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TRAYANA - The Multi Terrain Ambulance System

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Abstract
In emergency situations, rapid medical assistance is vital for saving lives but traditional ambulance services, which rely heavily on the road infrastructure, often face challenges when the terrain is difficult, roads are damaged, or the accessibility is limited. To counter these issues, TRAYANA is introduced as a combination of multi-terrain emergency response vehicle that can perform emergency operations through air, water, and land. The innovative vehicle is a VTOL (Vertical Take-Off and Landing) enabled quad rotor configuration powered by a turboshaft engine and features an amphibious operation element with a watertight and buoyant structure as well as a rugged ground traction system for all-terrain mobility. Such a versatile vehicle can operate under tough and unreceptive conditions including mountainous areas, flood zones, river deltas, and off-road areas. The design features a centrally located turboshaft engine that is mechanically connected to four independent rotors thus providing high power, prolonged operation time, and fast refueling. Brushless DC motors together with a buffer battery are used to power the auxiliary propulsion and other onboard systems. A sophisticated navigation and guidance system utilizes GPS, inertial measurement units (IMU), altimeters, and digital compasses to allow accurate flight and smooth handling. Supplementary situational awareness is provided by laser imaging detection and ranging (LiDAR), wind gauges, and barometers thus enabling the system to adapt swiftly to the prevailing environmental conditions. A twin communication system that combines telemetry for long distances and IoT-based 4G/5G connectivity guarantees live monitoring, unmanned control, and uninterrupted healthcare data streaming.

Keywords: *TRAYANA multi-terrain medical transport; VTOL; quad rotor; turboshaft engine; emergency healthcare delivery; integrated control systems; Internet of Things; autonomous emergency response.*

1. Introduction
Getting to the hospital fast really matters when someone has a serious injury or sudden illness. That golden hour right after is crucial for cutting down on deaths and bad outcomes later [1]-[3]. But regular ambulances on the ground get stuck a lot because of traffic jams, rough land, bad weather, or big disasters that mess everything up. Still, most of these setups only work in one way, either air or ground or water. They cannot carry much, run out of power fast, and do not connect well with medical gear. Flying ones on batteries move quick but need recharging too often, and the energy is not great. Ground or water ones cannot go up in the air easily and still need roads or paths. It seems like that means they cannot keep helping patients while moving them through different kinds of land that changes a lot. Current options fall short on steady care during the trip out [4], [5].

1.1. Limitations of Conventional and Autonomous Emergency Transport Systems
This paper looks at designing something called TRAYANA. It is an ambulance system that switches between air, land, and water all in one unit. What makes it new is using a turboshaft engine for taking off and landing vertically, plus add-on medical parts, and strong ways to talk during emergencies without needing regular setups. TRAYANA tackles carrying weight, lasting longer, getting places easily, and

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keeping care going all at once. Sort of a big step for future medical transport. Old school emergency services mostly use roads, so they slow down from jams, broken paths, or places you cannot drive to. Even in cities, rush hour makes it worse, and out in the country or after disasters, nothing gets through at all. Autonomous stuff and unmanned rescues try to help, but they are built for just one area, like only flying or only driving. They wobble too much or cannot hold patients and life support gear properly. See Achtelik and team in 2014, Doherty and Rudol in 2012, Singh again in 2020. Switching from air to land or water takes time in those single-mode things, which hurts in real crises. Plus, they do not see the full picture around them, and talking to others is spotty, especially in huge events [6]-[9].

1.2. Need for a Unified Multi-Terrain Emergency Medical Platform

With more storms from climate change and stuff breaking down, we need systems that work anywhere, hold up on power, and keep medical help going without stops. New tech in vertical flying, strong engines like turboshaft, combining sensors, and fast networks lets us mix it all into one thing. Sterbenz and others in 2010, Verma team in 2022, Zhao in 2025 talk about that. TRAYANA comes from this idea, putting flying, driving, and water travel together with medical tools right on board and good comms. It deploys fast, watches patients the whole way, links up with hospitals in real time. That pushes emergency help farther than usual roads allow, making responses way better overall [10]-[13].

