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Final project	Master's thesis
Thesis title	Developing a drone delivery system for blood in Bangalore, India.
Programme	Global Systems Design
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Preface

This project is a master’s thesis finalizing the Global System Design (GSD) programme at Aalborg University in Copenhagen. The content of the thesis is based on my personal interest in UAS technology and its impact in commercial market in following years. It aims to prove feasibility of a drone delivery service supporting medical sector.

I would like to thank the CEO of Novatech Robo for granting me opportunities for pursuing exciting projects and for supporting me during the process of developing my thesis.

Abstract

Nowadays UAV technology is booming. More and more people start to recognize the potential of implementing the technology in commercial market.
Drones are flexible and can substitute variety of commercial activities.

After spending several months in India I have recognized opportunities for implementing drones for transporting critical commodities. Contact with a major hospital chain has been established and UAV technology demonstrations took place. Novatech Robo and me being a representative, have agreed on a 4 phases development plan. The agenda of the plan is to prove feasibility of the concept over time.

The thesis scope is based on phase I of the development and it focuses on proving that the drone solution is going to be cheaper and will not damage the cargo.
An understanding of the current ways of transporting was based on research, eventually leading to comparison of blood delivery between a major Manipal Hospital HAL and lesser facilities. The comparison resulted in gaining sufficient background information to propose an d design an alternative.

Thesis elaborates on different challenges that are associated with implementing UAS, as well as examples of implementation to come in future.
Primary data was gathered in form of interviews as it proved to be a productive approach. Preparing 2 integrated flow charts for existing service and the service to be provide a good overview of UAS practicality.

The third drone prototype finally described in this paper is going to be used for finalizing phase I of development in near future.

List of content.

i. Terms and abbreviations.

Aileron – surface controls responsible for roll axis
Airworthiness – a measure of an aircraft's suitability for safe flight
APM board – Ardupilot Mega flight controller board
BTS – Blood Transfusion Service
CEMILAC – Centre for Military Airworthiness and Certification
CG – Centre of Gravity
ConOps – Concept of Operations
CSR – Corporate Social Responsibility
DGCA – Director General of Civil Aviation
DMAIC – Define Measure Analyze Improve Control – LEAN framework
Elevator – surface controls responsible for pitch axis
ESC – Electronic speed controller
FAA – Federal Aviation Administration. USA based
GLONASS – Global Navigational System – developed by Russia.
GPS – Global Positioning System – developed by USA.
LAR – Lethal Autonomous Weapons
Loiter – mode for a rotary-wing UAV when it maintains its height and position
LOS – Line Of Sight
MEP – Member of European Parliament
MoD – Ministry of Defence
PBL – Problem Based Learning
RC – Remotely Controlled
RTL – Return To Land mode for UAV
Rudder – surface controls responsible for yaw axis
SAA – sense-and-avoid
SOP – Standard Operating Procedures
sUAS – small Unmanned Aerial Systems
UAS – Unmanned Aerial Systems
UAV – Unmanned Aerial Vehicle
VSM – Value Stream Mapping
VTOL – Vertical Take-Off and Landing

ii. Introduction.

India is an emerging country with enormous population of 1,29 billion people.
This results with a major traffic issues in most of the big cities. Due to this situation I recognized a need for optimizing blood components delivery system, which could potentially save people's lives.
For that reason I have come up with an idea to use autonomous drones for the purpose as a substitute medium of the current ways of blood delivery.

Also the UAS technology is booming and gaining more and more fans around the globe. Commonly known as drones – these flying unmanned vehicles are very versatile, cheap and efficient.

My thesis project aims to design an alternative delivery service system for blood from blood bank at Manipal HAL hospital – major central hospital, to other, lesser hospitals.
The solution will not only modernize current ways of transporting high priority cargo. It will be cheaper and more versatile and has great potential to be utilized in saving lives.

I have chosen Bangalore in South India to implement the service since it is a growing city considered to have one of the worst traffic jams in the whole country. Also the city is called "The Silicon Valley of India" and is a major IT hub with rapidly emerging startups. This gives me an advantage while approaching open-minded officials whose permission is required for implementing the drone solution.

iii. Research questions and problem statement.

How can UAS be applied for transportation of critical commodities from hospitals? What is the benefit case of using this technology from logistical and economical perspective? What are the challenges associated with implementing it?
Analysis of BTS delivery system at Manipal Hospitals in Bangalore, India.
Design and development of an alternative delivery system using UAS.

iv. Scope and delimitations.

The scope of my thesis project has been reshaping over the course of my research.
I had the idea of implementing UAS in delivery system aiding medical sector. However only after I have conducted my research and gathered information I finally shaped the clear concept.

I have approached Manipal Hospital high ranking doctors at an event. Aside of technology showcase which was main theme of the event, a blood camp was organized. I had a chance to talk about opportunities for using drones for transporting small volume cargo.

Afterwards I had arranged a meeting at Novatech Robo Pvt Ltd premises with heads of blood banks at Manipal and Fortis hospitals and presented stability of a hovering quadcopter. I presented myself as Novatech Robo representative and a student associated with Aalborg University in Copenhagen, which brought more interest to the cause.

After several discussions about the opportunities and restrictions we decided on a long-term development plan consisting of 4 phases.

Phase I includes primary tests of the UAV solution's feasibility. Blood samples will be transported to smaller hospitals from Manipal Hospital HAL.

The goal is to prove that a drone can transport biomaterial cheaper and deliver the cargo undamaged. The blood used will be meant only for testing – not for transfusion.

In second phase clinical trials will be introduced. A group of 100 volunteers will have transfused 1ml of blood each. The blood will be shipped by the next UAV prototype. This phase can be considered as a first trial to ensure safety. Also at this level of development the system will be designed to utilize the speed of the next drone.

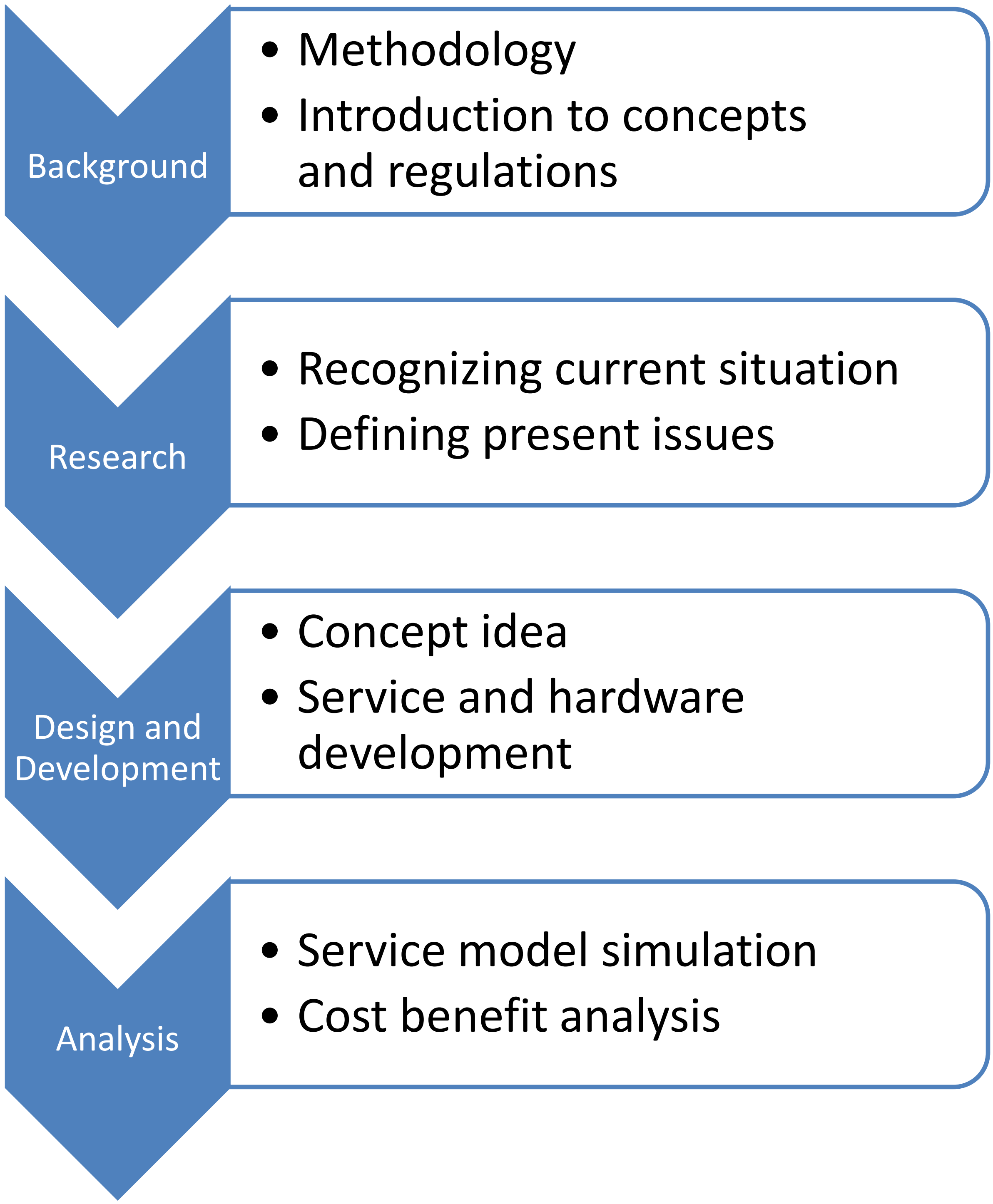
Phase III is when a whole unit of blood shipped by the drone is transfused to a single person. A successful proof of clinical trials on 100 people is required to move to next phase. Proving safety and feasibility in this phase gives a green light for a higher scale implementation involving more facilities and drones.

In the final phase an observation for 2 entire years has to be done to entirely prove that the drone solution is safe for cargo and patients.

Because of fact that the full development of the drone delivery service for critical commodities is going to be time consuming, I have narrowed the scope of this thesis to Phase I of development.

Also I have managed to design the new system and chose a drone for the first real transportation tests and conducted, however the time constraints and waiting time for testing permissions do not go in pair. The time didn’t allow me including the conclusive end of phase I in this paper.

v. Project structure.



1. Background.

1.1 Methodology.

a) Research section.

A set of chosen tools provides me with eventual strong understanding of common challenges with efficient deliveries in congested cities, and opportunities for process improvement via an alternative service system I am designing.

First of all I decided to go to a blood bank and gather overall information about demand for blood transfers and performance metrics and priorities.

Next, I used SIPOC tool as it gives a good overview of major business processes, without the need to get deep into all minor ones.

SIPOC is a graphic description of a business inputs and outputs that is very transparent.

For that reason I want to pair it up with the integrated flow chart.

I asked people responsible for managing orders to map integrated flow chart of a standard order from end2end perspective. Instructing them if needed in order to assure the mapping is done properly. Being certain no processes have been missed is vital for a proper analysis and eventually reaching the goal of this thesis.

Further I have gathered information about main performance metrics for blood delivery from the Manipal HAL hospital blood bank personnel was the group I focused on.

The hospital is planned to be the base of operations for the drone delivery service and the new service has to be crafted accordingly to that place and the available personnel.

I have allocated the feedback to 3 categories using KANO model.

b) Design and development section.

At the level when my initially formulated idea has been reshaped after VOC feedback analysis, I divided my focus both to hardware and system development.

Quadcopter development has been built upon service performance features defined by VOC.

A progression of 3 prototypes is described along with a description of principles of how do the quadcopters work, choice of quadcopter components, construction, tuning and Bill of Material for the final solution. Poka-Yoke mindset is present both in the construction and software.

When planning development of a new cheaper, innovative and user friendly service I focused on several things, while keeping business process efficiency in mind.

First I decided to think of new integrated flow chart. The priority was to make a significantly cheaper service, which will cover the demand. Lead time was of no priority at phase I development.

Integrated flow chart of To-Be system next to description of the processes owners, process durations and descriptions has additional information highlighting touch points and their types.

Further I decided on using one drone for the service opposing to 3 auto-rickshaws from the As-Is system. This way I reached satisfying resource utilization to ensure the investment is not bad.

I have prepared a SIPOC for To-Be situation, as I wanted to have a visually clear overall comparison of both - old and new models.

Next I have used 5S thinking to describe maintenance procedures for the quadcopter after every flight and overall Kaizen mentality in a base of operations workshop.
Further, thinking of Kaizen and Poka-Yoke concepts I came up with different fail proofing solutions for now and for future development. Also ideas regarding future desired ConOps are explained.

In the end I conducted a cost benefit analysis for both services to display financial advantages of my delivery service proposal.
The analysis includes initial investment and operation costs for 1 year to clearly display cost efficiency of drones.

1.2 Methods criticism and discussion.

Case study is an empirical inquiry providing analyzing a phenomenon. A mix of quantitative and qualitative research methods used to gather information from different sources for solving an identified problem. Using case study research allows me having a holistic understanding of the thesis problem and further display of its benefits. This concept is a flexible methodology tool that can be used across different fields. It forces people to take initiative and be creative with their approach.
However, too much flexibility can effect with confusion, overthinking and using wrong methods which do not bring any value.

Also I am familiar with Problem Based Learning after using the approach during my education at AAU Copenhagen, and I prefer it over the project based learning, where methods and content are fixed by

I believe that DMAIC framework would be beneficial in implementation. Some chapters of this thesis could be placed within DMAIC, however I chose to abandon the idea due to the scope of this paper. The framework is utilized the best when observed processes can be measured for a long time.

Setting, measuring and analyzing KPIs is a vital, yet long process. Also the part – "Control" of the framework requires monitoring processes over time after implementation. A larger sample has to be collected to give an educated review of the processes efficiency.

When gathering all data I could have chosen different approaches.
Surveying is a good method to gather quantitative data. Feedback about customers and their deeper feelings and emotions is what can be retrieved from this source of data.

I thought about preparing a questionnaire, which can be very useful. However a large sample is required to have results of any worth and the people involved in the new UAS delivery solution are a small group for now.

Instead I chose to interview several medical staff members at Manipal Hospital HAL. Even though the majority of people in the hospital speak fluent English it can be hard for some to express their wants and different preferences clearly enough for me to define the real issue.
I have encountered this situation while asking what integrated flow of delivery service processes and not being confident whether every step is included.

Personal informal interviews were a good choice for me from the outsider point of view. The people I talked to became more relaxed and interested when I told them about myself and the project. Also I could feel the appreciation of my face-to-face approach, since I noticed everyone being eager to explain to me the procedures and timings of a normal blood delivery.

Another observation of mine – after initial positive conversation it was much easier to define their wants for a satisfying service and about key performance metrics. This is something that I naturally encounter in India and thus my methods and approach to things has to adapt to different circumstances.

Choice of interviewing individuals instead of doing a Gemba Walk was significantly more efficient. The information gathered was coherent from one individual to another, thus after talking to 2 clinicians, 3 technicians, 1 wardboy and 2 auto rickshaw drivers I granted it as legitimate data.

Finding root causes of an existing problem, like generating waste, is the fundament of improvement. The fishbone chart: 5 Whys chart is a tool used for that and it brings greatest effects when brainstorming.

However I feel that tool will be unnecessary. Interviews ensured me that the root problems are obvious. The goal of my project automatically deals with these root problems, thus I relied on the interviews.

At the very beginning of the thesis development I assumed I will finish my thesis with simulating the system model in Arena software.

Arena is a powerful tool for including external factors based on sheer chance. It would have been valuable, but since there is only 1 drone in the model the plan seems unworthy to pursue due to its simplicity. If at some point a moment will come when the concept will grow into a more sophisticated and complex system, the Arena simulation will be a necessity verifying the real flow and its efficiency.

Next it is important to mention that part of my project involves experimental approach on defining stability settings for different UAVs.
The tests have been described and observations noted. Also I have highlighted the progression data in a table and a figure in the UAV development section.

Finally I think that SIPOC analysis is not vital for this thesis. However I remained with it, because of its clear overview of a business and can be useful for the reader.

Concluding the methodology I have researched in major part qualitative data.
Quantitative data is also present – I have gathered information about costs and time of each process.
Both case study and experimental approaches were present in this thesis.

1.3 Sources and literature review.

There are many sources of information that I have been using to prepare this project thesis.
The majority of knowledge about hardware was acquired over-time from number of forums, online videos, articles and academic projects.

The UAS are still waiting for their moment to bloom and rapidly penetrate commercial market. Due to this fact as for today there is a limited amount of legitimate academic sources about drones in comparison to informal casual forums.

Using forums and reading about drone hobbyists’ experiences, gave me some ideas about hardware I should test in future and overall concepts that might be useful. Those were helpful, as many people relate to other more comprehensive articles, which support some statements

However in general forums are an informal and unreliable source of knowledge. Several times while working with hardware I realized that information upon which I built some assumptions were wrong. I consider this logical that data collected from such source should not be taken for granted and requires verification.

The methodology framework I have prepared to finish my thesis was based in major part on course materials gathered during GSD programme. The book “LEAN Six Sigma process improvement tools and techniques” was my main source of theory. It contains academic content that can’t be questioned, hence I consider it as a perfect study supporting material.

I have also used two academic projects – a research paper on UAS applications produced by two Ukrainian nationals and a cost/benefit analysis of the Amazon Prime Air service also containing application section. Those are projects verified by professors, hence I consider these sources legitimate.

The articles I have studied differed one from another. Some of them seemed were written in very informal manner, yet included content expressed by reasonable people – Electronics and mechanical engineering professors, doctors etc. I have kept a reasonable amount of skepticism, while covering those materials. The benefit of getting familiar with several of such sources allowed me assessing all the contents and the data quality.
Articles from Forbes or American Express described some different applications of drones, yet to a basic extent.
Especially reading an article about Amazon Prime Air made me very skeptical. I have agreed with Amazon's idea to categorize complexity of ConOps for drone commercial applications, yet the closest ideas of implementation seem slightly impractical for me and for a small group of people.
While reading the material for the first time I had an impression that the content is biased and most likely sponsored for reaching desired response from public opinion.

Lastly I have gathered information about BTS standards from an official document "Standards of Blood Banking & Blood Transfusions Services". This document is supposed to be a guide line for any BTS activities on the territory of India. I have consulted some of the content with medical staff at Manipal Hospital HAL, to learn how are the regulations followed.

1.4 Blood banks in India[1].

Some blood banks are standalone buildings, while others are a part of a hospital and have designated area. No matter which kind they are, both have the same activity which is professionally called Blood Transfusion Services. BTS includes donor management, storage of blood, grouping and cross matching, testing for diseases, distribution etc.

According to Dr. Zarine S. Bharucha – coordinator at Technical Resource Group for Blood Safety, BTS is highly decentralized in India and vital resources are missing. Because of different standards from state to state and even between centres in the same city, quality standardization is a tough challenge. Because of this there is a need for creating quality consciousness among medical staff. Technical Resource Group is responsible for a set of comprehensive standards that are meant to bring paradigm change in BTS in India.

1.5 Manipal Hospitals and Oxymed Hospital Private Limited[2].

Manipal Hospitals is a major healthcare brand in South India. It is the country's third largest healthcare group with 15 facilities providing variety of medical care.
Manipal Hospitals have existed for past 50 years and over this time they grew to be a modern, well-prospering hospital chain with state-of-art equipment and highly experienced professionals.

[1] Standards for Blood Banks and Blood Transfusion Services, National AIDS control organization, Ministry of Health and Welfare, Government of India, New Delhi, 2007.
[2] https://www.manipalhospitals.com/about-us/

Manipal Hospital HAL is the flagship major facility of Manipal Health Enterprises, located in the heart of Bangalore. It has been established in 1991 and provides care in over 60 specialties.
I have chosen to establish a base of operations for the new drone delivery service system in this hospital, as it frequently sends blood samples to other facilities for testing and experiments.

The brand takes pride in its state-of-art equipment and modern procedures, thus introducing drones to them was exciting. High ranking doctors expressed their interest for modernizing deliveries with UAS

Manipal Northside Hospital was established in 1994 in the West North of Bangalore. The hospital caters to residents with a capacity of 83 beds. Their focus is on Gynaecology, Orthopaedics and General Medicine. However Manipal Northside Hospital was interested to test the drone solutions, because they also want to test samples from the outside.

Dr. Malathi Manipal Hospital is a relatively new hospital launched in 2008 in South Bangalore. The profile of this particular facility is secondary care for locals. Focus departments are Mother & Child Care, Intensive Care and General Surgery.

Oxymed Hospital Pvt Ltd[3] is a chain of hospitals that promote advanced non-invasive medicine for low costs. Established in 2000 and collaborating with Vasomeditech and American College of Advanced Medicine (ACAM), Oxymed brand is familiar with innovative ideas and are willing to join the drone trials.

1.6 Novatech Robo Pvt Ltd[4].

Novatech Robo has been established in 2012 by its current CEO – Imtiaz I. Khan. The company has been started with collaboration of associates in USA and Japan.
The organization is primarily focused on spreading awareness of robotics and providing trainings in robotics to variety of people.

Novatech Robo conducts Robofest international robotics competition for students, creating opportunities for rich and poor. This brings a sense of competitiveness, appreciation of practical knowledge and ambition to young people.

