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Offshore Drone Logistics Optimization and Corporate Feasibility

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Master's Thesis, INE-3900

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ABSTRACT

Drones can help offshore logistics to improve safety, increase production efficiency, and reduce CO2 emissions. Drones will also be used in the development of new energy solutions on offshore stations. Aim is to see new logistics and support infrastructure, which will complement what we now have on ships and helicopters. Johan Castberg FPSO requires offshore drone logistics operations and for that purpose literature review on history and types of drones is done to establish a multicriteria system. Based on that multicriteria system a drone fleet with different range and payload capacities is established. Keeping an eye on the advanced and upcoming drone technologies that can boost the use of drones in offshore logistics different power sources are discussed. To fulfil the objectives of offshore drone logistics in pre-operational and operational phase different challenges have been discussed in this thesis project that includes type of logistics model in supply chain, loading and unloading mechanisms with human safety and Environmental parameters, Operational and maintenance regime, and feasibility analysis of implementation of drone logistics. All these pre-operational and operational phase challenges discussed in details and solutions to different challenges are proposed.

Keywords

Drones, Offshore logistics, drone delivery, multi criteria system, drone selection, Johan Castberg, FPSO, Occupational safety, operations

1 Introduction

Drones, that are usually known as unmanned air vehicles (UAVs), or pilotless aircraft system have enormous important usage in diverse applications that are increasing day by day. From arial photography to military surveillance operations, parcel delivery to heavy and long-distance freight operations, agriculture usage to Industrial monitoring and delivery operations to disaster rescue and aid operations drones are considering be the suitable option. The thing that makes the drone most effective for all these advanced operations is the quick improvement in the technical aspects. As we know that to coop with advance problems, advanced solutions are needed. Where modern technologies have created so much ease there are also some advanced problems to deal with. Additive manufacturing, Block chain, Internet of things (IoT), augmented reality, robotics, and Artificial Intelligence have completely changed the way of production, testing, and distribution. So, with these advanced manufacturing, testing and distribution technologies conventional and old logistics methods cannot be used. Otherwise, they will nullify the higher effect or gross benefits that these advanced technologies have capable to deliver in overall supply chain mechanism[1, 2].

Drone Logistics is the technology of future. There was a time when logistics was done by the use of trains and ships than with the upgradation of industrial revolutions thing getting changes and logistics also start using advanced means of transportation to coop and integrate with advanced supply chain models. Now world is getting ready to welcome Industrial revolution 5.0 that will be more intelligent, and more user preferred by merging human capabilities with rational computing capabilities of advanced technologies. Use of these advanced technologies in all manufacturing techniques will advance the whole supply chain model of any product. Logistics being a most important part of any supply chain model cannot stay old fashioned.

Along with other potential applications, drone's usage in logistics has attracted significant attention for value enhancement in different logistics operations. Enhancement in drone technologies enables it to be considered as a key turning point in advanced logistics, as of now drones are not only capable of carrying short distance delivery operations but also passenger use and transportation at longer distance. Many legitimate surveys estimated the potential of drone logistics for example Markets and Markets published that the drone logistics and transportation market will amount to USD 11.20 Billion in 2022 and is expected to reach USD 29.06 Billion by 2027, representing a compound annual growth rate (CAGR) of 21.01% during the forecast period (Markets and Markets 2020). Use of drone in logistics have number of strengths that include humanitarian logistics support, reduction of delivery time, cost reduction, flexibility improvement, flying capabilities, and increase in sustainability. Using the drones many of the logistics operations can also be optimized such as warehousing, inventory management, route planning and transportation along with the reduction of overall costs of supply chain[3].

1.1 Background on Development of Drones

Before getting into the details that what are the things that make the advanced development of drones important, especially in logistics. it is also necessary to know about the historical development of the drones. That will provide the platform on which one can understand the necessity and implementation of drones for commercial purposes. It was 1783 when the idea of hot air balloons was used and concept of unmanned air vehicles came into existence but that was nothing much similar to what we expect about UAVs, in 1849 Austrian military uses the balloon bombs that were considered as the start of UAV but even they do not fall in the definition of drones of today's age. But this can be considered that the concept of drones was proposed for military purposes and by militaries around 170 years ago. Till 2006, when US civilian airspace permit the drone usage on civilian area, drones were majorly considered for military purposes. There was a gradual improvement process in technologies being used in drones till then but after considering the potential of drones for industrial and consumer benefits many industries start investing in the technology and after 2006 till now there is a boom of advancement in drone technologies. The factors that make the different industries to see the potential of drone's usage in respective areas includes less human interaction, can work autonomously, more responsive and time saving, environmentally sustainable and less operational cost[4].

The overall success and efficiency of UAV-based delivery system depends not only on the advanced technologies being used in drone but instead also on the number of drones being deployed, loading capacity, distance that drone can travel without need of refuel or charge that is known as endurance and routes for delivery[5]. Unlike the conventional means of logistics drones are not considered as tested mean and not accepted easily by the organizations considering some challenges like skilled labour required to maintain this kind of delivery system, lack of regulatory framework and current battery capacity used in delivery drones is still a major technical issue that also hamper the mapping routes of the drones[6]. At the same time there are some challenges that needed to be faced while implementing the drone logistics that can be grouped into technical, safety, organizational and regulatory challenges.

1.2 Scope

1.2.1 Equinor's case study

Johan Castberg (JC) is the new Floating Production Storage and Offloading (FPSO) that Equinor ASA has targeted for a production start from fourth quarter of 2024. JC will be supplied by onshore warehouse (Polarbase in Hammerfest). Timely, efficient, and robust logistics service for securing supply from onshore warehouse to JC is critical for offshore operations. Considering the position of JC and regulatory requirements for sufficient daylight, is a significant limitation to using traditional methods (helicopter) for logistics, this certainly reduces the utility of traditional logistics delivery thus using the drone logistics could be an alternative of traditional logistics methods.

The aim of this master thesis project is to establish a value chain model for offshore logistics of JC FPSO by utilizing the end customer delivery capability of UAVs and logistics optimization along with integrated business model for meeting the company's offshore logistics requirements.

The initial step includes literature review of current UAV technologies, especially their application for logistic operations. A multi-criteria system is built for serving as basic structure to evaluate current commercial UAVs that could meet the JC FPSO specified criteria requirements (i.e., carriage requirements, transport route, environmental conditions, flight sustainability requirements and limitations in operational domain), that is used to create suggestions for selection of these UAVs. Most importantly, the coordination in ongoing site tasks is in accordance with the layout to successfully carryout the delivery operations. After the selection of suitable drones this thesis project will proceed to optimize the suggested delivery routes, analyse the supply, and demand requirement, and to examine the cost verses benefit data and overall advantages to enhance efficiency. The key purpose of this thesis project is to provide overall value addition model in accordance with the company's offshore logistics requirements using drones. Not only this drone logistics is moreover a green solution to coop with worlds pollution problems as reports says that worlds logistics as a whole is responsible for 20% of the carbon emission in the world[2]. And current testing models of drone for offshore logistics have fifty times less carbon emission then regular used helicopters for logistics. This also include studying the business need, assessing the corporate feasibility and coherently integrate with the model already operating.

2 Literature Review

Drone and its Types

Most drones available at the moment in the market and certainly there will be more new types of drones available in the market in future. Considering and limiting the search to drones for commercial applications, most of the small and military drones are ignored in this literature review. Based on the number of rotors a drone possessed, its take-off and landing mechanism and its wing type, make them grouped in four main types

1. Single rotor Drone
2. Multi rotor Drones
3. Fixed wings Drones
4. Fixed wing Hybrid Drones

All these types of drones can be electric powered, and gas powered. Except multi rotor drones that are usually electric powered. Till now, commercial drones can be in the range of as low as $2000 and can be as high as multiple $100 000. This huge price difference is because of many factors such as camera and the sensors installed on the drone, its payload capacity, its flying performance that include speed, battery life or fuel capacity for single flight, wind resistance etc., material used to manufacture the drone and technical abilities of the drone such as flying autonomously or have fail safe mechanism or collision avoidance. These factors also make them distinguish from one another and the most important is commercial application of that drone[7].

All the attributes, pros, and cons of these four types of drones are discussed to narrow down the search of the drone that can full fill and meet required specified criteria (i.e., carriage requirements, transport route, environmental conditions, flight sustainability requirements and limitations in operational domain) of offshore logistics.

2.1 Single Rotor Drones

Single rotor drone is more likely resembled to real life helicopter in design and structure also, having one fairly large rotor and a small rotor on the tail. These helicopter shaped drones fairly combine the best attributes of tiny multirotor drone and large single-wing units. Reliance on the rotor helps and enables this type of drone to hover, launch and land vertically. Because they tend to be larger make them suitable to carry larger payloads. Due to only one rotor this type is more efficient than other multi rotor drones. Efficiency and range of single roto drones dramatically increase when use gas engines instead batteries. These drones are bit larger and more complex when compared with other types of drones especially multi rotor drone. Also, they are bit trickier to operate and dangerous because of large blades of the rotor[8].

Figure 1 Single Rotor Drone- Scheibel s-100[9]

Table 1. Single rotor drones' advantages and drawbacks

Advantages	Drawbacks
(VTOL) Vertical take and Landing	Single rotors are harder to fly than other types like multi-rotor drone. So, need expertise level to control the flight
Efficient for generating thrust and lifting high pay load	Can be dangerous because of heavy spinning blades of rotor
Have long lasting flight time, and increased when drone is gas powered	Would require regular mechanical maintenance.
Able to hover vertically in the air	Not as much stable as other types especially multi rotor drones
They are built to be strong and durable	Single rotor drones are much expensive, its complexity is one of the factors to increase its price.

2.2 Multi Rotor Drones

Multi-rotor drones are the most common type of the drone that are being used for commercial purposes. And among all types of drones this type is the cheapest option. Because of the number of rotors, a drone carry, they further classified into diverse types, such as a tri-copter (3 rotors), quadcopters (4 rotors), hexa-copter (6 rotors) and octo-copters (8 rotors) etc. quadcopter is most common among all the types of multirotor drones. Multi rotors provide the better stability and better control to the flight but at the same time they are becoming inefficient in the domain of flight time because the more rotors being added the less flight time drone will give. Because of the low speed and less flying time multi rotor drones are being used for aerial photography and video aerial inspection, leisure, agriculture, construction, security[7].

Figure 2 Multi Rotor Drone- quadcopter[10]

Table 2.Multi rotor drones' advantages and drawbacks

Advantages	Drawbacks
(VTOL) Vertical take and Landing	Have limited flying time, because most of them are electric powered and it is not easy to convert them into gas powered to increase the flight time. Usually with 8kg of pay load flight time is up to 40 minutes.
Give more control and stability while flying and are easy to manoeuvre	Have low cruise speed compared to other types of the drones.
Have the ability to hover vertically	have more parts that could break down, like rotors, blades, etc.
Cheaper than other types of drones, make them widely used commercially	Low pay load capacity up to 8kg(17.6lbs)

2.3 Fixed wings drones

Fixed wing drones uses the same principle of conventional airplanes and use wings to generate lift instead of the vertical thrust produced by rotors. Fixed wing drones do not have ability to take-off and land vertically (VTOL) and also cannot hover. This wing-based design provide a lot of advantages to the drone, static wings make the drone to stay in the air and improve its aerodynamics also make it more efficient. That increase the flight time of the drone as many fixed wing drones are gas powered so no need to worry about the battery charging. Flying time, speed and range of fixed wing drones make it ideal for surveillance, mapping, and other efficient commercial uses [7].

Figure 3 Fixed Wing Drone[11]

Table 3. Fixed wing drones' advantages and drawbacks

Advantages	**Drawbacks**
Need energy only to keep the forward motion going, while the wings provide vertical lift as it moves forward, this makes fixed drones much efficient in term of energy consumption.	No vertical take-off and landing (VTOL)
Can go at high speed compared to single and multiple rotor drones, because of having airplane profile instead of helicopter	Cannot hover, so take-off and landing need a lot of area (runway) like airplanes or launching/recovery equipment with distinctive design
Long flight time	Need expert level training to control and fly this type of drones.

2.4 Fixed wing hybrid drones

These are the hybrid drones made by combining the benefits of both fixed wing drone and ability to hover for (VTOL) vertical take-off and landing from rotor-based models. This concept has been evaluated from long time ago, from 1960's but did not have much success. However, with the modern technologies and new generation sensors like gyros and accelerometers, this type is getting more serious attention for mid-range and endurance limit fixed-wing hybrid drones. A vertical lift is used to take off the drone from ground the gyros and accelerometer works automatically and keeps the drone stabilized in the air. Then, programmed, or remote based control is used to guide the drone on to the desired location and same vertical thrust generated by rotors enables drone to land vertically on desired position.

However, this technology is still under development and not much of these drones are available in the market, but as the technology get matures many of these drones will be available in market for drone delivery purposes. Multiple types of Hybrid drones can be seen based on the position and working of rotor attached to fixed wing type such as:

1. A fixed-wing design paired with a vertical-lift motor
2. Tail-sitting aircraft that point vertically for take-off, then pitch over to fly horizontally
3. Tilt-rotor models that feature rotors or wings that can swivel from pointing upwards to a horizontal position[12]

Figure 4 Fixed Wing Hybrid C-30 UAV[13]

Table 4. Fixed wing hybrid drones' advantages and drawbacks

Advantages	Drawbacks
Vertical take-off and landing (VTOL)	Need expert level training to control and fly this type of drones because of advanced controls being used in this type of drones.
Long flight time	Technology is still in development and not much of these types of drones are available in the market.
Can go at high speed compared to single and multiple rotor drones, just like fixed wing drones	
Need energy only to keep the forward motion going, while additional rotor provide the vertical take-off and landing facility	

3 Methodology

3.1 Multi Criteria system

Based on the literature review done on the types of drones and their feasibilities and utilities, set of criteria based on the need of the JC FPSO is established in term of ten parameters mentioned as

Table 5. Multi-criteria system

	Criteria	Operational Conditions	Equinor's requirement
1	Payload capability	How much load a drone should carry?	The higher the pay load capability, higher will be the utility.
2	Flight time	How far a drone should fly before need of recharge or refuelling?	Refuelling is preferred to be done onshore so drone should be mid-range or endurance type.

3	Harsh weather condition	What are the weather conditions that drone should sustain?	Weather conditions provided by the company should be sustainable for drone.
4	Cruising speed	What should be the cruising speed of the drone?	High cruising speed will be preferred to make the delivery operation quick and time saving.
5	Cost	How much the cost of the drone should be?	Most economical option will be chosen
6	VTOL capability	Should the drone have Vertical take-off and landing mechanism?	Mostly offshore fields use the helipad, so vertical take-off and landing is mandatory.
7	Energy efficiency	How much Drone should be energy efficient?	Low carbon emission is the goal of future. So, most efficient alternative will be considered
8	least Maintenance Requirement	How frequently drone would need a maintenance?	Drone should spend the minimum time offshore. No maintenance can be carryout offshore. minimum the parts of the drone less will be the requirement of maintenance.
9	Safety	How much safe should be the Drone?	Drone should be as safe as possible to fly and conduct the logistics safely without damaging the humans and parts it is carrying especially while landing and taking-off.
10	Competency requirements	How much skill should be need for operating the drone?	Drone should be easy to use, with minimum training and its autonomous capabilities it should work.

Multi criteria system needs to be more specific and should help this value chain model to obtain maximum efficiency of drone logistics. These mentioned criteria are having the parameters of both pre-operational phase and operational phase. Getting start with the pre-operational phase following are the criteria that needs to be considered and will be the main part of this value chain model

1) Pay Load Capability
2) Flight Time
3) Harsh weather conditions
4) Take-off and Landing Mechanism

3.1.1 Pay Load Capability

The maximum amount of weight that a done can carry is its pay load capability. When talking about drone logistics the most important and often limitation comes underway is pay load capability of the drone. It differs with each type of the drone being used and diverse types of drones can carry different number of loads also, pay load capability stands on number of factors that decides the pay load capability of the drone.