2. Methodology

This part is about how we came up with the design for the TRAYANA ambulance system, and how we put everything together and checked if it works. We focused mainly on the big picture stuff, like new ways to integrate the parts, and for the usual methods, we just followed what was already in those older papers and referenced them (Figure 1).

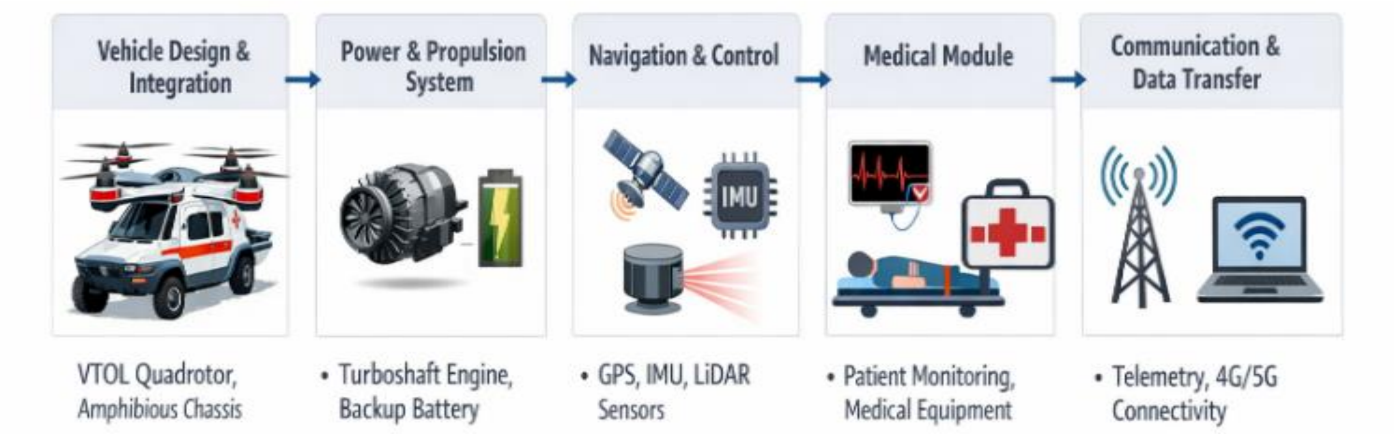

Figure 1 Methodology of TRAYANA

2.1. System Architecture and Design Approach

The whole setup is meant to be this modular thing that can handle different terrains for emergency transport, switching between air, ground, and water without much hassle. It has three main pieces, the VTOL propulsion that lets it take off and land vertically, the medical setup inside, and the base for moving on land or water. I think the modular idea makes sense because it lets you adjust for different missions, and keep things easy to fix or scale up. For the structure and how weight is spread out, we used those standard methods from drone designs in past studies, nothing too fancy there [14]-[16].

2.2. Propulsion and Power System Configuration

For power, they picked a turboshaft engine in the middle to power everything, since batteries just do not cut it for the load and how long it needs to run. The mechanical power goes to four rotors via a gearbox so they all push equally. Then for the electronics like sensors and medical gear, there’s an onboard generator, and a battery for backups during peaks or emergencies. Calculations for sizing the

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propulsion and fuel use came from regular rotorcraft models, it seems straightforward enough [17].

2.3. Multi-Terrain Mobility Implementation

Getting around on different terrains works in three ways, aerial with the quadrotor setup for hovering and controlling attitude through rotor differences, ground with some tough traction system for rough spots full of debris, and water by making the hull buoyant and sealed so it floats and moves in floods or shallow areas. Sensors pick up the terrain and environment to switch modes automatically, which sounds useful but I am not totally sure how seamless that is in real life [18].

2.4. Medical Module and Patient Monitoring Integration

The medical part is key for keeping patients stable on the move, with stuff like vibration dampening and monitors for heart rate, oxygen levels, blood pressure, temperature. We stuck to standard biomedical ways for picking sensors and getting data. The data gets sent live to hospitals so they can prep ahead, that continuity seems important [19].

