# Team 19: Last-Mile Drone Delivery

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R.U.D.O.L.P.H.

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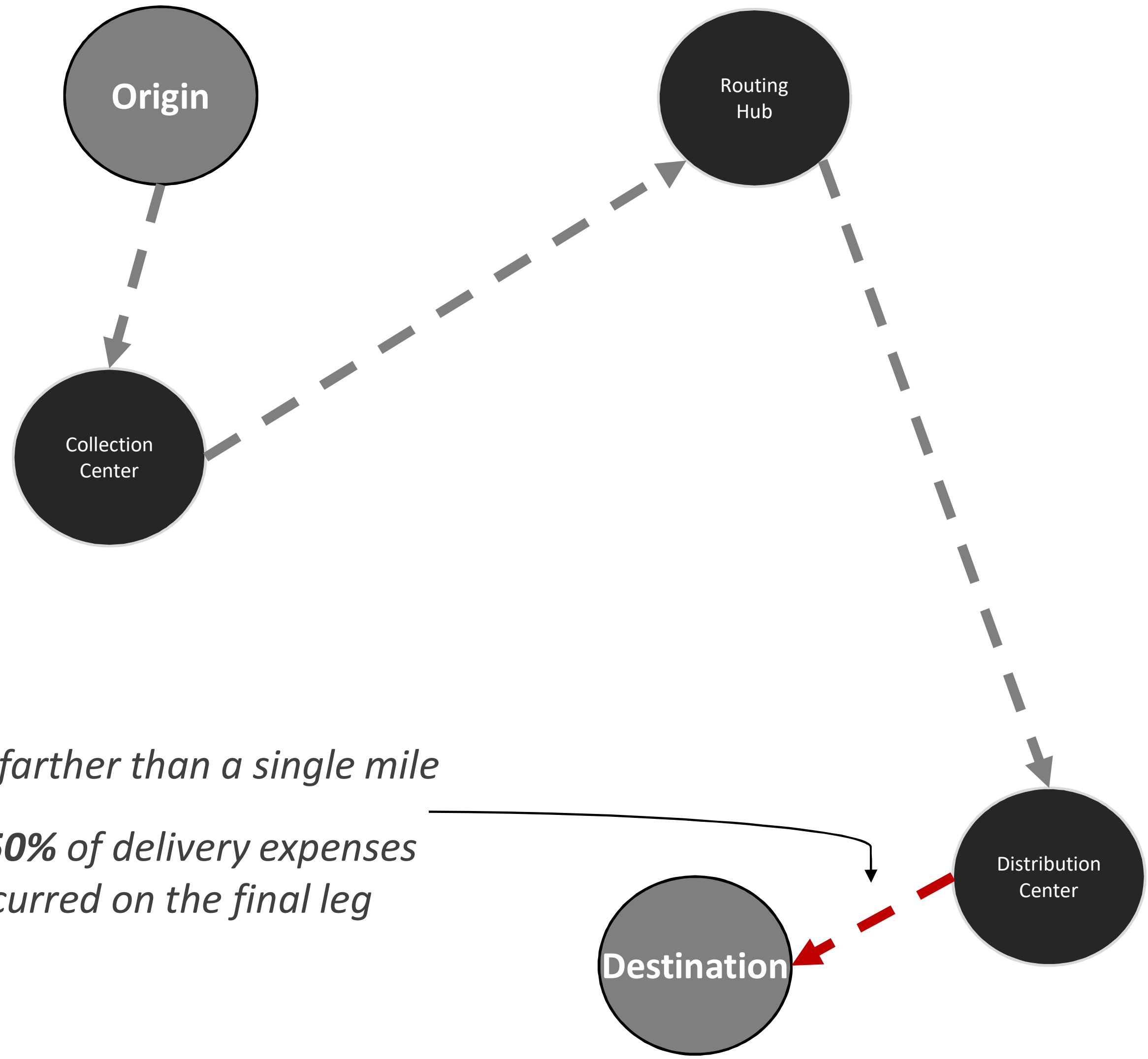
Regional Unmanned Delivery Of Light Packages to Homes

# Problem Scope

Last-Mile Business-to-Consumer (B2C) Shipping Challenges:

- Delivery demand densities vary by time and location
- E-commerce sales and subsequent cargo traffic volumes are surging
- Customers expect progressively cheaper and quicker shipping options




*Much farther than a single mile*

*Over **50%** of delivery expenses are incurred on the final leg*

# Mission Statement

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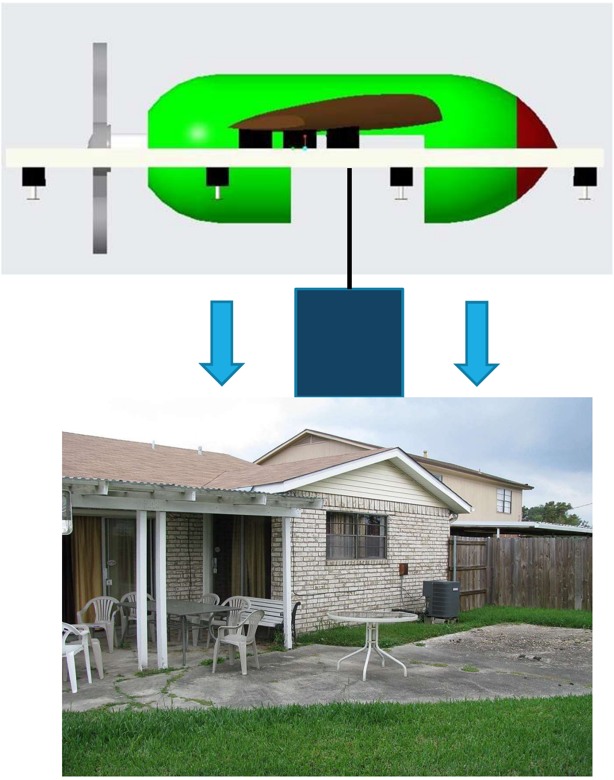
*To develop a drone package delivery system that performs last-mile delivery of goods in a **faster**, **safer**, and **cheaper** manner than current delivery methods.*



# Stakeholders

| **OPERATORS** of delivery system | | | | | | | **MANUFACTURERS** of delivery system | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **UPS** | **FedEx** | **DHL** | **Amazon** | **USPS** | **Grubhub** | **DoorDash** | **DJI** | **Yuneec** | **Parrot** | **Blade** |

*Packages: Primary Market* *Food: Secondary Market*

| **REGULATORS** of airspace | | | | **USERS** of airspace | | | | **PRODUCERS & CONSUMERS** of delivered goods |
|---|---|---|---|---|---|---|---|---|
| FAA | ICAO | Federal, State, & Local Authorities | Airports | Airlines | Military | Business | General | various business & individuals |

# Customer Needs

| Group | Rank | Need |
|---|---|---|
| Operators | 8 | Drone shall transport cargo faster than ground shipping. |
| | 7 | Drone shall transport cargo cheaper than ground shipping. |
| | 9 | Drone shall provide the range to bridge the last-mile gap. |
| | 11 | Drone shall carry multiple medium-sized packages. |
| | 19 | Drone shall efficiently plan and navigate delivery routes. |
| | 10 | Drone shall detect and avoid obstacles in its course. |
| | 23 | Drone shall operate normally in mild precipitation and winds. |
| | 25 | Drone shall operate normally in reduced visibility environments. |
| | 24 | Drone shall operate normally after repeated hard landings. |
| | 13 | Drone shall offer a remote piloting capability. |
| | 12 | Drone shall regularly transmit tracking data to a control center. |
| Producers & Consumers | 14 | Drone shall be securely and expediently unloaded. |
| | 15 | Drone shall deliver its payload in a safe and convenient location. |
| | 21 | Drone shall insulate its payload from weather conditions. |
| | 20 | Drone shall protect its payload from excessive loading. |
| | 22 | Drone shall notify customers of impending deliveries. |

| Group | Rank | Need |
|---|---|---|
| Regulators | 30 | Drone shall limit its noise, light, and air pollution. |
| | 27 | Drone shall avoid harming wildlife in the sky or ground. |
| | 5 | Drone shall avoid flying within restricted airspace. |
| | 1 | Drone shall comply with FAA Part 135 regulations. |
| | 2 | Drone shall comply with NextGen ATC LAANC regulations. |
| | 3 | Drone shall yield to commands from authorities. |
| | 4 | Drone shall avoid contacting nearby persons or structures. |
| | 6 | Drone shall notify other airspace users of its presence. |
| Manufacturers | 18 | Drone shall protect itself from criminal activities. |
| | 17 | Drone shall limit maintenance downtime. |
| | 26 | Drone shall limit its power draw. |
| | 28 | Drone shall prevent cargo movement. |
| | 16 | Drone shall be easily serviceable and reliable. |
| | 29 | Drone shall store performance data for evaluation. |

