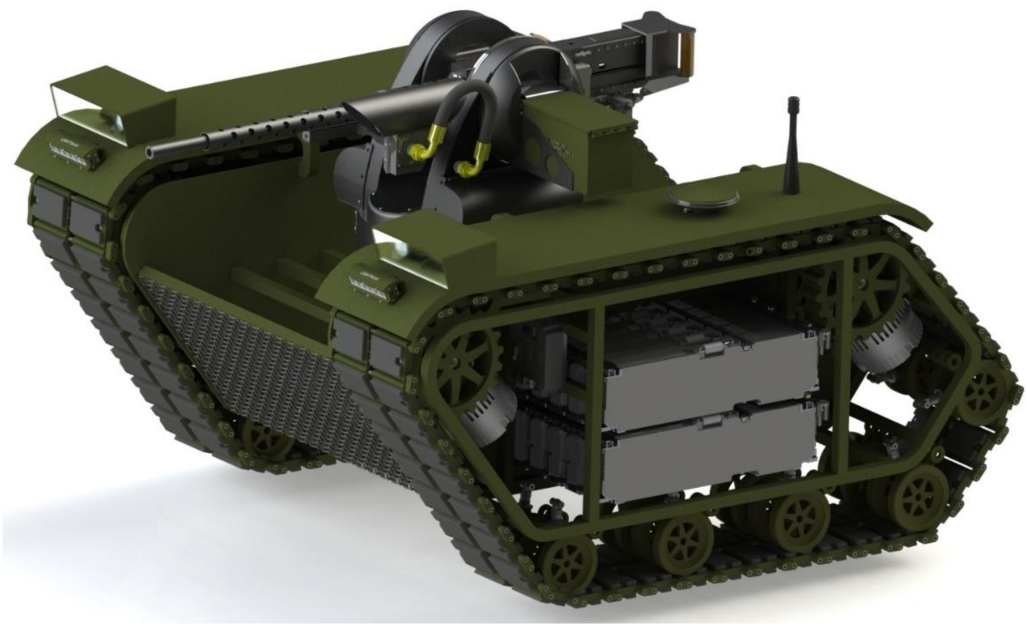


Figure 1. Rendering of the prototype

3 System stakeholders and motivation for the system

The following section lists all the identified stakeholders who can be affected by the decisions made during the course of the project. An ordered list (by priority) is provided in the tables below.

Stakeholder	Describe involvement	Describe influence	Describe contributions	Internal or external (I or E)
Military ground command	Also users of the system.	Great influence, if the system does not meet the requirements, it will not be used.	Define machine specifications (Parameters, requirements, operation principles).	E
Project team	Organization and maintenance of the project flow.	Great influence, project team’s decisions eventually lead to the failure or success of system.	Make decisions regarding the system development.	I
Media Outlets	Influencing the public opinion.	Medium influence, can slow the project, unlikely to have it shut down.	Can influence public opinion, which can itself affect the project.	E
Military communication unit	Influence development of communications and navigation system.	Medium influence. They are responsible of providing the communications and navigation system with the specifications needed to connect the project to their communication network.	Provide the specifications needed for the project to integrate in their communication networks. May also provide design of the communication system.	E

Company board of directors	Take important decisions regarding the system so that company would benefit as much from the project as possible.	Great influence as they will make high level decisions on project direction.	High level decisions on project flow. Can shut the project down.	I
Investors	Provide funding.	Major influence as they provide the means to put the project on tracks.	Have power to shut down the entire project.	E
Government	Indirect users of the system. Takes the heat if the system should find any opposition nationwide.	Great influence, provide regulations regarding arms production and trade within the country. Also is the main source of income for the military.	Regulations, laws and constitution provide the limits to arms production, trade and use. Provide funding to military.	E
Competitors (Milrem)	They want to complete a better product faster than us and get most of the market share.	Great influence: Limited market share and our product should be improved in areas our competitors are lacking.	Might undermine our system development. Increase our quality requirements and time constraints.	E
Suppliers	Provide components, parts, etc.	High influence, as it is difficult find suitable ones (can comply with higher military standards).	Can slow the project down by forcing us to find new suppliers.	E
Engineering Department	Provide technical/organizational support.	Limited influence as uncooperative employees can be replaced in this field.	Can slow down the project by forcing us to find a new team.	I

Manufacturers of the system and compatible systems	Produce different parts and the final product and influence system design.	Limited influence, as contracts with different manufacturers could be signed. Their design decisions will have small influence on the system.	Produce parts according to the required specifications.	E
System Engineers	Design and oversee the system development.	Very high influence. Responsible to oversee the development of the project as a whole and coordinate between the different engineers and management of the project.	Make important decisions regarding the system as a whole. They are also responsible of integrating the different systems together as well as oversee the progress of the different systems and make sure they work together flawlessly.	I
Military support units	They are going to be the users of the system.	Medium, the system has to meet their requirements.	Provide requirements regarding operation, maintenance and logistics.	E
Mechanical Engineers	Design structure and mobility systems.	Limited influence, as ineffective employees can be replaced.	Provide mechanical specifications for a balanced performance.	I
Electrical Engineers	Design the electrical system.	High influence. They are responsible for designing the whole electrical system which has a significant impact on the overall efficiency of the project.	Make important decisions regarding the electrical system in the project. Help impact other systems within the project scope.	I
Materials engineers	Choosing the best materials.	Without proper materials the AUGV wouldn’t meet system requirements.	Their output to the project would be proper material selection for the AUGV.	I

Programmers	Software development.	Great influence as this team is the only one capable of producing the AI we're looking for.	Can shut down the project, or dramatically slow it down as finding a replacing team seems hard.	I
Military Ground Personnel (Soldiers, medics, drivers)	Direct users of the system.	Limited influence, as most of them will not interact directly with the vehicle.	Cooperate with the machine to get the best results.	E
Softbank(Tech development company)	Company's recent history shows interest in military markets (bought Boston Dynamics). Most likely would be interested in buying the company if development shows success.	Limited influence, currently no signs of developing a competing product.	Might undermine our system. Potentially would alter project requirements and influence time constraints if they'd be developing a competing solution.	E
Electric network operators	They would like to get profit from developing necessary grid access to charge the AUGVs.	Medium influence. Without their cooperation they would hinder our ability to deploy the system.	They would provide necessary grid capability to strategic locations (test fields, military bases).	E
Environmentalist organizations	Influence public opinion.	Their influence on public opinion affects how willingly government would support developing such a system.	The most they can do is influence some of the product requirements. Or affect where production could be set up.	E

Stakeholder	Interests	Estimated influence	Estimated importance	Priority	Assumptions and Risks
Military ground command	Reduce the number of combat casualties.	High	High	1	Supportive, gives them advantage over opposing army. Reduces combat casualties.
Project team	Succeed with the project and be rewarded accordingly.	High	High	1	Supportive, want to make the project a success.
Media Outlets	Mostly moral interest, gain recognition.	Medium	Low	1	Opposing, as they might turn public opinion against the project.
Military communication unit	Establish a standardized network of communication for military use only network of communication.	Medium	High	1	The assumption is that they will provide the necessary requirements for integrating the system in their communication network. Risk is inability to provide adequate information and high level of secrecy.
Company board of directors	Succeed with the project and be rewarded accordingly.	High	High	1	Most definitely supportive, would like to see the project succeed. Risk would be that they'd shut down the project when major difficulties arise.
Investors	Financial interest, get a return on their investments.	High	High	1	Supportive, they need the project to be successful in order to get interests.

Government	Obtain advanced technologies for its army.	High	Medium	2	Supportive, wants to get advantage over other armies. May be influenced by public opinion and therefore cancel/oppose the project.
Competitors(Mi lrem)	Better and faster development of their system. Sale contracts.	High	High	2	Opposing, as they want to get the contracts and market to themselves.
Suppliers	Financial interest, sell as much parts as possible.	Medium	Medium	2	Supportive as the more we sell the more they are paid.
Engineering Department	Find the right mechanical parts.	Low	Low	2	Supportive, it is their job to make the project succeed.
Manufacturers of the system and compatible systems	Sign contracts to profit from manufacturing products. Work closely with other engineers to ensure all parts and system are integrated as planned.	Low	Medium	2	Assumption is that the parts will be manufactured according to the specifications. Risk is that they will fail to deliver the desired product.
System Engineers	Design and oversee the development of the system as a whole.	High	High	2	The assumption is that systems engineers are competent to carry out the design and implementation of the system. Risk is failure to meet deadlines and inability to design a successful system.