Drone's pay load capacity depends on the factors that are number and size of propellers, power of motor or engine, type of battery or fuel, weight of drone and atmospheric conditions in which drone will operate. Each of these factor corelate with each other and has effect on the other factor [14]. The most important thing that is needed to consider is that take-off weight is the heaviest weight capacity a drone can manage it to fly without having any complications.

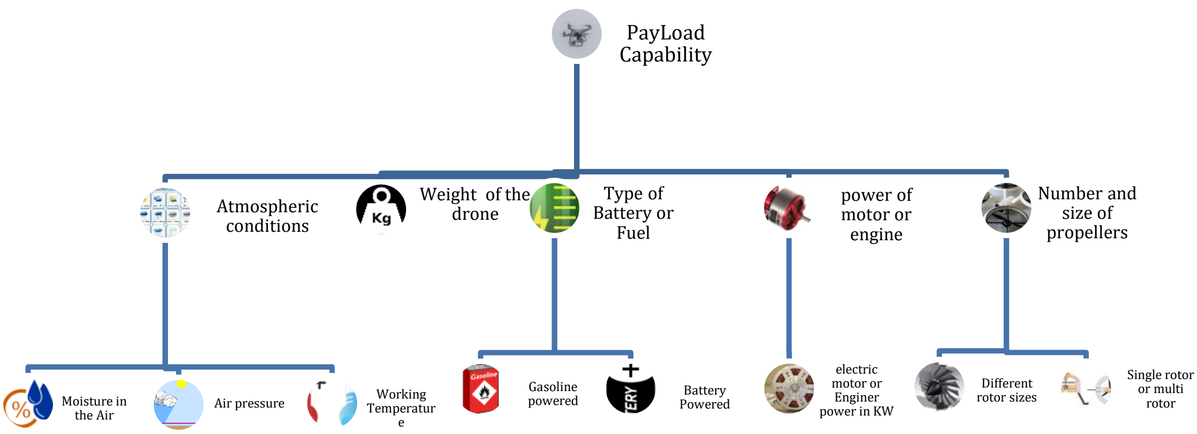


Figure 5. Payload capability

3.1.2 Flight Time

The time that a drone can stay air bound without refuelling or battery recharge is its flight time. When talking about the freight drones, flight time becomes the critical criteria to consider because delivery of any part or freight from point A to point B needs to be done without having the hurdle of recharge or refuelling. Technology is being developing day by day in drones and there are many options in the market available right now for freight drones for specified applications [15]. The main factors on which flight time depend is the power source a drone use. Current development and having an eye on future perspective the available power source for drone includes batteries, non-renewable, fuel cells, solar cells, and hybrid. Among them for short range, battery powered drones are the famous but specifically for offshore logistics applications this technology is not yet reached to this extent that it can cover long range freight logistics applications. Gas powered, fuel cells and hybrid source of power seems to be the best suitable and future of drones for long range logistics purpose.

Other factor on which flight time base includes weather conditions, weight of the drone, size of the drone and how the drone is flown.

3.1.3 Harsh Weather Conditions

One of the most important criteria for the selection of drones to do offshore and open sea operations is harsh weather conditions that a drone face. The main factors that are considered in harsh weather conditions are Air temperature, wind speed, precipitation, air humidity and icing. Harsh weather conditions are restricting the use of drones in offshore operations. When these criteria narrow down the search of feasible drone, only limited number of drones seems available in the market that can withstand these harsh weather conditions.

Harsh weather conditions strongly affect the drone endurance, aerodynamics, visibility, control, airframe integrity, airspace monitoring and sensors for navigation and other purposes. Research shows that global flyability is lowest over oceans and for common drone it is only 5.7 h/day or 2.0 h/day if considering the daylight hour restriction. But making the drone enough weather resistant can increase the flyability to 20.4 hours/day [16].

Specifically for offshore drone logistics following factors for harsh weather condition should be monitored and then according to those monitored and forecasted parameters a drone should be selected.

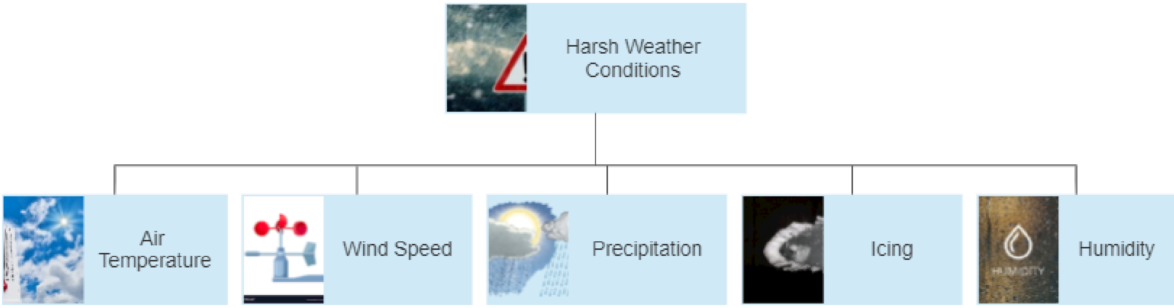


Figure 6. Harsh weather conditions

All these harsh weather parameters can be monitored and forecasted along the possible routes of the drone in open sea. Based on the data monitored in this criterion can significantly improve selection of most suitable drone for the offshore logistics fleet.

Most of the above-mentioned factors in harsh weather condition criteria can be determined and graphed to get the better overview of the conditions in open sea for drone operations. Especially the Air temperature and wind speed that effect the most drone operations can be forecasted based on the available data of past few years, which gives the good estimate of air temperature and wind speed range in a specific area of operation and helps in narrow down the drone's selection. Windographer is a software that is used for wind data analysis. It is used to review the recorded data by sensors those are installed on meteorological towers located on different potential farms, So Windographer is used to get the past weather data for Johan Castberg and Hammerfest surroundings at an altitude of 100m that is considered a safe flight height for drones by Air traffic control in Norway. So, the data collected by past few years is between the Hammerfest and Johan Castberg in open sea using the height of 100m.

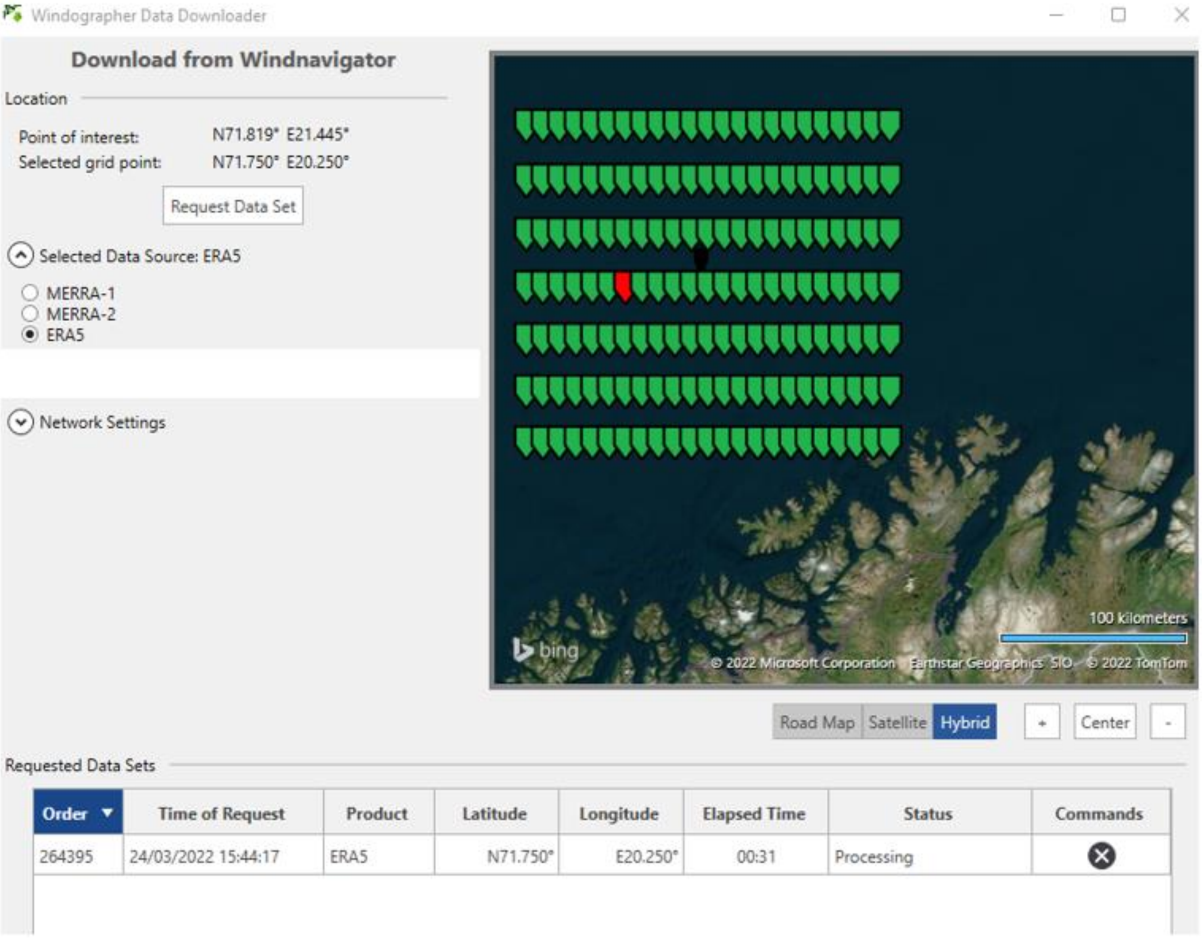


Figure 7 Area selection between Hammerfest and JC in Windographer

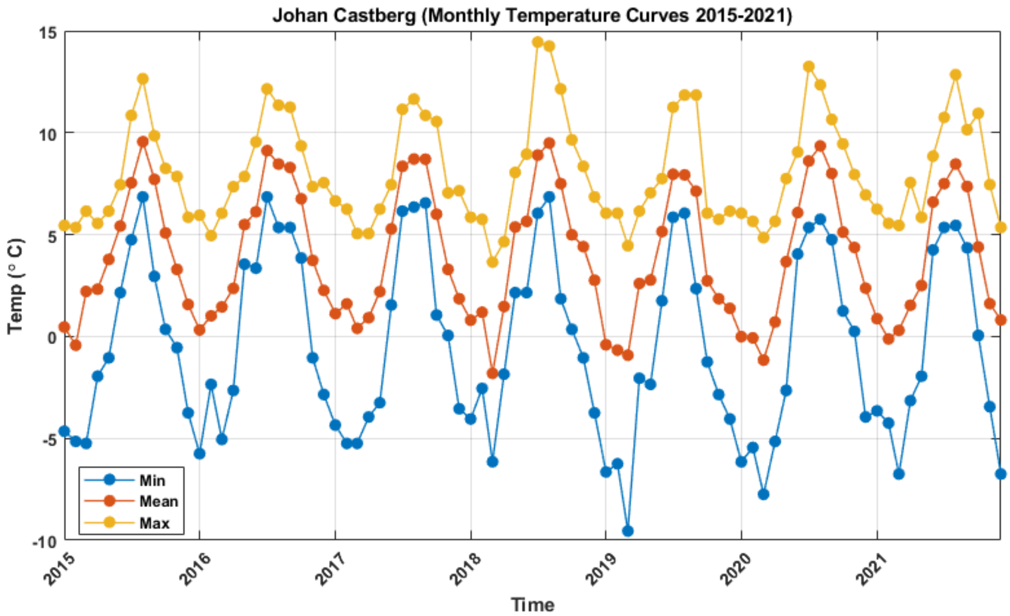


Figure 8 Temperature Graph for six-year data between Hammerfest and JC

Th above mentioned graph provides the air temperature graph based on the previous data of six years and Windographer plot this graph to provide the overview of maximum and minimum temperature that goes in last six years. According to the graph plotted by Windographer in the surrounding of Hammerfest to JC the minimum temperature goes to-10^0C and maximum temperature goes to +15^0C in last six years. This graph can now narrow down the drone selection search and will only allow the drones to enter the fleet those can sustain air temperature between -10 to +15^0C.

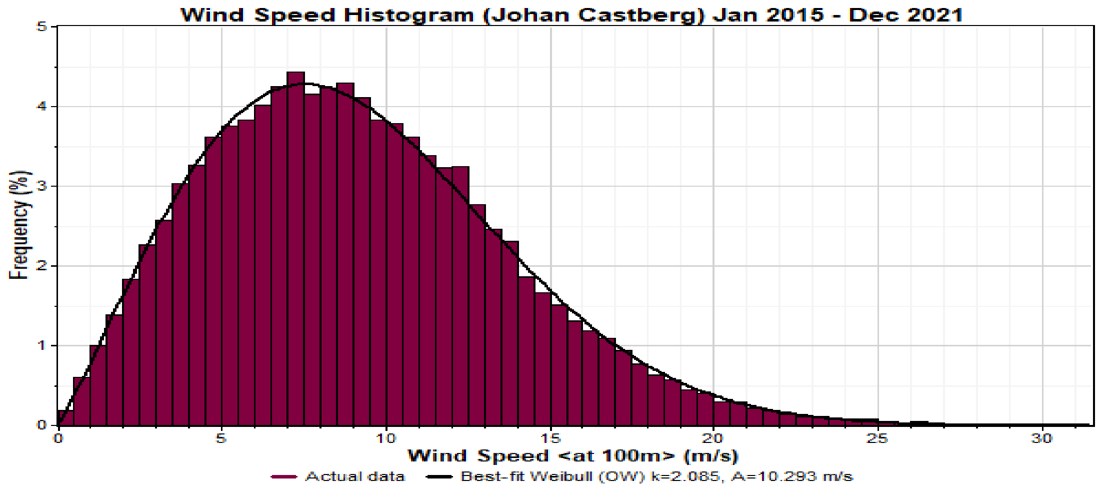


Figure 9 Wind Speed Histogram for Hammerfest to JC surroundings

Another crucial factor for harsh weather condition criterion is the wind speed because when it comes to drone flight wind speed matters a lot that normal commercial drones with weight cannot operate in hight wind speed. And when we talk about drone operations in an open sea then wind speed becomes the crucial factor. Using the Windographer data collected in last six year provided the histogram that gives the estimate of maximum wind speed at 100m height. According to the histogram Hammerfest surroundings towards Johan Castberg at the altitude of 100m experienced maximum wind speed of 31m/s but the maximum wind speed has quite low frequency, it means that most often the wind speed remains between 5 and 10m/s and usually can go up to 25m/s and 31m/s in swear conditions. This useful information would be helpful in the selection of drone for operating in this specific area. Each type of drone manages differently the wind speed so that is why this factor has its importance while choosing to correct drone for operations in high wind speed.