# System Requirements

| Weight | Specification | Marginal Value | Target Value |
|---|---|---|---|
| .15 | Drone delivery cost ($/mi.) | $3.00/mi | $2.50/mi |
| .1 | Drone cruise speed (mph) | 50 | 60 |
| .1 | Drone delivery range (mi.) | 20 | 30 |
| .02 | Drone flight endurance (hr) | 1 hr | 1.25 hr |
| .02 | Drone flight ceiling (ft) | 500 ft | 750 ft |
| .05 | Drone navigational positioning error (ft) | 5 ft | 1 ft |
| .02 | Drone power draw (Ah) | 20 Ah | 15 Ah |
| .03 | Obstacle detection distance (ft) | 400 ft | 500 ft |
| .05 | Obstacle separation distance (ft) | 100 ft | 150 ft |
| .01 | Tolerable wind speed (mph) | 15 mph | 25 mph |
| .01 | Drone system annual loss rate (%/year) | 5% | 2% |
| .01 | Drone system mean time to failure (years) | 5 years | 10 years |
| .03 | System mtc to ops time ratio (#) | .1 | .05 |
| .01 | Drone light pollution (lumens) | 1200 lum | 1000 lum |
| .01 | Drone noise pollution (decibels) | 90 dB | 50 dB |
| ***Vehicle Performance*** | | | |

| Weight | Specification | Marginal Value | Target Value |
|---|---|---|---|
| .1 | Payload size (cu in.) | 2016 cu in | 3024 cu in |
| .1 | Payload weight (lbs) | 10 lbs | 12 lbs |
| .03 | Payload on/off-loading time (sec) | 90 sec | 60 sec |
| .02 | Payload on/off-loading steps (#) | 5 steps | 3 steps |
| .03 | Payload acceleration exposure (Gs) | 3 Gs | 2 Gs |
| .05 | Payload delivery location error (ft) | 10 ft | 5 ft |
| .01 | Datalink bandwidth capacity (Mbps) | 5 Mbps | 10 Mbps |
| .01 | Datalink latency time (sec) | 2 sec | 1 sec |
| ***Payload Delivery*** | | | |

| Weight | Specification | Value |
|---|---|---|
| N/A | Compliance with CFR Part 135 (binary) | Yes |
| N/A | Compliance with FAA LAANC ATC (binary) | Yes |
| ***System Regulations*** | | |

| | | House of Quality | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Direction of Improvement | □ | ▼ | ▲ | ▲ | ▲ | ▼ | ▲ | ▲ | ▼ | □ | □ |
| Ranking | Normalized Weight | Customer Requirements | Compliance with FAA LAANC ATC directives | Fleet Loss Rate | Tracks distances from obstacles during entire flight | Flight Range | Variation in altitude, longitude and latitude | Maximum power draw | Flight Speed and acceleration | Payload weight, size and temperature regulation | Crash probability, speed and acceleration | Remote control with low latency | Ease of loading and unloading |
| 10 | 6% | Delivers packages at a faster and cheaper speed than ground shipping | 0 | 0 | 0 | 1 | 0 | -2 | 1 | -1 | -1 | 0 | 1 |
| 5 | 3% | Generates efficient routes and identifies landing sites automatically for safe delivery. | 0 | 0 | 1 | 2 | 1 | -1 | 0 | 0 | 0 | 0 | 0 |
| 6 | 3% | Can hold and lift multiple medium-sized packages. | 0 | 0 | 0 | -1 | 0 | -1 | 0 | 2 | 0 | 0 | 2 |
| 9 | 5% | Can takeoff and land vertically, and hover in place. | 0 | 0 | 0 | 0 | 2 | -2 | 1 | -1 | 0 | 0 | 0 |
| 10 | 6% | Does not collide with terrain, buildings, wildlife, or people and avoids restricted airspaces | 2 | -2 | 2 | 1 | 2 | 0 | 2 | -1 | 2 | 1 | 0 |
| 10 | 6% | Regularly transmits its telemetry data to air traffic control centers and company network operations centers. | 2 | 0 | 0 | 0 | 2 | -1 | 0 | 0 | 0 | 2 | 0 |
| 4 | 2% | Requires minimal maintenance and charging downtime | 0 | 1 | 0 | -1 | 0 | 1 | 0 | 0 | -2 | 0 | 0 |
| 9 | 5% | Resists external damage due to weather or stresses. | 1 | 0 | 2 | -1 | 2 | 0 | 2 | 0 | 2 | 0 | 0 |
| 8 | 4% | Has the range to bridge the last mile gap between distribution centers and consumer households. | 1 | 0 | 0 | 2 | 0 | -1 | 0 | -1 | 0 | 0 | 1 |
| 6 | 3% | Protects itself and its cargo from criminal activities, such as hacking, vandalism, or theft. | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 2 | 1 |
| 7 | 4% | Operates normally in mild precipitation and winds; quickly and safely returns to base during severe weather conditions. | 0 | 1 | 1 | 1 | -1 | -1 | 0 | 2 | 1 | 0 | 0 |
| 8 | 4% | Can be interfaced, stopped, and deactivated by police and rescue authorities. | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 10 | 6% | Retains the option to be piloted by a remote, manual operator. | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| 7 | 4% | Is visible during the day and night to individuals on the ground. | 1 | 0 | 0 | 2 | 1 | -1 | 0 | 0 | 1 | 1 | 0 |
| 3 | 2% | Can be interfaced by individuals with visual or auditory disabilities. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 178 | 1 | Absolute Value Sums | 14 | 12 | 14 | 14 | 12 | 15 | 12 | 12 | 12 | 12 | 12 |
| | | Sums | 14 | 8 | 12 | 12 | 12 | -11 | 12 | 12 | 12 | 12 | 12 |
| | | Importance Rating Sum (Importance x Relationship) | 0.662921348 | 0.5 | 0.539325843 | 0.539325843 | 0.47752809 | 0.584269663 | 0.47752809 | 0.47752809 | 0.47752809 | 0.47752809 | 0.47752809 |
| | | Relative Weight | 1 | 4 | 3 | 3 | 5 | 2 | 5 | 5 | 5 | 5 | 5 |
| | | Our Product | | | | | | | | | | | |