The education activities are the ones that generate income for the company. The majority of investments within the organization is R&D.
New product ideas are being developed along with projects requested from individual customers. Another R&D projects being invested in is developing a drone for shipping critical commodities in congested cities. It is among the most exciting projects and I am happy to be in charge of that.

[3] http://www.oxymedhospital.in/index.php

[4] www.novatechrobo.com

The entire idea for the whole UAV blood delivery concept was built not upon a goal of profit, but on wish to utilize modern solutions for enhancing BTS.

Altruistic stance of an organization earns positive perception from the publicity, which creates space for more implementations.

1.7 UAVs: definition, classification and technology.

1.7.1 UAV: definition.

Unmanned Aerial Vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot aboard. Drone technology can be also referred to as Unmanned Aerial Systems (UAS). They are becoming increasingly popular due to their flexibility and ease of traveling to places unreachable for humans.

Further in the chapter propeller based drones will be described. Jet-based UAVs are not within the scope of this project.

1.7.2 UAVs classification.

There are several ways of drone classification, however general distinctions can be done according to different control types, physical setup types and categories based on UAV's designation.

1.7.2.1 Flight control types.

First type of control is Remote Control (RC) for UAVs. This is the most common way to control such devices both in military and civil sectors.
Especially in civil – entertainment sector where pilots are flying various drones for fun, the ability to directly control them creates the excitement.

Second type is autonomous UAVs. Autonomy means device's ability to move on its own in 3 dimensional space without collision and to avoid potential obstacles.

When talking about an autonomous flying vehicle it is important to discuss several components required for achieving autonomy.

a) Obstacle avoiding.

Obstacle avoiding, or sense-and-avoid (SAA) is based on sensors detecting proximity, or objects.
Such can be as simple as implementing basic ultrasonic sensors, or sonar to detect proximity to a surface.

This feature of autonomy can be more sophisticated in terms of technology. Machine vision is an amazing advanced tool for such purpose.

A good example of machine vision for aeronautics is optical flow camera which recognizes movement vectors and speed of several moving or non-moving obstacles.

Such is a non-collaborative SAA concept. As the name suggests it involves focusing on only one vehicle moving autonomously without information exchange, or collaborating with other vehicles in the area.

A collaborative SAA is an ultimate goal for all UAS. In this concept a V2V network would be established and developed to a level, where high density of drones can travel in airspace in harmony and efficiently in terms of flow.

b) Sensor fusion.

Having uncountable amount of technology on an UAV is worthless, unless appropriate sensor fusion is implemented. Drones are a purpose-built devices. A set of sensors for the task has to be implemented. Depending on the designation different sensors can be used. Anything – starting from thermal imaging, temperature or pressure readings till mapping open and contained areas.

c) Communications.

Sensor fusion has to be programmed to work efficiently. A device needs a proper communication between sensors uploaded.
With implementation algorithms for different avoidance scenarios high level of autonomy can be reached.

d) Path planning.

Shortest way between point A and B is a straight line. However if terrain topography, no-fly zones and several activities in different places need to be taken, path planning has to be able to combine all that information for drawing an optimal and safe route.

e) Trajectory generation.

Once a path is ready all maneuvers during flight duration need to be prepared. Those don’t involve obstacle avoidance.
Information off most efficient take-off, cruise and landing specifics is generated.

1.7.2.2 Setup types.

Another way to classify drones is according to their physical setup. There are 3 general distinctions to discuss. Each of them has different pros and cons which essentially determine practical aspects of these setups.

Fixed-wing setup.

UAVs with fixed-wing setup are very familiar to everyone from their appearance. Airplane is an example of a fixed wing vehicle.

The way such vehicles achieve flight is based on their aerodynamic shape. Forward thrust is provided by one or several motors. Once enough force is generated aircrafts wings generate lift.

In order to position a vehicle in a proper angle of attack, control surfaces on the wings and tail are used to vector airflow.

Control surfaces and maneuverability they provide:

a) Rudder - positioned at the tail of an aircraft and it allows yaw axis movement.
b) Elevator - positioned at the tail of an aircraft and it allows pitch axis movement.
c) Aileron - positioned at the back of the wing airfoil and it allows roll axis movement.

Fixed-wing setup pros.

a) Less complicated maintenance

Because of less complicated construction fixed wing drones are easier and cheaper to service. One more motors used for generating thrust and control surfaces moved by servo motors are the elements that require maintenance.

b) Aerodynamic construction.

Aerodynamic shape of an aircraft causes generating less drag, because it is “cutting the air”.

c) Longer flight duration.

Flight duration is related to the previous point. Generating lift from the wings and essentially having ability to glide to some extent, reduces battery consumption.

d) High speed.

Speed is a second aspect of a fixed-wing setup positively affected by aerodynamics. It has the best possible body shape for reaching high speeds, because of the smallest amount of drag created.

Fixed-wing setup cons.

a) Necessity for a runway, or a launcher to take off – The setup needs space to be able to ascend and descend. Because of this the such UAVs are completely impractical in confined spaces.

b) Forward motion required to generate lift – A need for constantly moving forward affects flexibility of fixed wing UAVs. There are many uses of drones that require ability to hover steady in a specific location. Such performance is unavailable for this setup.

Rotary-wing setup.

Nowadays rotary wing setup UAVs are becoming more and more popular. They are much easier to control than fixed wing setup and overall provide bigger range of implementation.

An UAV with any rotary wing configuration gains lift from upwards thrust generated by one or more rotors. The maneuvering is done thanks to differential thrust on different motors. When a forward flight is required, then back rotors are providing more thrust essentially pitching the drone and vectoring the force forward.

Same concept is used to move in the pitch (elevator) axis.

The yaw axis is managed by differential thrust on the rotors position across each other.

There are also drones that have tilting rotors mounted on servo motors. This is specifically useful for racing drones, where high speed and maneuverability is required.

Different rotary wing setup configurations.

There are many different configurations for this UAV setup. They differ by the amount of rotors and the shape of a frame.

a) Helicopter.

A rotary wing setup vehicle which is known to everyone. A single rotor generates lift. It can be tilted to gain a desired attitude and motion direction.
It is important to note that helicopters have a small tail rotor generating horizontal thrust, which maintains rudder stability and continuous rudder rotation. Despite the fact such vehicles are considered as single rotors – not bicopters.

Picture 1. Helicopter UAV.[5]

[5] http://cdn.arstechnica.net/wp-content/uploads/2012/04/oct-4f7f45b-intro.jpg

b) Bicopter.

Bicopters are aircrafts which have 2 rotors tilting accordingly to maneuver, similar like in the case of helicopters. A tail stability rotor is not necessary. Both main rotors spin in different directions, essentially canceling out all forces that would cause the UAV spinning in yaw axis. Also smart design and perfect CG allow bicopters being steady while hovering.

Picture 2. Bicopter UAV.[6]

c) Tricopter.

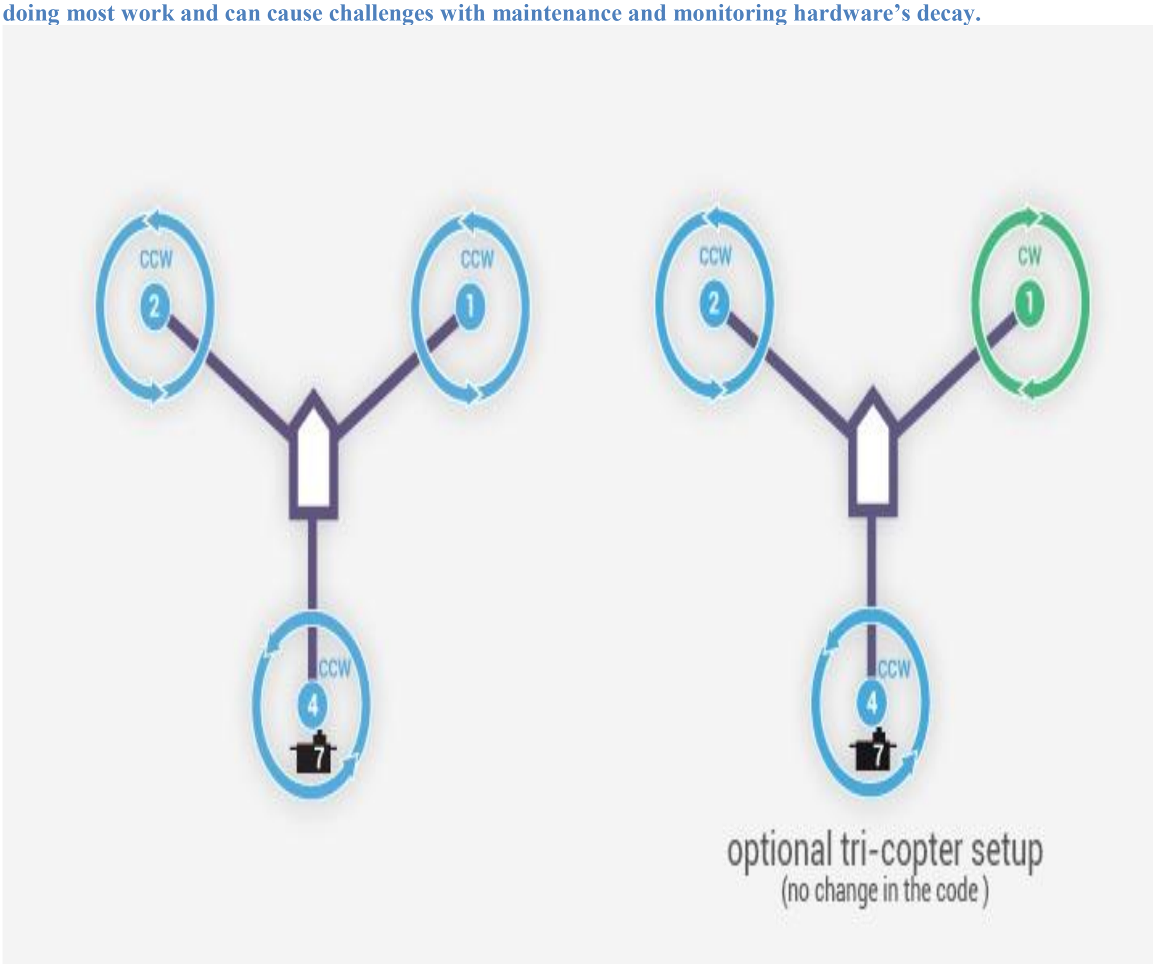
These rotary wing aircrafts most often come in the shape of "Y" where at each end a rotor is position. They have increased stability thanks to additional thrust source. This makes tricopters a better solution when strong wind is involved.

[6] http://www.suasnews.com/wp-content/uploads/2012/09/X1-Ocean.jpg

The disadvantage of this configuration is utilizing tail rotor much more than the two front ones.

Usually tricopters can't tilt their rotors. In order to perform maneuvers in all axes differential thrust is performed.

In order to fly forward the tail rotor needs to generate more lift and pitch the vehicle downward. That single tail rotor is doing most work and can cause challenges with maintenance and monitoring hardware's decay.



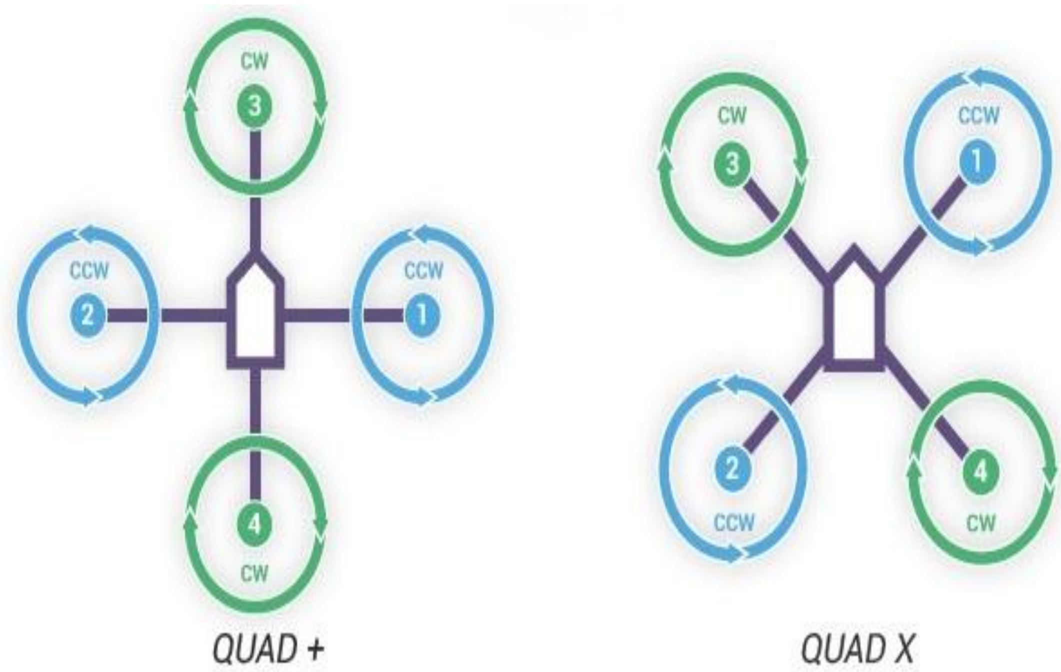
Picture 3. Tricopter UAV rotor setup[7].

[7] http://copter.ardupilot.com/wp-content/uploads/sites/2/2014/10/MOTORS_Tri.jpg

d) Quadcopter.

Rotary wing drones with 4 rotors are most popular nowadays. They are stability to efficiency ratio is very good comparing to other setups. Having symmetric construction provides even utilization of rotors, making their lifetime longer. When gaining desired attitude less heat is generated, because thrust comes from different sources.

Quadcopters can be used in “X” and “+” modes. However it is suggested to use the “X” mode due work being split among two rotors instead on one.



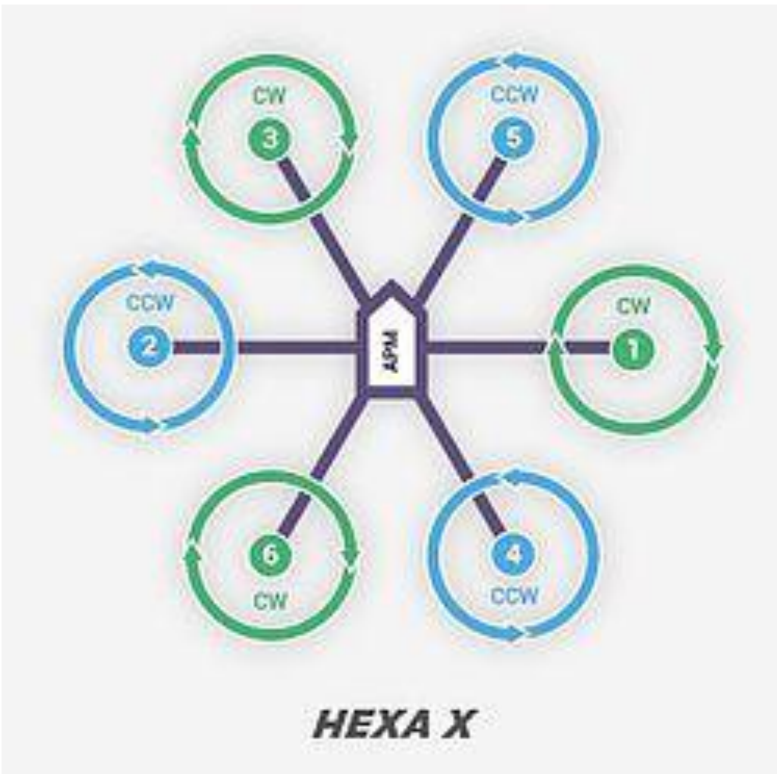
Picture 4. Quadcopter UAV motor setup[8].

[8] http://copter.ardupilot.com/wp-content/uploads/sites/2/2014/10/MOTORS_QuadX_QuadPlus.jpg

e) Hexacopter.

UAVs with 6 rotors are called hexacopters (or heksacopters). This kind of drones has greater payload than the previously mentioned. It is an obvious fact that more sources of thrust provide more lift. More stability in harsh conditions, like strong wind, can be achieved.

The drawback of having so many rotors is a greater power consumption, which essentially makes hexacopters better for short range missions, like video/photography in windy areas and for transporting heavier cargo.

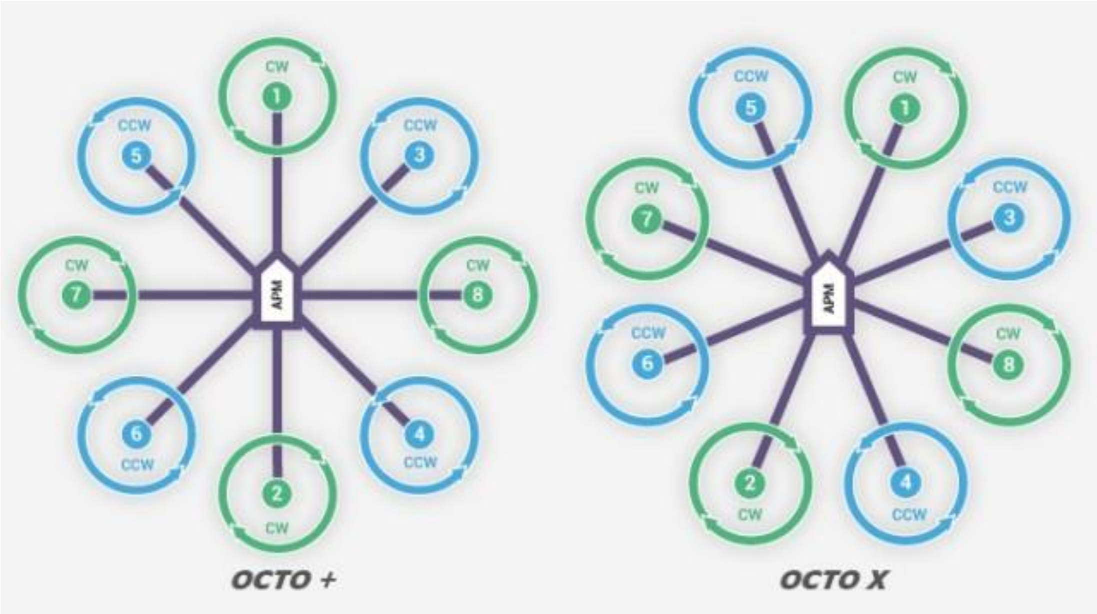


Picture 5. Hexacopter UAV motor setup[9]

[9] http://blog.oscarliang.net/ctt/uploads/2013/10/hexacopter1.jpg

f) Octocopter.

Octopter is a rotary wing drone with 8 rotors. Such provides greater payload in exchange for high battery consumption.



Picture 6. Octocopter UAV motor setup[10].

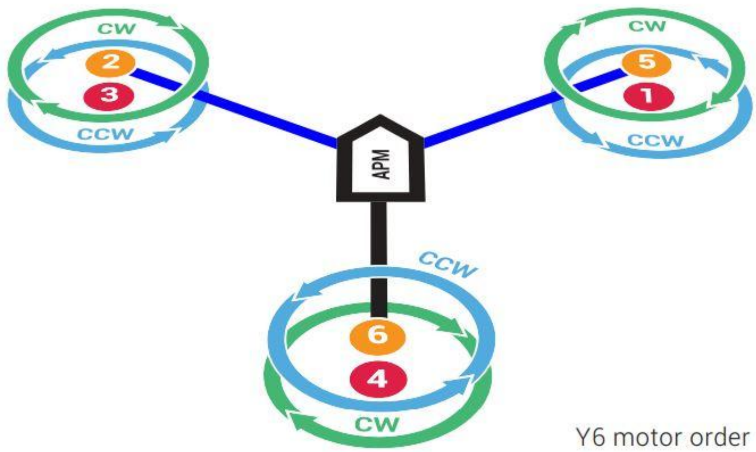
g) Y6.

Y6 is in fact a heksacopter constructed on a tricopter "Y" shaped frame. In addition to standard tricopter configuration additional set of rotors is mounted underneath the drone. Blade rotations are opposite to the closest (top) rotor to eliminate vibrations.

Y6 configuration has the same lift and power consumption parameters as a typical heksacopter. However it is a physically smaller vehicle, which make it more convenient for assemble, disassemble and transport.

It has potential to be changed into a VTOL UAV.

[10] http://blog.oscarliang.net/ctt/uploads/2013/10/octo-copter.jpg



Picture 7. Y6 UAV motors setup[11].

h) X8.

Similar to Y6 configuration being alternative to a hexacopter – the X8 is an alternation of octocopter. The drone is built on "X" shaped quadcopter frame and it has doubled set of rotors underneath.

Picture 8. X8 UAV motors setup[12].