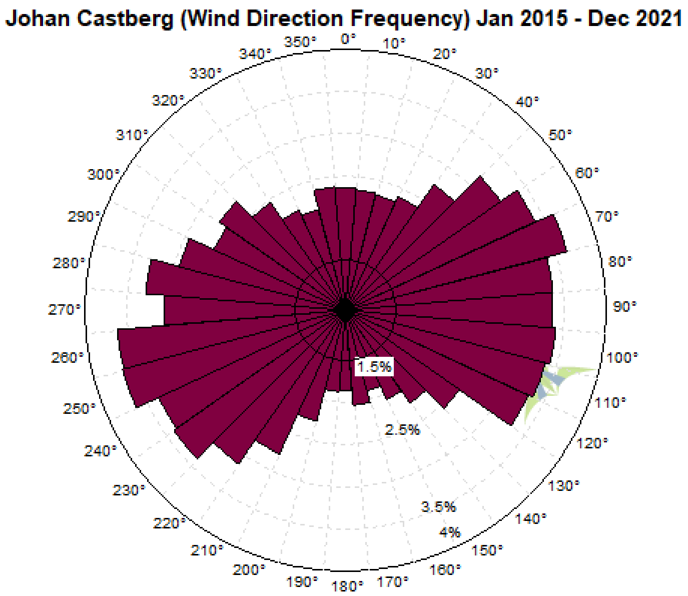


Figure 10 Wind Direction Frequency for Hammerfest to JC

While flying, wind direction also has its role in deciding the flight time and speed of drone. Windographer also provide the wind direction frequency flower histogram based on the past date of last six years. According to the data wind direct toward seven hundred or on its opposite direction 250^0. This information would be helpful in operation phase but not in the selection of drones.

3.1.4 Take-off and Landing Mechanism

Based on the high potential in commercial application drones are becoming the part of every industry. Among all the types of drones, multirotor drones are quite famous because of its vertical take-off and landing mechanism. Multirotor provide the enough stability to drone during take-off and landing so that it becomes used friendly but at the same time because of its structural characteristics among other Drawbacks, short flight time make it much restricted in commercial usage especially when it comes to lift heavy weight and stay airborne for long time. Compared to this fixed wing drones have the capability to carry more load and stay for longer time in the air, but its incapability of vertical takes off and landing restrict it use in much commercial applications. The most crucial part of drone flight is its take-off and landing. Based on the requirement specifically offshore logistics where most of the offshore platform for landing and take-off uses helipads and offshore vessels have most of the area no fly zone on them in order to maintain health and safety measures so vertical take-off and landing becomes the necessary feature of the drone. This requirement of the drone itself narrow down the search of suitable drone as it excludes the fixed wing drone from the list and invites the future search of drone technologies to take part and fix the problems being faced because of this restriction. For offshore logistics, we do not leave with many options when considering this criterion, so the only option left is vertical take-off and landing mechanism in the drone.

Because of carrying high payload for longer period fixed wing drones are most suitable options for offshore logistics but considering its limitation in vertical take-off and landing, this drone does not consider for offshore logistics. To use the potential of fixed wing drones with vertical take-off and landing, fixed wing hybrid drones took the place. If talk about the future of long-range drones that can carry heavy pay load and having the capability of VTOL, then tilt rotor with fixed wing or fixed wing hybrid drones are seems to be the best viable option in next coming years.

Comparing the tilt rotor with single rotor, tilt rotor has two rotors that is why having larger disk load than single rotor drones. If it is hovering, rotor's downwash clash with wings and reduce the effectiveness of thrust. But two rotors that spin in direction opposite to each other do not need ant tail rotor, that save the much engine power. Tilt rotor will be lacking in low speed-performance in helicopter mode compared to single rotor drone but when it can fly at twice altitude of single rotor drone and will produce twice the cruising speed. That makes it most feasible option for long range offshore logistics.

3.2 Drone Fleet Selection

Setting up the multicriteria system for the drone selection was an essential part of selecting the drone fleet for offshore operations. Commercial drone operations are not a new concept. A lot of companies are already using drones for delivery purpose but that is only for short range and not in harsh weather conditions. When talk about the offshore drone logistics operations than most of the drones available in market are still in testing phase and commercial applications for drones are restricted to short ranges. Based on the literature review and market survey the number of drones that are commercially available for operations with their limitations are listed in the following table.

Commercially available drones table provides diverse types of drones having a different range, body type, pay load capability, harsh weather withholdings, and source of power. During the market survey and findings, the thing came is that long range d freight drones for heavy payload are still in development and one can does not find an appropriate UAV for a specific application that is for than 300km range. Most of the long-range drones still fall under 300km range that is not sufficient for most of the offshore logistics purposes. To select the drone fleet from commercially available drones will give an idea of a logistics model for specific tasks in offshore drone logistics. Offshore stations those are in the radius of range of UAV so that UAV can return safely to the shore station without refuelling or recharging can be used for the testing phase and new improvement can be made for the long-range UAVs in future.

All the drones in the table have been searched out on the base of multi criteria mentioned above. For offshore logistics operations four main criteria needed to be considered that Drone should have enough range so that it can perform offshore operation without refuelling or recharging at the offshore station. Secondly, Drone should be able to carry enough payload with it that can satisfy the logistics operations of company and more payload capability of drone can make drone more favourable for selection. Thirdly, drone should be able to take-off and land vertically as offshore FPSO and stations are not capable to carry runways or other mechanism of landing then the VTOL. And fourth is that drones must be able to sustain harsh weather conditions because in an open sea weather conditions are not favourable for every type of drone.

Drone Name	Drone Type	Power (KW) and Type	Pay load capability	Flight Time or Range
Drone Delivery Canada FLYTE Model ROBIN XL	VTOL Hybrid	Multirotor Powerplant	11.3 kg MTOW: 80 kg	Max Range: 60 km
Drone Delivery Canada FLYTE Model Condor	Single Rotor Helicopter	2 Stroke Gasoline	180 kg MTOW: 476 kg	Max Range: 200 km
Load transportation drone FB3	Multi rotor (8 rotors)	Swappable battery	Up to 100kg of payload (170kg in total)	From 15 to 50 minutes
DB Schenker Volo Drone	Multi Rotor (16 rotors)	all-electric	up to 200 kg	up to forty kilometres
Delta Quad Pro #CARGO	Multi rotor Hybrid	LiPo battery powered	1.2 Kg	100 km
Sky front Perimeter	Multi Rotor	Fuel injected for high reliability and ease of use.	(7.5 kg) maximum payload capacity for 1 hour (5 kg) payload for 2 hours	(177 km) flight range
Scheibel's CAMCOPTER S-100	Single Rotor Helicopter	Gas powered	34 kg (75 lbs)	200 km
Fly Dragon FD-50 Hybrid heavy load drone	Multi Rotor	Hybrid Gas powered 23KW * 2	50KGS	up to 60 minutes or about 15Km and Maximum distance: 3km (Extra range requires additional range extender)
KARI TR-60 WE	Tilt rotor UAV	Powerplant 55hp Rotary	20KG	180km
APID 60s, Top Engineering	Single Rotor Helicopter	Gas powered	20kg	200 km
Navig8-56 by 4FRONT ROBOTICS	Hybrid (Gas + battery)		30kg	250km
JUMP 20 by ARCTURUS	fixed-wing Hybrid	190cc EFI Engine Battery Powered Jump	Up to 30 lb (13.6 kg)	185 km

From the above Table different UAVs have been listen in the graph based on their range, which provides a clear view of different available drones having different ranges as:

Figure 11 Drone Models Vs Range Graph

Every peak in the graph is providing a drone with high range among the other drones. We can estimate that drone models Navig8-56 by 4FRONT ROBOTICS is providing 250km range, Drone Delivery Canada FLYTE Model Condor is providing range of 200km, Scheibel's CAMCOPTER S-100 is providing range of 200km and APID 60s by Top Engineering is providing range of 200km. these drones are seeming good for the operations within radius of 100kms. But this is not the only one criterion on which they will be selected. These drones should also need to carry payload with them and drones with more payload capability will be preferred.

From the graph of payload Vs Drone models, it can clearly see that drone models DB Schenker Volo Drone, Drone Delivery Canada FLYTE Model Condor, Load transportation drone FB3, Fly Dragon FD-50 Hybrid heavy load drone and Scheibel's CAMCOPTER S-100 are the drones that can provide enough pay load facility that they can be considered for offshore logistics operations. All the mentioned drone models have the VTOL, it means that they satisfy the third criteria to be selected for our drone fleet. Also, from the harsh weather condition criteria the temperature limitations are also fulfilled by these drones.

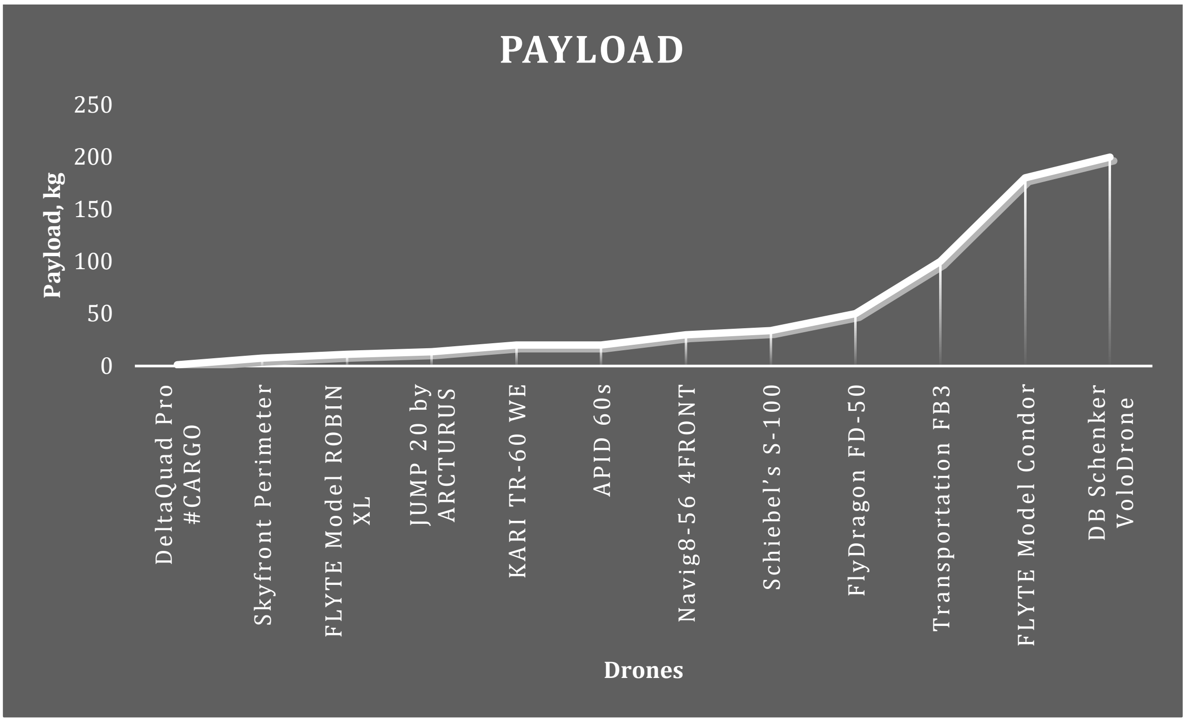


Figure 12 Drone Models Vs Payload Graph

For the selection of drones in drone fleet all the drones full fill the two criteria that is VTOL and weather conditions, and it is necessary that all the drones get comparison on the basis of range and payload capability, so the figure below provides the better results for the selection of drones.

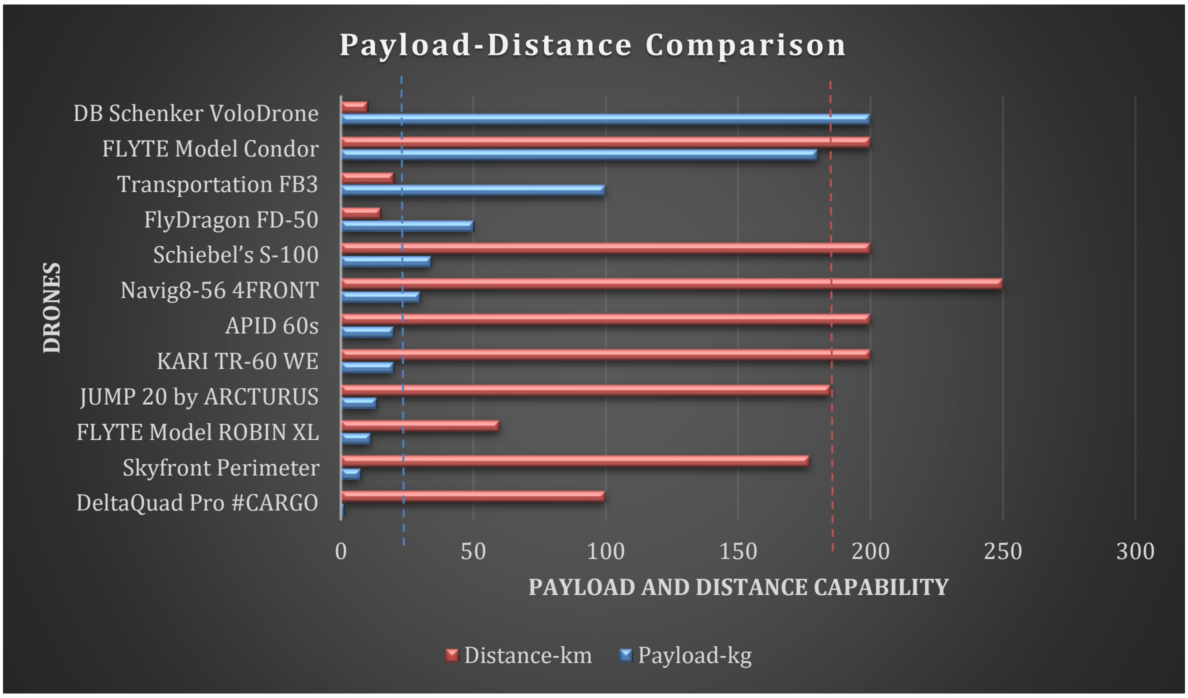


Figure 13 Drone Models Vs range and payload capability graph

Blue dotted line maximizes the payload capabilities of all drones and red dotted line maximize the Ranges of drones. All the common drones that cross the payload's blue dotted line and range's red dotted line are in the favoured zone of drone fleet selection. So, following drones with their respective attributes will be in the drone fleet that can carry offshore logistics in the range of 80 to 100km without refuelling or recharging.

Table 6. Proposed drone fleet

Drone	Range	Payload Capability
Drone Delivery Canada FLYTE Model Condor	200km	180kg
Scheibel's CAMCOPTER S-100	200km	34kg
Navig8-56 by 4FRONT ROBOTICS	250km	30kg

3.3 Strategic transformation

All of these drones have capability of VTOL and can sustain harsh weather conditions. So, by their range and pay load capabilities this fleet of drones can do operations offshore within the radius of 80 to 100km without refuelling or recharging. This fleet selection only gives us a brief overview of long-range commercial drones available in the market and their selection based on the multi criteria system proposed earlier. But this does not fulfil the requirement of our case study, that required offshore drone logistics operations in the radius of 250 to 300km without refuelling or recharging. For long range offshore logistics, these available drones are not sufficient, and they cannot carry payload for such a long distance. For this purpose, different companies are doing their best to increase the range of UAVs and some models are in test phase. Before getting into the final decision this is important to know about the technological trend for the upcoming years in drone technology that can change the entire concept of long-range logistics operations. For this purpose, Technological shift in future for drone technologies is the subject of discussion that can predict the new and upcoming technologies that can satisfy the range criteria for offshore drone logistics model.

3.4 Technological shift in Drone technology

Drones have successfully taken over the prominent position in commercial applications and their technology is still constantly evolving, it means that technology of future drones is currently in its progress. In order to understand how drone technology evolves with time Airdronecraze, that is an Amazon services LLC affiliated website for advertising program have published different generations of drone technologies in their report that gives an overview of drone technologies evolution. According to the report drone technologies have seven potential generations and most of the drone these days falls in fifth and sixth generation[17].

Technology generations have the following breakdowns:

First Generation: Includes all forms of aircraft with Basic remote control.

Second Generation: Includes additional features like Static design, video recording, pilot control, static photos, and mounted fixed cameras.

Third Generation: Static design, HD video, two-axis gimbals, basic safety models and assisted piloting became the additional features of this generation.

Fourth Generation: In this generation, Transformative designs, Three-axis gimbals, 1080P HD video or higher-value instrumentation, improved safety modes, autopilot modes become the addition.