# House of Quality

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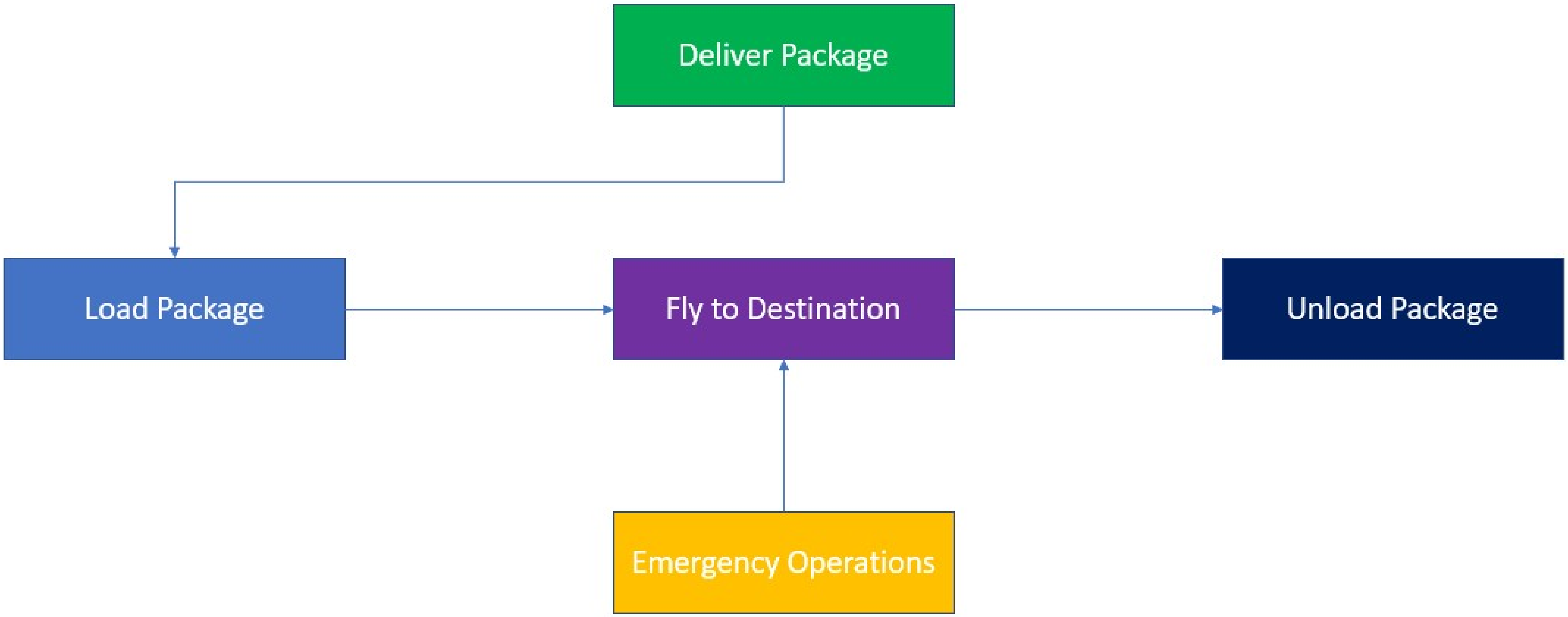
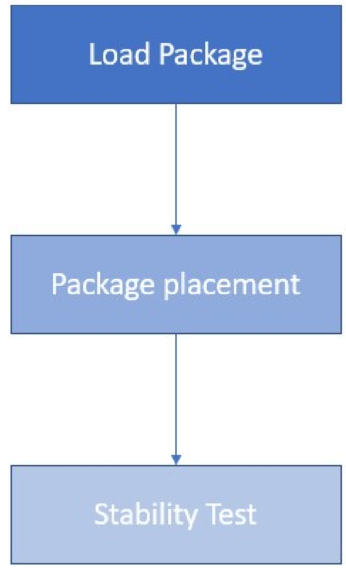
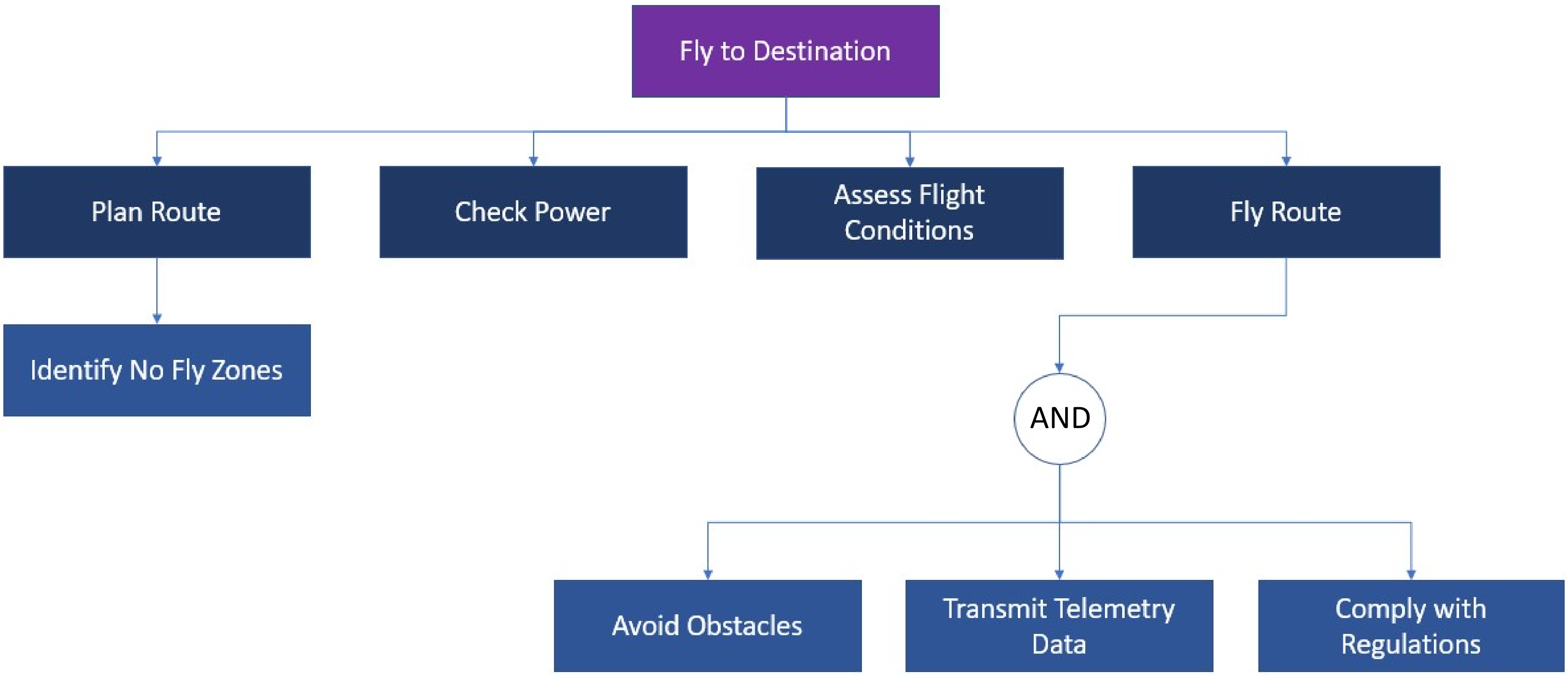
# Functional Analysis