Military support units	Safer gear transportation. Reduced number of casualties.	Low	High	3	Supportive, as the product would make their work safer and easier.
Mechanical Engineers	Meet the mechanical part of the system requirements.	Low	Medium	3	Assumption is that they will design the best possible mechanical parts with the available resources. Risk is that they will not meet system requirements and deadlines.
Electrical Engineers	Design electric networks and systems and develop current systems.	Medium	Medium	3	The assumption is that electronic engineers will be able to successfully design the electric system. Risk is failure to meet the requirements and lack of motivation.
Materials engineers	Select the best materials available for given budget and constraints.	Medium	High	3	Assumption is that they'd be motivated to select the best materials available.
Programmers	Develop an appropriate AI.	High	High	4	Supportive, they can gain recognition from their work[2] [SMPC3] . Risk is lack of motivation and lack of skills needed to finish the AI.
Military Ground Personnel (Soldiers, medics, drivers)	Support the current military operation.	Low	Low	4	Assumption is that they will cooperate and accept the role of the vehicle. Risk is that some people might be against working with advanced technology side by side.

Softbank(Tech development company)	Buying the company when solution is shown to be promising.	Low	Medium	4	Current assumption is that they are not developing a competing system, risk as we do not know for sure.
Electric network operators	Develop electric grid and earn profit.	Medium	Medium	4	They'd most probably co-operate. Risk that they might want to charge premium as this work would be for military.
Environmentalist organizations	Make sure that environmental impact of the project is low.	Low	Low	5	Assumption is that they wouldn't hinder the project. Might become risk when problematic or dangerous materials are used or when chosen production locations would affect the environment.

4 System concept introduction

The concept of the project is an Autonomous unmanned ground vehicle (AUGV). Its main purpose is to follow and/or support troops both in firepower and/or logistics. To do so it must be equipped with weapons and be able to carry supplies. It must be able to behave on its own in a certain number of predefined use-cases. It also needs to allow an operator to take over and pilot it.

To do so, the AI must be elaborate enough to resolve common issues on its own and to identify whether it's appropriate to request a command handover to an operator. It must be all-terrain, able to emulate human speed and its batteries have to last enough time to allow it to work during a whole operation. It must have an armour adequate to the kind of missions it's going to be used in. Finally, maintenance time and frequency have to fit in the military vehicle average, and use as much standard parts as possible.

There are no comparable system currently on the market, the AUGV we are designing is candidate in a race to achieve an A.I. guided machine. Getting approved first by the NATO or another powerful organization would allow it to become the gold standard and become adopted by a lot of forces. If it succeed to do so, the next logical step is to adapt it to serve in other cases, e.g.: domestic law enforcement.

5 System context

The following figure illustrates the context diagram for the proposed autonomous unmanned ground vehicle. It describes how the external entities will interact with the system. In addition, a description of the external entities is provided in the table following the figure.