[11] http://www.arducopter.co.uk/uploads/6/7/0/2/6702064/3853172_orig.jpg
[12] http://planner.ardupilot.com/wp-content/uploads/sites/5/2013/12/APM_2_5_MOTORS_X8-300x222.jpg

Rotary wing setup pros.

a) Vertical Take-Off and Landing

Contrary to a fixed wing setup – rotary wing drones are capable of take-off and landing vertically. Due to this flexibility and pallet of implementation of the UAVs is greater.

b) High accuracy

Having several rotors makes it easier to nullify the effects of external sources interfering with the flight.
Also hovering ability is the biggest advantage of all. Essentially these UAVs have an ability to stay exactly in the same position in 3D space. This is why they are so convenient for scanning confined areas, taking pictures or inspecting different types of infrastructure.

Rotary wing setup cons.

a) Range shorter than fixed wing setup

The biggest technological roadblock encountered with rotary wing drones is their limited flight time. The more rotors on the UAV the faster the battery is being drained.
Nowadays the majority of drones available on the market have an average flight time of 15 minutes.

b) Less aerodynamic that a fixed wing setup

Unlike fixed wing configuration – rotary wing drones don't have lift generating surfaces. Sustaining flight requires constant thrust coming from rotors and there is no opportunity to achieve any sort of gliding.

The negatively aerodynamic construction is a source of drags, which not only increases power consumption, but also reduces the top speed capabilities greatly.

VTOL.

Vertical Take-Off and Landing is a next step when discussing wing setups. We can classify both fixed wing and rotary wing aircrafts to this group.

VTOLs are aircrafts that have capability to take-off and land vertically like rotary wings, however a setup shift occurs when desired, transforming the vehicle into a fixed wing.

These ultimate aircrafts have all the advantages of both existing wing setups, while eliminating their weaknesses.

First VTOL attempts were done using tilt-wing technology, where a whole wing was tilting upwards allowing vertical lift. While the concept was logical the practice has shown its impractical aspects.

First of all while the aircraft is hovering, the massive wings surface turns into a sail that pushes the aircraft around and defeats its purpose of stability and accuracy. This situation is highly dangerous when attempting landing at an aircraft carrier.

Secondly the moment of transition from a vertical lift to a forward motion is not controlled completely and makes it inconvenient. The transition moment instead of putting an aircraft into a forward motion will make it stall as the fuselage of the aircraft will be pulled upwards to the wing, not otherwise.

Picture 9. Tilt-wing VTOL[13].

[13] http://www.anigrand.com/images/items/AA2028_XC-142/AA2028_XC-142_real_1.jpg

Tilt-rotor is another way for VTOLs to fly and transition between the flight modes. Rotors can be moved independently, which provides more maneuverability than tilt-wing using only differential throttle.

Controlling the tilt angles makes the hovering and the flight mode transition much smoother and safe, completely eliminating the stalling problem mentioned in a tilt-wing.

Picture 10. Tilt-rotor VTOL[14].

In effect the technology allows several modes:

a) VTOL – Vertical Take-Off and Landing
b) CTOL – Conventional Take-Off and Landing
c) STOL – Short Take-Off and Landing
d) STOVL – Short Take-Off and Vertical Landing

[14] https://upload.wikimedia.org/wikipedia/commons/8/87/US_Navy_061206-N-0458E-076_A_U.S._Marine_Corps_V-22_Osprey_helicopter_practices_touch_and_go_landings_on_the_flight_deck_of_the_multipurpose_amphibious_assault_ship_USS_Wasp_(LHD_1).jpg

Categories.

The last general distinction between UAVs is categorizing them according to their implementation field.

a) R&D

Research and development is a first step of any technology being introduced. R&D drones are mostly worked on by military and universities, where new approaches and designs are being developed and tested.

b) Combat

Combat UAVs are the reason they are associated with war and killing people. This is the sector where such remotely controlled aircrafts started to be widely used. The advantage of having combat UAVs is that there is no risk for military pilots.
On the other hand implementing drone technology in non-military sectors is challenging because of skepticism and lack of knowledge about the good and valuable opportunities.

c) Reconnaissance (rihnos population)

These are mostly fixed wing drones that can cover big areas and keep flying for a long time. Aside from military use reconnaissance drones are used for wildlife monitoring. They have been used to monitor Rhinos migration in Africa and to look out for poachers hunting for endangered species.

d) Logistics

Logistics drones are something that is being worked on more and more. The challenges arising with this particular category is having an aircraft which can have the right balance of payload, range and flexibility to be considered as a feasible solution.

e) Civil and commercial UAVs

Nowadays civil drones are being very popular. Quadcopters of various shapes, sizes and purposes – racing, photography and acrobatic flight are getting more and more fans. Many regulations are still blocking the widespread of UAVs among aficionados. The situation with civil applications is even more dire as laws are still being created.

1.8 UAVs: Challenges and opportunities.

1.8.1 Regulations and challenges around the globe.

Business Insider Intelligence has predicted that "*The market for commercial/civilian drones will grow at a compound annual growth rate of 19% between 2015 and 2020, compared with 5% growth on the military side(...)*"

This forecast shows that drones definitely have potential and should be invested in due to expected significant share in commercial market in near future.

There are many challenges associated with implementing drones.
It could seem that technical challenges are on the top of the list. This is partly true, especially when discussing battery powered drones, as majority of multirotor drones on the market has average flight time of ~15min.

However the biggest challenge is to reach the stage when drones are allowed to fly commercially.
The explosion in drone market is so major, that governments around the globe are struggling to keep up and set practical regulations for commercial UAVs. Essentially there is a lot of skepticism, due to the fact that drone technology can be misused.

Regulations for UAVs in USA.

Federal Aviation Administration is an organization that keeps introducing laws for drones in United States. As for today rules are still being created and changed.
In general FAA doesn't allow widespread of drones used commercially.
However there are limited opportunities for applying for permission for UAVs used in business. Few were given to people using the technology in agriculture cinematography, mining and real-estate. Unfortunately it has been done on such a small scale that it is underwhelming, considering the wide pallet of opportunities.

Today there are two ways to receive a permission for flying civil UAVs in USA[15]:

1. "Section 333 Exemption – a grant of exemption in accordance with Section 333 AND a civil Certificate of Waiver or Authorization (COA); this process may be used to perform commercial operations in low-risk, controlled environments."

2. "Special Airworthiness Certificate (SAC)[16] – applicants must be able to describe how their system is designed, constructed, and manufactured, including engineering processes, software development and control, configuration management, and quality assurance procedures used, along with how and where they intend to fly".

On the other hand some information about soon-to-come new laws has been released:

a) A theoretical exam has to be passed by a drone operator.
b) A drone has to be registered.
c) 200,- USD registration fee annually.
d) Flight below 400 feet.
e) Keeping the UAV in a line of sight at all times
f) Flying no closer than 5 miles from airports
g) No flights near densely populated areas like stadium etc.
h) No flights with a drone heavier than 55lbs (~25kg)

The way these basic rules are formulated suggests that remotely controlled vehicles are in the scope of the legislation. There is insufficient discussion about autonomous UAV's regulations, especially with the rule to keep such vehicle in the line of sight at all times.

Regulations for UAVs in Europe[17].

The stance of European authorities towards the future of drones seems more promising. The potential of the technology has been recognized. Predictions of a significant commercial share in the market and the variety of services that come along with UAVs are a strong motivating factors supporting the idea that drones should not be ignored, but invested in.

According to Jacqueline Foster – a MEP addressing Eurocomittee the main focus is on insuring safety, while introducing UAVs on high scale.

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[15] https://www.faa.gov/uas/civil_operations/

[16] http://www.theverge.com/2015/7/7/8883821/drone-search-engine-faa-approved-commercial-333-exemptions

Safety can be discussed in several ways.
First is ensuring that technology is safe and reliable in a sense of having backup solutions for potential malfunctions. As long as drones will be falling down from the sky they will not be considered as safe.

Secondly a standardized set of sensors needs to be installed on drones to ensure feasible obstacle avoidance. This point is especially important in a situation, when UAVs will be very common and their density in aerial space will be high. This rule gives more potential for autonomous drones.

Next registration and ability to track and disable drones are a must. Presence of terrorist attacks and public being concerned about potential misuse of drones, puts this issue very high in necessary regulations. Using a unique ID chips bound to each vehicle would make such control achievable.

Another matter is creating geo-fence areas, which would create no-fly zones. It is already clear that military territories, airports and other highly secured areas are prohibited. However instead of relying on people's good faith and law abiding, technology that would automatically reroute a vehicle should be implemented.

Lastly a category for different drones should be established. Recreational drone startups are booming and more and more enthusiasts are reaching for these remotely controlled devices. There is a significant difference between recreational UAVs meant for racing or taking family pictures and videos and professional, commercial purpose made.

Overall despite more promising attitude in Europe towards introducing drones, a lot of testing and feasibility proving has to be done.

Regulations for UAVs in India[18]:

All across India UAVs are banned for a commercial use. In general there are states where designated areas are created for RC aircraft hobbyists. Not abiding the rules can result in imprisonment or financial penalties, depending on state where the law is broken.

Aside from narrow range of possibilities for private drone enthusiasts the technology, its implementation and development is reserved to the Indian government and military agencies.
In fact in 2007 CEMILAC has stated that UAVs need to be recognized and cleared for their airworthiness in future. However same as in case of Europe – discussion about necessary regulations to come took place involving airworthiness.

Airworthiness is a wide term involving aircraft's ability to fly safely. For drones to acquire this status safety standards have to be set in future. The biggest concern is for an aircraft to fall down and harm people upon crashing. For this reason technology and designs have to be tested, simulated and evaluated. Once standards are set UAVs will be certified as airworthy - being cleared for use in designated operations.

[18] http://indianexpress.com/article/technology/gadgets/why-india-needs-rules-for-flying-drones-soon/

Nowadays using unmanned flying systems in India is being done with the permission of DGCA and MoD.
An organization called USAI is an association of UAS enthusiasts promoting the technology in order to introduce it to wider public.

1.8.2 CSR discussion[19].

Nowadays a concept of responsibly done business is very common. Corporate Social Responsibility is transparency of the company displayed to the public.

This matter is especially sensitive in case of UAV based business.
Up to 87 countries have drone presence in their military. However in recent years the number of drone enthusiasts has been growing.
http://www.csrandthelaw.com/2015/01/06/flying-high-the-human-rights-implications-of-investing-in-drones/
When in August 2014 the CEO of Amazon – Jeff Bezos, revealed his plan of implementing UAS in package delivery. He approached the U.S. Department of Transportation, which shortly replied by talking about few categories of risk.

a) Possibility of LARs emerging in form of drones and operating outside of warzones.
Efficient autonomy needs development and once completely independent flying vehicles will be present in our skies, much more opportunities for acts of terror and hacking will be present.
There have been events when Human Rights activist organizations like NGO, have been rioting against LAR development and picked up support rapidly.

b) Breaching moral aspects of our everyday life in a form of spying and illegal surveillance.
There is virtually no sufficient control as for today to avoid it.

Despite the skepticism towards UAV from an everyday average person I am confident that development of technology and people becoming more familiar with it will effect in rapid implementation after legislation is set in stone.

[19] CSR discussion on drones
Flying High: The Human Rights Implications of Investing In Drones.
January 6th, 2015 by Melinda Kuritzky

1.8.3 Potential business impact in future[20,21,22].

There is a big variety of business opportunities coming with UAS technology. There is a need to describe them to gain full awareness of drone technology.

a) In real estate drones are being used for **shooting videos of properties for commercials and displaying to customers.** This practice is deemed illegal yet many people still do that. The solution is significantly cheaper than renting an elevated crane or a helicopter with a special film crew.

b) A group in Texas has employed the use of drones for missing persons. Machine vision and heat sensing cameras provide ability to **detect a lost person at any time of day and night.**

c) According to a professor of electrical and computer engineering at Northeastern University in Boston, medical doctors are considering **transporting transplantation organs with drones**. That will require some guarantees and insurance for the implementation. Seriousness of the sector where the solution will be used in and value of the cargo make it a very challenging project.

e) **Maritime traffic** control can benefit from UAVs greatly. They can be utilized by searching for and detecting vessels. It would allow in-harbor coordination as well as detect illegal fishing activity which can cause dangerous situations.

f) **Monitoring traffic** can be more efficient if drones were patrolling streets and detecting law-breaking drivers. ConOps of such service would be detecting and offender, pursuing him while giving live feedback to police cars. This will effect in catching a reckless driver in no time. The benefit of this idea is vast cost reduction. There will be no need for controlling traffic with helicopters, which involves incomparable investment.

g) **Monitoring of the emergency situations of any origin** is a wide scope of implementation. It means anything from monitoring a situation after a tsunami, fire, avalanches etc.

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[20] A Cost-Benefit Analysis of Amazon Prime Air
Adrienne Welch Departmental Honors Thesis
The University of Tennessee at Chattanooga, Economics Department
Project Director: Bruce Hutchinson March 16th, 2015
Dr. Leanora Brown Dr. Aldo McLean Dr. Joe Dumas

[21] https://www.americanexpress.com/us/small-business/openforum/articles/need-know-want-drone-business/

[22] Analysis of UAS application in the civil field.
Volodymyr Kharchenko, Dmitry Prusov.
National Aviation University. Kiev, Ukraine.
20th June 2012

h) **Industrial site protection** means keeping surveillance at an industrial site at all time. Most of such places have dangerous locations for authorized personnel only. Having control over people at the site prevents from simple acts of vandalism as well as from organized crime or terror activities.

i) **Monitoring chemical processing facilities** is a hard thing to do, especially during emergencies. Surveillance from a helicopter can be dangerous if toxic fumes are released into the atmosphere. Using UAS allows getting close enough to the event to be monitored without endangering life of the operator.

j) **Monitoring the Gas and Oil Pipelines' infrastructure** can be a strategically useful activity. This particular industry has vast capital behind it. Progression of drilling sites and pipelines' needs to be frequently monitored for safety and efficiency issues. There is always a risk for somebody jeopardizing operations by destroying a whole industrial facility. Frequent monitoring can neglect such an event.

k) Spraying of chemicals in agricultural purposes is already being done with use of fixed-winged manned aircrafts. Using drones for this is a very practical solution. A camera can be mounted on a UAV for recognizing plants' condition. A special program will deliver feedback about weaker crops and adjust spraying to salvage them.

l) **Geophysical aerial photography** has existed for some time, however it can be enhanced by UAS solutions.
Geoinformatics is gathering data about natural resources, construction, agriculture and topography. The traditional ways of gathering the information is done via photography from satellites, which is not universal. The satellite solution can be used only when a clear visibility is available. Also limited time of observing a certain area is possible, since as soon as it moves behind the horizon, the signal will be lost.
UAS can be deployed quickly and monitor certain area as desired and for an extended amount of time. That is another astounding practical opportunity for drones.

m) **Air cartography** can be done in many ways. Below several of them are described:

- standard **topography mapping** of forests, lands, mountains and urban areas. Virtually any place is suitable.

- **oceanology**, meaning monitoring sea and sea life visible from the above. Can be useful for having feedback about fish and mammal migration. This can have a great impact on managing fishing and controlling population of endangered aquatic species.

- **ice reconnaissance** means monitoring ice to evaluate how much ice is melting and migrating. Planets ice melting has been a main reason for polar bears population going down. This is why more control and awareness of the process can have major effects on understanding climate changes on the planet.

n) **Monitoring public events for safety** would be essentially an extension of a CCTV camera. Deploying drones at a big event can ensure having no surveillance blind spots and constant control. Similar solution as with traffic control should be used.

1.8.4 Inspirational similar projects examples.

The concept of using UAVs for transporting cargo is not new by any means. However still today it hasn't been yet developed until the stage of implementation. There are two different projects worth mentioning that involve some solutions which I want to introduce in my proposal of a new delivery service system.

Amazon Prime Air[23][24].

Internet sales giant – Amazon has a project in development. Their aim is to introduce autonomous sUAVs for delivering goods to customers.
The brand is already known for their automated stock managed by autonomous machines. They have decided to further develop their state-of-art technology solutions for providing delivery service.

Amazon has designed two kinds of drones for delivering packages. The two models are used according to the distance to be travelled.
They are being called sUAVs to highlight the fact these vehicles won't be a major size aerial vehicles like military drones for example.

First is an octocopter that is supposed to deliver packages in a nearby area. This UAV will travel to the destination and find a suitable place to drop a package by using machine vision via onboard camera.
A rough estimate based on personal experience is that it will be able to travel around 20km total, given the fact it is a multirotor with high amount of rotors.

Picture 11. Amazon Prime Air octocopter.

[23] https://www.yahoo.com/tech/exclusive-amazon-reveals-details-about-1343951725436982.html
[24] www.amazon.com/primeair

The second drone being developed is a VTOL. It will be used for a longer range deliveries. The design of the UAV is interesting, because of its simplicity. It is clear that the designers decided to eliminate maximum of moving parts for prolonging lifetime of the vehicle.

4 rotors are being used to take-off vertically. Once a desired cruise speed is reached the sUAV will start tail rotors to provide forward motion.

Picture 12. Amazon Prime Air VTOL[25].

After getting familiar with the drone technology I am skeptical about some solutions they have described. Amazon has shot some promising promo videos, yet deciding how feasible and actually true the promises are, can't be judged yet. Especially UAVs range is a factor that will finally make Amazon Prime Air a real service, or a concept that is just theoretically feasible.

Also the personal delivery is aimed for people who have some area like a garden outside their 1 family house. So far no solution for delivery to congested cities with tall apartment blocks has been described. This narrows down the customer segments too much.

However the goal for Amazon Air Prime to deliver packages in 30 minutes, or less is ambitious and if implemented it will revolutionize shopping on internet and deliveries.

Amazon have distinguished 4 levels of vehicle capability for sUAVs for future. The higher the capability the higher allowed airspace access for the drone.
Every level has more advanced ConOps than previous one.

[25] http://g-ecx.images-amazon.com/images/G/01//112715/image-4._CR0,8,1340,762_.jpg

Level I – Basic:

Allows flying an remotely controlled UAV within LOS. Also safe locations have to be picked for basic level of airspace access. Lower level of hardware complexity makes it less safe in crowded areas.

Level II – Good:

A slightly more intermediate hardware is used. A set of sensors allowing V2V detection gives necessary feedback for a drone operator to choose a non-conflicting pathway. The control over the vehicle is still remote.
Also connection to GPS and WiFi via ground control is added for receiving basic geospatial data like weather conditions and air traffic.
The air access is extended in rular areas and limited in suburban areas. It has to be noted that since level II sUAVs will still be remotely controlled they have to be operated within LOS and below 200 feet due to ConOps limitations.

Level III – Better:

ConOps at level III will introduce autopilot and automatic deconfliction via collaborative V2V communication. Also individual internet connection will be introduced.

Level IV – Best:

The ultimate ConOps. It will allow flight between 200 and 400 feet in rural and urban areas. The long range non-collaborative SAA technology will allow safe navigation during both day and night. Also emergency landing sequences have to be developed.

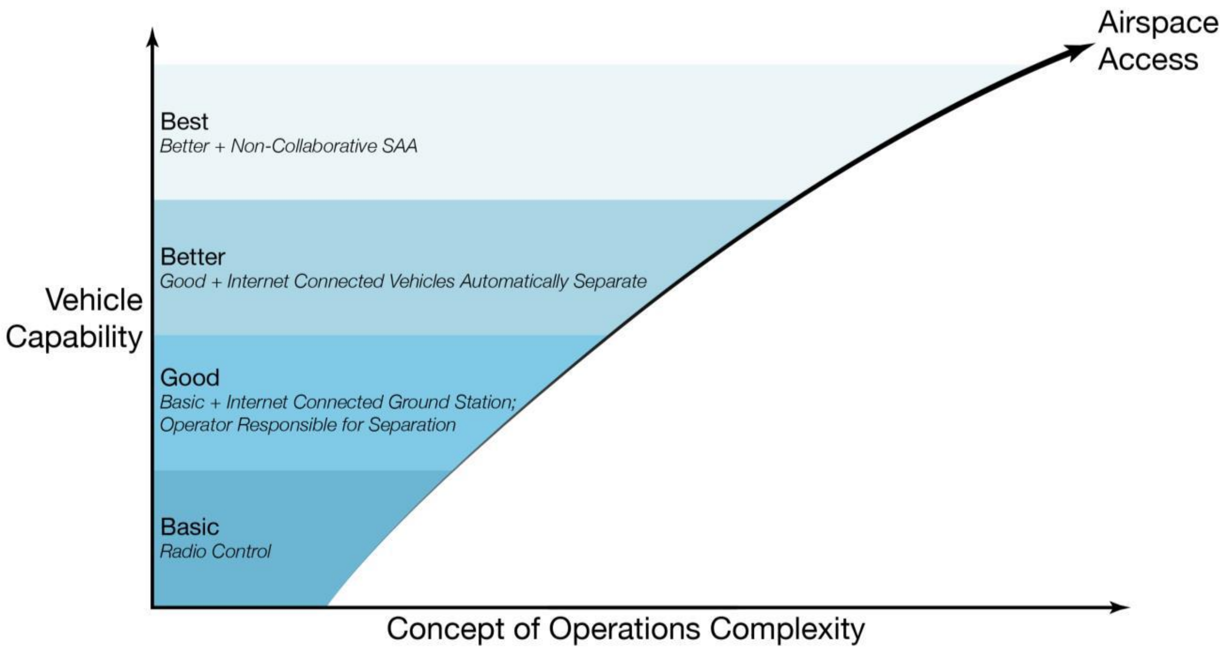


Figure 1. ConOps complexity[26].