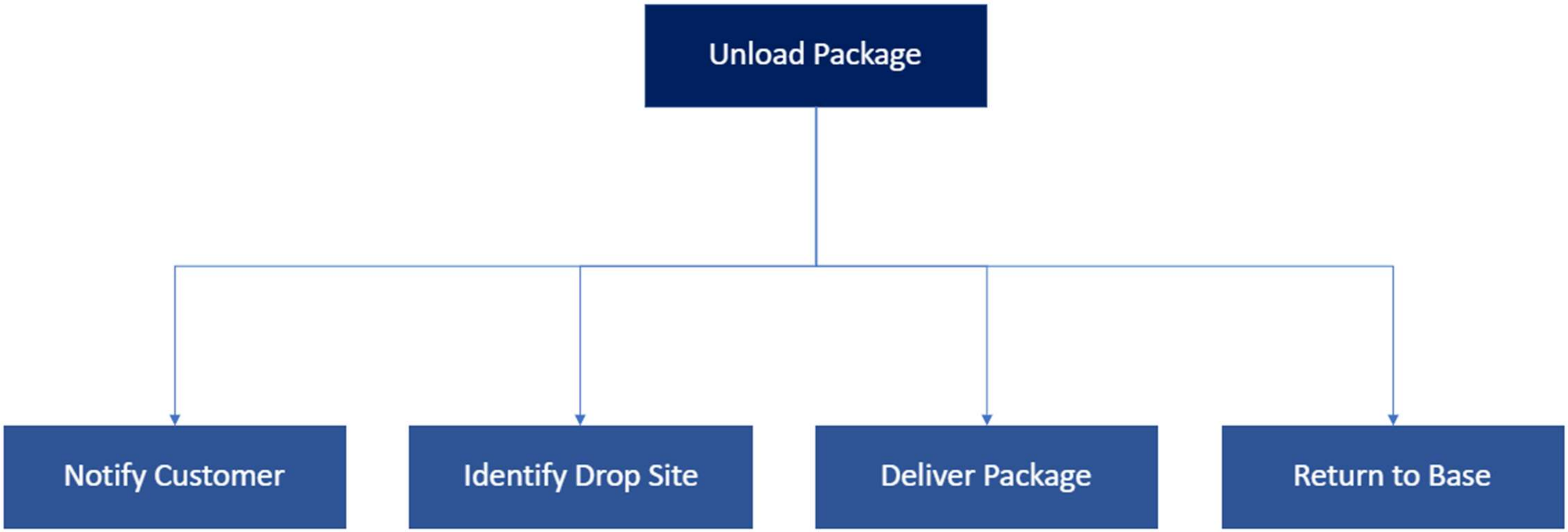





# Load Package Function




# Fly to Destination Function




# Unload Package Function

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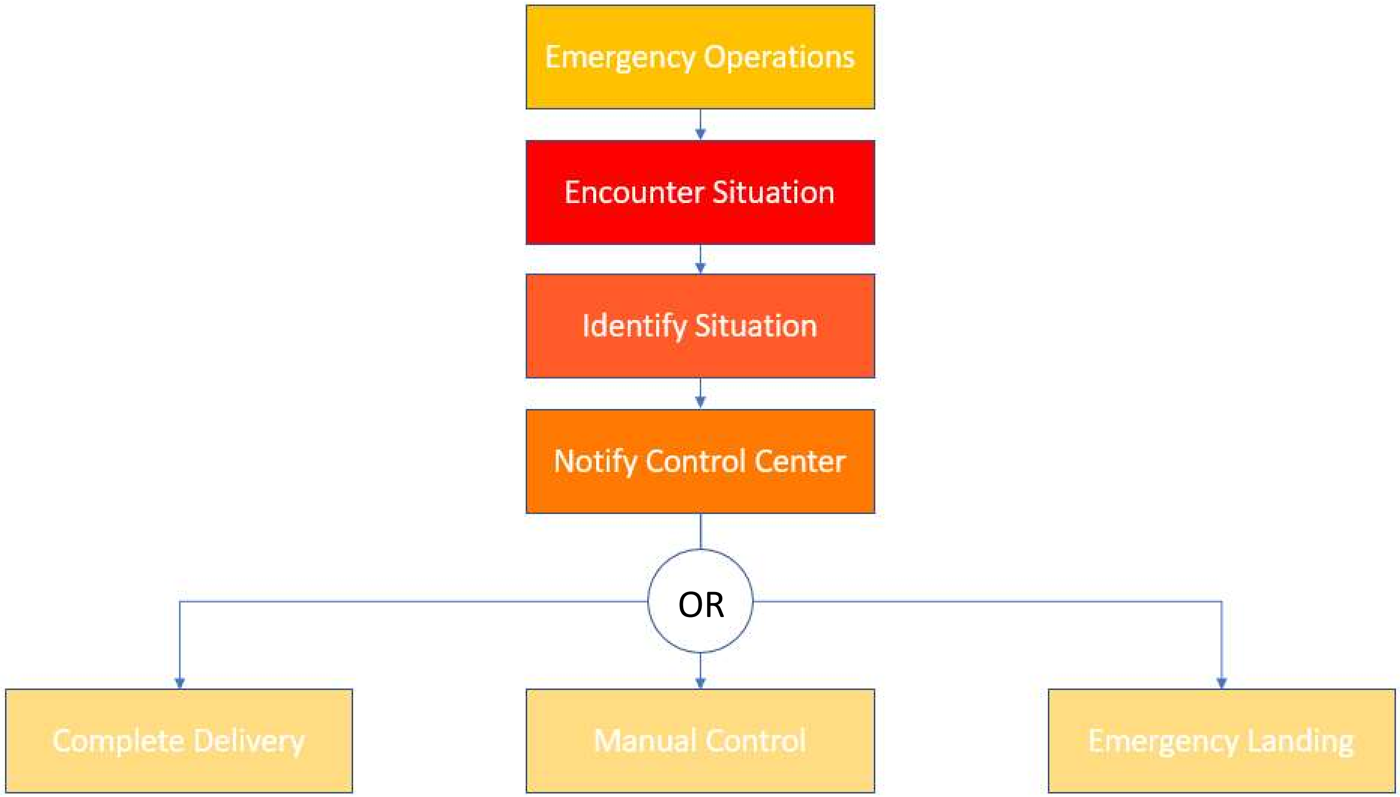


# Emergency Operations Function

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# Concept Generation – Vehicle Configuration

**Multicopter**

Industry baseline; common, affordable, and proven vehicle design

**Forward and Vertical Props**

Combination of forward engines for cruise and vertical engines for takeoff and landing

**Tiltrotor**

Directional propellers reduces the number of necessary engines

# Concept Generation – Vehicle Configuration

**Catapulted Fixed-Wing**

Assisted takeoff accommodates heavier payloads while fixed-wing plane improves range

**Helicopter**

Relatively simple, inexpensive, and developed vehicle design

**Coaxial and Pusher**

Tested, fast, less complex to control


**Modular Multicopter**

Modular engine and battery pods allow operators to tailor vehicle configuration to payload

# Concept Generation – Vehicle Configuration

**Blimp**

Small, autonomous blimps allow very precise delivery


**Rocket**

Reusable, guided rockets offer very fast delivery

**Santa**

Peak Performance

| Criteria | Baseline Multicopter | Forward & Vertical Props | Tiltrotor | Plane Catapult | Modular Multicopter | Traditional Helicopter | Coaxial Rotors & Push Prop | Rocket | Santa | Blimp |
|---|---|---|---|---|---|---|---|---|---|---|
| **Speed** | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | -1 |
| **Cost** | 0 | -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 |
| **Range** | 0 | 1 | 1 | 1 | 0 | -1 | -1 | 1 | 1 | 1 |
| **Safety** | 0 | 1 | -1 | -1 | -1 | 0 | 0 | -1 | 1 | -1 |
| **Durability** | 0 | -1 | -1 | 0 | 1 | 1 | -1 | -1 | 1 | -1 |
| **Delivery Capability** | 0 | 0 | 0 | -1 | 0 | 0 | 0 | -1 | 1 | -1 |
| **Payload Capacity** | 0 | 1 | 0 | 1 | 1 | -1 | -1 | 1 | 1 | 1 |
| **Maneuverability** | 0 | 1 | -1 | -1 | 0 | -1 | -1 | -1 | -1 | -1 |
| **Score** | 0 | 3 | -2 | 1 | 0 | -3 | -4 | -2 | 4 | -4 |
| **Rank** | 4 | 2 | 6 | 3 | 4 | 8 | 9 | 6 | 1 | 9 |
| **Continue?** | Yes | Yes | Yes | Yes | Yes | No | No | No | Busy | No |

# Concept Selection – Iteration 1
# Vehicle Configuration

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# Vehicle Configuration: Concept Changes


Tailsitter

Santa

Helicopter

Blimp

Rocket

| Criteria | Weight | Regular Multicopter | Forward & Vertical Props | Tiltrotor | Plane Catapult | Modular Multicopter | Tailsitter |
|---|---|---|---|---|---|---|---|
| **Speed** | 0.13 | 2 | 4 | 5 | 5 | 1 | 3 |
| **Cost** | 0.17 | 4 | 2 | 1 | 2 | 2 | 3 |
| **Range** | 0.13 | 3 | 4 | 4 | 5 | 3 | 4 |
| **Safety** | 0.21 | 4 | 5 | 2 | 3 | 3 | 2 |
| **Durability** | 0.08 | 3 | 2 | 1 | 3 | 4 | 3 |
| **Delivery Capability** | 0.17 | 4 | 4 | 4 | 1 | 4 | 3 |
| **Payload Capacity** | 0.08 | 3 | 4 | 4 | 5 | 4 | 3 |
| **Maneuverability** | 0.04 | 4 | 5 | 3 | 2 | 4 | 1 |
| **Score** | | 3.46 | 3.75 | 2.92 | 3.13 | 2.96 | 2.83 |
| **Rank** | | 2 | 1 | 5 | 3 | 4 | 6 |
| **Continue?** | | No | Yes | No | No | No | No |

# Concept Selection – Iteration 2
# Vehicle Configuration

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# Concept Generation – Payload Delivery

**Landing**

Current standard; common and proven delivery method


**Tether**

Lowering packages on ropes mitigates safety concerns of landing

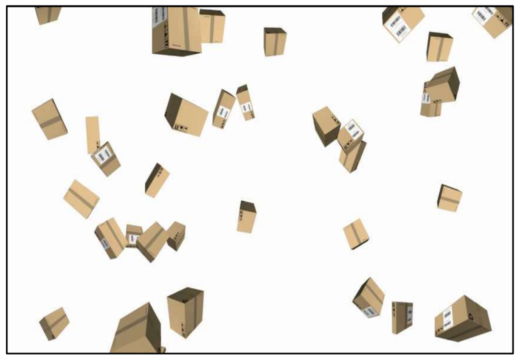
**Parachute**

Reusable parachutes offer relative simplicity and speed

# Concept Generation – Payload Delivery

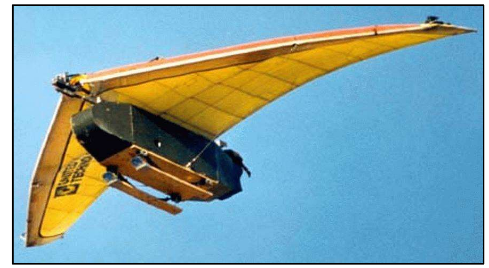
**Robotic Arm & Claw**

Precise control over package placement improves delivery convenience



**Drop**

Simplicity of aerial release reduces added vehicle weight



**Glider**

**Booster**

| Criteria | Baseline Landing | Drop | Parachute | Tether | Glider | Booster | Robotic Arm & Claw |
|---|---|---|---|---|---|---|---|
| Speed | 0 | 1 | 1 | 1 | 1 | 1 | -1 |
| Cost | 0 | 1 | 1 | 1 | -1 | -1 | -1 |
| Safety | 0 | -1 | -1 | 1 | -1 | -1 | 1 |
| Power | 0 | 1 | 1 | -1 | 1 | -1 | -1 |
| Payload Weight | 0 | -1 | -1 | 1 | -1 | -1 | -1 |
| Payload Size | 0 | -1 | 1 | -1 | -1 | -1 | -1 |
| Delivery Accuracy | 0 | -1 | -1 | -1 | -1 | -1 | 1 |
| Delivery Convenience | 0 | -1 | -1 | 0 | -1 | -1 | -1 |
| Score | 0 | -2 | 0 | 1 | -4 | -6 | -3 |
| Rank | 2 | 4 | 2 | 1 | 6 | 7 | 5 |
| Continue? | Yes | Yes | Yes | Yes | No | No | No |