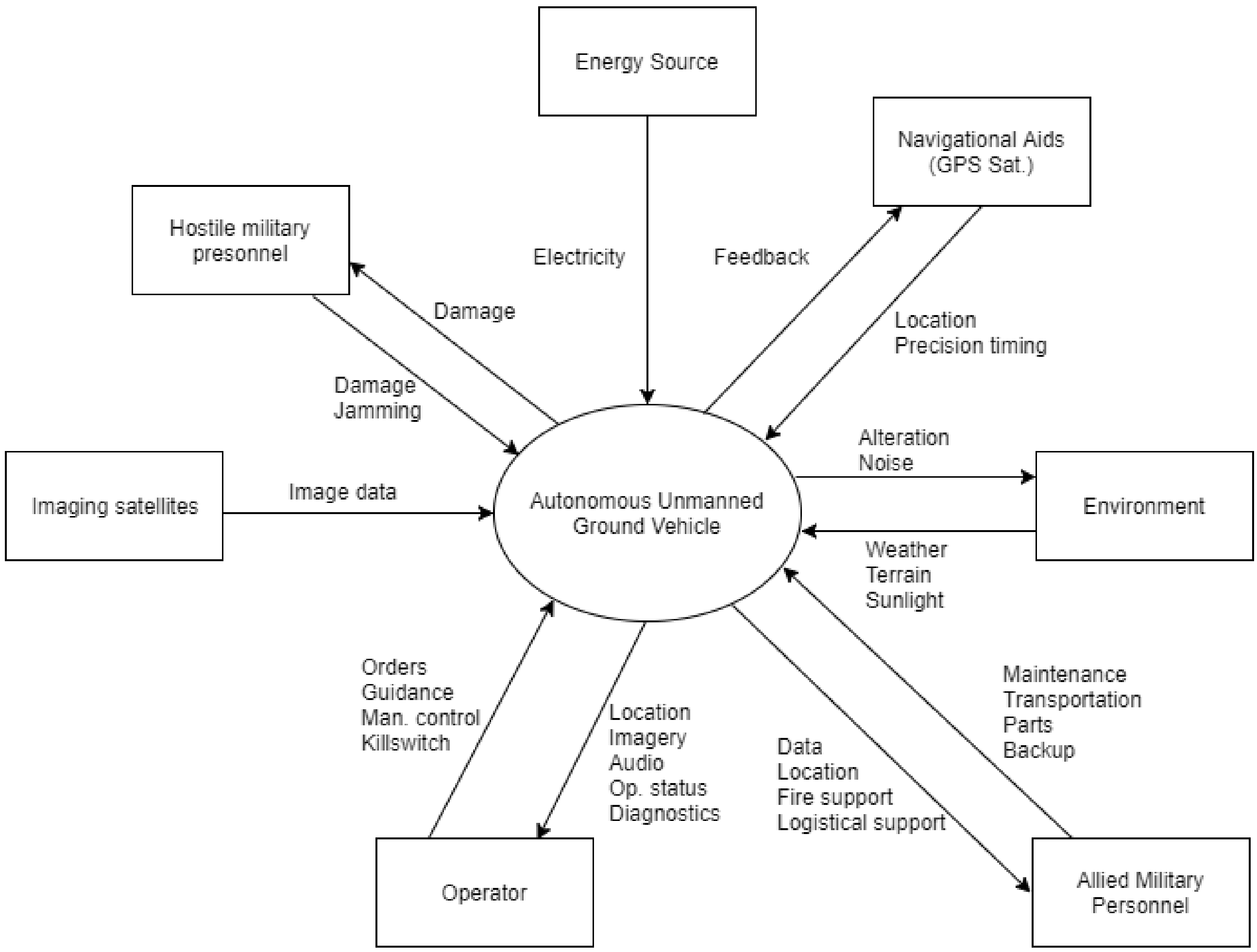


Figure 2. System context diagram

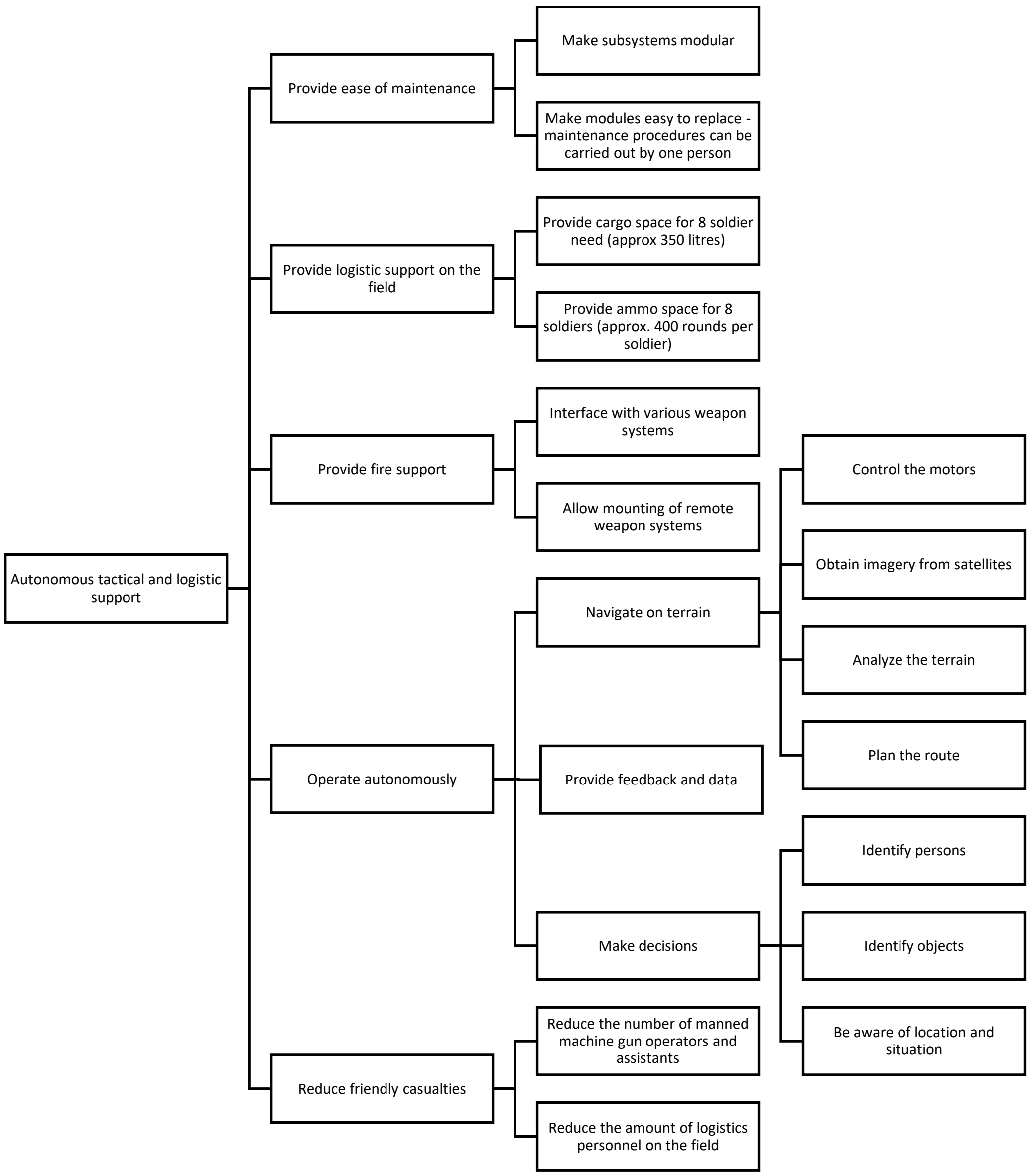
External entity	Description
Operator	Operator who is responsible for giving tasks to the UGV and helping it to solve complicated situations
Imaging satellites	Provides up to date, high resolution satellite images to aid the UGV onboard navigation system
Hostile military personnel	
Energy source	Batteries that provide all the necessary energy for the UGV
Navigational aids	Aids such as GPS satellites, GPS base stations etc. that help the system to navigate more accurately
Environment	
Allied military personnel	Users and maintainers of the system (troops on the field, logistics personnel, mechanics, etc.)

6 Needs analysis

The mission of the developed system is to provide fire and logistics support for the military. The mission can be decomposed into sub-missions as follows:

- Firstly, it must provide fire support for the troops as one of today's deficiencies in combat is still the need for manned machineguns. Gunner and the assistant are vulnerable as they need to be in one place for prolonged periods of time, or when in movement they are slow and easy targets for the enemy.
- Secondly the system must carry equipment for the troops. The purpose of it, is to reduce the amount of equipment needed to carry by soldiers in order to improve their mobility and it would help them to direct their energy towards accomplishing the tasks at hand instead of carrying heavy bags.

Those missions serve the main purpose of the system: reduction of human casualties and making the troops work more effective by reducing the amount of equipment needed to carry.



7 Requirements analysis

The main functional requirements for the proposed autonomous AUGV system are the following:

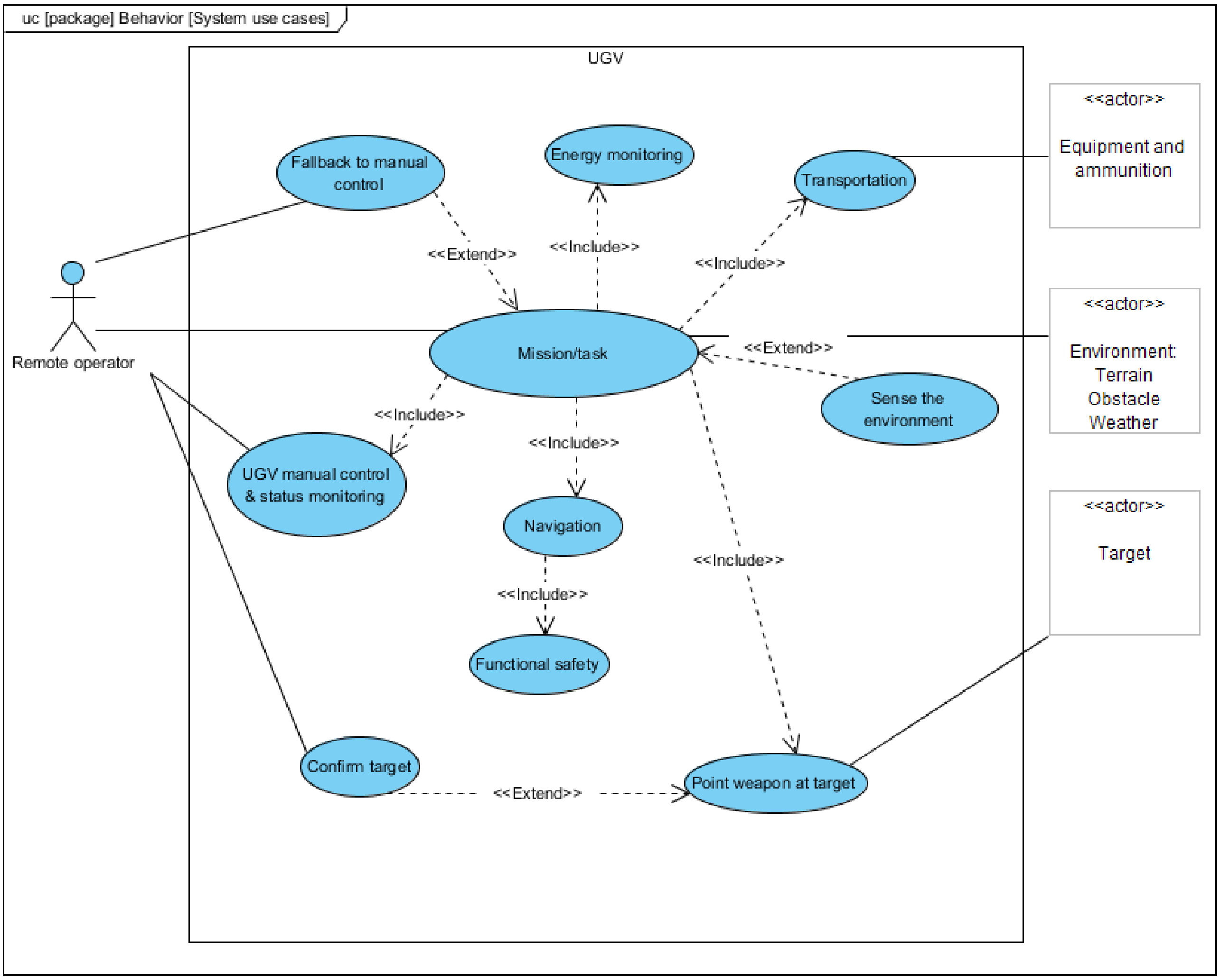
1. The AUGV must be able to navigate autonomously in unfamiliar territory with the aid of onboard sensors.
2. The AUGV shall be equipped with a manual system abort that stops all programmed operations.
3. The AUGV shall use electric motors and batteries for mobility.
4. The AUGV shall be capable of conducting operations by either autonomously or with remote control using line-of-sight (**LOS**) or non-LOS (**NLOS**) communications.
5. The AUGV shall communicate with its Respective Ground Stations (**GCS**).
6. The AUGV shall have appropriate interfaces to interact with attached Remote Weapon Station (**RWS**).
7. The AUGV shall be capable of neutralizing enemy targets both autonomously and remotely.
8. The AUGV shall be designed to be easily transported and deployed.
9. Must support the following missions: intelligence, direct and indirect fire support, attack of moving targets.
10. AUGV must be capable of operating in Biological/Chemical (**BC**) contaminated environments.
11. The AUGV should be able to carry sufficient cargo for 8 soldiers.