Fifth Generation: Includes Transformation in designs, 360° gimbals, intelligent piloting modes and 4K video or higher-value instrumentation.

Sixth Generation: This generation have the addition of Commercial suitability, design based on safety and regulatory standards, adaptability of platform and payload, automated safety modes, full autonomy and intelligent piloting models, airspace awareness.

Seventh Generation: This generation is underway and includes features such as complete commercial suitability, design based on fully compliant safety and regulatory standards, payload and platform interchangeability, automated safety modes, full autonomy and enhanced intelligent piloting models, full airspace awareness, auto action of take-off, land, and mission execution.

The seventh generation of drones is considered the next generation of drones, however it is already begun, as 3DRobotics has revealed the world's first all-in-one smart drone, Solo. Intelligent drones with self-monitoring capabilities, built-in protections, compliance technologies, and smart accurate sensors are regarded as a revolution in drone technology, particularly for the transportation, logistics, and commercial sectors. Indeed, all of these technologies will continue to advance, and drones will be deemed a safer and more dependable choice with their future acceptance, particularly in logistical and commercial applications.[17, 18].

Commercial Drones for logistics these days are almost considered as green source and example of this could easily be seen in top logistics companies like DHL and Amazon those are using commercial drones for logistics but as a green source it means that they are using these drones on battery and that is why most of the technological upgradation is taking place in battery or electrically powered commercial drones. These drones have many limitations when considered for the offshore or open sea logistics applications. According to the multicriteria set for offshore logistics these drones do not fit completely in required criteria. Especially flight distance covered in one charge is not possible with low range drones. To use the drones in offshore logistics still more development is needed in different drone technologies to make offshore operations more economical, safe, and autonomous, if talk about the advancement in drones for upcoming years, then the parameter those are under consideration can be grouped as:

3.4.1 Advancement in power source

Power Sources in UAVs are still limited because the power source available are inadequate. That limits the commercial use of drones to some applications. We are talking here about the long-range drones those can carry heavy payloads with them and can go as far as possible. There is many different type of power sources that are used in drones but each of them has their own pros and cons. Parameters like charging and discharging time, pay load capability, energy density, size and power density differs in each type of power source. To get to know the advancement in different power supplies first it is important to know about the different available power supplies options for drones. When talk about the different energy sources that are being used in drones, currently combustion engines are one of the most favoured sources of power considered especially for long range commercial drones, considering its limitations in many aspects there are electrical systems those have heigh efficiency and are more reliable with additional benefits of less are no greenhouse gas emissions with less noise pollution. Due to these additional benefits electrical systems are becoming more prevalent for different drone applications. Electrical systems include batteries, fuel cells (FCs) and solar cells. All the mentioned electrical systems utilize a battery that increase the system's energy density when the energy requirement is at peak. But batteries do not provide higher energy density then the main power source. Because they have low energy densities and higher power densities. That is why, the addition of the battery can only increase the endurance of the system and system's peak power capabilities but not to the desired point that limits the system's flight pattern[19]**.**

There is many different type of power sources those are available in the market that includes batteries, solar cells, FCs, and combustion engines. Most of them are being used in diverse types of drones and each type of power source is not for every type of drone. Based on application and usage of the drone each power supply has its limitations, some of the power sources have been disregarded because they were having more Drawbacks than the advantages in some applications because of either too heavy weight or size, having restricted movement or not having enough energy density to perform specific task in some applications. Most of the power supplies are defined by their respective power and energy densities.

The power density of the power source is the amount power that it can provide at specific instance and energy density is the energy that a power source can store so that for a specific period of time that amount of power can be delivered. According to the Ragone plot[20] super capacitors (SCs) have the large power density that is about (80-75000 W/kg) but at the same time have low energy density (0.09-0.1 Wh/kg), that allow super capacitors to provide large amount of power but only for the short period of time. On the hand Fuel Cells (FCs) have large energy density (200-3000 Wh/kg) but have low power density (1.5-20 W/kg) it means that FCs can provide low power but for extended period of time. Li-ion capacitors lies between the super capacitors and FCs as they have comparable large amount of power density (1000-55000 W/kg) and comparably long period of time because of having arguably high energy density (18-35 Wh/kg) [20].

All the possible power sources in UAVs, Combustion engine, Batteries, Hydrogen Fuel Cells, and Solar power have their pros and cons so before getting know about the technology of the future it is important to get know about each power source in details and to get the most feasible power source for future drones.

Combustion engines includes both petrol and diesel engines and have almost same components, which includes an engine block, which has pistons, combustion chamber, fuel injectors in diesel and spark plugs in petrol engine, and intake and exhaust valves. Mostly for UAVs two stroke engine is preferred that is quite common type of engine and have only two strokes and four stages, intake, compression, power, and exhaust. The main difference in diesel and petrol engine is that petrol engine has spark plugs to ignite the air fuel mixture, but diesel engine required fuel injectors to ignite the compressed air at high pressure. Sometime diesel engine requires glow plug to heat up the diesel before it enters the combustion chamber that is because diesel engine can face complications when it has to operate in cold climate. Other than that petrol engine has fast rotational speed compared to diesel engine because petrol engine has lighter components like pistons, connecting rid and crankshaft because of low compression ratio. But at the same time petrol engine has lower thermal efficiency compared to diesel engine [21].

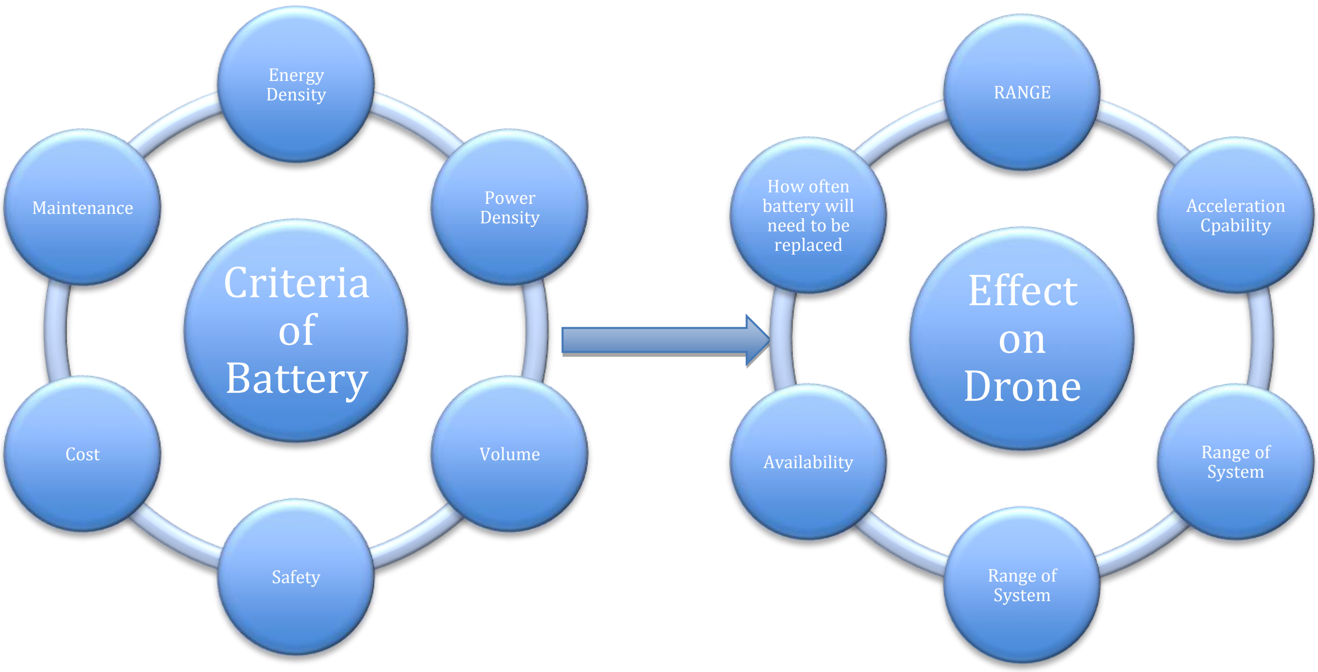
Petrol-powered engine has many variants like Kerosene, Ethanol, Methanol, and propane and have different performances depends on the conditions. Best fit for this engine is with fixed wing drones and one gasoline powered fixed wing drone can stay airborne for more than 20 hours. Best part is that weight of the drone is keep decreasing as the fuel consumed during the flight therefor it increases the range. On the other hand, diesel engines have highest effective efficiency among all the combustion engines and can be operated on a variety of fuels including some high density those are safer for environment too[21]. Diesel engines tend to be more robust than the gasoline engines, but this pro make it heavier and bulkier that makes it counterproductive when it comes to onboard drone.

Table 7. Combustion engines advantages and drawbacks

Advantages	**Drawbacks**
Long flight time	Heavier compared to batteries
Robust	Require complex maintenance
Small and light weight compared to other fuel cells	Produce greenhouse gasses
Good specific fuel consumption	Noisy

Batteries are a lot of diverse types of batteries being used in different UAVs and each of them have their own advantages and Drawbacks. The different types of batteries include Nickel cadmium (NiCad), Lead Acid (pb-acid), Lithium polymer (Li-Po), Alkaline, Nickel Metal Hydride (NiMH), Lithium-air (Li-air) and Lithium-Thionyl-chloride (Li-SOCl2) Zinc Oxide (Zn-O2),[22]. Li-Po and Li-Ion are two most common types of batteries that are used in UAVs. Li-SOCI2 batteries have two times higher energy density per kg and Li-air batteries can have seven times more energy density. But Li-air batteries are not widely available and are much more expensive compared to Li-ion and Li-Po batteries. Another type of Li battery is (Li-S) is seems to replace the Li-ion battery in near future because of its higher energy density and comparable reduced cost.

The factor that determines the best suitable choice includes its energy density value, power density value, volume, weight, safety, cost, and maintenance. Each of this mentioned factor affect drone in a different aspect, like drone's payload and acceleration will be effect by the power density of battery, energy density determines the range of the drone, cycle time of the battery will affect that how often the battery needed to be changed, and weight and volume of the battery effect the overall range of the system[23].



Li-ion batteries have the ability to deliver high power and energy per unit of mass of battery. Also have high energy efficiency, comparable light weight, no memory effect, and long cycle life. But at the same time cost is comparably high[24]. Because of comparable high energy density Li-air batteries can increase the range of the drones that would be near to gasoline engine. Compared to Li-ion battery Li-air battery can hold energy for 5 to 10 time more time with same weight and twice the energy for same volume[25].

Table 8. Battery types and specifications

	Battery Type								
	Pb-acid	NiMH	Li-ion	NiCad	Alkaline	Li-Po	Zn-O_2	Li-air	Li-$SOCl_2$
Nominal cell voltage (V)	2.1	1.2	3.6–3.85	1.2	1.3–1.5	2.7–3	1.45–1.65	2.91	3.5
Energy density (Wh/kg)	30–40	60–120	100–265	40–60	85–190	100–265	442	11 140	500–700
Power density (W/kg)	180	250–1000	250–340	150	50	245–430	100	11 400	18
Cycle life	<350	180–2000	400–1200	2000	NA, non-rechargeable	500	100	700	NA
Charge/Discharge efficiency (%)	50–95	66–92	80–90	70–90	45–85	90	60–70	93	6–94
Self-discharge rate (%)	3–20	13.9–70.6	0.35–2.5	10	<0.30	0.3	0.17	1–2	0.08
Rating	12 V	12 V	3.6 V	12 V	1.5 V	3.7 V	1.4 V	N/A	3.6 V
	2 Ah	2 Ah	2 Ah	1.8 Ah	2.2 Ah	2 Ah	Three hundred mAh		2.2 Ah
Costs (US$/Wh)	0.6975	0.8546	0.9361	2.678	1.6727	2.3095	0.3095	N/A	0.5492

Based on the literature review done on diverse types of batteries and compared based on different criteria that can provide the valuable results to choose appropriate battery for specific drone. Comparison of different batteries are done on the base of [19, 23, 25-28]

From the comparison table Li-Po batteries are seems to be the best viable option because of its high energy density, power to energy balance and long-life cycle. Overall using batteries as a power source in drones provide some advantages and Drawbacks as:

Table 9. Li-Po Batteries advantages and drawbacks

Advantages	**Drawbacks**
Easy to charge anywhere	Small amount of recharge cycle
No greenhouse gas emission	Low energy densities
Small and compact for drones	Comparably longer recharge period

Hydrogen Fuel Cells are being investigated as a new renewable and green source of power that would be the alternator to batteries. FCs has many types like Proton Exchange membrane (PEM), Phosphoric Acid FC (PAFC), FC polymer electrolyte fuel cell, Solid Acid FC(SAFC), Hight Temperature FC (HTFC), Alkaline FC (AFC) and Electrical Storage FC (ESFC) [29].

Proton Exchange Membrane FC is quite similar with battery in operation, having two electrodes one of them is cathode and other is anode, both are separated by a membrane and using an electrolyte they are connected. At anode, a fuel is supplied and at cathode oxidant is applied, that reacts with electrolyte and with each other also that cause the electrons to flow in outer circuit from one electrode to other inducing the voltage. Two types of biproducts are also produced in this process one is from the fuel and one is from the oxidant. A Hydrogen Fuel Cell has a fuel of hydrogen and air as an oxidant. Thus, in this FC water and air are produced as a biproducts. These types of Fuel cell have the energy density that is about 150 time more than Li-Po battery. Recent advancement has been made in UAV using FC as a source of power and that can fly up to 10h with the distance of 500km[30]. To use the FCs in drones it required to have a high-power density, rapid response to loads and continuous supply of hydrogen. Hydrogen is used as a fuel and phosphoric acid as a electrolyte in PAFCs[31].

There are certain advantages and Drawbacks while using the Hydrogen fuel cells as a power source in drones as:

Table 10. Hydrogen fuel cells advantages and drawbacks

Advantages	**Drawbacks**
No Direct Pollution	Significantly enormous size
No Sound	Operating costs depend on the availability of Hydrogen
Large energy density	Hydrogen gas tank need to be considered in designing the drone.
Instant charge	Drone balance get effected while hydrogen consumed onboard

In Solar Power Photovoltaic (PV) effect is most commonly used to convert the sunlight into electricity. This current is then either used directly or stored in batteries and the batteries are used later to provide power to the system. For solar power there are two technologies that are being used to convert the energy, PV systems and CSP that is concentrated solar power. CSP system directly convert the sunlight into electricity and then use the electricity to make the steam and run the turbine to generate the electricity[32]. For drones usually onboard solar panels are used and for that the only option left is fixed wing drones because solar panels required a large surface area but at the same time, they can also be used to extend the range of rotor types of drones. Including many advantages solar cells also have some Drawbacks as:

Table 11. Solar cells advantages and drawbacks

Advantages	**Drawbacks**
Low operational cost	Significantly large area is required
No Sound	Increase the size of the drone
Minimal maintenance cost	Require sunlight to operate.
Excellent carbon footprint	

3.4.2 Comparison of different power sources

To perform the comparison between different power sources there must be some reference. Based on the literature review to perform comparison the reference of ratios of different parameters can be used, that could give a better overview of pros and cons of each power source based on parameters. Based on the literature review parameters of different ratios like payload to flight time, flight time to weight, payload to weight, flight time to charge time and flight time to cost can compare different power sources. For this purposes review of different research papers has been done to get the desired result and having an overview of different power sources for that data has been collected from ([33], [19], [34], [35]) mentioned sources for four different power sourced UAV, s to get different parameters mentioned in the table. In the table for the flight time to weight ratio most preferable value is greater than one and it would be preferred to have as large value as possible because it indicates that flight time of UAVs is less affected by the weight, and it means few loses. Payload to flight time ratio would be preferred less than zero but closed to one as it will reflect good flight time even while having the capability of payload. For pay load to weight ratio if it would be greater than one it means that UAV have capability to carry more weights than itself so the larger value would be better and that will increase the area of applications. For flight time to cost ratio, the larger value would be better as it indicate the flight time per unit of cost so larger the value good will be the value of money. For the flight time to recharge ratio high value would be desired to get the maximum flight time over one recharge.