Overall Amazon has valid points while introducing 4 levels of ConOps for sUAVs. The progression of each level is backed-up by reason and the approach takes into consideration current skepticism from most of the global governments toward UAS.

My ultimate goal is to create hardware which will qualify as level IV ConOps.

Fixed wing drone blood delivery project at John Hopkins University of Medicine[27].

Ph.D. Timothy Kien Amukele associated with John Hopkins School of Medicine, Baltimore and Uganda's Marakere University has tested a way of transporting blood samples with a fixed wing drone.

The project has been developed in collaboration with several engineers familiar with UAS. The general idea is to be able to quickly shift variety of samples and medicine to and from rular areas which are hard to access quickly on land.

A number of 56 blood samples have been taken from volunteers at John Hopkins Hospital. Those samples were further refrigerated and further prepared for transportation in a

26 www.amazon.com/primeair

27 http://www.hopkinsmedicine.org/news/media/releases/proof_of_concept_study_shows_successful_transport_of_blood_samples_with_small_drones

container preventing leaking.
The UAV itself was a simple fixed-wing which had to be thrown by somebody – no independent take-off ability was available.
It has been flown several times for periods from 6 minutes to 38 minutes within LOS and below 100 meters. The air temperature at the time of testing was about 21 degrees Celcius.

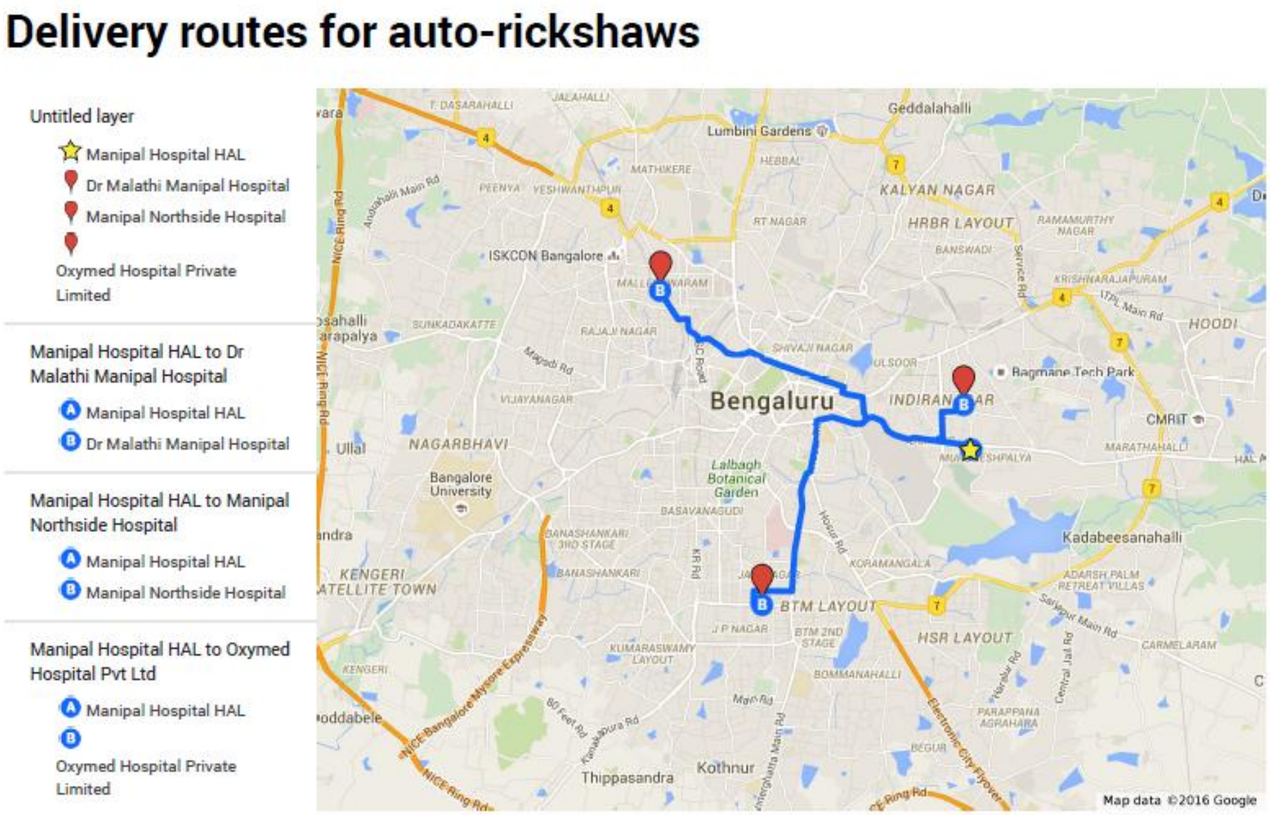
Timothy Amukele compared this particular idea to a pigeon carrier as the departure procedure is slightly similar.
Once airborne the drone follows a GPS location of the destination.
He has also said that biological samples are very fragile and external factors like rapid acceleration, impact or high temperature can destroy bloodcells.
For that reason all the samples have been tested and compared with ones that have not been flown at all.
33 common tests were conducted and the results shown no difference between samples.
However a single test of measuring total carbon dioxide (bicarbonate test) has been inconclusive, as the results have been varying from sample to sample.

The project has been a success and further development and testing is planned to take action in rular areas in Uganda. This is a very promising project that can save many lives.

The agenda of Amukele’s concept is very similar to mine – using UAS advantages for modernizing health sector and eventually saving life.

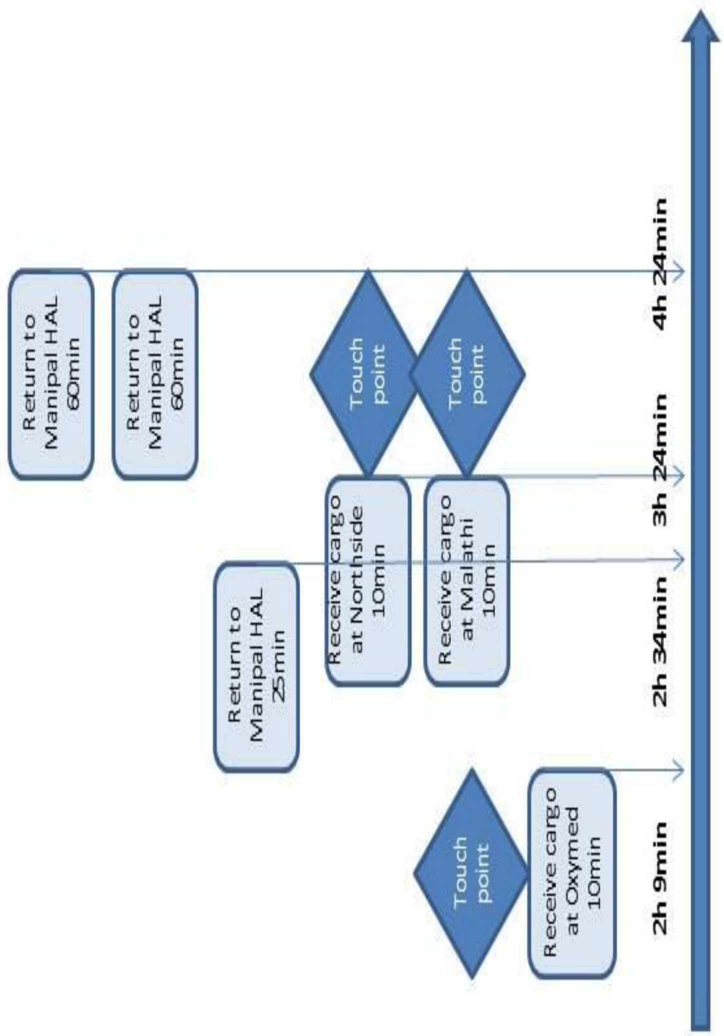
2. Research.

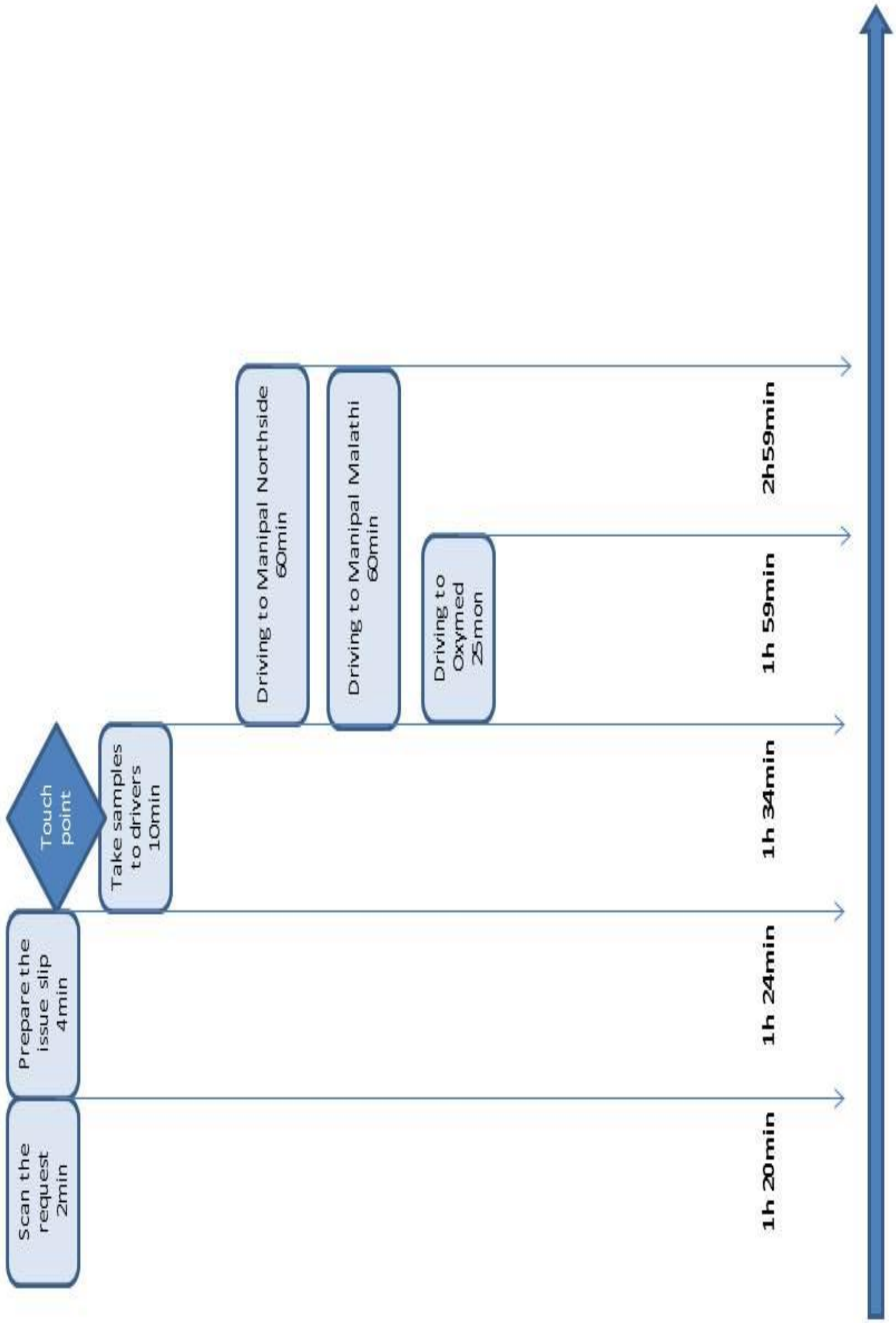
2.1 As-Is situation: Delivery routes for auto rickshaws.

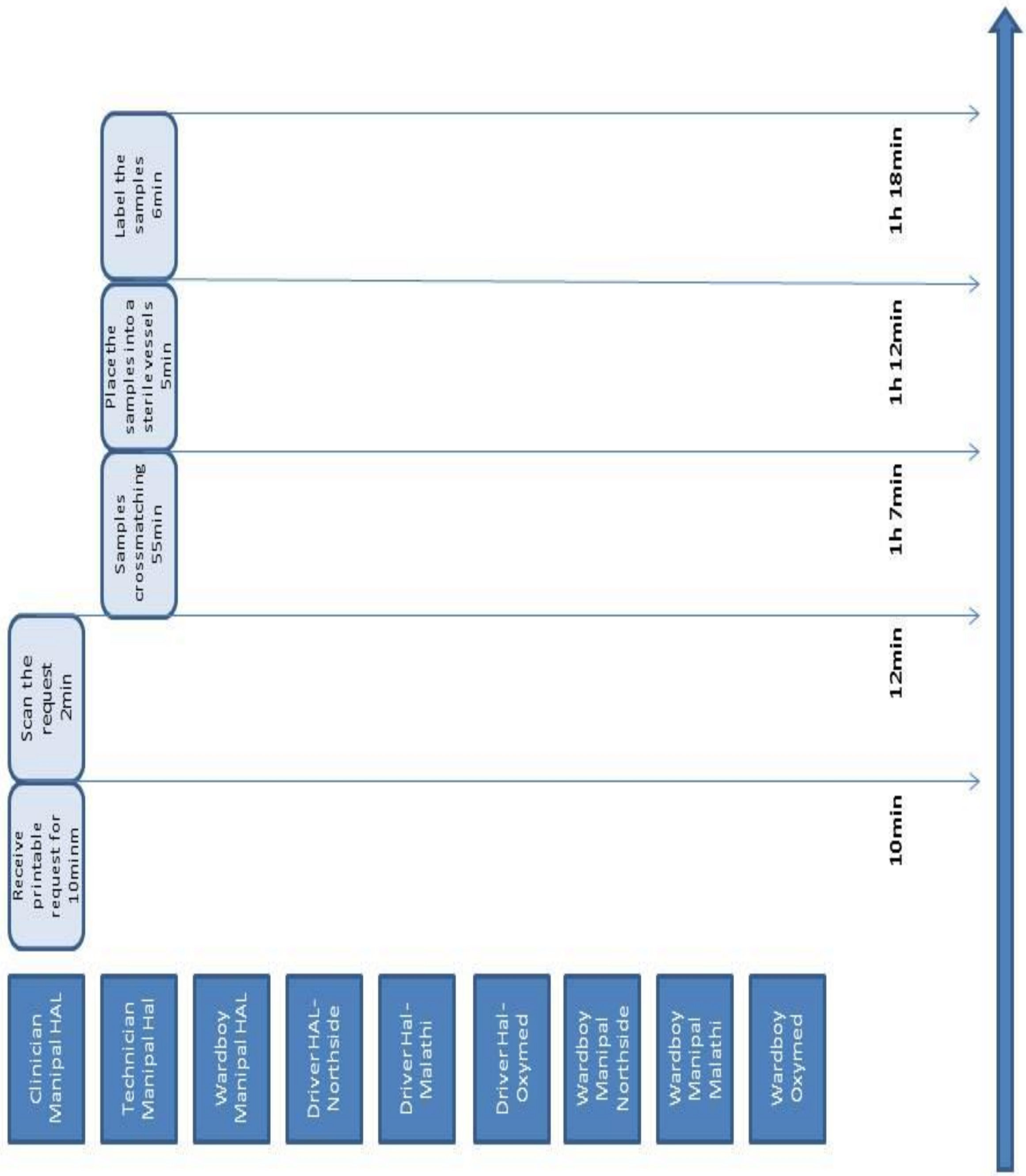


Prototype #3 Auto rickshaw delivery routes			
Route	Distance	Travel time	Service lead time
Manipal HAL → Manipal Northside	12,7 km	60 min	3h 39min
Manipal HAL → Malathi Manipal	10,7 km	60 min	3h 39min
Manipal HAL →Oxymed Hospital Pvt Ltd	3,02 km	25 min	2h 9min

2.2 As-Is situation: Integrated flow chart.




Scan the request 2min
Prepare the issue slip 4min
Touch point
Take samples to drivers 10min
Driving to Manipal Northside 60min
Driving to Manipal Malathi 60min
Driving to Oxymed 25mon
1h 20min
1h 24min
1h 34min
1h 59min
2h59min



Clinician Manipal HAL
Technician Manipal Hal
Wardboy Manipal HAL
Driver HAL-Northside
Driver Hal-Malathi
Driver Hal-Oxymed
Wardboy Manipal Northside
Wardboy Manipal Malathi
Wardboy Oxymed
Receive printable request for 10minm
Scan the request 2min
Samples crossmatching 55min
Place the samples into a sterile vessels 5min
Label the samples 6min
10min
12min
1h 7min
1h 12min
1h 18min

As-Is situation – Processes description.

I have collected information about all the steps involved in delivering blood with 3 separate auto rickshaws as it is being done today.
The processes flow is described below. For integrated flow chart see appendix.

Process 1:
Transfusion request form arrives to blood bank electronically. A blood bank clinician is responsible for receiving and printing it.
10 minutes are required to complete the task.

Process 2:
Scanning the printed transfusion request form and giving it to a blood bank technician.
2 minutes are required to complete the task.

Process 3:
Blood crossmatching handled by a blood bank technician.
It takes 55min to complete the task.

Process 4:
Placing the crossmatched blood into a sterile sealed container by a blood bank technician.
It takes 5min to complete the task.

Process 5:
Labeling the samples handled by a blood bank technician.
It takes 4min to complete the task.

Process 6:
Preparing the issue slip by a technician.
It takes 6 min to complete the task.

Process 7:
Taking samples and issue slips to drivers. Wardboy needs 10min to complete the task.
Physical touchpoint: Location.
The hospitals' staff member interacting directly with the service provider.

Process 8:
Driver 1 goes to first destination with the cargo.
It takes 60min to drive to the first location.

Process 9:
Driver 2 goes to second destination with the cargo.
It takes 60min to drive to the second location.

Process 10:
Driver 3 goes to third destination with the cargo.
It takes 25min to drive to the third destination.

Process 11:
Blood bank technician at first destination picks the cargo and takes it testing area.
It takes 10min to complete the task.
Physical touchpoint: Location.
The hospital's staff member interacting directly with the service provider.

Process 12:
Blood bank technician at second destination picks the cargo and takes it testing area.
It takes 10min to complete the task.
Physical touchpoint: Location.
The hospital's staff member interacting directly with the service provider.

Process 13:
Wardboy at third destination picks the cargo and takes it testing area.
It takes 10min to complete the task.
Physical touchpoint: Location.
The hospital's staff member interacting directly with the service provider.

Process 14:
Driver 1 goes back to Manipal HAL to return the icebox.
It takes 60min to complete the task.

Process 15:
Driver 2 goes back to Manipal HAL to return the icebox.
It takes 60min to complete the task.

Process 16:
Driver 3 goes back to Manipal HAL to return the icebox due to limited supply.
It takes 60min to complete the task.

Process 17:
Wardboy at Manipal Hospital HAL picks up the boxes dropped by drivers.
It takes 10min to complete the task.

2.3 As-Is situation: SIPOC.

S	I	P	O	C
Suppliers	**Inputs**	**Processes**	**Outputs**	**Customers**
Manipal HAL Hospital Donors	Order destination information Order specifics Transfusion request form Issue slip	1. Receiving a request form from another facility 2. Preparing the biomaterial for shipping 3. Labeling and issuing the biomaterial 4. Delivering the biomaterial to a driver 5. Transporting the biomaterial to another facility 6. Receiving the biomaterial at destination.	Specific order delivery Blood stock info update Issued slip confirming delivery	Manipal Hospital HAL Manipal Northside Hospital Malathi Manipal Hospital Oxymed Hospital Pvt Ltd

Figure 2. As-Is SIPOC

3. Design and development.

3.1 VOC defining preferences and performance metrics: KANO Model.

VOC preferences: KANO model

In order to define preferred features of the new service and for setting development priorities I chose future users as a research sample. I have talked to technicians and clinicians at Manipal Hospital HAL blood bank.