The use cases with descriptions are the following:

Use case	**Description**
Mission/task	This use case deals with the main mission/task the AUGV is supposed to accomplish.
Navigation	This use case deals with the navigation of the AUGV (both local and global navigation).
Transportation	This use case deals with the transportation of equipment and ammunition for the troops.
Sense the environment	This use case deals with the sensing of the environment around the vehicle.
Point weapon at target	This use case deals with the target identification and remote weapon system control.
Fallback to manual control	This use case deals with the situation when the AUGV is unable to determine what it should to and the decision making is handed over to human operator.
AUGV manual control & monitoring	This use case deals with the manual control by the remote operator and vehicle status monitoring and transmitting to the remote operator.
Energy monitoring	This use case deals with the power consumption optimization /monitoring for the AUGV (optimizing travel path to minimize energy consumption, mission abortion in case of stored energy becomes too low in order to travel back to base).
Confirm target	This use case deals with the situation when the AUGV asks for confirmation of the target (i.e the AUGV is unable to determine whether the target is valid or not).

Functional safety	This use case deals with the functional safety of the AUGV : action in case of the, physical emergency button / remote kill switch , activation.

The use cases are depicted in the following diagram:



In the following tables more detailed specifications for each use case is provided.

Use case	Mission/task
Description	This use case deals with the main mission/task the AUGV is supposed to accomplish
Primary actor	Operator
Supporting actors	Equipment and ammunition Environment Target
Preconditions	UGV is in operational condition
Guarantees	Required mission/task defined by operator is executed successfully
Trigger	Operator command
Main success scenario	UGV navigates to the specified location (commanded by remote operator) while avoiding obstacles
Extensions	Fall-back to manual control Sense the environment

Use case	Navigation
Description	This use case deals with the sensing of the environment around the vehicle
Primary actor	-
Supporting actors	Environment
Preconditions	-
Guarantees	UGV at required location
Trigger	UGV not at required location
Main success scenario	UGV navigates to the specified location (commanded by remote operator) while avoiding obstacles
Extensions	-

Use case	Transportation
Description	This use case deals with the transportation of equipment and ammunition for the troops
Primary actor	
Supporting actors	Equipment and ammunition
Preconditions	-
Guarantees	Required equipment and ammo transported to the troops at specified location
Trigger	
Main success scenario	UGV navigates to the specified location (commanded by remote operator) while avoiding obstacles
Extensions	

Use case	Sense the environment
Description	This use case deals with the sensing of the environment around the vehicle
Primary actor	-
Supporting actors	Environment
Preconditions	Most of the sensors are working
Guarantees	Data about the environment
Trigger	-
Main success scenario	UGV has sufficient information to traverse the terrain safely
Extensions	-

Use case	Point weapon at target
Description	This use case deals with the target identification and remote weapon system control.
Primary actor	-
Supporting actors	Target
Preconditions	-
Guarantees	UGV has commanded the gun turret to move to correct position
Trigger	Possible list of targets identified
Main success scenario	When the UGV has identified a list of potential targets, it notifies the operator who makes the decision onto which target to point the weapon.
Extensions	-

Use case	Fallback to manual control
Description	This use case deals with the situation when the AUGV is unable to determine what it

	should to and the decision making is handed over to human operator.
Primary actor	Operator
Supporting actors	-
Preconditions	UGV has identified possible targets
Guarantees	Complicated situation resolved by operator
Trigger	The AI in the UGV identifies a situation it cannot resolve by itself
Main success scenario	UGV recognizes a situation where it cannot make a decision. It notifies the remote operator who assesses the situation and makes the decision for the UGV. After that the UGV can continue its normal operation.
Extensions	-

Use case	AUGV manual control and monitoring
Description	This use case deals with the manual control by the remote operator and vehicle status monitoring and transmitting to the remote operator.
Primary actor	Operator
Supporting actors	-
Preconditions	UGV has enough energy to complete a movement UGV in communication range of the ground control statrion
Guarantees	UGV at required location, all relevant data transmitted to operator
Trigger	-
Main success scenario	UGV movements are directly commanded by the remote operator.
Extensions	-

Use case	Energy monitoring
Description	This use case deals with the power consumption optimization /monitoring for the AUGV (optimizing travel path to minimize energy consumption, mission abortion in case of stored energy becomes too low in order to travel back to base).
Primary actor	-
Supporting actors	-
Preconditions	-
Guarantees	Guarantees that the UGV can return to base
Trigger	-
Main success scenario	UGV during its task constantly evaluates the energy left in the batteries, makes corrections to route in order to minimize the energy consumption. Aborts the mission/task if not enough energy to return to base.
Extensions	-

Use case	Confirm target
Description	This use case deals with the situation when the AUGV asks for confirmation of the target (i.e. the AUGV is unable to determine whether the target is valid or not).
Primary actor	Operator
Supporting actors	Target
Preconditions	Amount of ammunition is not zero
Guarantees	Correct target will be eliminated
Trigger	Weapon pointed at the target
Main success scenario	When the weapon has been pointed at the target then the remote operator is notified. The remote operator decides whether to fire or not. After the decision in either case UGV continues to execute its main task.

Extensions	Point weapon at target

Use case	Functional safety
Description	This use case deals with the functional safety of the AUGV
Primary actor	-
Supporting actors	-
Preconditions	-
Guarantees	Safe operation of the vehicle when people are in near vicinity
Trigger	-
Main success scenario	In case of emergency button press by a person near the UGV, the UGV stops its movements and notifies the operator of the situation. Operator assesses the situation via video feeds and decides when the operation can be resumed.
Extensions	-

8 Suggested system design

In the following chapters the overall system design is presented.

8.1 System Functional Block Diagram

Functional Building blocks

Input functions:

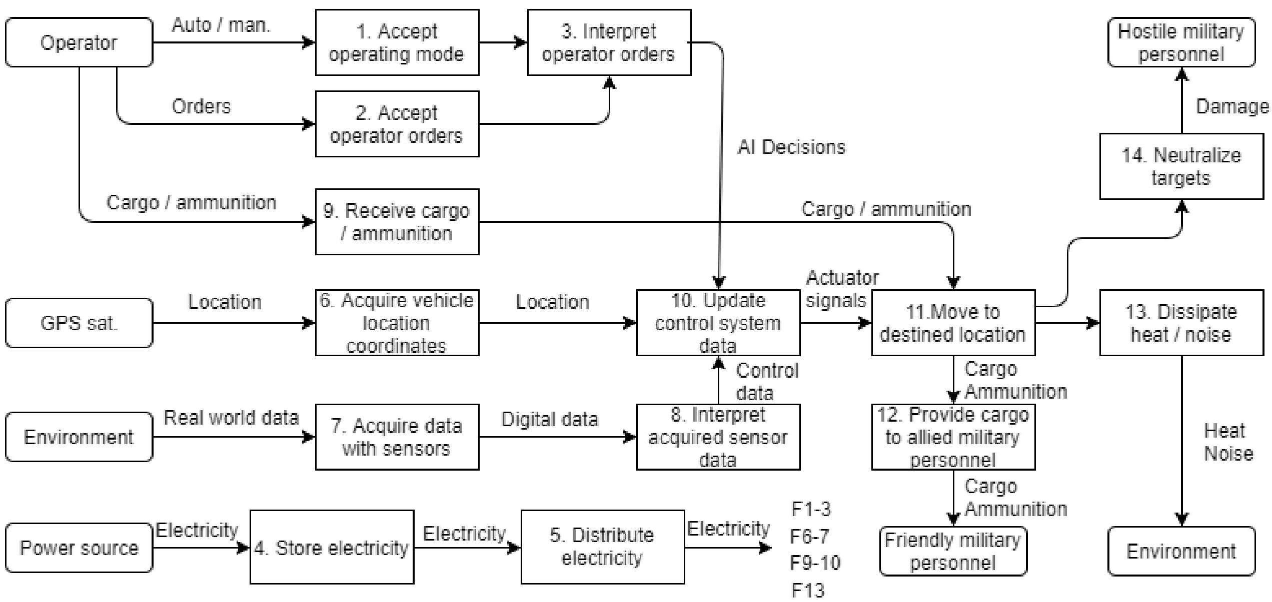
- Accept operator commands
- Store electricity
- Acquire data from sensors
- Accept automatic/manual operating mode
- Receive cargo / ammunition

Transformative functions:

- Interpret operator commands (AI)
- Update control system setpoints
- Distribute electricity
- Process data from sensors

Output functions:

- Provide operational status, location, imagery, audio
- Move to destined location
- Neutralize targets
- Dissipate heat, noise



8.2 Main system building blocks

The system main building blocks are described in the following table:

Software	AI and high-level software Embedded control SW
Electronic	Motor controllers Sensors Communication receivers/transmitters Battery management system
Electro-optical	Colour imaging camera Thermal imaging camera
Electromechanical	Electric motors
Electrochemical	Batteries
Mechanical	Framework/Chassis Armor Tracks Gearboxes
Thermomechanical	Battery heating unit

8.3 System design

The system is divided into five main subsystems:

1. Chassis
2. Electrical Power Subsystem (EPS)
3. Powertrain
4. Environment sensing subsystem (ESS)
5. Communication and data handling subsystem (CDHS)

Next all the subsystems and their functions are described.

8.3.1 Chassis subsystem

The chassis subsystem is composed of two main components: the track systems and the armour. The vehicle is built modularly using self-contained track systems that provide the necessary mechanical structure for the tracks, rollers and mountings for all the other subsystems.

Another key component is armour, which provides protection against fire from handguns and up to .50 calibre machine guns.

8.3.2 Electrical power subsystem

The main purpose of the EPS is to provide electrical power to the motors and other components. It consists of batteries and respective battery management systems. The latter being responsible for charging and protection of the batteries, and also battery thermal management (heating/cooling).

8.3.3 Powertrain

This subsystem handles everything related to the physical motion of the AUGV . It consists of the motors and respective motor controllers and gearboxes.

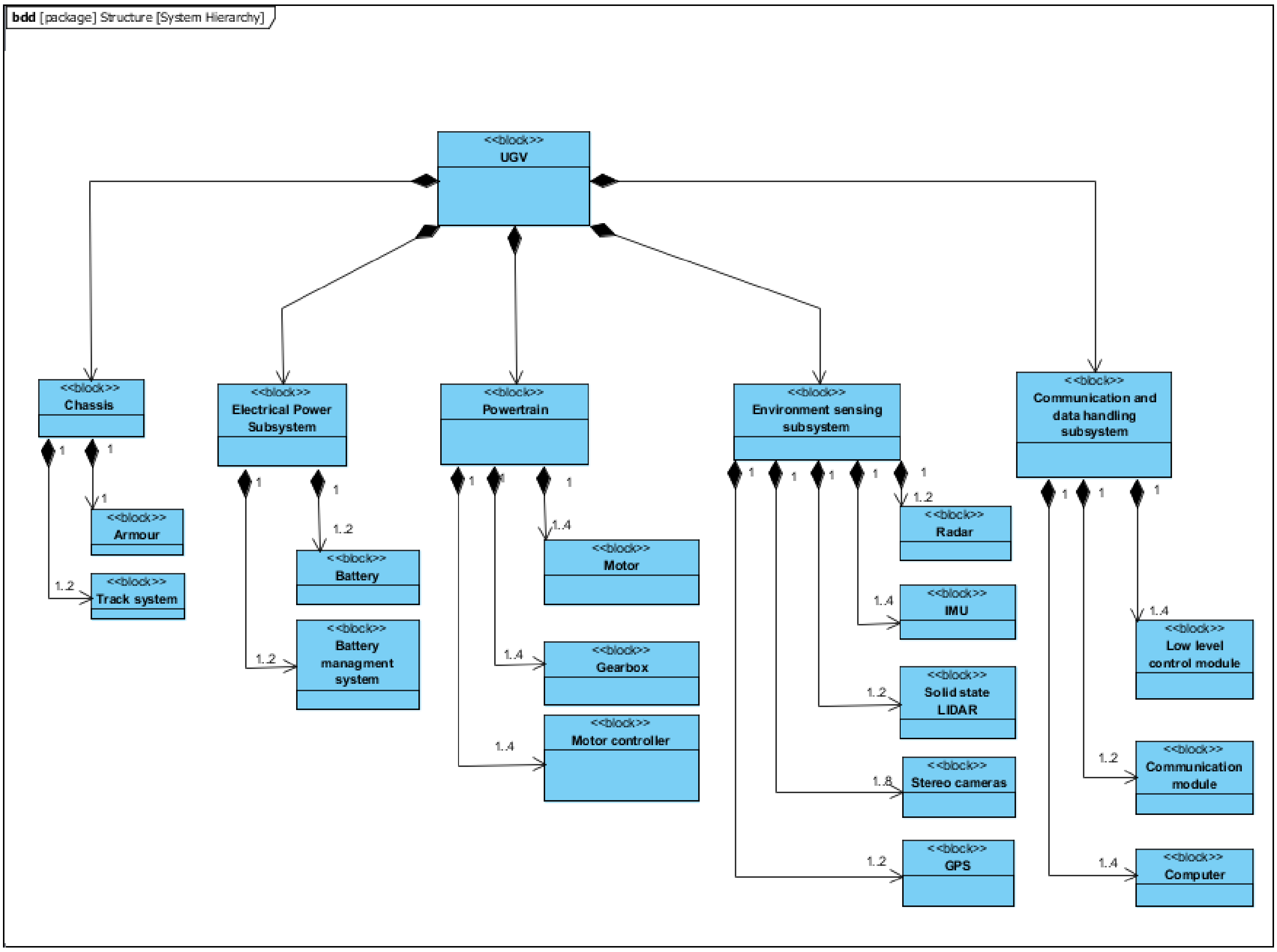
8.3.4 Environment sensing subsystem

This subsystem is responsible for providing all the necessary information about the environment around the AUGV for localization and navigation. This includes the inertial measurement units (IMU), GPS, thermal and colour cameras and radars.

8.3.5 Communication and data handling subsystem

This subsystem is responsible for communication with the ground control station (GCS) and data processing to provide the main functionality for the AUGV. This includes the communication modules and computers (multiple for redundancy purposes).

The block definition diagram for the system is presented on the following figure.



9 Use of ready components and existing systems

- For the UGV attitude sensing an inertial measurement unit (IMU) and attitude heading reference system (AHRS) solution from Vectornav is intended to be used. Namely model VN-110 which is a tactical grade (in terms of performance) IMU with environmental protection level matching to DO-160 standard.

- For the computing platform an Aitech product A195 RediBuilt GPGPU rugged computer could be used. The dual CPU solution (Intel Core i7 and NVIDIA TX1) provide sufficient computing capabilities for 1-2 stereo cameras. In total of four of those will be planned to use on the UGV, 2 extra for redundancy purposes.