Table 12. Power sources comparison

Power Source	**Ratios**				
	Flight time(min) /Weight(kg)	Payload(kg) /Flight Time(min)	Payload(kg) /Weight(kg)	Flight time(min) /Cost (USD)	Flight time(min) /Recharge time(min)
Battery	2	**0.25**	0.5	0.003618	0.23682
Hydrogen FC	**38.47265**	0.02	0.758461	0.017654	<250
Combustion	24.4657	0.043625	**1.021408**	**0.076528**	<120
Solar	5.6	0.015782	0.083233	0.000112	**<336**

In the table the bold formatted values show the best among all type of power source for each ratio. So that can be seen that combustion engines are best viable options as it gives the best payload to weight and flight time cost ratios. After combustion engine hydrogen cells comes the second most favourable option as it gives the best flight time to weight ratio and comes second and third among other ratios but when it comes to cost this option lag quite far behind compared to other options. But at the same time FCs provide high payload values, can go long distance, and have very quick recharge, these attribute makes this option quite feasible when it comes to reduce the carbon footprints.

3.4.3 Possible Improvements in power sources

Power sources affect the flight time of the drone, for logistics perspective long range drones are considered to be the future alternator of conventional means of logistics. To extend the flight time in one charge or one time fuelling is the main goal to achieve for improving the power source. At the same time to refuelling or recharging time, cost and least carbon emission with flight time are the main objectives that need constant improvement. Use of advanced technologies and combination of different power sources can improve power sources, but this process is ongoing process that never stops. But in near future there are some combinations and modern technologies those can significantly improve the flight time in reduces cost with least carbon footprints. In battery powered UAVs use of modern technologies in wireless charging like PV arrays, Gust-souring, Laser, and battery dumping can improve recharge time and cost factor with the use of Electro-magnetic field-based techniques. The technique that can implied on all type of power sources and help them in improvement is hybridization.

3.4.4 Hybridization

When two or more power source works together to run a system it is called hybrid system. Usually, one of two power source is used to generate the other or one source is preferred and other is used to improve efficiency and for specific times. Idea of hybrid power source is that one power source has more advantages than other in normal conditions and the other one would have specific advantages in some specific conditions. Overall, both source helps the system to operate efficiently in energy and fuel that at the end increase flight time also[36]. As we have discussed above the advantage and Drawbacks of different power sources. The Drawbacks of some sources can be resolved by the advantages of some sources. But the thing that matter is the good combination that generate the concept of hybridization. By combining two power sources overall advantages of the system can be increased keeping the Drawbacks minimum[37, 38].

Hybridization is usually categorized in five diverse types (PH) parallel hybrid, (MPV) mild parallel hybrid, (SPH) series parallel hybrid, (SH) series hybrid, and (PIH) plug in hybrid. All of these hybrid systems have their own advantages and dissaving based on the application and type of use of these systems. Using the literature ([39-43]) following diverse types of hybrid system

Table 13. Hybridization and types

Hybrid system Type	**Working**
Parallel Hybrid (PH)	PH can function while using any of the two source or one individually at a time when both sources are used, they are used in equal proportion.
Mild Parallel Hybrid (MPV)	MPH system use one main power source and use the other source when the assistance is required.
Series Parallel Hybrid (SPH)	SPH uses both power source in different ration, it can use 100% of both or 40% and 60% of sources So to regulate the systems overall efficiency or to decrease the usage of fuel by using alternator source in low power requirement conditions.
Series Hybrid (SH)	In SH system one source is used to generate the power of second source and only main source is connected with power system and second power source is not connected with power system. Like happen in battery powered system while having petrol/diesel generator to charge the main battery system.
Plug In Hybrid (PIH)	In PIH system one main power source is used permanently while uses grid power via plug to recharge that actually avoid the use of combustion engine for recharge purpose.

There are many distinct aspects on which use of hybrid system depends such as availability, cost, application, and user preference. There are some areas in the world which are not feasible for the use of renewable energy specifically in the north of the Norway that is cold and dark for half a year so combination of different source of energy are required for the operations without being affected by harsh conditions[44]. Secondly, use of hybrid system as a power source affectively reduces the carbon footprints. Some famous hybrid combinations include gasoline-electric hybrid, solar hybrid, plug-in hybrid electric, and hybrid containing super chargers SCs.

For UAVs, the most famous hybrid power source is Gasoline-Electric Hybrids because it provides quick reactions of electric motor with the gasoline powered flight’s advantage that significantly increase its flight time. Also, system can easily divide the power between the dual power source and system can easily stop and start using the electric motor when needed[45]. Advantages and Drawbacks of different power sources are given as

Table 14. Hybridization models

System	**Advantages**	Drawbacks
Solar Hybrid	High flight time, reduces the power fluctuations present in pure solar powered system.	Flight range and applications are limited.
Gasoline electric Hybrid	Electric motor provides quick reaction, combustion engine provides long flight time.	System gets bulky, complex and cause pollution.
Plug-in Hybrid	Mostly depends on solar that is why more efficient.	System gets bulky and complex.
FC and SC Hybrid	High power and energy density, Eco friendly.	rely on hydrogen availability, hight initial cost, system gets bulky.
Li-ion and SC Hybrid	Long endurance, high power, and energy density.	System gets limited in cycles of batteries and recharge rate.

3.4.5 Conclusion for Power Source

Reviewing different source of powers that are currently available for UAVs, their shortfalls, and solutions currently available for them has been addresses and shortcomings for specific power sources has been highlighted. While addressing the different shortcomings of different power sources, it is important to mention that most solutions increase the system's complexity. Combustion engines are robust but are quite heavier. Batteries and FCs can provide the long range because of their manoeuvrability but still they get failed when they have to provide the peak current when it is required and drains the power source at drastic rate. Hybrid system can improve the flight time of drones. But this system needs to be comparable in size and weight to an existing drone while the efficiency is increasing by improvement in current system. Hydrogen FC are a good option and works effectively in hybrid system as they have LI-Po batteries, but at the same time Li-Po batteries have Drawbacks of usage in drones because they have low energy density have short flight time, have comparably long recharge time and can be hazardous to environment. SCs have high energy density, short recharge time and almost infinite cycle life. So, SCs are seems to be the replacement of Li-Po batteries in Hydrogen FC hybrid power system. Further research is needed and required to further access the potential of hybrid power supplies in diverse types of UAVs.

4 Offshore Drone Logistics Model in Supply Chain

Supply chain can be described as an integrated process that have different number of business entities like supplier, manufacturer, distributer, and retailer and all of them work together to transform raw material into final product. This process of transforming raw material into final desired product is done in distinct phases that include obtaining raw material, convert the raw material into desired final product, and deliver the final product to the customers. Any supply chain model is divided into two processes, one is production planning and Inventory Control process, and the other is Distribution and logistics process. Chain is usually having a forward flow of material and backward flow of information, but current Advancements also alter the chain and includes reverse logistics, for recycling, remanufacturing and re use. The following flow chart provides the basic flow of raw material into final desired product.

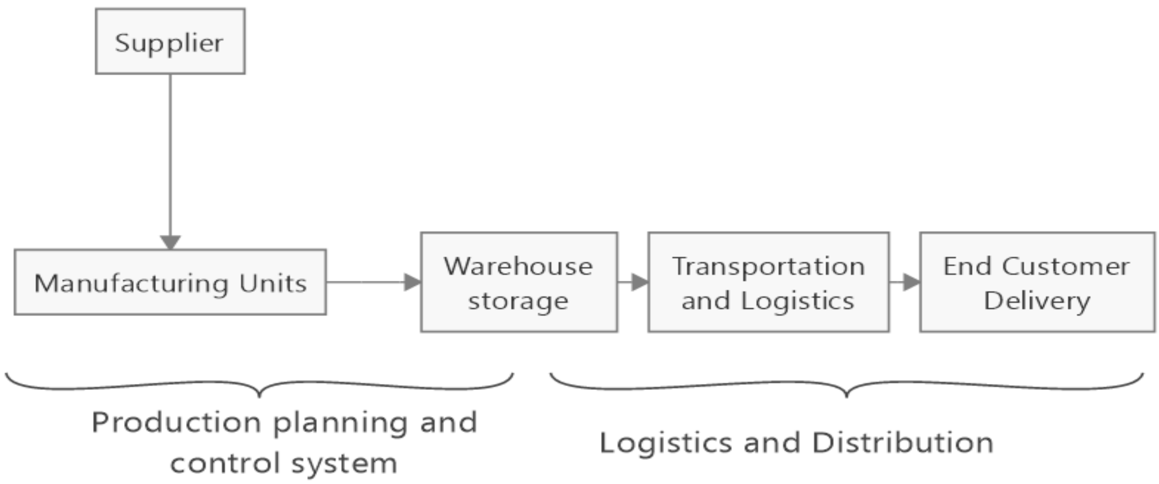


Figure 14. Supply Chain General Model

The production planning and Control process includes the manufacturing of the product and then its storage, sub-processes, and collaboration of all these processes. Moreover, design and management of whole manufacturing system that includes raw material scheduling, manufacturing process and scheduling, material handling, design and control are also included in this process of supply chain. Inventory management includes sub tasks like the management and design of storage policies, work in process inventories and most importantly final product storage. All these processes are main tasks of any supply chain process but in this thesis our focus area is about logistics part of the supply chain. Logistics and production planning and inventory control, both processes are dependent of each other and get affected by each other. Especially when it comes to coop with the recent problems came when new and advanced technologies are being used in manufacturing process, that also demand advanced logistics process so that overall supply chain model could be effective otherwise old or conventional logistics model can nullify the beneficial effect of advanced manufacturing and internet technologies.

Logistics and Transportation process includes the transportation of retrieved products from warehouses to end customer. In this process of supply chain product can be stored in inventory and delivered on demand of end customer or it can directly be delivered to end customer based on the different model of supply chain. Among other logistics models those contain, ships, drones and the truck or combination of several transportation bodies our concern is drones logistics for this purpose a model that is used is:

The Pure-play Drone based Logistics Model (PD) Uses only drones to deliver the product from Inventory to end customer. Inventory could be distributer's storage deport or manufacturing facility. Because of the limitation of drones that drones cannot go so far to deliver the product to end customer and also have limitation to lift more than a certain amount of weight, drones missed a lot of end customer deliveries those are out of their range or weight limits

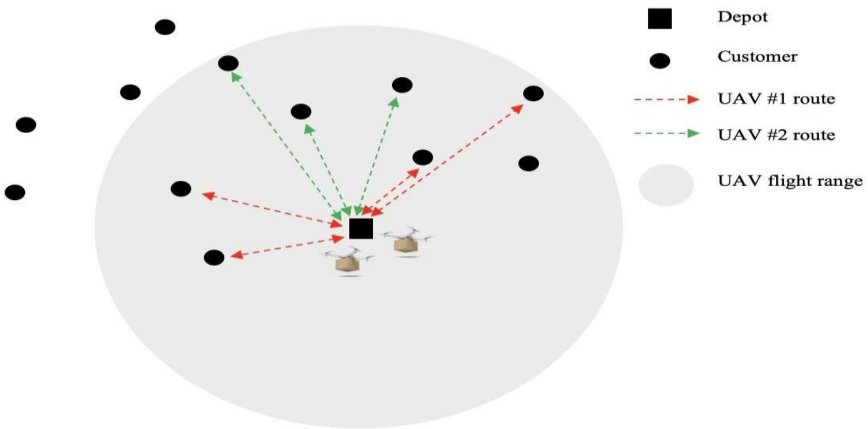


Figure 15 The Pure-Play Drone logistics model [46]

Almost every logistics model firmly depends on three strategic level questions that are[47]:

1) Make to stock or make to order
2) Push or pull Inventory
3) Inventory centralization or decentralization

Before getting to the final decision made for the drone logistics model specifically for offshore purpose. All these strategic decisions needed to explain in detail their advantages and Drawbacks in drone logistics model.

Make to Order or Make to Stock are two different manufacturing process strategies but as all the process in supply chain are highly connected that is why these manufacturing process have high impact on logistics also, The make to order (MTO) approach waits for the purchase order or confirmed demand from end customer to initiate the advanced planning and scheduling for manufacturing and after the order for the product is confirmed than this order is placed in production queue. On the other hand, make to stock (MTS) approach is based on the forecasted data about the demand from the end customer and production is started and product is stored in inventory way before the order is confirmed from the end customer.

Push or Pull system in Inventory play especially key role when it comes to the inventory cost, carrying cost and ordering cost. Push system is based on the forecasted demand of the customers and in order to meet that forecasted demand there must be inventory, so the companies started manufacturing the enough products to meet the demand and in other words companies push their products to customer side. MRP (Materials requirement Planning) is an example of push system that includes the financial calculations, operations and planning for logistics. It is a computer-based information system that keeps control and make sure about the raw goods and materials that are needed for production and it must be available when needed. Main advantage of this system is that company had enough products on time to satisfy the customer's demand. Push system also have some Drawbacks, product usage depends on the forecast and that usually get inaccurate that increase the inventory storage cost for the company.

Pull inventory control system on the other hand starts when the order from the end customer end initiates and company only makes enough products to meet the customers' requirements. Advantage of this system is that there is no inventory left at the end that can increase the cost for carrying the product in warehouse for the company. Just In Time

(JIT) is the example of the pull system. The main purpose is to keep the inventory level to its minimum so that only that number of products are made that can satisfy the customers need and JIT eliminates all the waste by reducing the storage space by minimum and so the cost for the company[48].

Push-Pull System is the best possible combination of push and pull inventory control system that can provide lean inventory strategy. Based on the product type it is really important to provide the product to customer without having unnecessary delay. That is why some companies uses combination of both system and stabilize the supply chain and reduce the product storage. With the use of push-pull inventory control system planners can develop decent and controlled guidelines for short as well as long term production needs.

Inventory centralization or decentralization is a concept related to inventory management system that when different operations related to product are carried out at centralized location and where the product is manufactured there product is also stored known as centralized inventory and in the other hand when different operation of a product are carried out at different places and product moves from one location to another for different operations and then stored at different place that is near to end customer other than where it was manufactured that is known as Inventory decentralization**[49].**

Use of Drones in Offshore Logistics involve a lot of new and advanced technologies throughout the supply chain. Especially considering the Equinor case study, where logistics have to done from onshore to offshore and demand will come from offshore FPSO, whole supply chain depends on the product but here in this case product is not fixed, it depends on the operational demand of FPSO. Make to Order with Inventory centralization having push-pull system-based logistics model will work for JC FPSO. Based on the advanced manufacturing technologies like 3DP and in the presence of AI, Blockchain, IoT and other advanced technologies it will be possible to have an advanced manufacturing unit onshore. Getting operational problem demand from offshore 3DP prints the part and having the Inventory centralization model product will be pulled by demand comes from offshore and for JIT delivery drones will be the best viable option that completes the whole supply chain model.

Considering that not all the demand will be pull based, there are possibilities that some regular thing also needed to be transported offshore using the same logistics model. For that purpose, having the inventory onshore with forecasted products in the warehouse will be feasible, by doing this there would be combination of push and pull inventory management system. If some specific requirement-based product order came from offshore pull system of logistics will work and if demand of some expected product from inventory come, then push system of logistics will operate and product will be delivered on time.