# Concept Selection – Iteration 1
# Payload Delivery

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# Payload Delivery: Concept Changes

**Robotic Arm & Claw**

**Booster**

**Glider**

| Criteria | Weight | Landing | Drop | Parachute | Tether |
|---|---|---|---|---|---|
| **Speed** | 0.17 | 1 | 4 | 3 | 2 |
| **Cost** | 0.04 | 2 | 4 | 1 | 3 |
| **Safety** | 0.21 | 2 | 1 | 3 | 4 |
| **Power** | 0.04 | 1 | 3 | 4 | 2 |
| **Payload Weight** | 0.13 | 3 | 2 | 1 | 4 |
| **Payload Size** | 0.08 | 3 | 2 | 1 | 4 |
| **Delivery Accuracy** | 0.21 | 4 | 1 | 2 | 3 |
| **Delivery Convenience** | 0.13 | 4 | 1 | 2 | 3 |
| **Score** | | 2.67 | 1.92 | 2.21 | 3.21 |
| **Rank** | | 2 | 4 | 3 | 1 |
| **Continue?** | | No | No | No | Yes |

# Concept Selection – Iteration 2
# Payload Delivery

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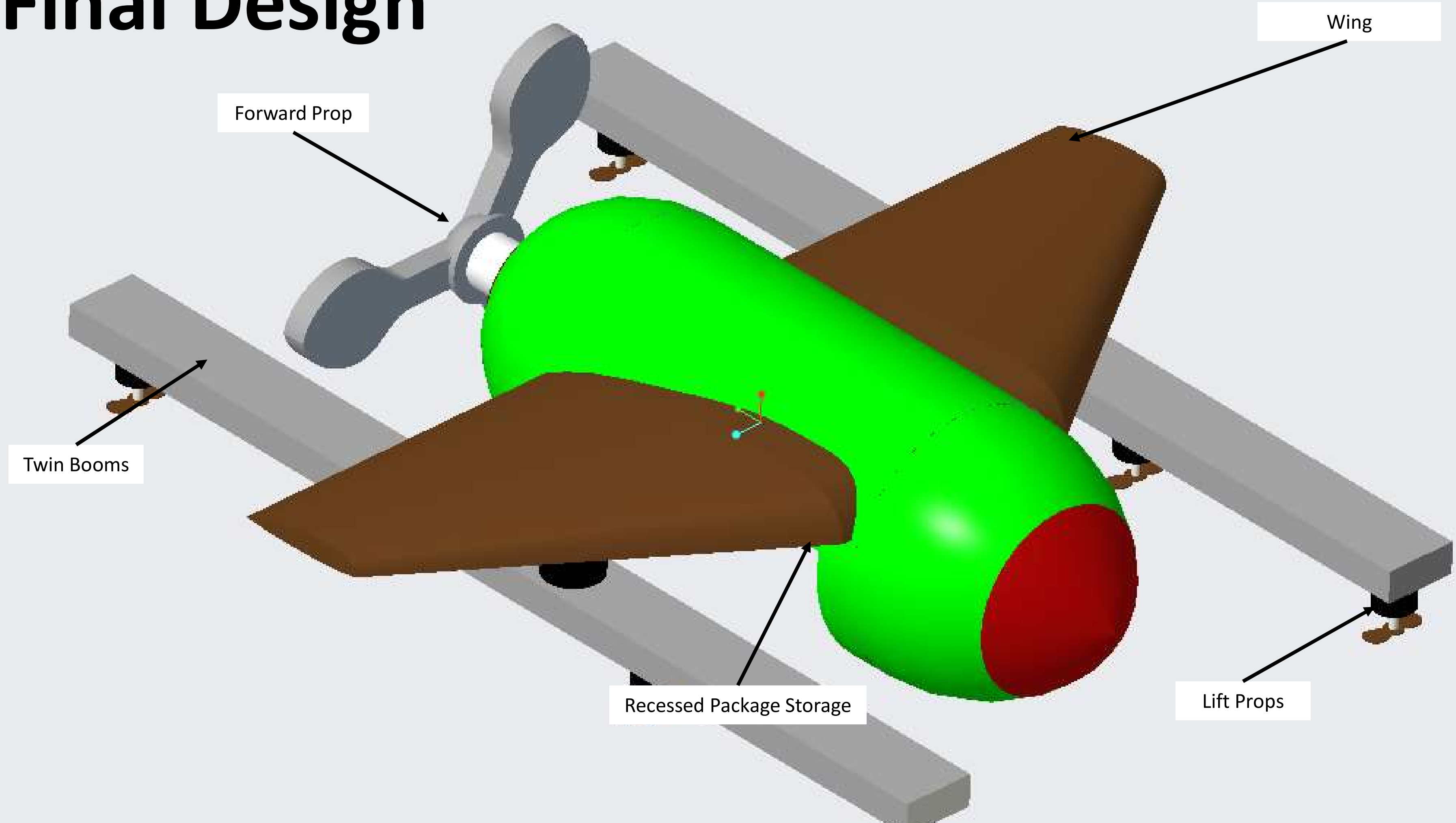
# Final Design



# FMECA

| ID | Purpose | Failure Modes | Failure Mechanism | Failure Detection | Failure Compensation | Failure Effects | Risk Level (1-Low, 5-High) | Severity | Preventative Measures | Risk Score |
|---|---|---|---|---|---|---|---|---|---|---|
| Lifting Rotors | Vertical Takeoff/Hover | Broken Blade | Impact, overstress, fatigue | Flight control system | Redundancy, transition to gliding flight | Loss of lift in hover/vertical flight | 3 | 4 | Construct of sturdy material, frequent inspection | 12 |
| | | Motor Failure | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Flight control system | Redundancy, transition to gliding flight | Loss of lift in hover/vertical flight | 3 | 4 | Construct of sturdy material, frequent inspection | 12 |
| Propulsion Rotors | Forward/Reverse Thrust | Broken Blade | Impact, overstress, fatigue | Flight control system | Redundancy, transition to gliding flight | Loss of forward/reverse thrust | 3 | 2 | Construct of sturdy material, frequent inspection | 6 |
| | | Motor Failure | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Flight control system | Redundancy, transition to gliding flight | Loss of forward/reverse thrust | 3 | 2 | Construct of sturdy material, frequent inspection | 6 |
| Wings | Provide lift in forward flight | Structural failure | Impact, overstress, fatigue | Inspection | Transition to vertical flight | Loss of lift in forward flight | 2 | 3 | | 6 |
| Control surfaces | Control drone flight | Structural (control surface) failure | Impact, overstress, fatigue | Inspection | Usage of other control surfaces/lifting motors for flight control | Inability to control aircraft | 1 | 5 | Construct of sturdy material, frequent inspection | 5 |
| | | Failure of control surface actuator | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Inspection/Testing | Usage of other control surfaces/lifting motors for flight control | Inability to control aircraft | 2 | 5 | Frequent Inspection, Use reliable motors | 10 |
| | | Control surface binding | Lack of lubrication, warping of components | Inspection/Testing | Usage of other control surfaces/lifting motors for flight control | Inability to control aircraft | 2 | 5 | Testing in many conditions | 10 |
| Vision System | Detect and identify obstacles, delivery zones, landing zones | Failure to detect | Blocked line of sight, software failure | Inspection/testing | Redundancy | Loss of ability to avoid obstacles, deliver package, take off and land safely | 2 | 4 | Redundant systems, frequent inspection | 8 |
| Flight Control System | Direction of drone for naviation and safe flight | Navigation Failure | Software | Software testing and validation | Return to base, emergency landing | Loss of ability to find base, dropoff zone, or waypoints | 3 | 3 | Extensive testing | 9 |
| | | | Bad input | Input accuracy validation | Return to base, emergency landing | Loss of ability to find base, dropoff zone, or waypoints | 2 | 3 | Extensive testing | 6 |
| | | Control failure | Bad input from air data system | Air data system validation from redundant sensors | Redundancy, emergency landing | Loss of control | 3 | 5 | Frequent inspection of air data system | 15 |
| | | | Control software malfunction | Software testing and validation | Emergency landing | Loss of control | 3 | 5 | Extensive software validation | 15 |
| Power System | Provide power to flight control system and propulsive sources | Battery Failure | Chemical, impact | Voltage Sensor, Inspection | Redundancy | Loss of power in all systems | 2 | 5 | Use a reliable battery, swap batteries often | 10 |
| | | Power Distribution Failure | Wires severed | Voltage Sensors, Inspection | Redundancy | Loss of power in some or all systems | 3 | 4 | Frequent Inspection | 12 |
| Package Carrying System | Safely retain package, protect package from damage | Retention motor failure | Motor Failure | Inspection | Speed and Altitude Reduction, Emergency landing or return to base, redundancy | Uncomannded Release of Cargo | 3 | 4 | Frequent Inspection | 12 |
| | | Retention latch failure | Impact, overstress, fatigue | Inspection | Speed and Altitude Reduction, Emergency landing or return to base, redundancy | Uncomannded Release of Cargo | 2 | 4 | Frequent Inspection | 8 |
| | | Package container failure | Impact, overstress, fatigue | Inspection | Speed and Altitude Reduction, Emergency landing or return to base | Uncommanded Release of Cargo, Loss of cargo protection | 3 | 3 | Frequent inspection and replacement | 9 |
| Package Lowering Tether | Lower package to ground at a safe rate | Cable structural failure | Impact, overstress, fatigue | Inspection | | Uncommanded release of cargo | 2 | 4 | Frequent Inspection | 8 |
| | | Lowering Motor Failure | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Inspection | Use of ratchet mechanism to retain package, emergency landing | Uncommanded release of cargo | 3 | 4 | Frequent Inspection, Use reliable motor | 12 |
| | | Cable Ratchet Failure | Impact, overstress, fatigue | Inspection | Use of motor to secure package | Uncommanded release of cargo | 3 | 4 | Frequent Inspection | 12 |
| | | Hook Failure | Impact, overstress, fatigue | Inspection | Use of retention latches to restrain package, return to base | Uncommanded release of cargo | 2 | 4 | Frequent Inspection | 8 |
| | | Premature Package release | Altimeter failure, structural failure of release mechanism, release motor mechanism failure, software failure | Inspection | | Uncommanded release of cargo | 1 | 4 | Frequent Inspection, Testing of Altimeter and release software | 4 |