- For controlling the motor, a suitable Sevcon Gen-4 motor controller will be used.

- For the battery solutions, Lithium-Ion battery modules from Kokam will be used, as at the moment it seems that this is one of few manufacturers that produce water cooled military grade battery solutions. Also the rated energy density (260Wh/kg) and high rated output (100C) make this option suitable. In addition Kokam has advertised themselves as manufacturer who can provide custom solutions which may be necessary.

- For vision based navigation and object identification Multisense-21 long range stereo cameras from Carnegie Robotics are suitable for this application. The long range, customizability (options to have also IR imaging sensors) and Gigabit Ethernet connection make this a suitable choice as the same component can be used in different configurations throughout the vehicle, minimizing the number of different products/interfaces that need to be handled in the mechanical and software engineering sides.

- For the global navigation a GPS module is necessary. As in the initial design phases access to military grade GPS solutions may be difficult a consumer level solution with acceptable environmental and performance requirements will be used. One good solution is provided by Swift Navigations - the Duro, which is a ruggedized GPS/GNSS module with built in RTK (Real Time Kinematic) to enhance the position accuracy to centimetre level.

For choosing the most suitable electric motor for the UGV a formal trade-off analysis was performed.

The key criteria for the motors are: price, weight, torque and speed characteristics. The selection that is common to all of the motors is size and overall power output, so those cannot be used in the selection process. So, the aim of this process is to find the optimal motor given the dimensional and output power constraints.

The weighing factors are chosen to be in range of 0.1 to 1 (omitting zero as then the criteria wouldn't be listed at all). Having in total 5 criteria, means that the sum of the weighting factors must be 2.25.

For the value ratings an actual measurement method is applied. This method is usable as each of the criteria can be measured and a suitable step function can be defined to provide a more objective effectiveness rating.

In the following tables, calculations for each of the alternatives are provided.

Hohomer HM10

Criteria	Weight	Meas.	Value	Score
Price (Euros)	0.65	921	2	1.3
Torque/Amp (Nm/A)	0.25	0.3	4	1
Torque (Nm)	0.3	31.8	4	1.2
Weight (Kg)	0.75	47	1	0.75
Rated speed (RPM)	0.3	3000	3	0.9
			Total score	5.15

Motenergy 1302

Criteria	Weight	Meas.	Value	Score
Price (Euros)	0.65	733	5	3.25
Torque/Amp (Nm/A)	0.25	0.15	2	0.5
Torque (Nm)	0.3	18.75	1	0.3
Weight (Kg)	0.75	17	3	2.25
Rated speed (RPM)	0.3	5000	5	1.5
			Total score	7.8

Golden Motor HPM-10kW

Criteria	Weight	Meas.	Value	Score
Price (Euros)	0.65	800	4	2.6
Torque/Amp (Nm/A)	0.25	0.28	3	0.75
Torque (Nm)	0.3	28.9	3	0.9
Weight (Kg)	0.75	18	3	2.25
Rated speed (RPM)	0.3	4700	4	1.2
			Total score	7.4

Domel AZ220-55-P172A

Criteria	Weight	Meas.	Value	Score
Price (Euros)	0.65	1030	1	0.65
Torque/Amp (Nm/A)	0.25	0.28	3	0.75
Torque (Nm)	0.3	22	2	0.6
Weight (Kg)	0.75	27	2	1.5
Rated speed (RPM)	0.3	2050	2	0.6
			Total score	4.1

From the total scores we see that two products: Motenergy 1302 and Golden Motor HPM-10kW, came very close with scores 7.8 and 7.4 respectively. The other two scored significantly lower and their scores will not be analysed further.

To make the selection between Motenergy and Golden Motor products we should still consider each of the scores for criteria separately. The Torque and Torque/Amp ratings are low on the Motenergy one, meaning that those should be compensated by the gearbox ratio, which is possible due to the high nominal speed of the motor. As the gearbox will be present regardless of motor selection and the ratio difference wouldn't introduce any significant cost changes those parameters are not important. One may think, that the higher torque ratings on the Golden Motor product would lead to higher torque output on the final solution.

Unfortunately, this is not the case as the gearbox torque limitation would start to limit the upper torque value, and the only gain would be higher top speed of the UGV.

As a conclusion the Motenergy 1302 motors will be chosen to be used on the UGV, due to its low price and weight combined with its high speed and moderate torque output characteristics that will be compensated by proper gear ratio selection.

10 System performance requirements (non-functional requirements)

Non-functional req.	**Minimum acceptable level**	**Desired level**
Reliability	Minimum acceptable time between failures is 27 hours (same as M1 Abrams).	Given the fact that our system is less complex than the M1 Abram, and more modern, we can aim for the best MTBF found in the previous document, which is 167 hours.
Compatibility	In order for the system to be used widely the system must be implemented in accordance to NATO STANAG 4586 - “Standard interfaces for Unmanned Control systems”. This means that the data link, C2 (command and control) and HMI (human-machine interface) must be implemented according to this document so that the system would be compatible with already existing solutions used.	In addition to NATO STANAG 4586, the US military also uses SAE AS-4 JAUS - “Joint Architecture for Unmanned Systems”, specifying the same areas as the NATO standard, but is mainly used by the US DOD. Achieving compatibility with both of those standards would be desired.
Functionality	The AUGV shall be capable of operating across grass, dirt and loose sand and climb inclines up to 15 degrees.	The AUGV shall be capable of operating across grass, dirt, **snow** and loose sand and climb inclines up to **30** degrees.
Performance	Movement speed 15-20km/h Range of 100km Payload 500 kg Cargo capacity 600 litres Operational temp. range -40 to 85 C Ability to withstand assault rifle fire (up to 7.62mm rounds) Range of detecting/identifying objects 250m Weight: 500kg	Movement speed 40km/h Range of 200km Payload 800 kg Cargo capacity 800 litres Operational temp. range -40 to 85 C Ability to withstand heavy machinegun fire (.50 cal) Range of detecting/identifying objects 500m Weight: 300kg

Maintainability - Measure of the ease of accomplishing the functions required to maintain the system in a fully operable condition.	Mean time to restore(MTTR) = Time to diagnose and detect the fault + Time to secure any necessary replacement / re-coding + Time to effect the replacement / repair + Time to restore the system to full operation MTTR = 1+3+7+1 = 12 Hence the longest acceptable time to restore is 12 hours Built-in test equipment for most crucial parts of the system, necessary to return to safety: ● Motor fault indicators ● Battery fault/capacity indicators ● Tracks condition/state ● Some level of sensor/GPS errors detection	MTTR = 15 mins + 1 hour + 3.5 hours + 15 mins The desired time to restore is 5 hours. Built-in test equipment for additional parts of the system: ● Parts already listed in min. acceptable level cell ● Improved sensor error detection ● GPS connection test ● Communications test
Availability - The system must be available to perform its function correctly when called upon.	The longest acceptable time to restore is 12 hours. The minimum acceptable time between failures is 27 hours of action. Minimum acceptable availability is $1 - \frac{12}{27}$ = 0.5555 = 55.55%	The desired time to restore is 5 hours. The desired time between failures is 167 hours of action. Desired availability is $1 - \frac{5}{167}$ = 0.9700 = 97%

11 User interface / Operator interface

As many functions of the system require input from the operator, the operator interface design needs to be considered also. From the use-cases it can be seen that most of the interactions that the operator has with the UGV are notification based, where the input from the operator is a quick decision. This means that the operator interface must be really well thought out so that would be possible. In order to design it, primary functional requirements have to be established. These are listed below:

- Have the capability to control and monitor the AUGV.
- Be flexible as the user and mission requirements may vary, the system attributes can be easily changed.
- Must be capable of executing maintenance software and displaying appropriate status results.
- Have ergonomically designed operator control and displays.
- Be capable of operation within the specified environmental conditions.
- Must be easily deployed and transported.
- Have the capability to control and monitor audio-visual payloads, data link and C2 interfaces during the mission.
- Must permit dynamic mission re-tasking during all phases of operational mission execution.