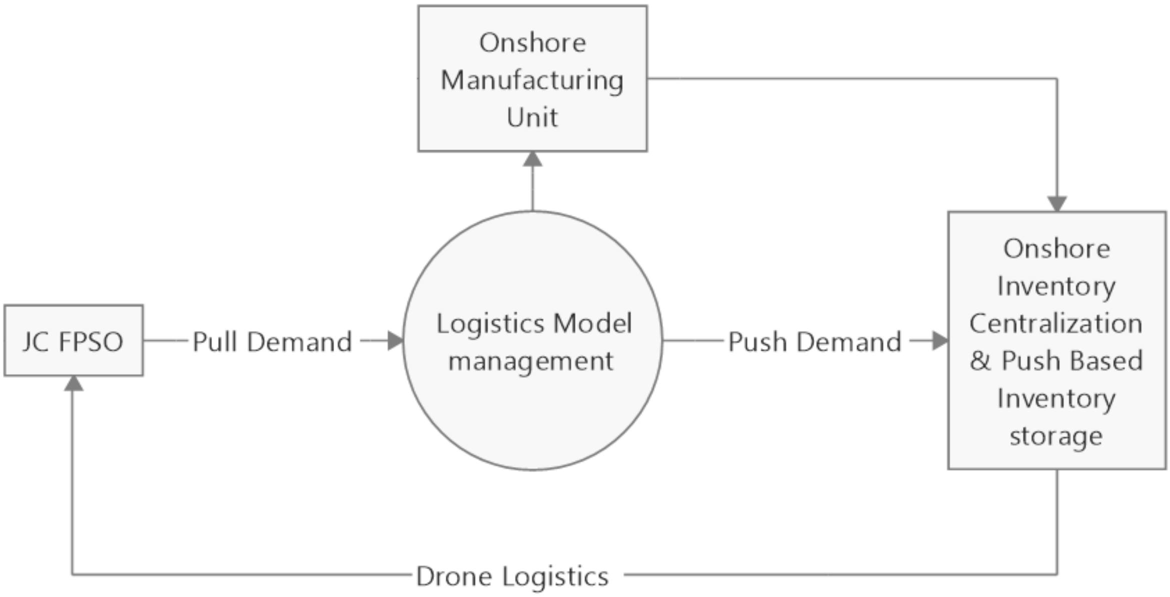


Figure 16. JC FPSO Logistics Model

5 Loading and Unloading mechanism with occupational safety and health

5.1 Methods of loading and unloading:

Different modes for delivery drone are:

Zipline: Zipline is a drone delivery system being used in remote areas of Africa for saving lives of the people. Zipline is the world first commercial drone delivery service that is supplying medicines to the remote areas where fast delivery is required. The company is aimed to deliver medicines in Rwanda to almost twelve million people within time limit of 15-35 minutes. The people living in remote areas order the medicines by using mobile to the zipline, the order is then packed at the delivery station and is then sent by the drone to the customer. The customer also get notification that there order has been dispatched. In the zipline process the drone does not land at the destination instead, they use parachute landing to deliver the order at the customer place. Before delivering parcel, the drone drops to a height of 15-20 meters. Zipline drones are designed to carry load up to 1.5 Kg and they have the range up to 150 KM to deliver the parcel. Zipline have fixed wings so they can be used to deliver heavy loads for longer distances. Zipline drones can withstand in extreme weather conditions such as heavy rainfall or winds. The weather conditions can have minor impact on the delivery process of the drones. [50]

Drop off method: The method of this type of delivery through drones is based on the process in which the parcel is delivered from the delivery section of the company on a drone. At the destination where the order is to be delivered, the drone just descend to a lower height, and it drops off the parcel at that place. The food companies are using this type of delivery service to deliver the food in populated areas where high traffic is the major crisis.

Vertical take-off and landing (VTOL): Vertical take-off and landing (VTOL) are becoming popular delivery method in the field of drone technology and many companies are making experiments on this technology to deliver their services to the customer doorstep. VTOL is the type of delivery vehicle that take-off and land in the vertical direction. The most common shape of such vehicles is quite like the helicopter however, these days hybrid drones are also being used such as quad plane and tail sitter designs. They are being propelled with the help of gasoline, batteries, or solar energy. Different modes for take-off are being adopted by these delivery drones such as short take-off and landing, vertical take-off and landing and conventional take-off and landing method. In conventional take-off and landing type the drones use a runway for take-off. The drone is propelled by fixed wings, and they are also called horizontal take-off and landing drones. Short take-off and landing drones are like conventional drones, but they use short runway for take-off. This type of drones is used in remote areas where there is limited space such as military air space and they can take-off on short runway.

Vertical take-off and vertical landing drones that take-off and land vertically. These drones can only be controlled by rocket, and they are mostly used in ballistic missile that are controlled either manually or remotely[51].

Parachute landing: In parachute landing delivery method, it is ensured first that the wind speed is safe enough for deployment of parachute and if the speed of the wind is high then pitch-up technique is used to reduce the wind speed. For parachute landing, the autopilot follows a path for base and final leg approximation, it will follow the procedure to lower the height of the drone. In case of emergency, the autopilot will not lower the height and will deploy the parachute at the point of landing[52].

Net arrest: In the method of delivery, the delivery drone is arrested with the help of a net at the delivery point. The delivery done is lowered at the destination where the parcel is to be delivered. A net is used at this place to capture the drone safely and after the landing of the drone with the help of a net safely, the parcel is taken off from the drone.

Conclusion: The above discussed delivery methods can be used for delivery of the tools or other items at the offshore locations. There are some disadvantages associated with these delivery methods. In case of drop off method, some tools being delivered at offshore rigs are sensitive therefore there is a risk that when being dropped from a height, there are chances that the tool can be break which may lead to failure of operation for the purpose. Similarly, in case of parachute landing, the 70% area of offshore is no fly zone where we are not allowed to fly drones or parachute. Therefore, having limited space in offshore location as there are antenna and other equipment placed in such places for networking, this method of delivery is also not practically feasible. The net arrest technique is also not feasible at the offshore locations because of the issue of limited space.

The only method of delivery that can be put into practice is the vertical take-off and landing method for delivering the materials in offshore areas. We know there are small runways in each of the offshore rigs or other places, therefore this method of delivery of parcel can be deployed in offshore locations as there is not risk associated with the damage of the parcel or to the safety of the delivery drone as compared to the other delivery methods.

5.2 Regulations:

It is important that all the companies operating the drone for delivery purpose must have a legal instructor (lawyer) who can guide the stakeholders about the legal requirements about the drone operations. The lawyer will assist the company on paperwork, what regulations can be violated during drone delivery operation, and he will also assist the company to acquire the permits from the concerned authorities for the operations of the drones.

FAA issued first nonmorality UAV permit in 2006 and then it started to develop regulations to ensure the drones operation safe for commercial and recreational use. In the period from

2006 to 2014, FAA issued only two permits per year for commercial flights based on the number of requests for drone flights. After that Amazon and other companies announced to expand their business by commercial flights of drones and in 2015 and 2016 FAA issued 1000 and 3100 drone permits, respectively. Today, there have been about 1.2 million UAVs and half million recreational drone permits registered on FAA. In the FAA reauthorization act of 2018, the FAA have been directed to allow drones to start delivery operations under some regulations and carrier rules. The federal aviation authority (FAA) focus is to make sure the operations done by drones to deliver goods safe. Therefore, the operators of the drones must follow some regulations to ensure the safety of drone operations. The drone operators must go through part 135 of the air carrier certification before they began the supply operation by drone. The operator of drone who wish to operate the drone beyond the visual limit are bound to obtain air carrier certificate 14 C.F.R part 135. The pilots operating under part 107 do not need to get the license but they must ensure to acquire adequate aero traffic knowledge and safety test of the drone operations. Usually, the air carrier certificate is issued to the pilots operating the drones in the overseas areas. Night operation drones are required to be equipped with anti-collision light and the pilot must gain additional training on night operation.

European union aviation safety agency (EASA) has published a regulatory framework for drones to deliver parcel into urban areas, to deliver medicines or essential goods into crisis areas. EASA by following the consultation NPA 2021-09 has published new results ED Decision 2022/oo2/R.

Following are the address areas of the EASA decision:

- Establishment of geographical zones and EUROCARE ED 269 as the standard unique format
- Predefined risk assessment dedicated to beyond visual line of sight operations for linear inspection of infrastructures
- Developing a list of training patterns for the pilots of the drones and the drone pilots themselves will choose that what kind of training do they require depending upon their area of operation
- Revision of the forms allowing the operators to operate the drone in cross border areas

- According to the new regulations of Europe about drone operations, every pilot who is operating a drone having weight more than 250g and having a camera on it must register themselves at flydrone.no.

In Norway you can fly in the open category (A1, A2, A3) without applying for authorization. The requirements to fly drones in Norway are:

- Make sure to mark your drone with operator number
- Make sure that drone must have valid liability insurance
- Before flying drone, make sure that there is no restriction to fly it in this area
- Drones heavier than 250 g are bound to acquire valid AESA competency certificate

If the operator is a citizen of any state of EASA, then he must be registered as UAS operator in his country and his AESA certificate is valid in Norway to fly drones and if he is not a citizen of EASA state then he must register himself at flydrone.no and must attend A1/A3 course and exam.

In open category the rules that apply to the pilots are:

- The pilot must maintain visual line of sight
- The weight of the drone must be less than 25 kg
- The drone must fly within 120 m closest point from the earth
- Drones are not allowed to carry dangerous goods
- Drones are not allowed to drop the items
- Drones must be marked with operators' registration number

Open category is classified into three classes A1, A2 and A3 and the difference between them is.

- A1. Fly light drones with few limitations of distance to uninvolved person
- A2. Fly drones within built-up areas 60 m from the uninvolved person
- A3. Fly drones up to 25 Kg, minimum 150 meters from residential, industrial, and commercial areas

One can fly drone at night if he can see it. It is important that the drone must have a flashing light on it when flying at night so that it must be visible. According to new regulation, from

July 1, 2022, the drones flying at night must have green flashing light. To get approval for flying drones in specific category there are certain options for the pilots such as.

- Applying for authorization through specific operation risk assessment (SORA)
- Applying by using predefined risk assessment (PDRA)
- Declare to operate standard scenario (STS). For this category, the pilot must have passed the STS exam and the drone must have C-classifications
- Apply to become a light UAS operator (LUS).

The areas where there is no fly zone, and you are not allowed to fly drones in those areas. A list of such areas is given below:

- Area within 5 km from the airport
- Nature conservation areas
- Embassies
- Military areas
- Areas with sensor restrictions

5.3 Health and safety:

Hazard: Anything that has the potential to harm is called hazard.

Likelihood. Likelihood are the chances of occurrence of any unwanted or unplanned event.

Consequence: Consequence is the severity level of the unplanned or unwanted incident.

Risk: Risk is the product of likelihood and severity.

$$Risk = likelihood \times severity$$

In general:

Risk is "How much are the chances of an incident and what should be the level of severity of that incident."

Risks to drones:

There are risks associated with any emerging technology specially to the drones flying at height such as striking with other drones, birds, or property. These accidents can lead to civil proceedings having data protection or safety issues to the drones. The issues associated with drones' delivery is that they cannot open the mailboxes, porches where the parcels to be delivered can be covered or the backyard of landing areas may have dogs inside leading to the safety issues with drone delivery system. A delivery drone has many small components and millions of lines of soft wares. Any incident to the drone can lead to discontinuity of the flight or the whole delivery process will be disconnected. The moving blades of the drones has the potential to harm or injure anything they may hit or due to fast movement at height they become more dangerous to destroy anything that they may encounter on their route of flight. Many factors can contribute to the failure of the drone operation including the failure of the parts of the drone, the climate conditions such as fog, rain, wind or sand, the radiations, or the environmental parameters such as tress or animals can disturb the delivery operation of the drones by striking with the flying drone. Another possible reason to the failure of the drone flight is that the data team may not enter the correct data in the flying drone such as the change in the environmental parameters like rain, change in temperature, humidity or the exact location of the destination may not be recorded in the drone that can also affect the safe operation of the delivery drone. To ensure the safety of the drone operations one must consider the many factors such as sensors, the wings of the drones and the reserve batteries or fuel of the drone. Off course, all these parameters also increase the weight of the drone.

Below is the list of the potential risk that a flying drone may encounter during its flight.

- The failure of the sensors can lead towards the blind flight and as a result, the drone can hit something during its flight
- There could be obstacles on the route of the drones in highly crowded airspace areas
- The strike of the drone with an electrical line, a bird or some tree can lead to the failure of any function of the drone
- There is potential hazard that the drone can hit ant wild animal to whom it is unable to detect during its flying operation
- The drones cannot be able to navigate its destination sometimes that can lead to the delay in the delivery time or loss of the delivery
- The drone can face harsh weather conditions during its flight such as high wind, fog, or rain
- The drones having cameras installed over them have the privacy issues to the people or places above that they fly
- Other climate challenges such as lightening, thunderstorm or some areas where signal jammers have been installed can also disturb the operation of the drones

- The drones have the risk of being attacked or hijacked by someone
- Chances are there that the drones can deliver the parcel at wrong address
- Drones can also hit some person and high possibilities are there that person can be seriously injured due to striking with the flying drone
- The failure of any component of the drone such as sensor, battery or wings may lead to the fall of the drone from height and hit to anyone that may come on its route resulting into serious harm to some person or damage to the property or environment

The faults in the drone operation system, or misuse of the drones can lead to serious concerns about the breach of legal bindings that may cause fines, sanctions, or imprisonment to the employer breaching the safety laws. The current agreement between the CAA and HSE explains that HSE is responsible for the enforcement of any risk arising by the drone operation while CAA are responsible for the enforcement of safe operations of the drones.

The calculation of risk is based on the criteria of how much are the chances of an incident and what adverse effect of these incidents should be. In case of calculation of risk matrix for drones we must say that the possibility of having an incident when flying a drone above in the air is three, the consequence of the incident by striking of drone with human or property may cause severe damage leading to loss of any organ of human or destruction to the property. That is why the severity level should be selected four and the risk will be:

$$Risk = 3 \times 4 = 12$$

The risk value comes out to be twelve. According to the risk chart the twelve is in the yellow zone that is moderate level of risk.

Severity

Likelihood	Negligible	Minor	Moderate	Major	Catastrophic
Almost certain	5	10	15	20	25
Likely	4	8	12	16	20
Possible	3	6	9	12	15
Unlikely	2	4	6	8	10
Rare	1	2	3	4	5

Figure 17. Risk matrix

Standards:

In the field of supply chain ISO has set many standards. Some standards that come under the drone delivery domain are as follows:

- ISO 9001 standard that specifies requirements for a quality management system
- ISO 13485 for additional quality management certification
- ISO 27001 certification for information security
- ISO 14001 Standard for environmental management system
- ISO 18185 standard for electronic cargo seals for tampering detection on freight containers
- ISO 21384-3 Unmanned aircraft system
- ISO/TC 20/SC 16/WG 4 UAS traffic management
- ISO/TC 20/SC 16/AG 5 Detect and void (DAA)
- ISO/TC 20/SC 16/JWG 7 Unmanned aircraft system (Noise measurement)

The health and safety of the drone operations can be ensured by introducing some advancement in the drone technology. These suggestions will make sure the safety of the delivery operations of drones as well as to the other humans or environment that might be affected by any failure in the drone flaying operation.