2.5. Navigation, Control, and Communication Systems

Navigation pulls in GPS, inertial stuff, altitude, and environment sensors to keep it steady, and the control system handles flight stability, mode changes, and avoiding obstacles. For communication, its dual with telemetry for long range and cell or satellite for reliability, sending commands and medical info without breaks. We adapted protocols from earlier work on similar platforms.

2.6. System Validation and Performance Evaluation

To check it all, we ran simulations for air drops, ground paths, and water moves. Looked at things like how much it can carry, thrust extra, how long it lasts, range, comms working, and medical monitoring nonstop. Used math and sims to see if its feasible and safe, but some parts might need real tests to confirm. Overall, it feels like a solid concept, though the integration could get messy in practice.multi-terrain emergency ambulance system hinges on the design of a single, modular platform that can seamlessly operate in the air, land, and water, while at the same time providing uninterrupted medical care and maintaining communication networks. This methodological approach sees sterilization of various aspects such as system-level requirement analysis, modular architecture design, multi-terrain mobility implementation, power system selection, embedded control, and performance validation (Table 1).

Table 1 Parts used in the TRAYANA

Component	Purpose	Specification
Turboshaft Engine	Primary propulsion for quadrotor VTOL	Powerplant: Turboshaft; Rated Power: 400–600 kW; Fuel: Jet-A
Mechanical Transmission System	Power distribution to rotors	Transmission Type: Gear-train;
Quadrotor Rotor Assemblies (×4)	Generate lift and control	Rotor Dia: 2.5–3.5 m; Disk Loading: UAS heavy-lift class
VTOL Structural Frame (Sky Dock)	Structural backbone	MTOW Capacity: 735 kg; Load Class: UAS Heavy
Integrated Generator	Onboard electrical generation	Electrical Supply: 10–20 kW; MIL-STD-704 compatible
Buffer Battery	Critical system backup	Battery Type: Li-ion; Capacity: 2–5 kWh;
Medical Pod (Med Pod)	Patient enclosure & medical systems	FAA Payload Class: Medical Transport

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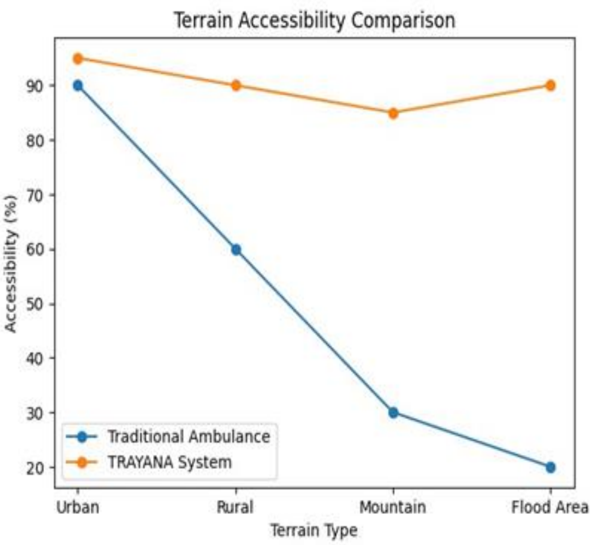
ECG Sensor	Vital sign monitoring	Physio Sensor: IEC 60601-2-47 compliant; Range: 30–240 bpm
SpO_2 Sensor	Oxygen saturation monitoring	Range: 70–100% saturation
Blood Pressure Sensor	Non invasive BP monitoring	Range: 40–250 mmHg
Temperature Sensor	Body temperature monitoring	Range: 30–45 °C
GPS Receiver	Geolocation and navigation	Positioning: RTK optional; Accuracy: ±1.5 m
Inertial Measurement Unit (IMU)	Attitude stabilization & control	IMU: 6–9 DOF; Drift: Low bias instability
LiDAR	Obstacle detection & terrain mapping	Range: 50–150 m; Scan Rate: High refresh for avoidance
Barometric Altimeter	Altitude measurement	Altitude Range: 0–3000 m;
Telemetry Module	Control & status communicat-ion	Band: 5G mesh / UAS C2 link; Range: 15–20 km (LOS)
Satellite Communication Unit	Beyond-Line-of-Sight (BLOS) comms	SATCOM: L-band or Ku-band; Coverage: Global
Ground Mobility System	Mobility on land surfaces	Ground Speed: 60–90 km/h;
Amphibious Hull Structure	Buoyancy & water transition	Buoyancy Margin: 1.2 × WTOW; Sea State: Shallow water
Embedded Control Unit	Sensor fusion & autonomous control	Processor: Real-time safety certified; Autonomy Level: Semi/Full