There are many ways how such an operator interface can be implemented. One example that uses a tablet based handheld system is depicted in the figure below.

Figure 3. Tablet based operator interface

Such a solution could be easily used for operators who themselves are on the field, near the machine.

Another solution that can be considered is a more elaborate system that would be mounted on a vehicle which would provide more physical controls (buttons, switches, etc.) providing an environment with more tactile feedback and easier controlling of the UGV while wearing gloves. One such an operator station example is presented on the figure below:

Figure 4. Stationary operator interface

12 Development and testing

The first task in the development of the project was defining the project and the needs that this project fulfils. We investigated the available technologies and what technologies needed further development to meet the requirements for AUGV. We viewed previous work done in this field and started thinking of ways to create a new unique system. We decided what tasks and objectives the system will accomplish; thus a clearer view of the design was developed. Then we worked on creating the design and decided what components and parts we should use to implement the system. After viewing few proposed designs, we finally agreed on all aspects of the project and defined the final design shown in this document.

- **Verification**

During every life cycle stage, all components, parts, and subsystems of the AUGV will be compared to the requirements specified in the design of the system. This also includes the system itself as whole according to the design description.

- **Validation**

Stakeholders are included in the development at all stages, their needs and requirements are taken into consideration when deciding if the system accomplishes its purpose of design. This system is validated when it achieves its intended use and meets stakeholder's requirements in the intended operational environment.

It is important to note here that verification and validation are done in parallel throughout the life cycle of the project.

Most critical area that needs to be addressed during testing is definitely the AI. Proper identification of friendly troops is needed to provide safe operation.

A test plan that will determine the sufficiency of the system and the feasibility of continuing and further develop the engineering of the system is developed. In this test plan, we create a schedule for further testing and decide the testing equipment and what available resources we could use. We decide what type of data is collected, methods of collecting the data, and how the data is analysed and processed.

- **Development testing**

In this stage, we test the different subsystems and components separated from one another to determine if the components and subsystem function as desired. Most of components are already manufactured and tested by their manufacturing party. Components that need to be developed and tested by our team include tracks, chassis and armour.

- **Developmental testing**

In this stage we test the system as whole. This stage mainly focuses on observing the interaction and behaviour of the different component when integrated together in the subsystems and the system as a whole. In this stage we determine if the system meets the operational and performance requirements set during the system design stages.

- **Operational testing**

The system is tested in different real environments(Forest, urban, winter etc). the AUGV is included in military force training programmes, where identification of people and actions taken are observed with most attention.

13 System operations and maintenance

- **Storage.** After completing a mission the AUGV can be stored in either its respective Ground Control Station (GCS) or kept where the troops are currently stationed.
- **Transportation.** The vehicle offers great off-road mobility. The AUGV can be transported by helicopters internally or as slung load.
- **Installation.** No installation needed. The vehicle will start operating immediately after being deployed. Cargo will be constantly loaded and weapons constantly attached.
- **Routine maintenance.** AUGV maintenance checks will primarily consist of, but not limited to, AI testing to ensure that it's working correctly. Failures in AI are the most costly. Testing of all the subsystems and components will be performed as well. After 200 working hours (approximately 2-3 months) a 50 man-hour maintenance check is performed. Every year a 200 man-hour maintenance check is performed.
- **Emergency maintenance.** If the AUGV has been in a conflict and received damage, it is repaired and tested before returning to operation.
- **System modification and upgrading.** The most critical upgrading would deal with software updates on the AI side. It would mean the vehicle would have to retreat from the battlefield to perform an upgrade. There would be a testing phase to check the new features work as intended. Upgrading other subsystems is more straightforward. These other subsystems are not as experimental and do not need as much testing. One advantage of having a system with several subsystems in a modular design is that modifying one of them does not directly affect the others.
- **System disposition.** When an AUGV unit comes to the end of its life-cycle, or it suffers damage beyond repair, many of its components can be recycled to be used in building other units or as spare parts. Disposing of the batteries is the most challenging, but nowadays it is possible to recycle them. When a major upgrade of the AUGV comes, older units will be removed from operations gradually.

14 Cost of development and maintenance

Analysis for cost of system development is broken down into two tables: hardware and software.

In the hardware table an overview and approximate costs of ready components is given. Components that require engineering are listed also.

In the software table a list of functions that have to be developed is given in accordance with necessary software licences, including costs, for system development.

Needed man-hours and cost of development cannot be approximated without specialist guidance and is postponed until such an opportunity arises.

Hardware				
Ready components	**Cost [€]**	**To be engineered / built**	**Man-hours**	**Cost [€]**
Computing platform	3350	Tracks	Needs specialist guidance	
Vision systems	170 - 420	Armour	Needs specialist guidance	
Radar	215	Chassis	Needs specialist guidance	
IMU/AHRS	670			
Motors	1200 per unit			
Motor controller	790			
Batteries	560 - 690			
Arms	15000			

Software				
To be developed	**Man-hours**	**Cost [€]**	**Licences**	**Cost [€]**
Artificial intelligence	Needs specialist guidance		CAD (SolidWorks)	8K initial + 2K/year subscription
Control system (Motion and arms)	Needs specialist guidance		AI implementation	SW not yet chosen
			Control implementation	SW not yet chosen

15 Risk assessment

The weakest and most uncertain parts of the design for the system are the following:

1. Artificial intelligence
2. Motion system
3. Armour
4. Structural design
5. Batteries

15.1 Analysis, development and test to eliminate or reduce these weaknesses to an acceptable level

1. Artificial intelligence

- Training of AI in simulation environment
  - the simulation environment is by definition limited to testing in foreseeable conditions, real world behaviour is more complex
- Failure to recognize the environment
  - in case of failure, it’s critical for the AI to be aware of its situation in order to notify an operator
- Failure to notify operator in case of problems
  - in case of failure of the AI, if the operator isn’t able to pilot the system, it’s basically lost until someone comes and picks it up

2. Motion subsystem:

Motor system is one of the essential subsystems in this system. The failure of this subsystem directly affects the system as whole.

The motion subsystem has two main weaknesses:

- Motors overheating - the risk of overheating can be caused by long run-time as well as the temperature of the environment. This risk can be reduced by testing the system in extreme conditions that could lead to the overheating of the motors (long period run time, high temperature environment, etc.). Outcomes of these tests will help determine further design decisions and develop the subsystem to eliminate or further reduce any potential design failures.

- Gearbox failures - the risk of gearbox failure is a common risk in automobile systems. There is a variety of issues that can rise and cause the gearbox to fail. This risk can be reduced in testing different types of gearboxes and assessing the performance of each of these types to decide the most suitable with the system.

3. Armour

The armour is also an uncertain part as the

- Too fragile if optimized for weight
  - A compromise in motor size, vehicle size and armour thickness has to be worked out by the engineers.
- Not enough armour (uncovered parts)

    - Armour could be divided so that the most crucial parts for vehicle operation (motor, control system, batteries) are more protected than others (E.g. gear compartment).
- For testing, prototype chassis could be built and tested against light- and heavy machine gun fire.

4. Structural design

One of the parts of the design that is very uncertain is the overall structural design. To resolve the issue careful analysis regarding the terrain handling must be done where following points are considered:

- weight of the vehicle
- centre of gravity in different operational cases
- contact area with ground

Based on the analysis several prototype designs should be tested in a virtual environment. Testing with real hardware would be unreasonable, as scale models wouldn't be feasible as gravity doesn't scale, thus any tests done with scale
models would be invalid.

From the results of the simulations a real prototype can be built and tested in various operating conditions. For testing centre of gravity and weight in different situations (various payloads etc) simple adjustable mechanism with weights could be used to change the mass and centre of gravity.