Some of the suggestions are here below:

- Hiring of skilled pilots for delivery drone operations and they must be given sufficient knowledge and training on safety of drone delivery flaying operations
- GPS supportive devices that have been installed on drones for correct positioning and mapping, must be up to date and no malfunctioning must be there that can affect lead towards to failure of the safety and security of the delivery drones
- The supply chain management system such as tracking, and tracing of drones and customers must be modified so that the drone's operation can be made more dependable and secure
- Navigation technology must be introduced in the delivery drones that could detect the obstacles before it encounter (such as trees, birds, buildings, or other drones) to the drone on its route. This would be helpful to avoid any unwanted crash of the delivery done
- The efficiency of the drone delivery also relies on the weather conditions such as high wind, rain, storm, or humidity. Such modifications need to be developed in drone technology that it might not be affected by such extreme weather conditions and continue to fly without any failure in its components or route
- It must be ensured that drone must be filed with great caution in densely populated areas as well as airspaces so that the collision incidents of drone with other space crafts must be avoided

6 Operations and Maintenance regime

Operational phase of the drone logistics involves plenty of challenges. Once right drones are selected in the drone fleet to do the specific tasks of transportation and to play the righteous role in whole supply chain model their operational needs and requirements must be listed, and all the legislative requirements must be fulfilled in order to make the logistics model reality based. Operational part of the drone logistics gets restricted by the number of challenges that includes:

1) Legislative Challenges
2) Refuelling and Recharging Units
3) Human Resource
4) Maintenance Regime

6.1 Legislative Challenges

Operational Phase of drone logistics is first resisted by the legal legislatives because it is not possible for all type of cargo or weight carrying drones to do operations without having rules and regulations. For the safety of air traffic that is the safety of other drones in flying zone also aircrafts, birds, humans and for the safety of the ground livings in case of malfunctioning of drones CAA Norway under the ministry of Transport and communications has given a detailed regulations of drones in which almost all categories of drones are mentioned with their regulations of flight within Norway. These regulations are applied to all flying models of aircrafts without pilot onboard in Norway, including Svalbard and airspace above the Norwegian congenital shelf and Norwegian economic zone.

Considering the rule of law all drones are categorized in three diverse types, VLOS (Visual Line of Sight) it means that and aircraft without pilot on board is flown in such a way that the aircraft can be observed all the time without using the camera or other equipment. EVLOS (Extended Visual Line of Sight) means that an aircraft without pilot onboard is flown beyond the visual line of sight of the pilot in command, but visual control is maintained by one or more observer. BLOS (Beyond Visual Line of Sight) means that aircraft without pilot onboard is flown beyond the visual line of sight of the pilot in charge and other observers. For this purpose, advanced cameras and communication system is used. Mostly long-range drones fall in this category of the drones.

Having an eye on the types of UAVs we have in drone fleet for offshore logistics, all the shortlisted drones fall in the third mentioned category that is BLOS. To operate BLOS UAVs CAA Norway have provided regulations in (Revised by Act of 20 May 2016, No 510, 17 September 2018 No 1337) Sections 56–59. The regulation is attached herewith Appendix II.

Based on the regulations mentioned by CAA Norway to operate the freight drones in specified area of application these regulations must be full filled.

6.2 Refuelling and Recharging Units

Refuelling and recharging are the challenge for offshore drone logistics because offshore carriage FPSO would not want to have enough human resource and equipment on it all the time to refuel or recharge the drone. The biggest challenge is that all the drones would need to refuel or recharge onshore and in their flight from onshore to offshore and then offshore to onshore would be on single refuel or single recharge. Having fuel supply offshore for drones is itself a challenge and then keeping the fuel and recharging station offshore on FPSO involves a lot of safety issues with it. So, refuelling, and recharging station will be set up onshore.

Depends on the type of the drone having in the fleet for offshore logistics and the type of fuel that drone use, like for battery powered drones there must be advanced technology-based charging stations and for petrol- or diesel-powered drones there must be fuelling station. Other than that hydrogen fuel cells need supply of hydrogen for their operations. Technology advancement have made the things easy for the battery powered drones, the parking area of the drones can be used to charge the battery powered drones by wireless charging. Getting to its specified parking position would be enough to recharge the drones with wireless charging or plug in charging. For petrol- or diesel-powered drones there must be fuel filling station near parking area of drones so that whenever drone have to go to take off position its fuel first filled and then moved to take-off position. In case of Hydrogen fuel cell powered drones, there must be enough hydrogen fuel supply in the inventory to refuel the drone before next usage. All these refuelling and recharging will take place onshore refuelling and recharging stations where drone fleet will be parked. Human resource would be required for the refuelling purpose in this initial phase of drone logistics but with advancement of technologies especially artificial intelligence autonomous recharging and refuelling techniques are expected to work instead of human resources.

6.3 Human Resource

Human Resource is also a challenge when drone logistics will be operational especially offshore because it is not an easy task to have the expert employees offshore and they stay there constantly to perform tasks related to drone logistics. For this purpose, keeping the minimum requirement of human resource especially offshore is aim, having refuelling and recharging station onshore will minimize the human resource offshore. But take-off and landing mechanism for freight will required some of the human resource involved to perform some tasks. Expert human source is required, to perform the drone flight, to assist the drone flight by checking and fit to flight requirements of the drone, for refuelling and recharging of the drones and for maintenance regime, all these purposes required human resource, but the good thing is that all this human resource will be needed onshore that will reduce the carbon footprints as compared to human resource needed offshore at FPSO.

6.4 Maintenance Regime

Maintenance is the main part of operational phase of drone logistics. All the drone in the fleet required maintenance to do the required operations without any abruption[53] [54]. For this reason, there must be some maintenance regime established that can take care of the drones for long-term running without any faults and errors. This regime can be divided into multiple steps, but all the sub steps of maintenance regime will lay under two types of maintenance that are:

1) **Preventive Maintenance:** All the maintenance work that is done before the failure occurs in drone will be categorized as preventive maintenance. As name shows it will be done in order to save the drone form any failure. So, this is a maintenance strategy that is based on restoring or replacing an asset at a fixed interval of time regardless the condition of equipment. Scheduled check, replacement and restoration tasks are the example of preventive maintenance. This preventive maintenance involves many subs maintenance levels like Time based maintenance (TBM), Failure Finding Maintenance (FFM), Risk Based Maintenance (RBM), Condition Based Maintenance (CBM) and Predictive Maintenance (PDM). All these types of maintenance will be discussed in detail to apply on drones' operational phase to keep them safe from all possible failures[55].
2) **Corrective Maintenance:** Corrective maintenance involves all the maintenance measures taken after the failure has occurred and it involves two sublevels of maintenance that are Deferred Corrective Maintenance (DCM) and Emergency Maintenance (EM).

Again, these two types of maintenance will be divided into subgroups like showed in the diagram below:

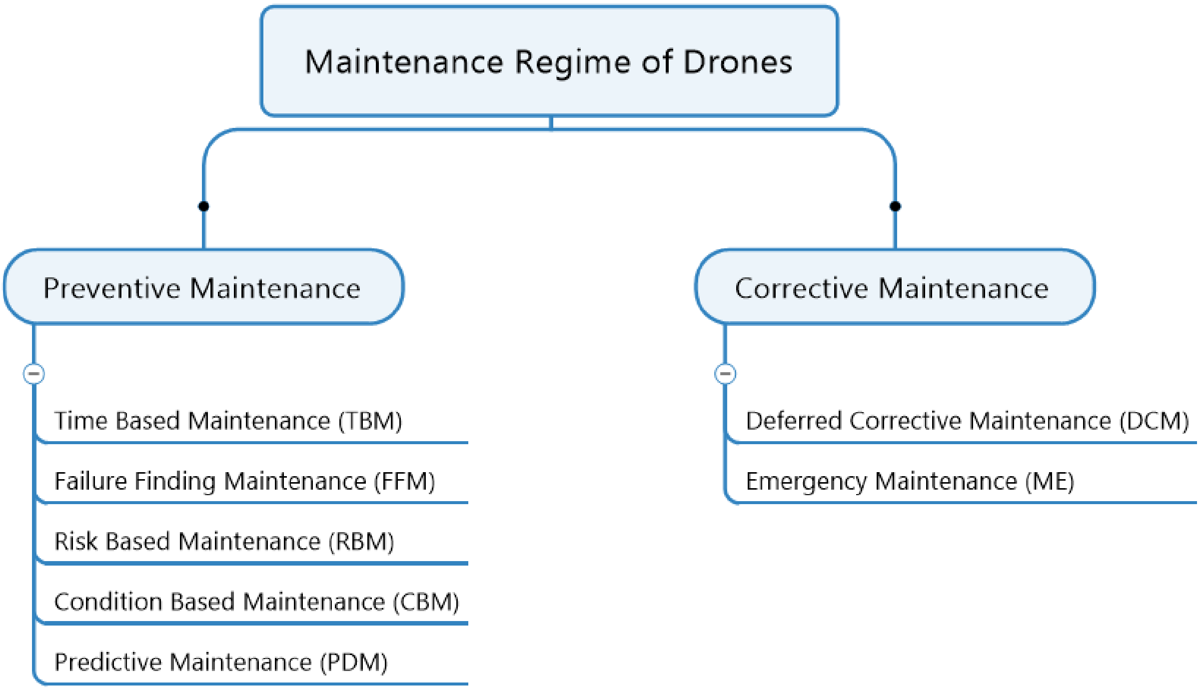


Figure 18 Maintenance regime for drones

6.4.1 Preventive Maintenance

Time Based Maintenance (TBM)

Time based maintenance (TBM) is a type of preventive maintenance that is done on regular intervals and on fixed time schedule regardless the functioning of equipment. Having the regular check of every function part of the drones on a fixed interval is necessary to prevent any likelihood of failure. This time-based maintenance can be scheduled based on specific running hours of the drone. And routine checks of drone before flight can also fall in this category of the maintenance.

Failure Finding Maintenance (FFM)

Maintenance of such an equipment and parts those are not functional until and unless some failure happened. This mean that fail safe mechanism in drones, some safety valves in gasoline powered engines of drones and trip transmitters, this equipment only works when something failure happened in the system. But they should work when something failure happened that is why their scheduled maintenance is necessary to make sure that these mechanism works finely when needed in case of any failure. Because in normal operating conditions these fail-safe mechanism do not work and this failure finding maintenance do not prevent the system from failure but simply detect it. Most of the time schedule of these failure finding maintenance are derived from legislative requirements that make sure that every failure detecting mechanism in the system works fine when it comes to need of it.

Risk Based Maintenance (RBS)

As we know that the relation of risk, likelihood and consequences are given as

Risk = Likelihood X Consequences

So, the use of risk assessment methodology in maintaining those equipment and parts of drones those have elevated risk in case of failure is known as risk-based maintenance. As a result, the parts, and the equipment in drones those have high likelihood and consequences of failure goes in frequent maintenance schedule and reduce the risk of overall system. This maintenance provides the most economical solution to reduce the risk of failure of overall system. Risk-based maintenance is essential for the drones as they carry parts having severe consequences in case of failure and frequency and scope of this maintenance continuously optimized based on the findings from different tests in inspections through risk assessment. Risk-based maintenance involve fuel tanks, batteries, and hydrogen tanks in hydrogen fuel cell powered drones.

Condition based maintenance

Most of the failure does not happen suddenly, or at once but most of the failure do give some time or warning before goes to complete failure or occur completely. If the failure is found in its initial stages than there is a possibility to take some preventive actions to stop the complete failure of the system or at least avoid the consequences of failure. This sort of actions or maintenance that is done in that short span of time is known as condition-based maintenance.

Condition based maintenance needed physical evidence that a failure is happening or about to happen. For this maintenance different monitoring techniques are required especially for the drones that can sense the failure in its initial phase and can do the presumptive actions of maintenance to reduce the risk of failure or reduce its consequences. Concept of Condition based maintenance can be explained by the P-F Curve diagram given as below

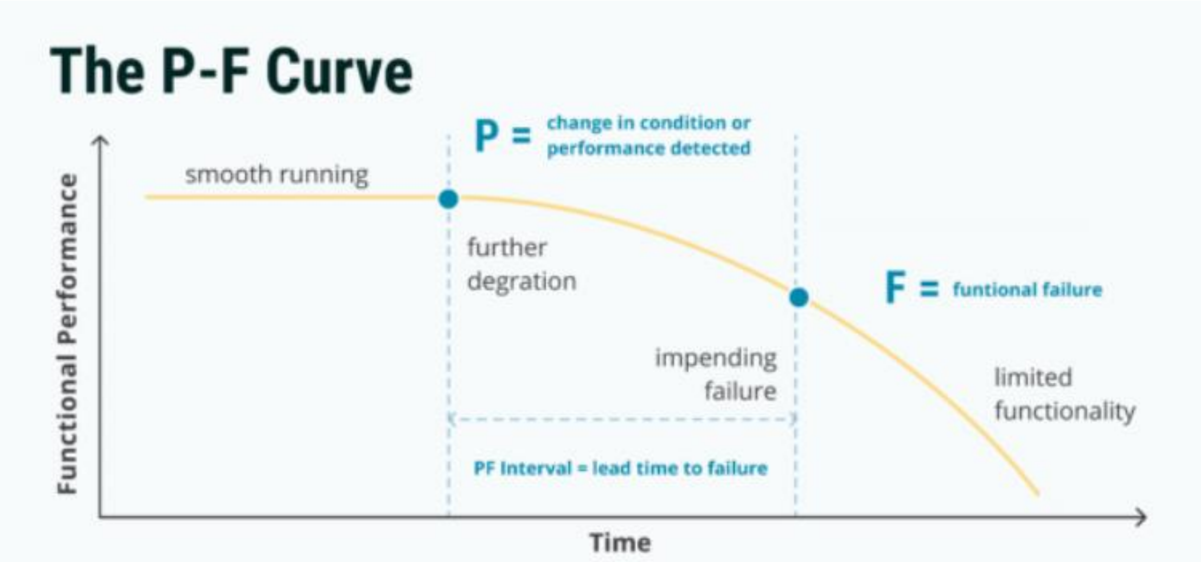


Figure 19 P-F diagram for CBM[55]

In this diagram initial x-axis straight line shows the smooth-running equipment and at point P there is some change in condition that is other than normal or smooth run and system start collapsing toward the downside means lower values of Functional performance or y- axis. When system reached at point F, that is functional failure of the system here system get collapsed and complete failure of the system occurs. The time between the point P where failure was detected on its initial stage and the point F where system failed completely, this time is known as P-F interval and this interval is the opportunity for inspection and detect the failure reason and maintain the system to its original performance. Here one thing is important to mention that condition monitoring can only help to find the failure on its initial phase it cannot help to fix the problem, but CBM works in this P-F interval to fix the issue and safe the mechanism from complete failure and the thumb of rule is that for CBM the time duration allowed is one-half or one-third of the PF interval[56]. But the cases where P-F intervals shows large variability CBM in not much effective.

Predictive Maintenance

Predictive maintenance is the same as Condition based maintenance but with the introduction of modern technologies such as AI, IoT and machine learning, produces the difference between Predictive and Condition based maintenance. Now, Predictive maintenance is considered as an extension but in most advanced form of CBM where using the most advanced sensors it can be predicted that when the system can go to unstable position and at that specific moment maintenance can scheduled and do intervention. Most of the companies are trying to adapt this maintenance regime as it can provide enough time to do maintenance before system can go into complete failure and by this system can be secured.

6.4.2 Corrective Maintenance

Deferred Corrective Maintenance

Deferred maintenance is the type of corrective maintenance that is done after the failure of the system has occurred and then it involves repair, restore, or replace the failed parts of the system. It comes when the system runs to failure strategy or when unplanned failure comes. But this maintenance is done after the emergency maintenance so compared to emergency maintenance this maintenance is scheduled but its interval cannot be determined before failure occurs, but intervention is deferred that allow the room for proper planning and scheduling.

Emergency Maintenance

Emergency maintenance comes right after the system get failed and it is immediate that just breaks into strict weekly schedule and disturb the schedule. Emergency maintenance is corrective maintenance that involves restore, replace or repair of various parts of the system that becomes the reason of the system failure. Emergency maintenance also specifically designed to save the saved parts of the system from other failed parts just to prevent the consequences of the failed system. Among all the maintenance Emergency maintenance is avoided as much as possible and to avoid this maintenance other maintenance works following strictly the schedule. Most world class organizations ensure to have less than 2% of their total maintenance emergency maintenance[55].