2.7. Flow Chart and Graph



Graph 1 Terrain Accessibility Comparison

The accessibility comparison illustrates a classic contrast between an infrastructure-bound and adaptive emergency response system: conventional ambulances show a steep drop in accessibility with increasing terrain complexity, from highly effective in cities to full-scale operational failure in hilly and flood-impacted areas, while the TRAYANA system keeps almost steady access across all terrains by dynamically switching between aerial and ground as well as amphibian modes. It's kind of interesting how the graph points out this big edge for TRAYANA. You know, being able to work without relying on all that infrastructure. It keeps accessibility high even in rough areas, which probably helps get medical help to more people faster during disasters or in remote places. I might be oversimplifying, but that stands out as the main thing (Graph 1).

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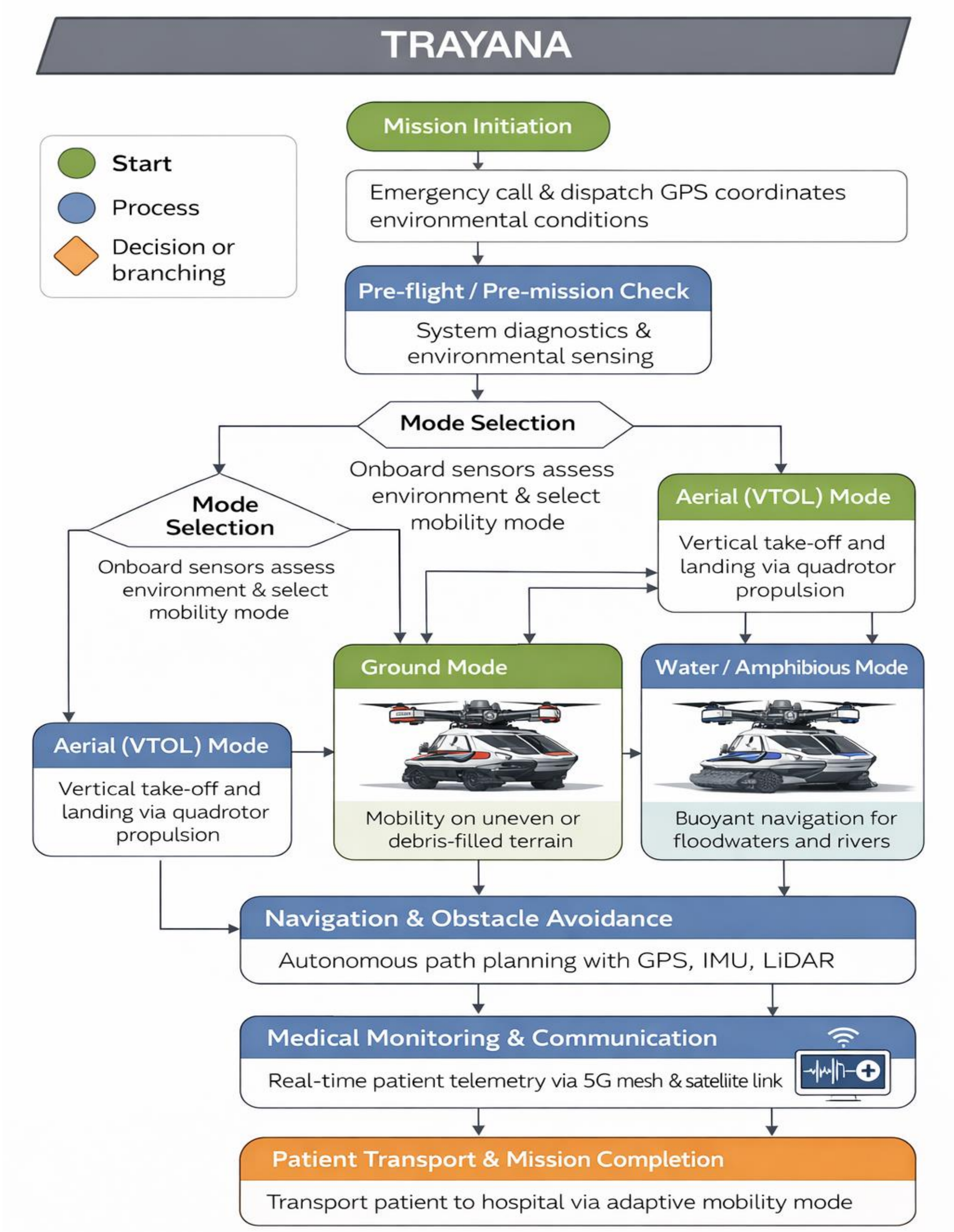