The information was gathered in a comfortable conversation where different issues were discussed and questions related to UAS technology answered. When the hospital personnel has provided all the answers they could think of I categorized them according to KANO model satisfaction diagram

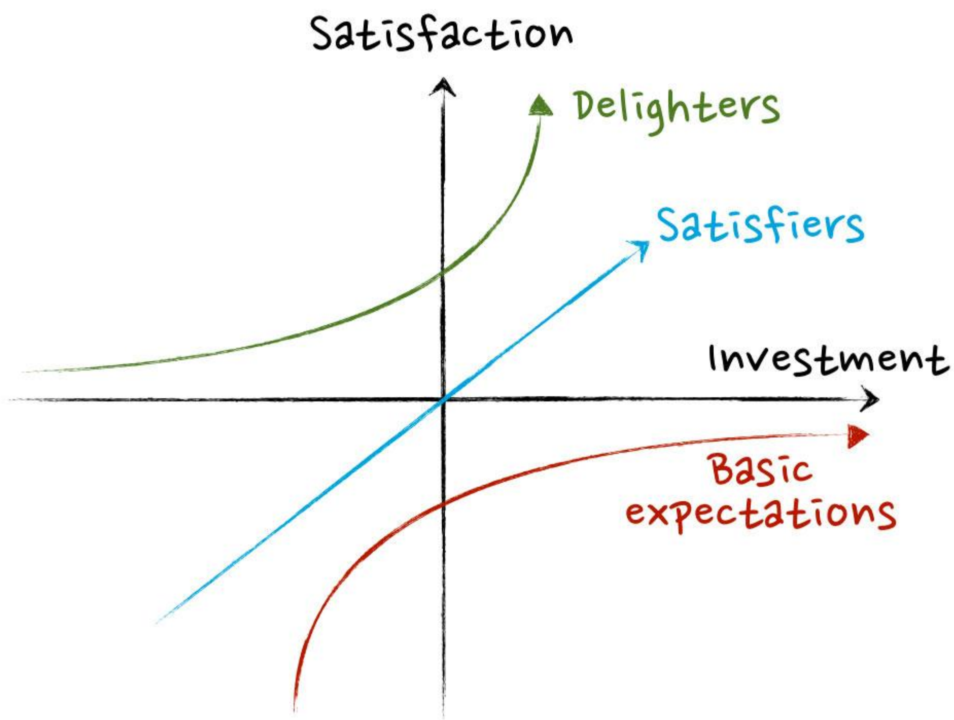


Figure 3. KANO model[28].

[28] http://cdn02.mindtheproduct.com/wp-content/uploads/2013/06/kano-model-2.jpg

a) Basic expectations - (taken for granted, not mentioned, self-evident

- Transportation available independently from weather.

Blood delivery is required every day and for this reason vehicles need to be able to deliver products in all kinds of weather. In Bangalore this means shipping blood despite big traffic issues related with seasonal monsoon rains.

- No danger for people and animals

However the blood is transferred it has to be done in a safe way. There is no difference whether shipping is done on land, on water, or in the air. The focus is on not endangering anyone in the process.

- Cargo has to be delivered intact

Biomaterials can be very fragile and special shipping conditions need to be maintained[29].

b) Satisfiers.

- Timely deliveries

Timely deliveries are essential when dealing with biomaterials. If shipping timings will be more delayed, customers are dissatisfied. Cargo shipped on time results with satisfaction.

- Cheaper service

Cost for the service provided is one of the primal things directly related to customer satisfaction.

c) Delighters.

- Modern

Manipal Hospitals is a part of a larger Manipal group, which is also involved in university level education. For that reason the innovation mentality is present throughout all the Manipal divisions. Modern and interesting ideas are always welcomed.

[29] *"Standards Bloodbanks & Blood Transfusion Services*", National AIDS Control Organisation, Ministry of Health and Family Welfare, Government of India, New Delhi 2007.

- Easy to use system

Idea of a new autonomous technology substituting typical ways of shipping creates excitement, yet it should be sufficiently user-friendly to truly amaze people.

- ETA information

Current ways of blood delivery don't provide exact ETA to the destination-end of the flow. Having this information sent to the customers is a significant customer experience improvement.

- Much cheaper service

Good cheap service is satisfying, however much cheaper solution, like 1/3 of the costs, would definitely be a winning feature of the service.

- Brand new service

Idea of being involved in a unique exciting ways of shipping biomaterials provokes positive attitude towards UAS.

- Environment friendly

Nowadays pollution is a serious matter and environment friendly solutions are welcomed and rewarded with approval.

- Autonomous

Autonomy is a sign of modern technologies being used. Launching blood delivery service with drones will bring prestige to Manipal brand.

- Traffic-independent

Very busy and congested traffic in Bangalore is the primary reason for slow shipping. Solution allowing independence is another major feature.

Identifying performance metrics.

I have used the same approach for identifying performance metrics during the same interview. Since the scope of development phase I aims for a small scale delivery and with a non-complicated system identify them was not challenging as with VOC preferences case.

a) Price per km.

HAL Hospital has to pay for the delivery of blood according to MRP rate per km. The rickshaw solution is considered expensive. The rate per kilometer is much higher than it would be at the times of the day without peak hours. However according to the model the deliveries will take place exactly at the time of peak hour, when rate per km is significantly higher. Also some extra charge is involved into ensuring the drivers will be available twice a day – morning and evening.

It can seem surprising to a westerner, reliability of auto rickshaw drivers can vary. Especially in the monsoon rain season, they tend to refuse to do their job and wait until raining stops. For this reason the extra fee is included resulting in higher price.

b) Delivery according to ETA.

It is very hard to provide ETA in Bangalore during peak hours. A morning trip of 25min in the very early morning can take 2h before noon. This causes delivery time being very unstable, which can be a reason of cargo being spoiled. I recognize and advantage of drones in this case. Being traffic independent ensures that the drone will deliver the cargo coherently with provided ETA.

3.2 Hardware development – prototyping.

3.2.1 Blood-carrier drone concept.

Defining the concept of drone through the scope of KANO model has brought me ideas about technical solutions ensuring customer satisfaction.

General requirements for the phase I of development was delivering samples blood samples for testing by a drone with a cargo container container. I was assured no special cooling for cargo will be required at this level. Despite acting not accordingly to standards for BTS we agreed on testing blood samples which were not cooled during transportation. It was not of any danger to anyone as the samples were meant strictly for testing[30].

The drone will be operated only by a maintenance technician. Medical staff won't have to interact with it as the cargo will be delivered to a designated landing area. The UAV will leave the area automatically, while the cargo will remain behind at the landing pad ready to be collected.

A modular product is a good choice, because at this early stage of development it is a cheaper solution and overall more convenient for prototyping and customization. Using ready components like motors, frames and flight controllers is a reasonable solution. Perhaps in future the will be place for an integrated product with custom crafted electronic components. Everything will depend on the progression of the whole project.

It is important to note that sufficient amount of tests have to be conducted to ensure success of every single delivery. When introducing a technology with relative amount of bad fame, a single failure can doom whole development of the project.
Developing the drone required for the service consisted of three different prototypes.

From the CSR point of view my solution will affect all three bottom lines accordingly:

a) **People:**

On one hand public opinion can be against automated solution which potentially takes away a job from a person. Also skepticism which grew from bad fame of UAS and social paranoia might block the implementation process.

On the other hand auto rickshaw drivers have no reason to worry about customer shortage, due to the population of Bangalore.

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[30] "*Standards Bloodbanks & Blood Transfusion Services*", National AIDS Control Organisation, Ministry of Health and Family Welfare, Government of India, New Delhi 2007.

Another thing is that contributing to modernizing BTS activities mean modernizing health sector. That argument is a very significant advantage on the side of drones.

b) Planet:

When discussing companies applying TBL environment friendly activity is greatly appreciated by public opinion. Minimizing negative environmental impact, like pollution is a priority to many huge companies.

Through that scope I see my solution as having an advantage. UAS logistics solutions generate virtually no pollution. I used this fact while lobbying drone topics for press and television. Specifically - raising awareness of drones and their applications in various sectors.

c) Profit:

I’m aiming to create not only modern, but also cheaper blood delivery service. Having the service being more than 50% cheaper, yet more efficient is a very competitive feature.

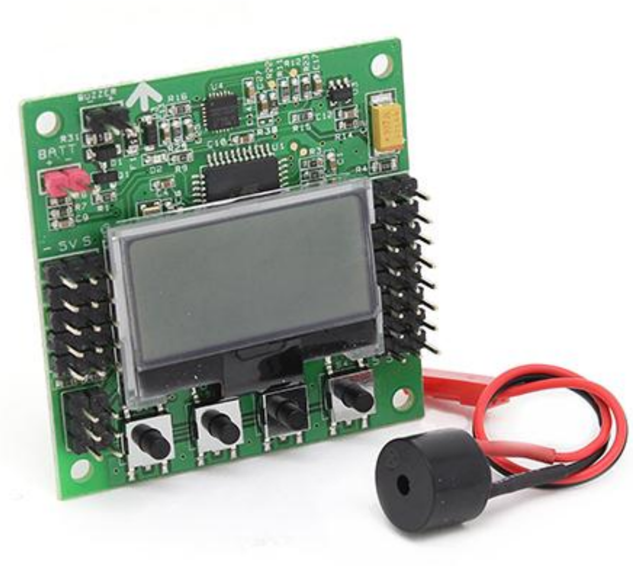
I already had very positive feedback regarding idea of using drones that are relatively cheap.

3.2.2 Drone prototype #1 HMR250 kk2.1

I have started with a smaller quadcopter built on a racing carbon fiber frame HMR250. The reason for starting with a small racing quadcopter was having a cheaper R&D unit that is so compact it can be tested indoors.

First prototype was meant for testing stability of the smaller drone and the flight controller.

a) For the initial me and another person working with drones, decided to pick KK2.1 board to be our first flight controller. It has preprogrammed firmware supporting many varieties of rotary-wing UAVs.



Picture 13. KK2.1 board[31].

b) The motors used were U2206 KV2200 Waterproof Brushless motors for multicopters.
c) ESC 15 Amp.
d) Carbon fiber 6 inches propellers.
e) Battery 1700mAh 3S LiPo 15C.

Construction of the UAV built on HMR250 frame step by step is very complicated and basic soldering skills will be sufficient to assemble the whole vehicle.

First of all connections from voltage distribution board to ESC and to battery have to be soldered properly. Then the distribution board has to be insulated with a thin layer of insulation tape.

Once completed, the wiring can be placed between two bottom plates which are the base of the drone. Further the motors have to be mounted on designated spots and connected to ESCs. A very important task is too place KK2.1 board carefully, to ensure perfect stability and orientation.

Finally the propellers are placed on rotors and fixed tightly. The battery has to be placed inside the frame and fixed in a way preventing it to vibrate and get displaced.

[31] http://www.hobbyking.com/hobbyking/store/catalog/54299bz.jpg

Stability tuning – PID control loop.

To achieve flawless stable flight many things need to be considered. First of all the center of gravity (CG) has to be placed in the right place. Propellers need to balanced which means that each blade is exactly the same weight. Such propeller reduces the amount of vibrations during flight and is maximally efficient.

Once these hardware adjustments are secured tuning software starts. PID control loop continuously calculates an error value which is difference between a desired set point and a measured process variable. Proportional Integral and Derivative calculations are ongoing.
What it means in practice for a quadcopter or any rotaty-wing AUV is:

a) Proportional factor is used for calculating error in real time in order to calculate sufficient output to correct it. The bigger the value of "P" the more power is used to stabilize the drone.

When value of "P" is too low, the vehicle will not use sufficient thrust to keep itself in level and most likely will flip and crash. Lower "P" is also responsible for a slower response to inputs from a RC transmitter.

Proportional term being too high results in over correcting the error resulting in another error. That means the drone will be oscillating at high frequency and frequently overheat the motors.
A balance is required for reaching a smooth stable hovering and flight.

b) Integral term is technically not required for an UAV to fly in a stable manner. However the situation changes when external factors like wind are present. Since "I" is used for calculating the accumulated error over time it can predict adequate response in form of output - countering the continuous gusts of wind. With "I" value being low the vehicle will keep drifting wherever an external force takes it.
"I" value being too high result in over correcting like in the case of proportional factor. However in this case oscillations are happening with smaller frequency.

d) Derivative term is used for calculating future errors based on current error. What it means in practice is that it has a dampening effect on both proportional and integral term. The higher "D" value the slower response from outputs.
It is not required to be used for quadcopters, however it can be used to minimally lessen vibrations.

For each of the term a limit can be set. Limit is the maximum percentage throttle allowed to correct an error. Altering these numbers gives small results for a delicate fine tuning.

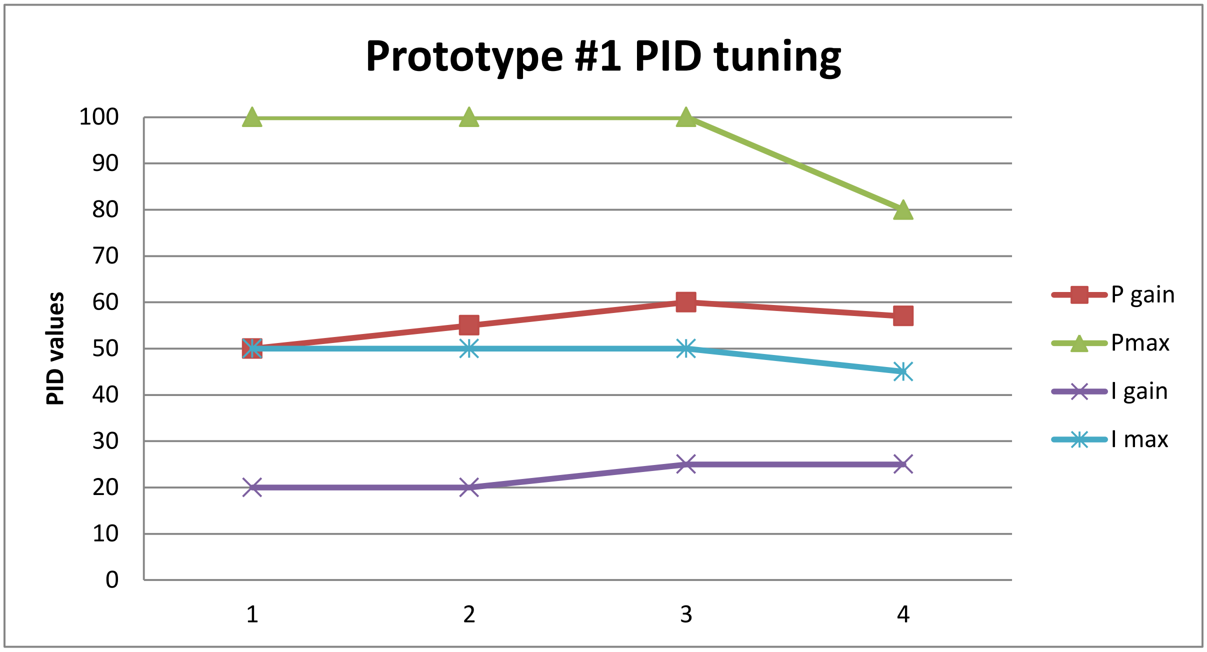


Figure 4. Prototype #1 PID tuning.

Prototype #1 PID tuning				
Attempts	P gain	Pmax	I gain	I max
1	50	100	20	50
2	55	100	20	50
3	60	100	25	50
4	57	80	25	45

Table 5. Prototype #1 PID tuning.

Figure X visualizes PID tuning attempts with KK2.1 controller.

Attempt #1.

In the first attempt the drone was quite unstable and had slow response to inputs from RC transmitter. Additionally it has been drifting to the sides due to the light wind.
The conclusion was that the "P" value was too low and perhaps the same was with the "I" value. However it is a good practice to change one setting at the time to be able to control every slightest alteration in flight stability.

Attempt #2.

Based on the conclusion from the first attempt I decided to increase the “P” with increment of 5 aiming for sharper response from inputs and stable flight. The outcome was still unstable flight and continuous drifting.

Attempt #3.

Both “P” and “I” values increased by 5, to correct both instability issues. The change resulted in no drifting, yet minor oscillations were still present.

Attempt #4.

I have reduced the “P” value by 3 and “Pmax” by 20 and “Imax” by 5. This was the best result I have managed with KK2.1 board. I have managed to reach an acceptable stability.

Unfortunately experimenting with the board is very inconvenient for more complex projects.

Device provides no feedback is and it doesn’t support additional hardware like cameras or GPS. Shortly after I have abandoned KK2.1 flight controller and moved to Arduino-based APM board 2.6.

3.2.3 Drone prototype #2 HMR250 APM 2.6 board

The idea of second prototype was to asses stability gained by using APM 2.6 flight controller and telemetry antenna.

Otherwise the whole setup is almost the same as prototype #1,

APM 2.6 is superior to KK2.1 due to many facts. First one supports external GPS and telemetry antenna. It allows connecting a Power Module, which gives feedback about charge in the battery. It allows datalogging providing variety of feedback and is based on Arduino.

Picture 14. Prototype #2.

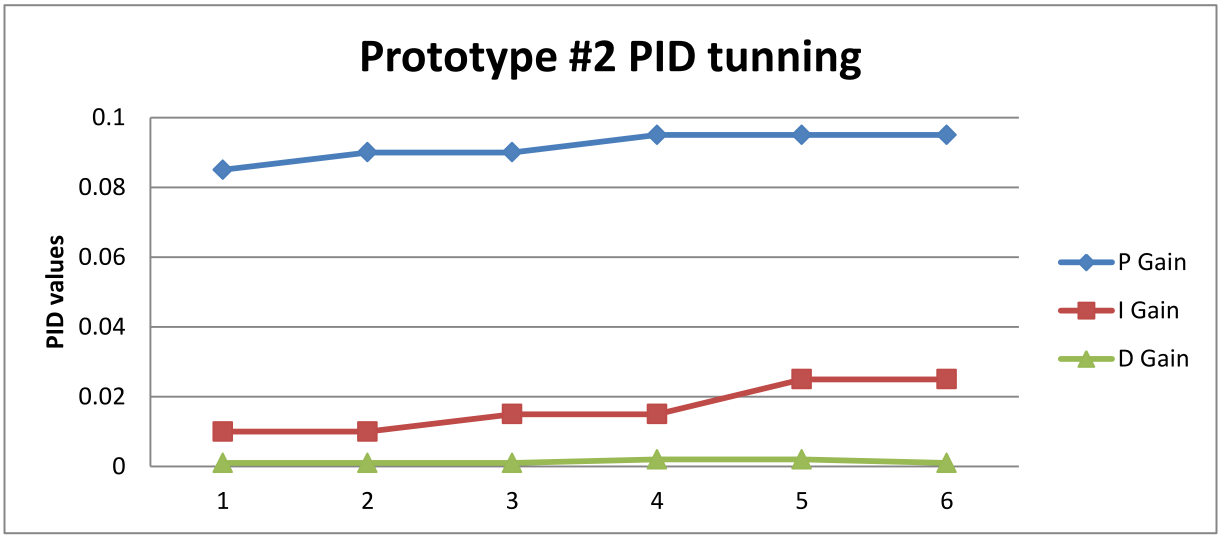


Figure 6. Prototype #2 PID tuning.

Prototype #2 PID tuning			
Attempts	P Gain	I Gain	D Gain
1	0.085	0.01	0.001
2	0.09	0.01	0.001
3	0.09	0.015	0.001
4	0.095	0.015	0.002
5	0.095	0.025	0.002
6	0.095	0.025	0.001

Table 1. Prototype #2 PID tuning.

Attempt #1.

First thing I have notice is that APM board has completely different values provided and previous KK2.1 board experience can't help me with transferring previously tested settings. The lowest "P" value available for selection is 0,08 and "I" value 0,01. "D" gain is set on default at 0,003, but I took it to 0,001.
First trial resulted in a flight that was out of control – meaning high frequency oscillations and drifting to the sides.

Attempt #2.

Proportional term increased by 5 – stability has increased, yet drifting has amplified.

Attempt #3.

I have increased Integral term by 5 and it reduced drifting, yet negatively affected stability of the drone.

Attempt #4.

I have increased Proportional term by 5 and Derivative term by 0,001. The logic behind this alteration was to improve stability further and at the same damp the minor errors of both "P" and "I".
The results was as expected to an extent. I've experienced return of drifting which indicates insufficient value of "I".

Attempt #5.

Increasing the Integral term by 10 has reduced drifting almost completely.

Attempt #6.

In the end I have reduced the Derivative term to 0,001. As I hoped the quadcopter has become slightly sharper in calculating the errors and a satisfying leveled hover was achieved.

Despite successful stability of the second prototype, I realized the need for a bigger device that would have more thrust available to be independent from strong wind as well as for having a greater capacity to be feasible for shipping cargo.
Also prototype #2 has maximal flight time of approximately 10-12 minutes, depending on utilization.

Prototype #3 purpose was to reach 3 facilities that agreed for testing blood delivered by the drone. My goal was a drone that can travel at speed of 50km/h and flight time of around 30 minutes. These parameters will ensure that the UAV will be able to cover the distance while still having a safe reserve at the end of the trip.

3.2.4 Drone prototype #3 DJI F450 APM 2.6.

Prototype's #3 purpose was to reach 3 facilities that agreed for testing the alternative blood delivery. My goal was making an UAV that can travel at speed of at least 50km/h and with flight time of around 30 minutes. These parameters will ensure that the UAV will be able to cover the distance while still having a safe reserve at the end of the trip.
The solution will have a cargo box that will open, release the blood samples and then instantly fly away back to base.
Functions like opening a box, can be programmed on available channel and triggered when desired.

a) DJI F450 frame.

I've built the drone on a DJI F450 quadcopter frame made of carbon fiber with embedded voltage distribution board. The frame provides right dimensions for constructing a sufficiently sizeable drone.

Figure 7. DJI F450 quadcopter frame

b) Telemetry RSSI 2.4 GHz

Telemetry provides remote information flow via RF connections. It allowed me tuning the quad remotely, which is very convenient. It also allows tracking drone's position, setting waypoints on the map and given tasks associated with these locations.