| ID | Purpose | Failure Modes | Failure Mechanism | Failure Detection | Failure Compensation | Failure Effects | Risk Level (1-Low, 5-High) | Severity | Preventative Measures | Risk Score |
|---|---|---|---|---|---|---|---|---|---|---|
| Lifting Rotors | Vertical Takeoff/Hover | Broken Blade | Impact, overstress, fatigue | Flight control system | Redundancy, transition to gliding flight | Loss of lift in hover/vertical flight | 3 | 4 | Construct of sturdy material, frequent inspection | 12 |
| | | Motor Failure | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Flight control system | Redundancy, transition to gliding flight | Loss of lift in hover/vertical flight | 3 | 4 | Construct of sturdy material, frequent inspection | 12 |
| Propulsion Rotors | Forward/Reverse Thrust | Broken Blade | Impact, overstress, fatigue | Flight control system | Redundancy, transition to gliding flight | Loss of forward/reverse thrust | 3 | 2 | Construct of sturdy material, frequent inspection | 6 |
| | | Motor Failure | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Flight control system | Redundancy, transition to gliding flight | Loss of forward/reverse thrust | 3 | 2 | Construct of sturdy material, frequent inspection | 6 |
| Wings | Provide lift in forward flight | Structural failure | Impact, overstress, fatigue | Inspection | Transition to vertical flight | Loss of lift in forward flight | 2 | 3 | | 6 |
| Control surfaces | Control drone flight | Structural (control surface) failure | Impact, overstress, fatigue | Inspection | Usage of other control surfaces/lifting motors for flight control | Inability to control aircraft | 1 | 5 | Construct of sturdy material, frequent inspection | 5 |
| | | Failure of control surface actuator | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Inspection/Testing | Usage of other control surfaces/lifting motors for flight control | Inability to control aircraft | 2 | 5 | Frequent Inspection, Use reliable motors | 10 |
| | | Control surface binding | Lack of lubrication, warping of components | Inspection/Testing | Usage of other control surfaces/lifting motors for flight control | Inability to control aircraft | 2 | 5 | Testing in many conditions | 10 |
| Vision System | Detect and identify obstacles, delivery zones, landing zones | Failure to detect | Blocked line of sight, software failure | Inspection/testing | Redundancy | Loss of ability to avoid obstacles, deliver package, take off and land safely | 2 | 4 | Redundant systems, frequent inspection | 8 |

# FMECA: Top Half

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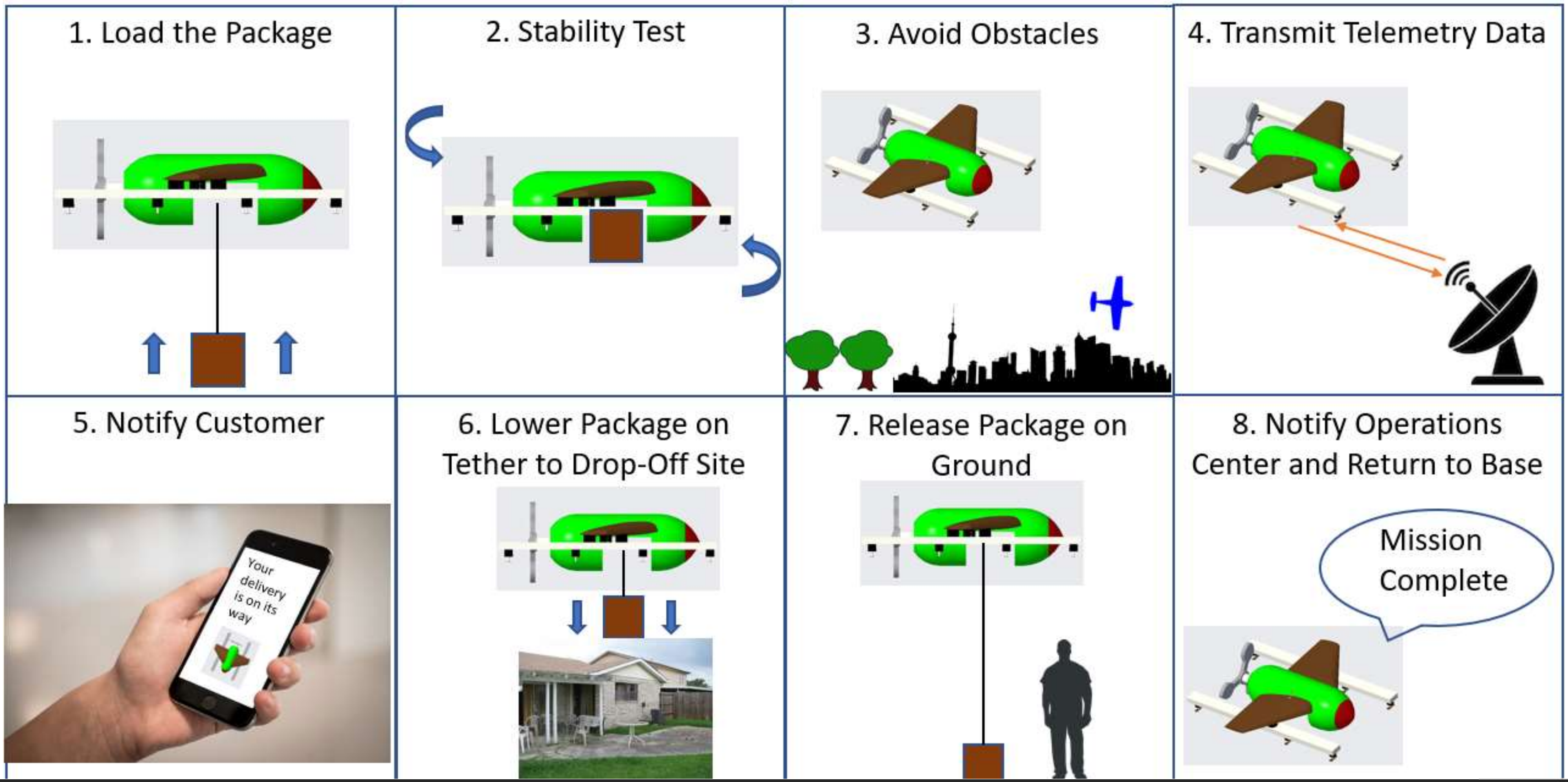
Regional Unmanned Delivery Of Light Packages to Homes