Flow Chart 1 **FAA/UAS-Aligned Parts and Requirements for TRAYANA Multi-Terrain Emergency**

The diagram illustrates the operation of TRAYANA-that is an intelligent, fully automated emergency response system-an intelligent platform for mobile response not limited to traveling by way of road vehicles. The underlying triggering system may be engaged in the event of an emergency call; thereafter it attempts to collect GPS and environmental data to find out the route and carry out checks on the general operations of the device. The onboard sensor systems will then assess the terrain conditions and autonomously choose the best mode of transport in accordance with the particular environment in which the system is operating (Flow chart 1).

3. Results and Discussion

3.1. Results

The TRAYANA multi-terrain emergency ambulance demonstrates substantial improvements over conventional systems in key operational metrics

(Table 2).

Table 2 Performance Metrics

Metric	Value / Performance	Description
Total Take-Off Weight (WTOW)	735 kg	Includes patient, Med Pod, engine, transmission, rotors, frame, electronics, and fuel.
Maximum Payload Capacity	520 kg	Allows additional equipment, medical supplies, or heavier patient loads.
Rotor Thrust	238.9 kg per rotor	Provides sufficient margin for VTOL maneuvering and safe transition between mobility modes.
Hover Power Requirement	320 kW	Within 500 kW engine capacity, ensuring stable VTOL operation.
Endurance (100 kg fuel)	1.33 hr	Adequate for typical emergency missions; can be extended by increasing fuel load.
Maximum Range	106 km (100 kg fuel) / 213 km (200 kg fuel)	Enables rapid access to remote or disaster-affected areas.
Structural Load (Safety Factor 2.5)	18,029 N	Confirms the vehicle frame and rotor mounts can safely support mission loads.

3.2. Discussion

3.2.1. Multi-Terrain Accessibility

TRAYANA's quadrotor VTOL architecture with hydro-plane and amphibious mobility allows trouble-free access to remote flood-ravaged, and badly infrastructure-deprived areas. Sensor-led automatic mode selection avails the best mobility for any given terrain.

3.2.2. Payload and Endurance Advantage

The enhanced payload capacity (up to 520 kg compared to battery-powered UAVs) with long operational endurance (1.33 hrs with 100 kg fuel) now acts as a source of support for emergency medical missions.

3.2.3. Medical Support Reliability

The vibration-isolated Med Pod and integrated vital monitoring system secure patient safety during the aerial, ground, and water transit, whereas real-time telemetry allows for continuous communication with the concerned hospitals to better prepare the treatment team, thus improving outcomes.

3.2.4. Operational Safety and Stability

Structural load and rotor thrust calculations suggest sufficient margins of safety in both hover and lateral flight modes. The hover performance analysis indicates that the turboshaft engine is sufficiently overpowered to make it robust in emergencies under variable load and environmental conditions.

3.2.5. Communication and Situational Awareness

The bi-communication backbone (5G mesh + satellite link) allows real-time monitoring, navigation, and mission coordination across disaster-stricken and remote areas, improving overall efficiency of response.

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