For the Phase I development telemetry is the component allowing programing delivery mission and its route.

Figure 8. Telemetry kit.

c) I chose U3508 KV750 Waterproof Brushless Motors. The fact that they are water proof is very important for providing weather independent service. Also the payload capacity provided by additional thrust will be sufficient to support cargo shipping.

d) Power module is an important fool-proofing add-on. Connecting it to the on-board circuitry provides feedback of the current state of the battery. I am able to know how much charge is left at any time.

Thanks to power module I can program fail-proofing options like emergency RTL in a situation when battery charge reached 50%.

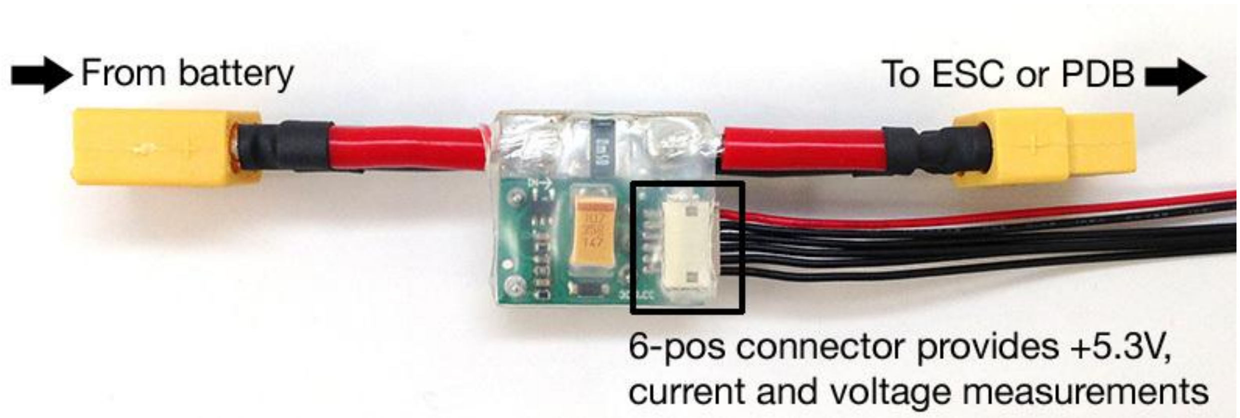
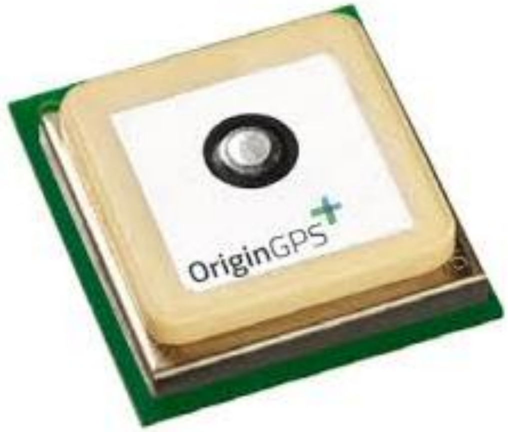


Figure 9. Power module add-on[32].

e) Multi SISO Hornet – GPS and GLONASS module. This module allows pairing up American and Russian navigation systems, thus vastly increasing strength and accuracy of the signal. The secret lies in the fact that GLONASS satellites are staying at completely different orbit than GPS ones. Both navigation systems combined are superior to them on their own.
Using this module is a fail-proofing solution ensuring reliable accessibility to navigation system.



d) I have used simple plastic 12 inch propellers for this drone. They have provided satisfying stability and limited vibrations.

[32] http://www.buildyourowndrone.co.uk/ardupilot-mega-power-module-xt60-connectors.html

Picture 15. Prototype #3 propellers[33].

e) 40 Amp ESCs are required to support my choice of motors.

f) Battery 3S 5000mAh LiPo 35C

f) Arduino Ultrasonic sensor. Four of them required at every end for obstacle SAA.

g) Transmitter Avionics RCB6i with receiver.

h) Cargo box made of plastic and closed with a servo motor.

i) Avionic AV9A 9g Servo motor is used to open and close the hatch of the cargo container.

j) Avionic AV6AC battery charger

[33] http://g02.a.alicdn.com/kf/HTB1Z2WnJpXXXXXaXpXXq6xXFXXXY/5-Pairs-Set-font-b-12-b-font-font-b-Inch-b-font-APC-1238-font.jpg

Picture 16. Avionic AV6AC battery charger.

Picture 17. Basic version of prototype #3

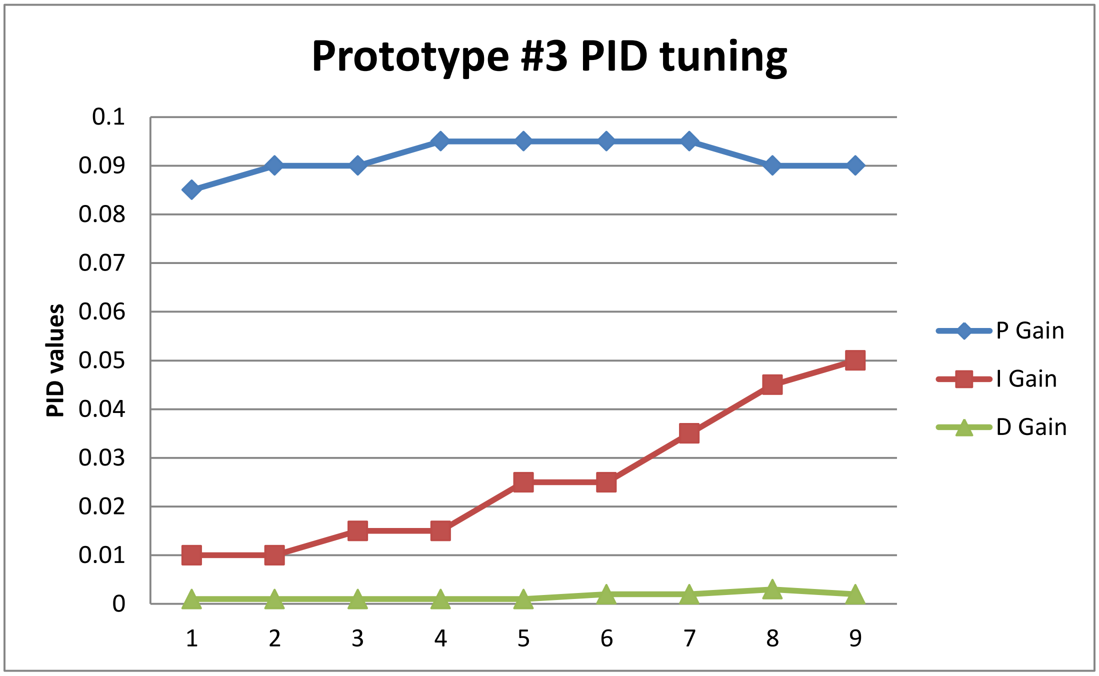


Figure 10. Prototype #3 PID tuning.

Prototype #3 PID tuning			
Attempts	P Gain	I Gain	D Gain
1	0.085	0.01	0.001
2	0.09	0.01	0.001
3	0.09	0.015	0.001
4	0.095	0.015	0.001
5	0.095	0.025	0.001
6	0.095	0.025	0.002
7	0.095	0.035	0.002
8	0.09	0.045	0.003
9	0.09	0.05	0.002

Figure 11. Prototype #3 PID tuning.

Attempt #1

I have followed to procedures from previous tuning experience and started with very low Proportional term value and the lowest possible Integral term value.

The drone was struggling to level itself, based on “P” values, however the drifting that I had to deal with was dire. Very quickly I realized that Integral term has to be increases significantly.

Attempt #2

In order to verify how much more drifting will be occurring if I try to stabilize the drone first, I increased the “P” by 0,05. The drone became more stable, yet the drifting away has been slightly amplified.

Attempt #3

Further I increased Integral term by 0,005 for addressing to minimize drifting. It has indeed reduced, however lack of stability based on “P” has returned.

Attempt #4

“P” value has been raised to 0,095. The observations were again return of the level stability of the vehicle. However the drifting has amplified again.

Attempt #5

I have increased the “I” value by 0,01. I progressed with a bigger increment to see how much effect will it have on the drifting issue. I’ve noted significantly reduced drifting and higher stability. However oscillation started being present, which can be a sign of imbalance between Proportional and Integrated terms.

Attempt #6

Next I decided to increase the Derivative term by 0,001 to reduce the oscillations reported in previous attempt. The oscillations reduced, yet drifting came back.

Attempt #7

Further I reduced “P” by 0,005 to avoid oscillations and increased “I” by 0,01 to get rid of the drifting. The drone’s drifting has reduced, however the oscillations were still present.

Attempt #8

I have increased the “D” value to 0,003 hoping for damping oscillations. However the response from inputs was too slow and drifting was still present to a minor extent.

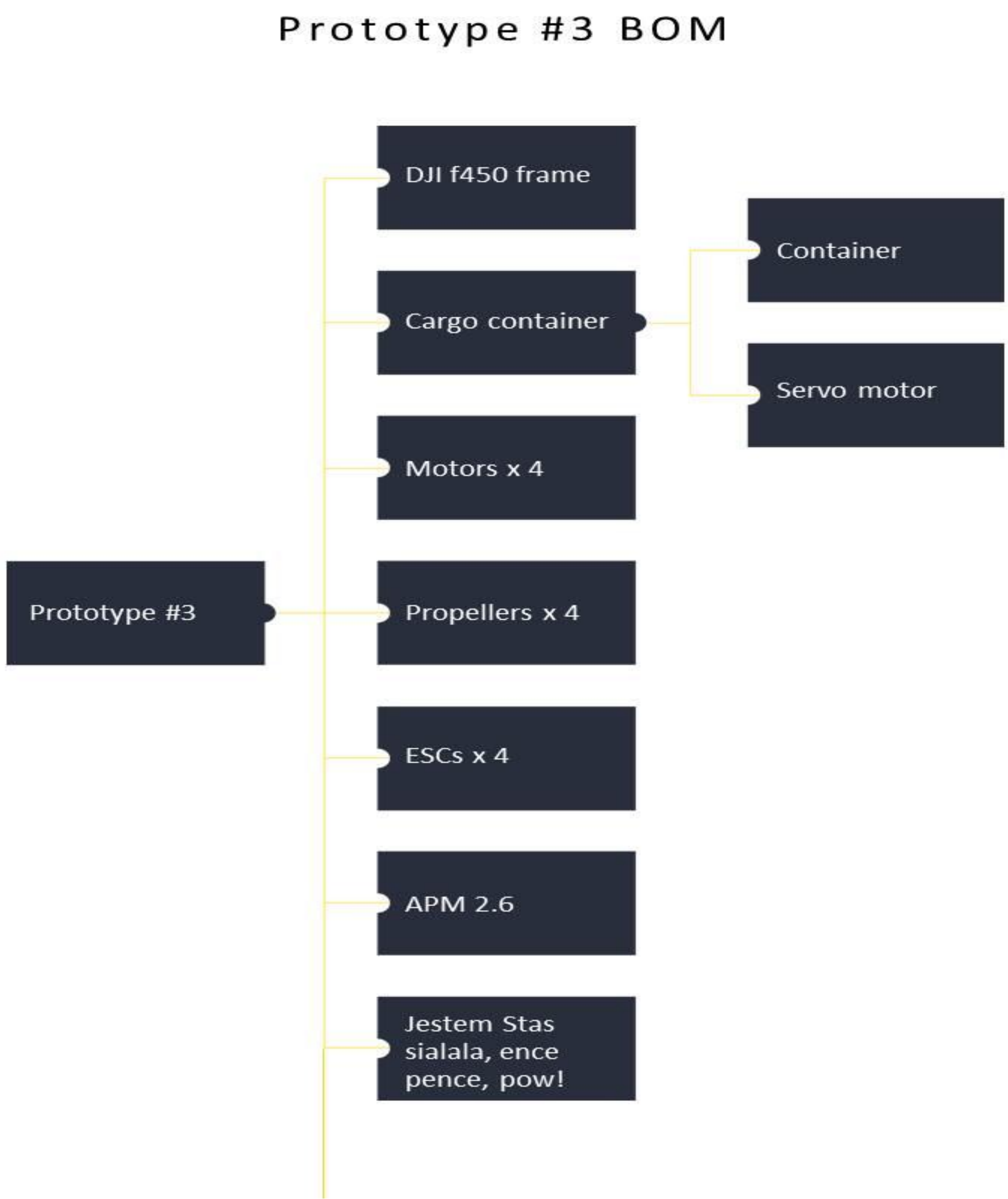
Attempt #9

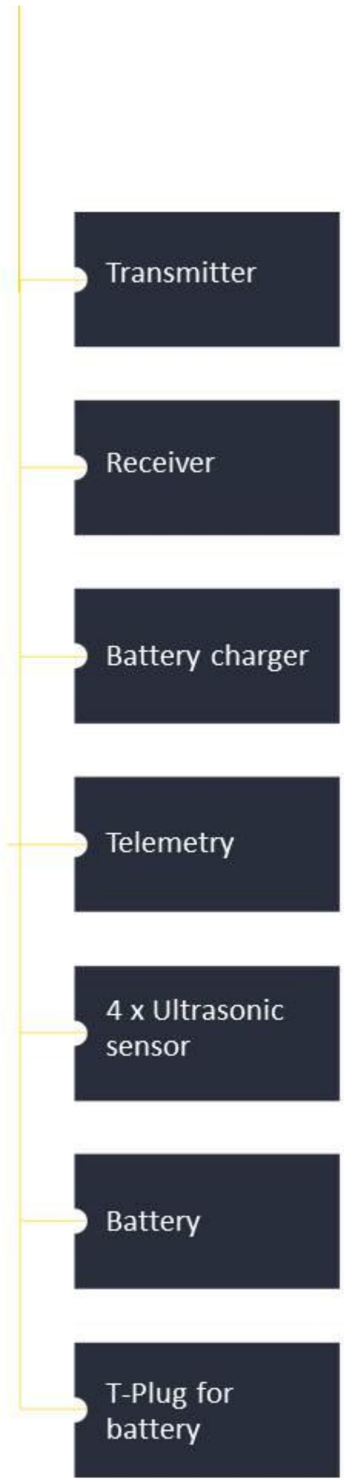
In last attempt to stabilize the UAV I have increased the “I” to 0,05 and reduced “D” to 0,002. This finally resulted in a stable flight based on “P” gain, quickly regaining level after influence of external factors and no vibrations, which was achievable thanks to dampening with a Derivative term.

The prototype #3 has been tuned sufficiently for being able to perform a smooth autonomous flight to designated destinations.

3.2.5 BOM: Prototype #3

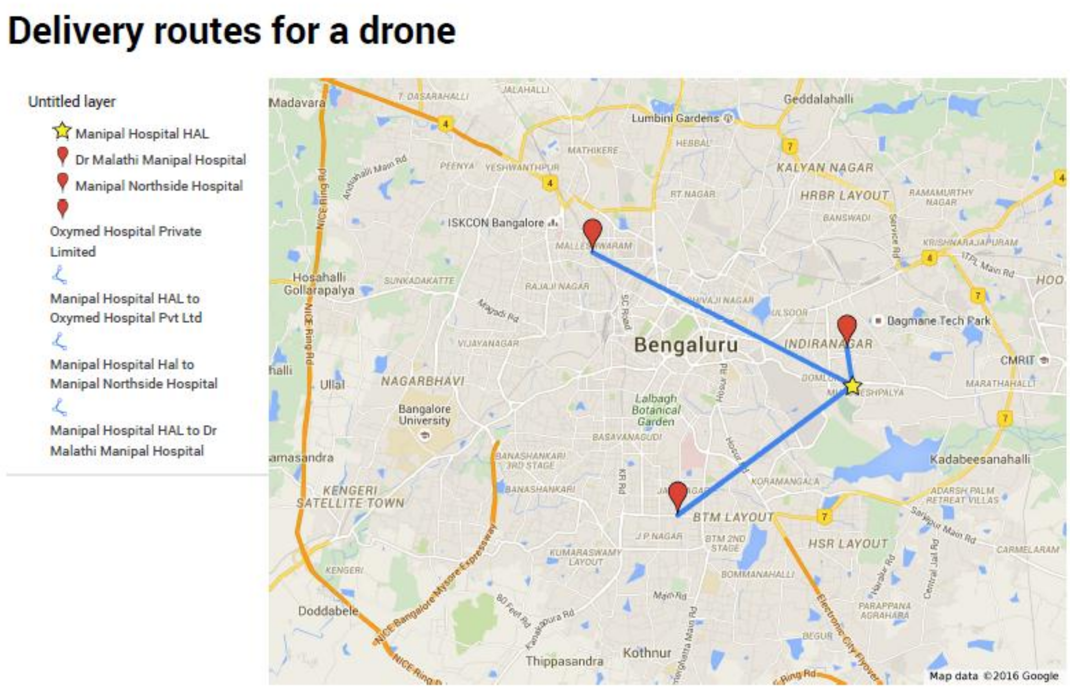
Bill of materials includes all the components required to construct the prototype #3 drone and to make it capable of completing its designated function at Phase I of development.
The hierarchy of the BOM is from the left to the right. The UAV is a modular product, hence the shape is almost a flat line. Only 3 levels are present in the frame. Because of this I illustrated it in a vertical position for a clear view.




Transmitter
Receiver
Battery charger
Telemetry
4 x Ultrasonic sensor
Battery
T-Plug for battery

3.3 Service design.

3.3.1 To-Be situation: Delivery routes for the drone.



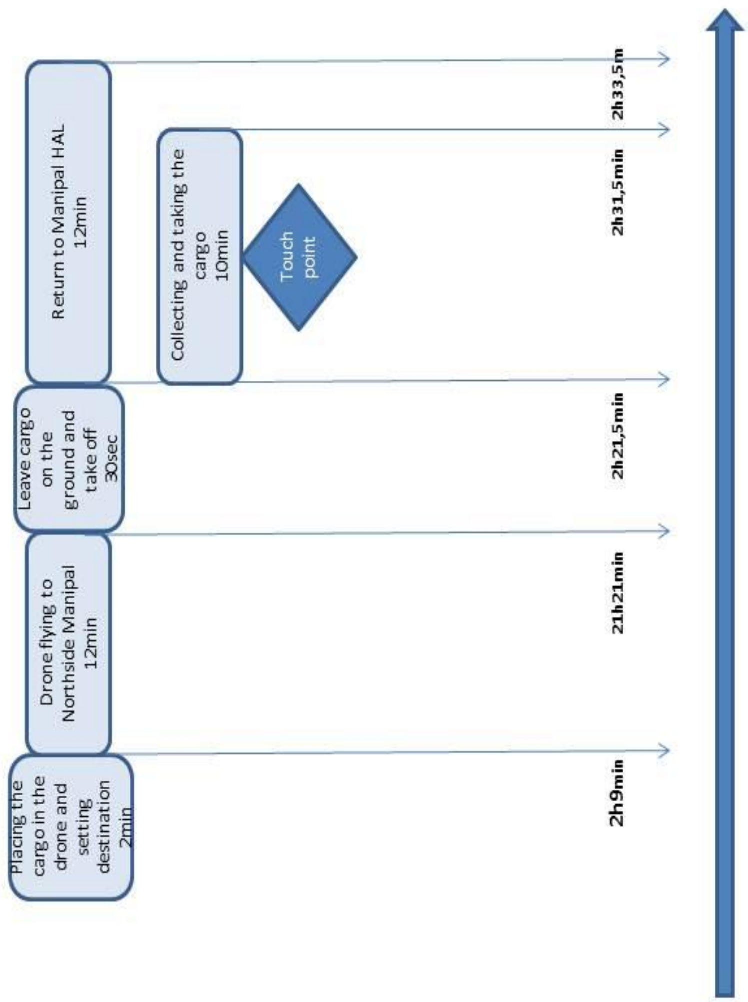
Prototype #3 drone delivery routes			
Route	Distance	Travel time	Service lead time
Manipal HAL → Manipal Northside	10,7 km	12 min	2h 32min
Manipal HAL → Malathi Manipal	8,5 km	10 min	2h 7min
Manipal HAL →Oxymed Hospital Pvt Ltd	1,2 km	2 min	1h 49min

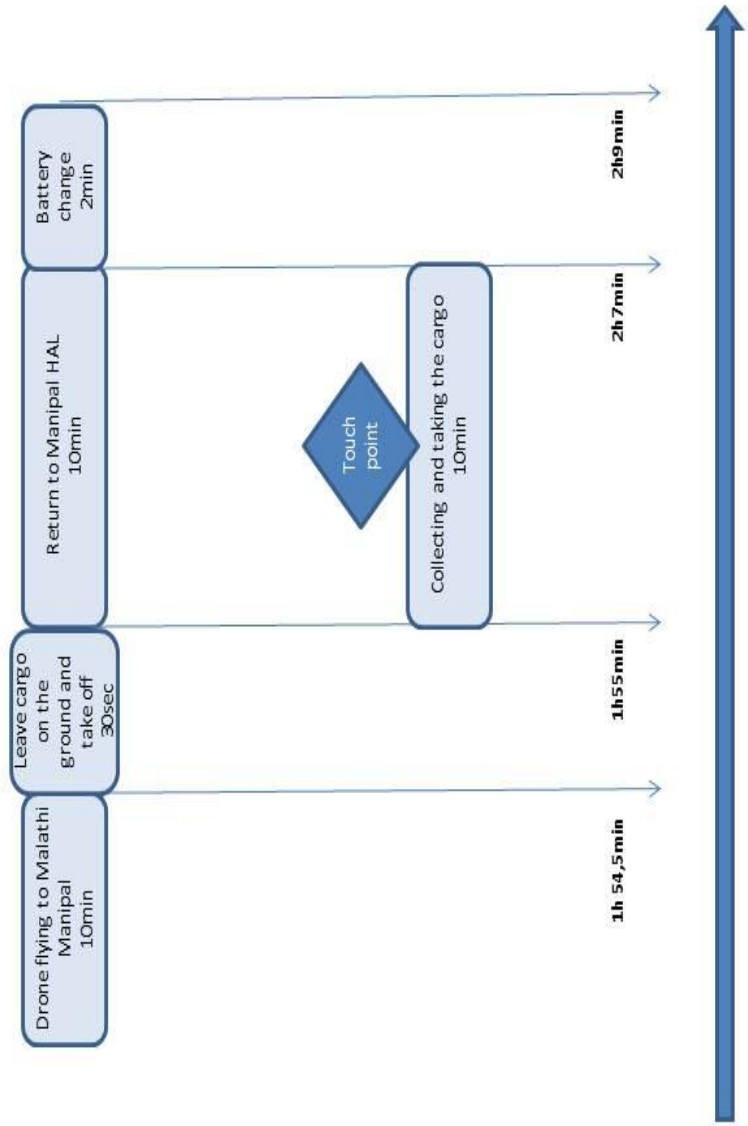
The new integrated flow chart is based on the As-Is situation. No existing processes can be casted away, as all of them are completely necessary to complete the service. For this reason I realized I need overlap the additional drone preparation activities and overlap them with cargo preparation.