| ID | Purpose | Failure Modes | Failure Mechanism | Failure Detection | Failure Compensation | Failure Effects | Risk Level (1-Low, 5-High) | Severity | Preventative Measures | Risk Score |
|---|---|---|---|---|---|---|---|---|---|---|
| Flight Control System | Direction of drone for naviation and safe flight | Navigation Failure | Software | Software testing and validation | Return to base, emergency landing | Loss of ability to find base, dropoff zone, or waypoints | 3 | 3 | Extensive testing | 9 |
| | | | Bad input | Input accuracy validation | Return to base, emergency landing | Loss of ability to find base, dropoff zone, or waypoints | 2 | 3 | Extensive testing | 6 |
| | | Control failure | Bad input from air data system | Air data system validation from redundant sensors | Redundancy, emergency landing | Loss of control | 3 | 5 | Frequent inspection of air data system | 15 |
| | | | Control software malfunction | Software testing and validation | Emergency landing | Loss of control | 3 | 5 | Extensive software validation | 15 |
| Power System | Provide power to flight control system and propulsive sources | Battery Failure | Chemical, impact | Voltage Sensor, Inspection | Redundancy | Loss of power in all systems | 2 | 5 | Use a reliable battery, swap batteries often | 10 |
| | | Power Distribution Failure | Wires severed | Voltage Sensors, Inspection | Redundancy | Loss of power in some or all systems | 3 | 4 | Frequent Inspection | 12 |
| Package Carrying System | Safely retain package, protect package from damage | Retention motor failure | Motor Failure | Inspection | Speed and Altitude Reduction, Emergency landing or return to base, redundancy | Uncomannded Release of Cargo | 3 | 4 | Frequent Inspection | 12 |
| | | Retention latch failure | Impact, overstress, fatigue | Inspection | Speed and Altitude Reduction, Emergency landing or return to base, redundancy | Uncomannded Release of Cargo | 2 | 4 | Frequent Inspection | 8 |
| | | Package container failure | Impact, overstress, fatigue | Inspection | Speed and Altitude Reduction, Emergency landing or return to base | Uncommanded Release of Cargo, Loss of cargo protection | 3 | 3 | Frequent inspection and replacement | 9 |
| Package Lowering Tether | Lower package to ground at a safe rate | Cable structural failure | Impact, overstress, fatigue | Inspection | | Uncommanded release of cargo | 2 | 4 | Frequent Inspection | 8 |
| | | Lowering Motor Failure | Temperature, contamination, over/under-supply of power, moisture, lack of lubrication (https://www.dfliq.net/blog/5-things-that-commonly-cause-electrical-motor-failures/) | Inspection | Use of ratchet mechanism to retain package, emergency landing | Uncommanded release of cargo | 3 | 4 | Frequent Inspection, Use reliable motor | 12 |
| | | Cable Ratchet Failure | Impact, overstress, fatigue | Inspection | Use of motor to secure package | Uncommanded release of cargo | 3 | 4 | Frequent Inspection | 12 |
| | | Hook Failure | Impact, overstress, fatigue | Inspection | Use of retention latches to restrain package, return to base | Uncommanded release of cargo | 2 | 4 | Frequent Inspection | 8 |
| | | Premature Package release | Altimeter failure, structural failure of release mechanism, release motor mechanism failure, software failure | Inspection | | Uncommanded release of cargo | 1 | 4 | Frequent Inspection, Testing of Altimeter and release software | 4 |

# FMECA Bottom Half




# Concept of Operations

Regional Unmanned Delivery Of Light Packages to Homes

# Financial Analysis – Inputs

| Cost Center | Model | | | Units |
|---|---|---|---|---|
| | Pessimistic | Realistic | Optimistic | |
| **Development** | | | | |
| Sensor Processing | 2500 | 2000 | 1500 | lines of code |
| Vehicle Control | 6000 | 5000 | 4000 | lines of code |
| Payload Weight | 5 | 10 | 15 | pounds |
| Empty Weight | 12.5 | 25 | 37.5 | pounds |
| Office Space | $ 1,500.00 | $ 1,000.00 | $ 500.00 | ($/month) |
| Engineer Wage | $ 10,000.00 | $ 8,210.00 | $ 7,500.00 | ($/month) |
| **Procurement** | | | | |
| Materials | $ 12,000.00 | $ 10,000.00 | $ 7,500.00 | ($) |
| Assembly | $ 6,000.00 | $ 5,000.00 | $ 3,500.00 | ($) |
| Data Storage | $ 750.00 | $ 500.00 | $ 250.00 | ($) |
| Factory Space | $ 2,000.00 | $ 1,500.00 | $ 1,000.00 | ($) |
| **Operation - Drone System** | | | | |
| Utility Rate | 33% | 35% | 40% | (% flying time per day) |
| Loss Rate | 10% | 5% | 3% | (% fleet lost per year) |
| Hazard Rate | 5% | 2% | 1% | (% fleet broken per year) |
| Discount Rate | 9% | 10% | 11% | (% financial return per year) |
| Speed | 50 | 55 | 60 | (mph) |
| Endurance | 0.75 | 1 | 1.25 | (hrs) |
| Power | 0.6 | 0.5 | 0.4 | (MW) |
| Electricity | $ 109.10 | $ 104.50 | $ 100.25 | ($/MWh) |
| Technician Wage | $ 33.92 | $ 29.12 | $ 26.90 | ($/hr) |
| Controller Wage | $ 44.58 | $ 37.98 | $ 34.62 | ($/hr) |
| Repair Factor | 15% | 10% | 8% | (% of price per repair) |
| Data Link | $ 1.25 | $ 1.00 | $ 0.75 | ($/hour) |
| **Operation - Truck Alternative** | | | | |
| Truck Economy | 6 | 8 | 12 | (mpg) |
| Truck Speed | 25 | 35 | 50 | (mph) |
| Truck Maintenance | $ 2.00 | $ 1.75 | $ 1.00 | ($/mi) |
| Gas Price | $ 3.43 | $ 3.07 | $ 2.66 | ($/gal) |
| Driver Wage | $ 31.43 | $ 27.83 | $ 17.92 | ($/hr) |

**Main Drivers:**

Costs:

- Equivalent Lines of Code
- Operating Weight and Payload Capacity

Savings:

- Gas Prices
- Truck Economy & Maintenance

*Discount Rate:* ***10%***

# Financial Analysis – Model

| *Realistic* | Annually | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Object | Relationship | | | | Costs | | | Year | Past Value | Present Value |
| | Coefficent | Exponent | Months | Engineers | Software | Hardware | Overhead | | | |
| VC Code | 74.37 | 1.71 | 98.24 | 8.19 | $ 806,587.99 | $ 117,500.00 | $ 98,244.58 | (1.00) | $ 1,022,332.57 | $ 1,124,565.82 |
| SP Code | 3.15 | 1.38 | | | | | | | | |
| Payload Weight | 8,000 | - | | | | | | | | |
| Empty Weight | 1,500 | - | | | | | | | | |