5. Batteries

Batteries are also one of the weak spots of the system as:

- Capacity in various climates (extreme temperatures)
    - Cold temperatures reduce the driving range of an electric vehicle. They also affect the charging. For example, most Li-ion batteries cannot be charged below freezing. Hot temperatures are detrimental as well, since once a battery is damaged by heat, its capacity cannot be restored.
    - Cooling as well as warming systems could be designed to prevent these risks from happening. Tests at different extreme temperatures must be performed.
- Overcharging issues
    - Most commonly used batteries for electric vehicles cannot accept overcharge. That is, when fully charged, the charge current must be cut off. This poses a safety hazard as a battery becomes unstable when charged to a higher than specified voltage, with the possibility of venting with flame.
    - Properly designed charging equipment is necessary. Also, protection circuits must be built into the battery pack that do not allow exceeding the set voltage, including temperature sensors.
    - Testing the charging of the battery to higher voltages until it is under stress.
- Short lifespan
    - Batteries degrade after a certain amount of cycles. Batteries for electric vehicles are still quite short-lived.
    - Careful selection and extensive testing are necessary to choose the right battery for this specific application.

15.2 Most potential risks/failures that the system might be subject to

In this section the most potential risks and failures that affect the system as a whole are brought out and their likelihood and consequences are analysed.

1. **AI failure during operation.**

    - The likelihood of this risk is medium, because it's an emerging technology but yet it's something we're going to test a lot
    - This issue is very critical, as if the AI crashes without giving control to the operator, the system is simply unusable.

2. **Third parties unable to deliver on time or delivering out of specification items**

    - It is moderately likely that one of the third parties will fail to deliver their products on time or deliver parts that are out of spec. It could be that they deliver late and their parts don't work sufficiently with other parts.
    - This issue is very critical as the unmanned vehicle will have many different intricate parts that work together. If one of those parts was out of spec, it will cause the whole system to fail. Not having parts on time can also delay the finishing of the system.

3. **Being late to market**

    - High likeliness, as we are just in the first phases, while others have been developing such systems for a long time.
    - Criticality is medium-high because in arms trades, large long-term contracts are made, which we will miss out on if we fail to deliver.

4. **Reduction of available funds.**

    - Not very likely that investors may want to withdraw their investments. This could be due to late delivery of the system or that it no longer interests them.
    - Quite influential as funds are essential to achieving anything these days. If investors pull out their support, these is a real chance that the system could come into a halt.

5. **Laws against autonomous weapons are enforced**

    - There have been movements towards regulating (banning operation) of autonomous weapons. This is a risk that has to be accepted.
    - This risk can be considered moderately influential to the whole system, as when these kinds of laws are adopted the design process must be changed to focus on other areas this kind of platform can be used.

6. **Being hacked**

    - The risk of system being hacked to take over the control of the machine is not extremely likely. The implementation of strict software and hardware security policies would help to reduces the likeliness of this.
    - This issue is rather critical as being taken over, could cause harm to friendly forces, enemy can catch the machine and could reverse engineer the system.

7. **Getting stuck on difficult terrain**

   - Not very likely as the system is engineered on the basis of other systems, that have been proven efficient. Also the development methodology should reduce it.
   - Consequence is quite high ,as not being able to manoeuvre on difficult terrain makes the system almost useless.

15.3 Risk cube

The risks and failures identified in the previous section are depicted on the risk cube below. Numbers in the table correspond to the risks in the previous section (i.e. 1 - **AI failure during operation.**)

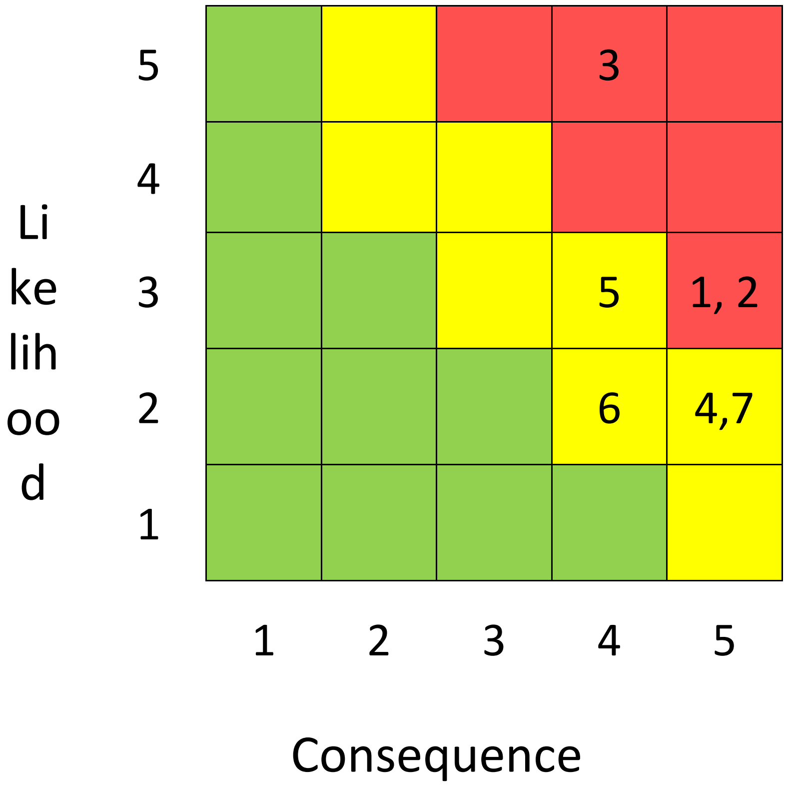


Figure 5. Risk matrix

15.4 Risk mitigation practices

1. **AI failure during operation**

One of the risks for the whole system is AI failures, for example AI failing to recognize situations where it cannot take proper decisions and hand control over to operator. In order to mitigate this risk AI first of all needs to be extensively tested both in virtual environments and in physical world.

2. **Third parties unable to deliver on time or delivering out of specification items**

Parts need special machinery to be built. Subcontractors provide this machinery to create parts. Subcontractor might fail to deliver these parts on time, or the parts do not meet the specifications. Keeping direct and consistent contact with subcontractors is always the best way to avoid any risks that may arise at their end. Specification of parts must be stressed to avoid failure of meeting these specifications. If any part doesn't fulfil requirement, it's better to know in order to make necessary adjustments. If subcontractor is not able to manufacture parts to specification. A schedule of delivery must be agreed upon with subcontractors.

3. Being late to market.

Finishing the product later than others will cause us to miss out on contracts which are usually long-term and large in arms trade. Having started too late, insufficient funds and lack of proficient engineers/scientists are main causes for being late. Consequence would be us getting only a small fraction of the market. The development could be accelerated by rapid prototyping and quick testing of critical parts. Also by AI training and testing in virtual environment.

4. **Reduction of available funds**

The reduction of funds is common with projects that may become uninteresting to its investors. This can be because of failure to deliver a working system on time. It can also because the system is outdated and there is a better system that investors choose to invest in instead of your system. This risk can be mitigated in two different ways. First is to find new investors. When the projects is starting, a list of possible investors must be compiled. This list will come handy when the project needs urgent funds if an investor pulls out or investment turned out to not be enough. There must be more than one source of funds since the inception of the project. The project must have more than one investor (or more than one investing group). The second way is to consider cheaper alternatives to the parts used. Cheaper parts may not deliver the desired performance, but they are a good way to reach minimum required performance with less financial spending. This can be a risky endeavour as these cheaper parts may be unsuitable alternative. However, choosing good alternatives could eliminate unwanted risks in the future.

5. **Laws against autonomous weapons are enforced**

Only possible action to try to mitigate the issue is by lobbying against this in military and government circles proving that the benefits will overweigh the negative aspects of such solutions. One way to mitigate the risk is in development phase consider also alternative uses for the AUGV, so that when such laws will be enforced then the development could be shifted from military uses to civil uses as one example.

6. **Being hacked**

Control can be gained by an unwanted operator; insufficient security standards would make it likely that the system would then be totally unusable. Adopting the same security standards as aerial drone manufacturers have done seems like a plausible option.

7. **Getting stuck on difficult terrain**

Ability to move on difficult terrain is determined by a number of factors: weight, centre of gravity, dimensions etc. To mitigate the issue firstly a number of different solutions should be tried out in virtual simulation environment, as building scale models wouldn't help due to the fact that gravity doesn't scale. After the simulation, the best solution should be prototyped and tested.