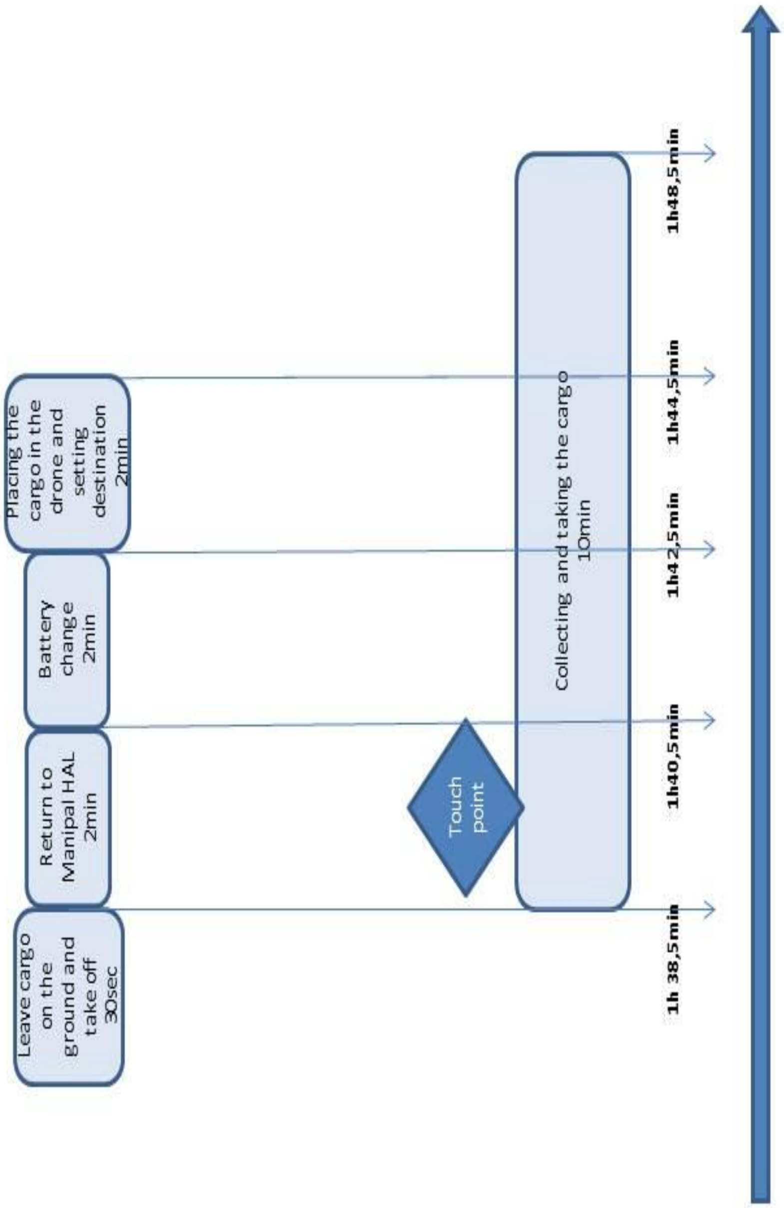
Also the drone's shipping capabilities like speed and range have been evaluated to build the system. I have realized that I can use a single drone to sustain daily demand of 2 sample deliveries to each of 3 facilities – Manipal Northside Hospital, Dr Malathi Manipal Hospital and Oxymed Hospital Private Limited.

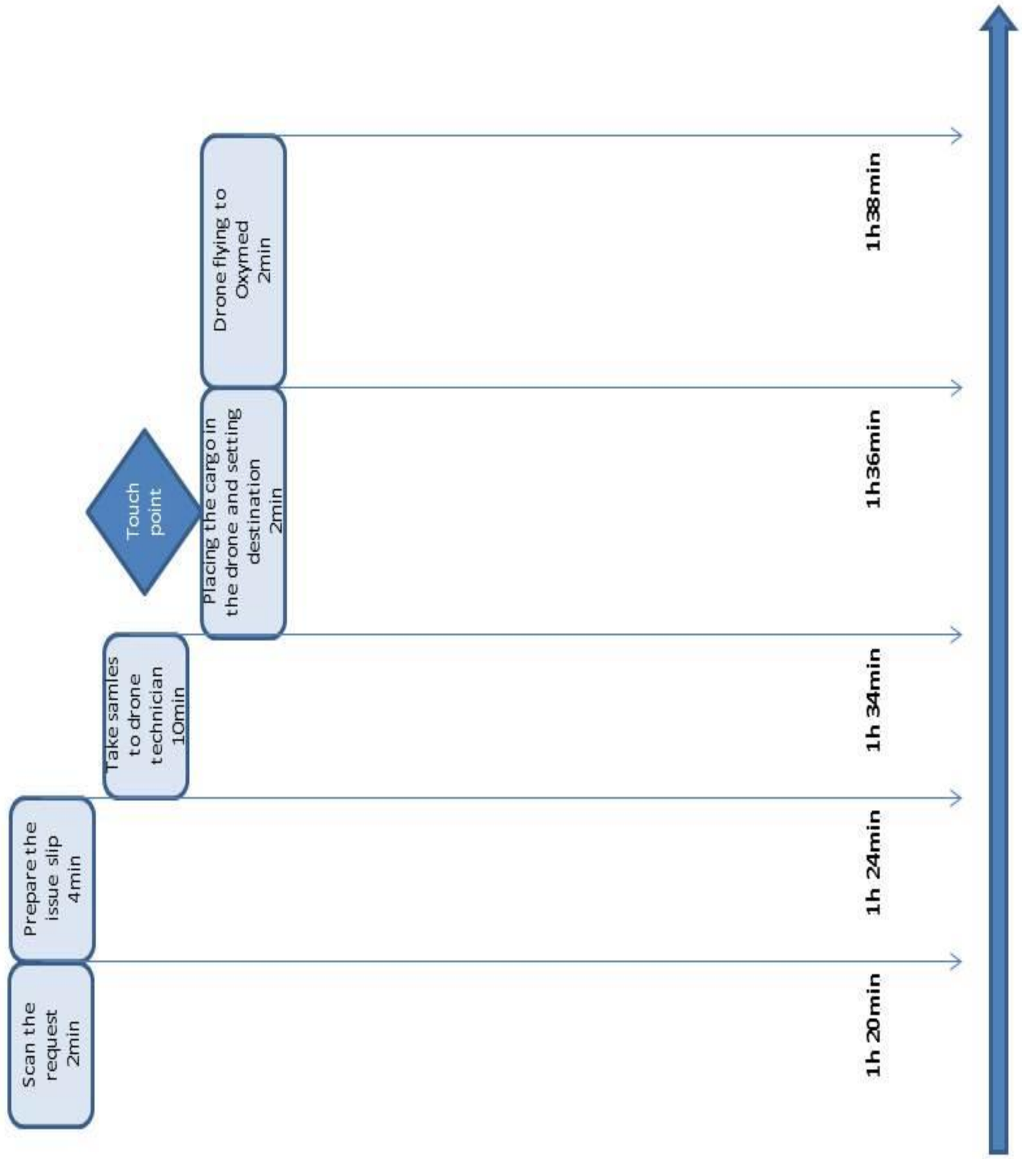
I came up with additional customer touch points for providing satisfying service experience and information flow.

3.3.2 To-Be situation: Integrated flow chart.

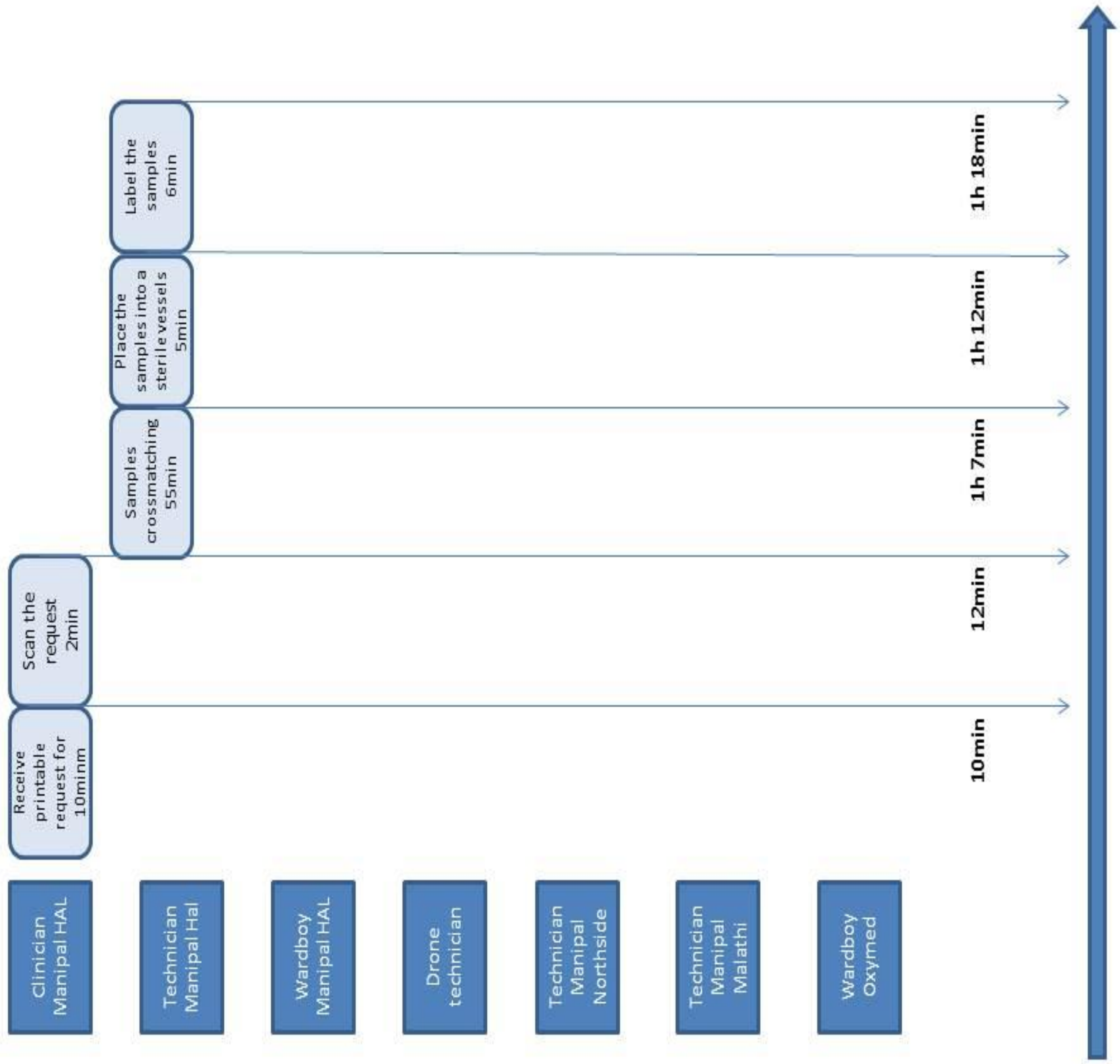



Drone flying to Malathi Manipal 10min
Leave cargo on the ground and take off 30sec
Return to Manipal HAL 10min
Battery change 2min
Touch point
Collecting and taking the cargo 10min
1h 54,5min
1h55min
2h7min
2h9min


Leave cargo on the ground and take off 30sec
Return to Manipal HAL 2min
Battery change 2min
Placing the cargo in the drone and setting destination 2min
Touch point
Collecting and taking the cargo 10min
1h 38,5min
1h40,5min
1h42,5min
1h44,5min
1h48,5min



Scan the request 2min
Prepare the issue slip 4min
Take samles to drone technician 10min
Touch point
Placing the cargo in the drone and setting destination 2min
Drone flying to Oxymed 2min
1h 20min
1h 24min
1h 34min
1h36min
1h38min



Clinician Manipal HAL
Technician Manipal Hal
Wardboy Manipal HAL
Drone technician
Technician Manipal Northside
Technician Manipal Malathi
Wardboy Oxymed
Receive printable request for 10minm
Scan the request 2min
Samples crossmatching 55min
Place the samples into a sterile vessels 5min
Label the samples 6min
10min
12min
1h 7min
1h 12min
1h 18min

To-Be Integrated Flow chart.

I have collected information about all the steps involved in delivering blood with 3 separate auto rickshaws as it is being done today.
The processes flow is described below. For integrated flow chart see appendix.

Process 1:
Transfusion request form arrives to blood bank electronically. A blood bank clinician is responsible for receiving and printing it.
10 minutes are required to complete the task.

Process 2:
Scanning the printed transfusion request form and giving it to a blood bank technician.
2 minutes are required to complete the task.

Process 3:
Blood crossmatching handled by a blood bank technician.
It takes 55min to complete the task.

Process 4:
Placing the crossmatched blood into a sterile sealed container by a blood bank technician.
It takes 5min to complete the task.

Process 5:
Labeling the samples handled by a blood bank technician.
It takes 4min to complete the task.

Process 6:
Preparing the issue slip by a blood bank technician.
It takes 6 min to complete the task.

Process 7:
Taking samples and issue slips to a drone technician. Wardboy needs 10min to complete the task.
Physical touchpoint: Location.
The hospitals' staff member interacting directly with the service provider.

Process 8:
Drone technician places the cargo inside the drone and sets a destination.
Requires 2min to complete the action.

Process 9:
Drone flies to first destination with the cargo – Oxymed Hospital Pvt Ltd.
It takes 2min to fly to the first location.
Virtual touchpoint: ETA mobile notification.

Process 10:
Drone lands, releases, the package and takes off.
It takes 30sec complete this action.

Process 11:
Wardboy collects the cargo.
10min necessary to complete this action.
Physical touchpoint: Issue slip printout and delivery location.

Process 12:
Drone comes back to Manipal HAL.
2min required for completing this action.

Process 13:
Drone technician battery changing at Manipal HAL.
2min required for completing this action.

Process 14:
Drone technician places the cargo inside the drone and sets a destination.
The cargo kept waiting labeled for the drone to come back.
Requires 2min to complete the action.

Process 15:
Drone flies to second destination with the cargo – Dr Malathi Manipal Hospital.
It takes 10min to fly to the first location.
Virtual touchpoint: ETA mobile notification.

Process 16:
Drone lands releases the package and takes off.
It takes 30sec complete this action.

Process 17:
Blood bank Technician collects the cargo.
10min necessary to complete this action.
Physical touchpoint: Issue slip printout and delivery location.

Process 18:
Drone comes back to Manipal HAL.
10min required for completing this action.

Process 19:
Drone technician battery changing at Manipal HAL.
2min required for completing this action.

Process 20
Drone technician places the cargo inside the drone and sets a destination.
The cargo kept waiting labeled for the drone to come back.

2min required to complete the action.

Process 23:
Drone flies to third destination with the cargo – Northside Manipal Hospital.
It takes 12min to fly to the first location.
Virtual touchpoint: ETA mobile notification.

Process 24:
Drone lands releases the package and takes off.
It takes 30sec complete this action.

Process 25:
Blood bank Technician collects the cargo.
10min necessary to complete this action.
Physical touchpoint: Issue slip printout and delivery location.

Process 26:
Drone comes back to Manipal HAL.
12min required for completing this action.

3.3.3 To-Be situation: SIPOC.

S	I	P	O	C
Suppliers	**Inputs**	**Processes**	**Outputs**	**Customers**
Bloodbanks Novatech Robo Donors	Order destination information Order specifics Transfusion request form Issue sleep Updated ETA	1. Receiving a request form from another facility 2. Preparing the biomaterial for shipping 3. Labeling and issuing the biomaterial 4. Delivering the biomaterial to a driver 5. Transporting the biomaterial to another facility 6. Receiving the biomaterial at destination.	Specific order delivery Blood stock info update Issued slip confirming delivery Trip completed notification	Manipal Hospital HAL Manipal Northside Hospital Malathi Manipal Hospital Oxymed Hospital Pvt Ltd

3.3.4 5S approach: servicing quality and in-house cleanliness standardization.

UAS are a type of technology that require check-ups before and after every single flight. This is called the autonomous maintenance and its concept is that regular maintenance is the best protection from a possibility of a malfunction occurring. We can qualify this particular type of hardware check-ups as a Poka-Yoke practice.

Since it is such an important part of ensuring that the delivery service system will perform flawlessly I used 5S mentality for standardizing quality maintenance procedures and environment in a base of operation workshop.

a) Seiri – sort.

The very first base of operations and the workshop will be in one of available rooms on a ground floor of Manipal Hospital HAL. Since in the phase I of development no specially prepared room will be available, it is important to arrange it with having 5S mentality.

Sorting all the unnecessary things like furniture, office items, papers and any sort of things that will have no use for maintenance has to be done. The equipment to be brought in to the workshop has to be selected carefully.

The necessary equipment includes spare drone components, wiring, soldering tool with lead metal and flux, insulation tape, a PC or laptop, batteries and charger.

b) Seiton – set in order.

Every single tool and part needs to be set in order and accordingly to the frequency of use. PC or a laptop will be the most frequently used tool in the workshop, because it will be used for loading the destination location and for feedback during flight. It has to be in easy accessible area close to the window to make sure the signal PC – UAV is strong.

Charged batteries and a charger should be in close proximity to the laptop, because changing battery for a new one and charging the old one are the most frequent actions after supervising the flight from a PC.

The rest of the tools and spare parts can be positioned in two different areas for an easy find. All the components need to be arranged clearly in on some box. Analogically, tools for repairs should be kept in a separate box. Such order will allow good flow in the workshop and finding necessary things quickly, while remaining compact.

c) Seiso – sweep.

Some maintenance procedures may leave a lot of small waste in form of wiring, flux paste covering surfaces. Also tools that have been used and then dropped somewhere are a reason of flow disturbance and in some cases – danger. It is vital to keep the workshop environment clean and all the tools in their designated places.

d) Seiketsu – standardize the activities.

Maintenance is a very important part of avoiding failures. This means that besides standardizing work environment cleanliness, the hardware check-up procedures also need to be standardized. Every single time the same scenario and sequence need to occur with the same focus on details and quality of the job:

- checking propellers – scratches, cracks or being bent qualify a propeller as damaged.

- checking motors – motors need to spin smoothly without emitting undesired sounds. They also have to be checked for presence of external bodies inside.

- blowing high pressure air in the motors to remove particles of dust from the inside. This will keep the motors in a good condition and prevent them from heating.

- checking ESCs connections – if too much heat is generated in motors during the flight the ESC connections may loosen up. This is very dangerous, because an ESC wire that will disconnect will make a motor stop resulting in an instant flip and crash. These connections have to be checked carefully for their tight fixation.

- checking soldered areas and insulation on electronic components – similar as with ESC connections all soldering locations need to be looked upon. Some soldered areas and insulation glue can melt from undesired overheating or physically loosen up due to vibrations. A visual inspection and reaching the components will be sufficient to assess whether the proper condition of the elements is maintained.

- checking vibration damper efficiency – vibration damper removes the vibrations on gyroscopes and accelerometer within flight controller. If it is not efficient the drone will start being unstable, which will further cause increased battery drain.