| *Realistic* | Daily | | | | | | | | | | Annually | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Performance | | Costs | | | | | Savings | | | Future Value | Present Value |
| | Availability | Usage (mi.) | Power | Overhead | Manager | Repair | Mechanic | Fuel | Truck | Driver | | |
| 1 | 100% | 462 | $ 438.90 | $ 8.40 | $ 319.03 | $ 285.60 | $ 254.34 | $ 177.29 | $ 808.50 | $ 367.36 | $ 17,108.56 | $ 15,553.24 |
| 2 | 97% | 448 | $ 425.38 | $ 8.14 | $ 309.20 | $ 276.80 | $ 251.11 | $ 171.83 | $ 783.59 | $ 356.04 | $ 14,901.97 | $ 12,315.67 |
| 3 | 94% | 434 | $ 412.27 | $ 7.89 | $ 299.68 | $ 268.27 | $ 247.74 | $ 166.54 | $ 759.45 | $ 345.07 | $ 12,847.32 | $ 9,652.38 |
| 4 | 91% | 421 | $ 399.57 | $ 7.65 | $ 290.44 | $ 260.01 | $ 244.26 | $ 161.41 | $ 736.05 | $ 334.44 | $ 10,935.76 | $ 7,469.27 |
| 5 | 88% | 408 | $ 387.26 | $ 7.41 | $ 281.50 | $ 252.00 | $ 240.68 | $ 156.43 | $ 713.38 | $ 324.13 | $ 9,158.88 | $ 5,686.94 |
| 6 | 86% | 395 | $ 375.33 | $ 7.18 | $ 272.82 | $ 244.23 | $ 237.02 | $ 151.61 | $ 691.40 | $ 314.15 | $ 7,508.74 | $ 4,238.49 |
| 7 | 83% | 383 | $ 363.77 | $ 6.96 | $ 264.42 | $ 236.71 | $ 233.27 | $ 146.94 | $ 670.10 | $ 304.47 | $ 5,977.83 | $ 3,067.57 |
| 8 | 80% | 371 | $ 352.56 | $ 6.75 | $ 256.27 | $ 229.42 | $ 229.47 | $ 142.42 | $ 649.45 | $ 295.09 | $ 4,559.07 | $ 2,126.84 |
| 9 | 78% | 360 | $ 341.70 | $ 6.54 | $ 248.38 | $ 222.35 | $ 225.61 | $ 138.03 | $ 629.44 | $ 286.00 | $ 3,245.75 | $ 1,376.52 |
| 10 | 75% | 349 | $ 331.17 | $ 6.34 | $ 240.72 | $ 215.50 | $ 221.72 | $ 133.78 | $ 610.05 | $ 277.19 | $ 2,031.54 | $ 783.25 |
| 11 | 73% | 338 | $ 320.97 | $ 6.14 | $ 233.31 | $ 208.86 | $ 217.78 | $ 129.65 | $ 591.26 | $ 268.65 | $ 910.44 | $ 319.10 |
| 12 | 71% | 327 | $ 311.08 | $ 5.95 | $ 226.12 | $ 202.42 | $ 213.83 | $ 125.66 | $ 573.04 | $ 260.37 | $ (123.19) | $ (39.25) |
| 13 | 69% | 317 | $ 301.49 | $ 5.77 | $ 219.15 | $ 196.19 | $ 209.86 | $ 121.79 | $ 555.38 | $ 252.35 | $ (1,074.70) | $ (311.30) |
| 14 | 67% | 308 | $ 292.21 | $ 5.59 | $ 212.40 | $ 190.14 | $ 205.88 | $ 118.04 | $ 538.27 | $ 244.57 | $ (1,949.13) | $ (513.27) |
| 15 | 65% | 298 | $ 283.20 | $ 5.42 | $ 205.86 | $ 184.29 | $ 201.90 | $ 114.40 | $ 521.69 | $ 237.04 | $ (2,751.24) | $ (658.62) |

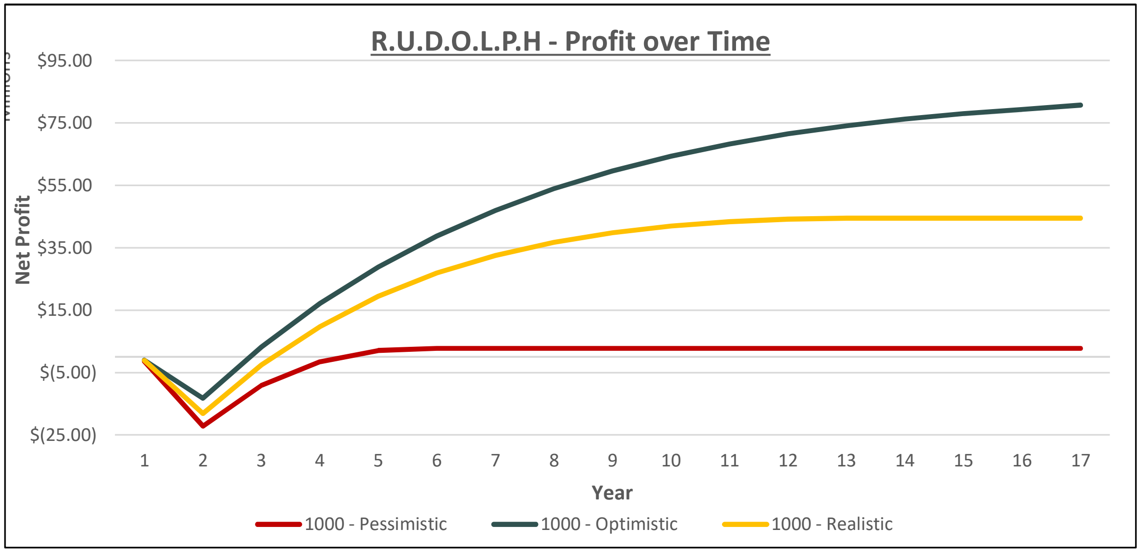
# Financial Analysis – Outputs

## Profitability Metrics:

- Break-Even Time: **3.04 years**
- Cost-per-Mile: **$2.82**

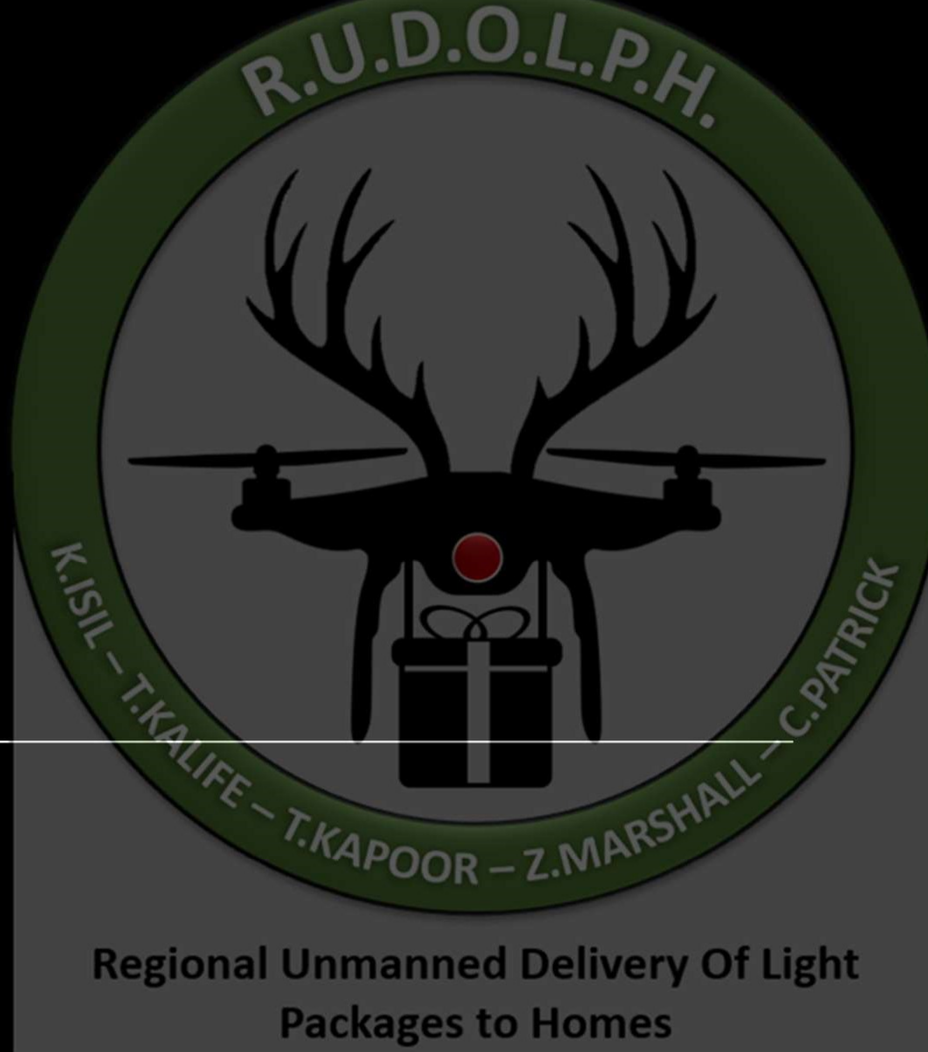
## Analysis Limitations:

- Regulatory & Insurance Costs
- Driver Estimates




| Summary | Pessimistic | Realistic | Optimistic | Year(s) |
|---|---|---|---|---|
| **Development** | $ 1,417,365.86 | $ 1,124,565.82 | $ 991,027.51 | -1 |
| **Procurement** | $ 20,750.00 | $ 17,000.00 | $ 12,250.00 | 0 |
| **Operation** | $ 24,904.74 | $ 62,589.28 | $ 93,661.05 | 1-15 |
| Net (per unit) | $ 4,154.74 | $ 45,589.28 | $ 81,411.05 | |

# Questions?


R.U.D.O.L.P.H.
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