- check if container is intact and if it keeps the temperature – the cargo container has to intact. A simple visual inspection will deem it as good to use or not. Simple thermometer can be placed inside after completing the first delivery loop to assess temperature isolation capabilities of the container.

- checking and charging the battery – this is the last maintenance procedure. It can be done after the drone left for the next location. A battery will be taken out of the drone and the new one will be placed instead. Once the drone is airborne sufficient time will be available for connecting the battery from a previous flight to charge. The charger also gives feedback on the current state of the battery. In case any cells have degraded, the battery has to be disposed of in a proper manner.

e) Shitsuke – sustain.

Sustaining the cleanliness in a workshop is a process requiring commitment and focus. To assist a drone technician with taking on this approach visual guidance will be provided.

A checklist with maintenance sequence procedures will be displayed clearly near the maintenance bench. The technician will have the opportunity to make sure the sequence he follows is correct and then mark the procedure as completed.

Also labeling the boxes with tools and components will help in stocking them in an orderly fashion. It is important to also note the amount of components left to be sure the stock contains sufficient spare parts.

3.3.5 Future development: Kaizen - Poka-Yoke.

Despite working on launching phase I of the service implementation I have already set some goals for phase IV in the future.

The ideas have been born over the course of getting familiar with actual demand and scope for blood transferring. Also the future plans are built upon Kaizen and Poka-Yoke concepts, to ensure constant improvement and prevent failing in the process.

a) Manufacturing discussion.

Since Phase I of the development did not include manufacturing any components at all. However the plan for future is to design and manufacture the body of the drone. That will not include the electronic components, but the fuselage, or frame and the outer shell of the UAV.

Instead of using only widely available components I want to create a unique design. For that I plan to extend my knowledge of SolidWorks software to be able to model a drone that is sophisticated in terms of aerodynamics and unique. The ideal plan is to first design a CAD model and to test its aerodynamics with a CFD analysis add-on.

Next step is manufacturing the drone. The first prototype of the very final solution will be built with using subtractive prototyping techniques. UAV’s fuselage will be shaped from stereofoam according to CAD design. Once ready – fiber glass coating will be applied and treated by hardening resin.

At the stage when a UAV is shaped and tested the design can be approved. It will be very important to conduct many tests to ensure that the prototype is working as desired, since further manufacturing methods will be costlier.

A final version of the drone will be produced with a mix of additive and subtractive manufacturing.

The frame of the UAV will be CNC milled out of carbon fiber, due to its material strength and light weight. It will ensure the high quality of the device.

Also I plan to use 3D printing for creating an aerodynamic outer shell for the drone. The volume of the drones required for the last phase will be definitely greater than in phase I, yet still too minor to consider manufacturing techniques like injection molding.

It is also vital to include design-for-assembly and design-for-disassembly thinking. Since the product will still be modular and maintenance every day will be a must, it is important to be able to assemble and disassemble the UAV without a need to destroy the device in the process. The fuselage has to be designed in a way providing clearly designated areas for electronic components. Reliable fixation points need to be designed to allow easy access for a technician to do the maintenance work.

b) Tilt-rotor VTOL: Y6 configuration.

My goal is to end up with an unique tilt-rotor VTOL based on Y6 configuration – a delta wing aircraft with 6 total rotors.

Take of will happen like with any other multi-rotor, yet on a desired cruise height the rotors will be turned into forward position, changing the vehicle into a fixed wing aircraft. The front 4 rotors will provide thrust necessary for forward motion, while tail rotors will disable, to lower the battery consumption. I assume right now, that the speed will be sufficient with using only the front rotors.

An idea to test ducted fans is also present, yet as for it can't be assessed whether it is a viable solution. A pilot and a heavy duty-jet engineer I had a chance to discuss the matter with has said that propellers confined within a duct can generate up to ~ 26% more thrust. This fact means two things for me – potential to reach higher speeds, or increase the payload of the vehicle by roughly ¼.

In general the idea to have a final VTOL UAV is because of its advantages I have mentioned in the background section. The small logistic footprint and energy efficiency makes VTOL an inevitable and ultimate outcome.

c) Kaizen and Poka-Yoke.

Constant improvement and fail proofing are important things for the final ultimate solution, since there is no place for failure. Drone technology enthusiasts are fighting to push the technology in different sectors, but before it is done the safety matters have to be ensured.

Another thing is planning overall system that will provide feedback allowing constant improvement.

I have described Kaizen and Poka-Yoke solutions within 4 level hierarchy of mistake proofing frame, to address the different ideas at different levels of improvement and failure prevention.

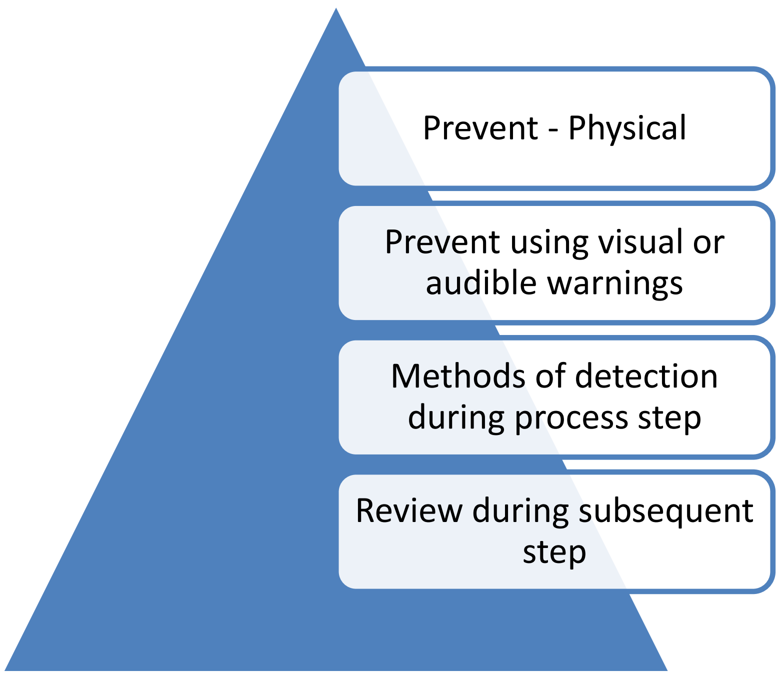


Figure 12. Fool-proofing hierarchy pyramid.

Mistake prevention hierarchy:

Level I Prevent (Physical) – eliminating possibility of performing an erring action. Level I are the top effectiveness solutions.

- *Parachute.*

Despite the fact that I don’t expect the UAVs to fall down I need to consider precautions in case such event occurs. Effective use of parachute will allow retrieving the UAV and its cargo intact.

- *GPS + GLONASS module.*

Both of the navigation systems paired together into a single module provide significantly better position signal, due to the increased amount of satellites used to triangulate the signal.
Also GLONASS satellites are on an orbit which has different proximity to the surface of Earth than GPS. This is why having both of them together will provide better than ever results.

- *Emergency stop-and-loiter.*

A well thought-through reaction algorithm has to be crafted to react accordingly to a situation where the drone has to stop almost instantly. Obstacle avoidance is an important autonomy feature that the system has to rely on.
However there might be situations, when the drone will have to stop in midair and loiter for a specific amount of time. For example until some obstacle will move away and unlock the only path available.

- *Anti-bird module*

South India has quite a population of predatory birds easily noticeable every day. A special anti-bird module emitting frequencies that scare away birds is an absolute must. There have been known cases when drones were attacked by eagles etc.

- *Gimbal for a camera and cargo.*

It can be vital to have a gimbal device for cargo. This particular idea appeared after getting familiar with the fixed-wing drone delivery project described in *Similar Project Examples* subchapter.
Biomaterials can be very fragile, thus having a device that would keep such cargo in a same position at all times and with dampened vibrations can be a condition of successful delivery.

- *Ducted fans/propeller guards.*

If ducted fans will prove to be efficient, they will also provide additional safety. Confined propellers are an amazing and simple tool to avoid external objects damaging the blade.
If it will turn out that ducted fans are not a feasible solution I want to input a simplistic propeller guards to protect the blades.

Prevent using visual or audible warnings – detecting error immediately after being made.

- *Alarm for temperature rising in cargo bay.*

An important action for ensuring proper shipping conditions. Different biomaterials have different temperature tolerance and breeching those needs to be alarmed instantly.

- *Alarm and RTL after battery charge drops to 50%.*

Despite the condition of the batteries being always monitored there is a chance that a slightly defected or old power supply will drain battery significantly faster.
Also in a scenario where external factors cause unexpected amount of maneuvers or intense flight stabilization the battery will drain also faster. For that reason I want the drone to ring an alarm and switch into RTL mode and return to base instantly for changing battery.

- *Camera for recognizing landing pad and its clearance.*

Besides travelling to the exact destination location there is a way to improve a landing procedure and make it safer. Mounting a camera with a function of recognizing a proper landing area is viable. Already DJI drones have such camera on some of their drones and it results in smooth landings.
Also alarm has to be sound if the drone landing pad is not clear for landing. This will prevent it from hovering until battery charge drops to zero.

Methods of detection during process step – inspection and detection.

- *ISSR telemetry*

A telemetry antenna onboard the drone. It will be connected to the base of operation at all times allowing position tracking. Also the same antenna is the device recognizing the RF beacon at the destination location.

- *Sonar.*

This is a proximity sensor that will be placed on the sides and the back of the drone to avoid hitting any surfaces.

- *Optical flow.*

An advanced machine vision camera. Optical flow allows recognizing obstacles, their trajectory vector and their speed. It will be one of the most important tools for non-collaborative SAA.

- *RF beacon.*

Radio frequency beacon will be placed at the destination location, to enhance the accuracy of landing exactly at the designated landing pad.

Review during subsequent process step – general tools and platforms to aid analysis and design

- *ETA + percentage of route covered displayed and updated twice*.

First time when the first ETA has been provided, which is before starting preparing the cargo for shipping. Second time is when the drone is departing to ensure accuracy and evaluate whether standardization of processes has occurred.

- *Connecting to onboard camera to inspect surroundings.*

Ability to connect to the onboard camera and review surroundings in real time can prove to be useful.

- *Creating an online platform for the service.*

Kaizen solution for managing the UAV and its route. Another purpose is automating and managing the cargo demand and inventory better. A Kanban pull system introduction would be beneficial.

- *Mobile feedback to people involved in the processes.*

Since not everyone involved in the process will be monitoring the system flow from an online platform I suggest building a mobile feedback system for the rest people involved with the service processes. Also such feedback will give a feeling of job done initially increasing satisfaction.

4. Cost/Benefit analysis.

Cost/Benefit analysis.

I have prepared a cost/benefit analysis of the UAS blood delivery solution to display it's progression and agenda. In addition I have inserted different tables for comparison of both As-Is and To-Be scenarios.

Drone		
Costs	MRP	USD
Electricity cost/km	-1.0	-
Total route/day	77.4	1.2
Electricity cost/day	-77.4	-1.2
Cash In-flow/km	10.0	0.2
Profit/km	9.0	0.1
Daily cash-in flow	696.2	10.5
Daily profit	618.9	9.3

3 Auto rickshaws		
Costs	MRP	USD
Petrol cost/km	-2.1	-
Total route/day	105.7	1.6
Petrol cost/day	-219.8	-3.3
Cash In-flow/km	15	0.2
Profit/km	12.9	0.2
Daily cash-in flow	1365.4	20.6
Daily profit	1145.6	17.3

The 2 tables above display daily profit for two delivery services.
The income is dependent on the route length, cost per km and the cash in-flow. It is transparent that Manipal Hospital HAL will save 746,5 MRP (11,3 USD) daily, by using the UAS solution. It is important to note that the table displaying daily costs for 3 rickshaws involves costs of all of them providing an entire day transportation – morning and evening trip two ways.

Another table displaying yearly costs from the Manipal Hospital HAL perspective below clearly shows the difference in the prices for the services provided.

Costs after 1 year	Total MRP	Total USD
UAS solution	73967.65	1114.98
Rickshaw solution	16384.79	246.98

Below a table illustrating individual daily and monthly incomes for each driver according to the route they have to cover. The reason for this table is show income of every single driver to have an understanding about expenses and income from their perspective.

	Rickshaw #1		Rickshaw #2		Rickshaw #3	
	MRP	USD	MRP	USD	MRP	USD
Petrol cost/km	-2.10	-0.03	-2.10	-0.03	-2.10	-0.03
Total route/day	50.80	0.77	42.80	0.65	12.08	0.18
Petrol cost/day	-106.68	-1.61	-89.88	-1.35	-25.37	-0.38
Income/km	20.00	0.30	20.00	0.30	20.00	0.30
Daily cash In-flow	1016.00	15.32	856.00	12.90	241.60	3.64
Daily profit	909.32	13.71	766.12	11.55	216.23	3.26
Monthly profit	28188.92	424.92	23749.72	358.00	6703.19	101.04

Finally I have conducted a cost benefit analysis for 24 months from the moment the service stars running. The analysis focuses on a scenario of Phase I of development and the system model for it.

Additional information to be noted that an investor, whom I can't disclose is ready to put in 20000 MRP every month to ensure that the service will be launched successfully.

Costs - UAS solution	Months											
Year 1	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Initial investment	-152,869.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drone price	-72,869.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Extra parts for 1 year	-80,000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Operation costs	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5
Technicians salary	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0
Charging the drone	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5
Cash-in flow	20,279.0	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6
In-flow for the service	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6
In-flow from investor	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0
Profit	-151,784.7	-126,997.6	-102,210.5	-77,423.4	-52,636.3	-27,849.2	**-3,062.1**	**21,725.0**	**46,512.1**	**71,299.2**	**96,086.3**	**120,873.4**
Year 2	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Initial investment	-80,000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Drone price	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Extra parts for 1 year	-80,000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Operation costs	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5	-19,194.5
Technicians salary	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0	-12,000.0
Charging the drone	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5	-7,194.5
Cash-in flow	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6	43,981.6
In-flow for the service	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6	23,981.6
In-flow from investor	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0	20,000.0
Profit	**65,660.5**	**90,447.6**	**115,234.7**	**140,021.8**	**164,808.9**	**189,596.0**	**214,383.1**	**239,170.2**	**263,957.3**	**288,744.4**	**313,531.5**	**338,318.6**

It is visible that before the service starts bringing profits it needs 7 months to cover initial investment, while being supported by an investor.

As mentioned before, the agenda is not to generate vast profit, but to follow the spirit of CSR and altruism and this way expand on the market.

The biggest investment is preparing spare parts for maintenance and potential repairs for a whole year. To verify exactly how many of these components will be required annually an overtime observation of the ongoing-service has to be conducted.

5. Conclusion.

During my thesis progression I have conducted several analyses and spent much time on educating myself about UAV technology.
Also getting familiar of reality of Indian crowded cities and logistic challenges caused by that have resulted in my good understanding of these issues.

There is clearly a lot of development to be done until an advanced service system is introduced. Despite the fact I didn't reach the end of the Phase I of the development, I believe that I have a solid fundament for implementing more advanced system in the future.

Cost/benefit analysis has proved that in fact the Phase I model is going to be a cheaper delivery service for the Manipal Hospital.
First level of development will not generate much income for Novatech Robo, yet it will highlight the CSR thinking within the organization. For the future UAS based delivery system to be really feasible more drones and locations have to be present in a system model. Only then the cost efficiency, speed and accuracy of drones can be truly utilized.

With a more complex model, different customer wants will appear. Also more business process excellence tools will be required to measure, standardize and improve service performance over time.

Overall I am confident that pursuing UAV commercial applications is a path with great potential in the end.

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7. Appendix 1. Relevant paragraphs from :
"Standards Bloodbanks & Blood Transfusion Services".

"Preparation of blood components"

General principles

E-1.1 Sterility
The sterility of all components should be maintained during processing by the use of aseptic methods and sterile pyrogen free disposable bags and solutions.

E-1.2 Seal
Blood bags that allow transfer of component without breakage of the seal (closed system) should be recommended. If the seal is not broken, the viability and stability of the component is assured. The seal will not be considered broken if a sterile connection device is used resulting in a closed system.

E-1.2.1 If the seal is broken during processing, components stored between 40C + 20C must be transfused within 24 hours and component stored between 220C + 20C should be transfused as early as possible and not beyond 6 hours.

E-1.2.2 Once the frozen components are thawed, these should be transfused at the earliest and positively within 6 hours.

E-1.2.3 At the time of preparation of the final components the integrally connected tubing should be filled with aliquot of the components and sealed in such a manner that it should be available for subsequent compatibility and assay testing if needed.

E-1.3 A process of feedback should be in place with the clinician in order to periodically assess the efficacy of all blood components".

Storage and transportation.

Blood bank refrigerator/walk-in-cooler should have inside temperature of 40C ± 20C and should have a system to monitor temperature continuously or at least the temperature should be recorded every 4 hours. An alarm system and a provision for alternate power supply should be available.

H-1.4 Deep freezer should have inside temperature of -300C or -800C having temperature indicator/recording facility with alarm system and provision for alternate power supply.

Getting familiar with general principles of blood components preparation, it is transparent that bloodbanking involves very strict in terms of sterility and preparation standards.

Blood delivery service I want to introduce is not involved in preparing the biomaterial, yet being aware of sterility standards is required from Corporate Social Responsibility point of view. Responsible business in health sector is a crucial factor that can cause success, or failure. Moreover, a success can mean saving somebody's life, while failure – prematurely ending it.

"TRANSPORTATION

"Whole blood, red cell concentrate, should be transported in a manner
that will maintain a maximum temperature of 100C ± 20C.

Platelet/granulocyte concentrate stored and transported at 220C ± 20C.

Components stored frozen should be transported in a manner to maintain them frozen.
When these are issued for transfusion, these should be thawed at 370C prior to issue.
The temperature during transport should be monitored".

Transportation standards are very clear, yet no less important than sterility of the biomaterial transported.
As long as temperature of blood components' is maintained and constantly monitored, the transportation method will be approved.

STORAGE AND EXPIRATION

H-3.1 *Whole blood*

H-3.1.1 Whole Blood should be stored at 40C ±20C in plastic blood bags.

H-3.1.2 Whole blood collected in anticoagulant citrate-phosphate-dextrose solution (CPD) should have an expiry date, not exceeding 21 days after phlebotomy. Whole blood collected in anticoagulant citrate-phosphatedextrose with adenine (CPDA-1) should have an expiry date not exceeding 35 days after phlebotomy.

H-3.1.3 Whole blood in heparin solution should have expiry period not exceeding
24 hours after collection.

H-3.2 *Red Blood Cell Components*

H-3.2.1 *Red blood cells*
Red blood cells which are separated in a closed system should have the same expiry date as the whole blood from which it is prepared. The time of removal of plasma is not relevant to the expiry date of red cell concentrates. However, if an open system is used, the expiry date should be 24 hours after separation.

Red cell concentrate should be stored at 40C + 20CRed cells containing additive solutions such as SAGM, ADSOL, NUTRICEL should be stored up to 42 days with day of collection considered as day zero. At midnight (12 'O' clock) the day is completed, e.g., if platelets are separated on first of the month, expiry date should be 6th midnight.

H-3.2.2 *Frozen red cells*
The expiry date for glycerolized (low or high) frozen red cells is 10 years and should be stored between -800 and -1960C.

H-3.2.3 *Washed and deglycerolised red blood cells*
Washed red blood cells and deglycerolized red blood cells should be stored at 40C + 20C and should be transfused as soon as possible and within 24 hours after processing.

H-3.2.4 *Leucocytes depleted red blood cells*
Leucocyte-poor red blood cells should be stored at 4 0C + 20C. It should have the same expiry date as whole blood from which it has been prepared, if closed system is used. In case of open system, the expiry will be within 24 hours.

H-3.3 *Platelet concentrate*
The platelet concentrate should be stored between 220C + 20C with continuous gentle flat bed agitation (60-70/min) or a rotor (5 – 10 cycles/min.) maintained throughout the storage period. The expiry date of platelet concentrate prepared in a closed system should be 3 days after the collection of original blood. The expiry date may be extended to 5 days or longer when special plastic bags or anticoagulants are in use.

H-3.4 *Granulocyte concentrate*
The storage temperature for leucocyte concentrate is 220C + 20C. It should be transfused as soon as possible and not later than 24 hours of phlebotomy.

H.-3.5 *Plasma*

H-3.5.1 *Single donor plasma*
Single donor plasma should be separated from whole blood at any time upto 5 days after the expiry of the whole blood. The plasma separated after expiry date should be used for fractionation. If separated during shelf life, should be stored for 1 year at -300C or lower and used as plasma for transfusion.

H-3.5.2 *Fresh frozen plasma and cryoprecipitate*
These components should be stored at -300C or below and should be stored no longer than 12 months. If Fresh Frozen Plasma remains unused at the end of 1 year at -300C, it may be labelled as “plasma & used up to 5 years (i.e. 4 more years). If FFP is stored at -60o C or below with

continuous monitoring it should be used up to 5 years.
H.4 Expiry date of any component should be calculated by considering the day of collection as day zero.