7 Offshore Drone Logistics feasibility

Corporate feasibility analysis examines all of a project's important aspects, including technical, economic, legal, operational, and scheduling issues, in order to determine the project's chances of success. A feasibility study consists of any project's or plan's early stage of design. It is used to critically identify the strengths and weaknesses of a project. It can assist in identifying and assessing possibilities and dangers in the natural environment, as well as the resources needed for the project and its probability of success. In case of Drone logistics on a large scale and usage of long-range UAVs in offshore conditions it is exceedingly difficult to find its feasibility with testing it. Commercially the use drone is just one decade old and drone logistics in offshore conditions is in its testing phase that will keep quite blank spaces in feasibility analysis especially in operational feasibility studies. But to get a brief idea of feasibility of drone logistics it is important to cover all the related topics of this project. When talk about the feasibility of drone logistics following feasibility studies needed to study to get answer to the question that is it possible in reality to have drones for offshore logistics? The outcome of a feasibility study is a well-informed decision on whether or not to start a project.

1. Economic Feasibility
2. Technical Feasibility
3. Operational Feasibility
4. Schedule Feasibility
5. Contractual Feasibility

7.1 Economics Feasibility

There are various strategies for assessing financial feasibility of the project such as cost-benefit analysis and break-even analysis, but the two most common approaches are bottom-up and top-down.

Bottom-up approach: this involves breaking down a huge quantity of work (tasks) into little, measurable bits, then estimating each item in monetary worth, and combining the estimates. these cost estimates are collected from the personnel in charge of various project tasks. These individuals should be specialists in their fields so that each task and each small component could be estimated rightly.

Top-Down approach: In this approach top management and business analysts assist the financial team with their experience on the range of different projects expenses provide an estimation that could cover all the expense of the project.

In case of drone logistics bottom-up approach is necessary as well as Top-Down approach will assist to estimate the total expense of the project. As this type of offshore logistics is not so common so that any expert can give a brief overview of the costs so break down of every activity to its small bits are needed so that an overview of reality-based cost analysis can be obtained before starting the project.

Other than these approaches there is one thing that most challenging in the start of the project that is to decide that which of the model should be adopted for drone logistics, and which one will be most suitable in term of finance, technology, human resource, and operations. The available options for drone logistics are:

1) Purchase of new drones
2) Manufacturing of drones by company
3) Outsourcing the drone logistics to some x y z transportation company

Every option has its own advantages and Drawbacks in term of finance, human resource, and operations. A brief estimate can be obtained by comparing all these viable options.

Table 15. Cost analysis

	Initial Cost	**Technological gain**	**Need of Human Resource**	**Operational and maintenance cost**
Purchase of Drones	HIGH	HIGH	LOW	HIGH
Manufacturing of drones by company	HIGH	HIGH	HIGH	LOW
Outsourcing the drone logistics	LOW	LOW	LOW	HIGH

Economic feasibility in case of drone logistics depends on the choice made by the company to adapt the initial stage of the drones. If company opts Purchase of drones that is seems to be most feasible option based on the literature review that has been done so far than there will be high initial cost for the purchase of drones but by doing this top trending technology can be opted to do the safe operation comparing it with manufacturing by company itself that will boost the initial cost for setting up the drones manufacturing units and hiring the professionals for drones manufacturing. And that will increase the cost in term of human resource also. One of the many benefits by doing this is that for long term company will be on its own in term if drone logistics it can produce variety of drones for number of applications in logistics and transportation. But again, that is a separate industry and need a lot of initial cost to set up manufacturing units and professionals in drone industry. The second most important benefit by manufacturing own drones will be reduction in cost of maintenance and operations. Having the professional in the manufacturing units can also maintain the UAVs and help to train professionals for safe and cheap operations.

Outsourcing drone logistics seems not to be a feasible option because by doing this it will not be possible to get full benefits of advanced technologies and because this logistics type is in its initial phase there are few companies those offer this sort of services. And instead of paying huge amount of outsourcing amount in each term it is beneficial to buy the drones and make a team of professional to maintain them and operate them for logistics purposes.

7.2 Technical Feasibility

The technical evaluation considers software, information technology and security concerns. It can assist to determine whether a suggested technological solution is required for the project, and how difficult it will be to implement, and whether the business has sufficient talent and knowledge to implement the solution.

In case of drone logistics there are a lot of modern technologies that engage in operations, so taking care of the thing to have enough trained human resource would be challenging. Different breakdown of the technologies that engage in this project could be listed as, Drone power source technologies, drone communication technologies, technologies involved in maintenance of drones and supply chain demand advanced manufacturing technologies, all these advanced technologies can challenge the project management when it comes to real operations. The other aspect of this technological feasibility in this drone logistics is that these drones' logistics with advanced technologies have to integrate with other advanced manufacturing technologies to make the whole supply chain model beneficial. There is seems that drone logistics have high feasibility of success in term of integration with other advanced manufacturing technologies to get the maximum benefit from whole supply chain model.

7.3 Operational Feasibility

The goal of operational feasibility analysis is to determine whether or not the proposed solution will address the business problem. The operational feasibility assessment looks at how the project will fit into the performing organization's current day-to-day operations. Furthermore, operational feasibility aids the project manager or relevant department with the performing organization in determining if current work practices and procedures support the project development process and how project changes may affect the organization's day-to-day operations.

In case of offshore drone logistics, the operational feasibility could be challenging when it comes to weather conditions because in an open sea and cold climate conditions feasibility of successful operations get low. But if schedule of drone operations is done so that weather do not affect too much than this challenge can be faced. Operational feasibility also involves maintenance regime and skilled human resource to carry put successful operations.

7.4 Schedule Feasibility

A schedule feasibility template usually investigates the project's duration and determines whether it is too long to complete before it is successful. The feasibility of a project schedule assesses how much time the team will need to complete the project and whether all timelines and durations can be met, as well as whether sticking to these schedules will be enough to meet the organization's needs. It is also crucial to figure out whether the schedules are required or optional. For example, in drone logistics operation is an ongoing process and to set a preferred timeframe for delivering a fully functional logistics system in supply chain model. If it is recognized that this deadline may be missed because the project team requires additional time to evaluate functionality and build an error-free operation. A missed deadline is bad enough, but poor functionality is even worse. This predicts the schedule feasibility and this term in this project is going to use for operational phase of the project. Shifting conventional logistics with advanced drone logistics is gradual process and need a lot of testing and time to fully shift the logistics mode.

7.5 Contractual Feasibility

A contractual feasibility study evaluates whether or not the proposed project meets legal and contractual requirements. In case of drone logistics as mentioned in the CAA Norway [57] There are legal requirements associated with it and meeting it is the responsibility of the company before getting this project in operation. Regulation regarding flight operations and regulations regarding maintenance are strictly needed to be followed[58].

8 Conclusion

Commercial use of drones in logistics is not a new idea, many big companies are setting infrastructure for drones to be a permanent part of their logistics team. But use of drones in offshore logistics is somehow in its initial and testing phase. There are a lot of challenges that offshore drone logistics needed to face before getting into operations. In this thesis, while having a case study of Equinor's offshore logistics from Hammerfest to their FPSO in the Barnet Sea it was needed to develop multi criteria system and a value chain map that can provide solutions to most of the challenges faced while considering drones for offshore logistics purpose.

Firs part of thesis involves the literature review on background of drones their potential use for commercial purposes especially in offshore logistics. To integrate with advanced manufacturing technologies in advanced supply chain models, use of drones in logistics operations seems to be the integral part for future otherwise conventional means of logistics and transportation will fade the potential of advanced technologies in whole supply chain model. Equinor have provided the case study for Johan Castberg FPSO that is about 240km offshore from Hammerfest onshore station. To do the offshore logistics use of drones involves a lot of challenges. Starting with the selection of appropriate drone, which needs some criteria on which commercially available drones can be shortlisted for testing purpose. A multicriteria system based on ten criterions have been proposed on which four most important criterions have been shortlisted to investigate their parameters in reality based operational model.

Based on the proposed multicriteria system a market survey has been done to select the available commercial drones that can fulfil case study's need. That drones should have an operational range of 250-300km radius without having refuelling or recharging, must be able to carry payload as much as possible, must have Vertical take-off and landing (VTOL) and can sustain harsh weather conditions. Due to the fact that drone technology for commercial purpose is not well established yet, In the drone fleet, selected based on the proposed multicriteria system fleet can operate in the radius of 80-100km without refuelling and recharging. To fulfil the needs of case study Technological shift in drone technologies has been discussed in which based on the different upcoming technologies some solutions have been proposed and in feasibility analysis different models of economic feasibility have been proposed based on their advantages and Drawbacks decisions for the future strategies can be made.

For the offshore use of drone's different logistics models have been studied and based on their advantages and Drawbacks some suggestions made that will help to select an appropriate logistics model for the advanced supply chain. Operational phase of the drones involves different challenges some of the important challenges have been studied and discussed including the maintenance regime that plays a key role in operational phase. Different Loading and unloading mechanism have been discussed keeping an eye on health and safety of humans and environment to help deciding the best suitable option for operations. Whole case study involves pre-operational and operational challenges and workable solutions also been discussed including the future prospects and potential of use of drones in logistics especially in offshore logistics.

Overall, based on the literature review done on background and diverse types and technologies of drones a multicriteria have been established and based on that proposed multicriteria market survey is done to shortlist the most appropriate and multicriteria satisfying drone models but due to lack of many suitable options new and upcoming technological trend have been discussed that can full fill the offshore logistics requirements. Different pre-operational and operational phase Challenges are also discussed, and workable solutions have been proposed with future prospects of drone technology in offshore logistics.

9 Future perspectives of offshore Drone Logistics

With the rising digitisation, future should expect a shift in the logistics industry. Drones play a key role in paving the way for this future, increasing efficiency and productivity while cutting costs and reducing carbon footprints across the logistics value chain. The entire supply chain will be transformed by drone delivery, which will improve order fulfilment, inventory management, warehouse operations, and more. Drone logistics effects strong in three areas of logistics industry that are revolutionization of Last-mile delivery, Enhancing Efficiencies of Warehouse, Workforce Transformation, and Bringing Privacy and Data to the Forefront.

Considering the financial perspective More than one hundred billion parcels were transported in 2020, and by 2030, that number is likely to double. However, corporations are experiencing rising prices, unprecedented market demands, and expanding labour shortages as a result of this exponential growth. Businesses are forced to change in order to stay competitive, and to stay ahead of the curve, they must invest in sophisticated digitalization and automation of logistics models[59].

Digitalized and fully autonomous logistics model is the future of drone logistics. For offshore logistics the best integrated logistics model with advanced technologies like IoT, AI, Block chain etc. includes the drones and fully autonomous operation through digitalized communication. For all this there is enormous potential in research of modern technologies that can increase the range of drones and can carry more payload with them. There would be significant reduction in carbon footprints when logistics will be autonomous and done by drones for offshore purposes that will also reduce the human resources need at offshore stations.

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1 Appendix – I

Market Survey for Drone Fleet Selection

Drone Name	Drone Picture	Power (KW) and Type	Pay load capability	Flight Time or Range	Link
Drone Delivery Canada FLYTE Model ROBIN XL		Multirotor Powerplant	11.3 kg MTOW: 80 kg	Max Range: 60 km	https://dronedeliverycanada.com/technology/#sparrow
Drone Delivery Canada FLYTE Model Condor		2 Stroke Gasoline	180 kg MTOW: 476 kg	Max Range: 200 km	https://dronedeliverycanada.com/technology/#sparrow
Load transportation drone FB3		Swappable battery	Up to 100kg of payload (170kg in total)	From 15 to 50 minutes	https://flyingbasket.com/
DB Schenker Volo Drone		all-electric	up to 200 kg	up to forty kilometres	https://www.volocopter.com/solutions/volodrone
Delta Quad Pro #CARGO		LiPo battery powered	1.2 Kg	100 km	https://www.deltaquad.com/vtol-drones/cargo/#1637877287196-3475c6d0-8a5b
Sky front Perimeter		Fuel injected for high reliability and ease of use.	(7.5 kg) maximum payload capacity for 1 hour (5 kg) payload for 2 hours	(177 km) flight range	https://skyfront.com/?gclid=CjwKCAjwlcaRBhBYEiwAK341jbJKnTypIZzl7x3qCkhtUHbQdZ67nOfqHfF9SSPdNTRHUJQmz88zMRoCjJYQAvD_BwE
Scheibel's CAMCOPTER S-100		Gas powered	34 kg (75 lbs)	200 km	https://schiebel.net/products/camcopter-s-100-system-2/

Fly Dragon FD-50 Hybrid heavy load drone		Hybrid Gas powered 23KW * two	50KGS	up to 60 minutes or about 15Km and Maximum transmission distance: 3km (Extra range requires additional range extender)	http://www.dronefromchina.com/new/Palledrone-heavy-drone-from-RotorX.html
KARI TR-60 WE		Powerplant 55hp Rotary	20KG	200km	https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Documents/Events/2015/December-YILF2015/day1/S1_KARI.pdf
APID 60s, Top Engineering		Gas powered	20kg	200 km	http://www.navaldrones.com/APID-60.html
Navig8-56 by 4FRONT ROBOTICS			30kg	250km	https://www.4frontrobotics.com/uavs
JUMP 20 by ARCTURUS		190cc EFI Engine Battery Powered Jump	Up to 30 lb (13.6 kg)	185 km	https://www.avinc.com/uas/jump-20#:~:text=The%20JUMP%2020%20is%20a,ideal%20for%20multi%2Dmission%20operations.

10 Appendix II

CAA Regulations for BLOS UAVs

Section 56. Beyond visual line of sight (BLOS)

BLOS flying may only be performed if the license from the CAA Norway covers this type of operation.

Section 57. BLOS flying at altitudes of up to 120 meters in Class G airspace

BLOS flying at altitudes of up to 120 meters in Class G airspace or Class G airspace with an established Radio Mandatory Zone (RMZ) may only be performed if NOTAM to inform about the activity has been issued. The NOTAM shall be issued at least 12 hours before the activity commences. In exceptional cases, BLOS flying in Class G airspace with an established Radio Mandatory Zone (RMZ) may nevertheless be performed by permission from the flight information service and on the conditions laid down by the flight information service. The flight information service may only authorize such flying if it is clear that the flight can be conducted safely and without obstructing other air traffic.

Section 58. BLOS flying at altitudes of up to 120 meters in controlled airspace

BLOS flying at altitudes of up to 120 meters in controlled airspace may only be performed in active danger areas or restricted areas.

By way of exception, BLOS flying may be performed outside danger areas and restricted areas subject to clearance from the air traffic control service and on the conditions laid down by the air traffic control service. Clearance may only be granted if satisfactory separation can be established between the aircraft without a pilot on board and all and any other aircraft.

Section 59. Mandatory lights

For all BLOS flying, the aircraft shall be fitted out with white low-intensity lights with a light intensity of at least 10 candelas, where flashes are produced by rotating lights (strobe lights) at a rate of at least 20 flashes per minute[57].

Section 38. Requirements for organisation

The operator shall have an accountable manager, operations manager, technical manager, and quality manager. The same person may fulfil several functions. The CAA Norway shall be notified of any changes to the organisation.

The accountable manager has overriding responsibility for the undertaking. The accountable manager must be able to substantiate that the organisation is adapted to the size and complexity of the undertaking. The accountable manager must be 18 years or older.

The operations manager shall ensure that operations are conducted in accordance with the undertaking's operations manual. The operations manager must meet the requirements set out in Section 46 first paragraph.

The technical manager shall ensure that the undertaking's aircraft are airworthy. The technical manager must be able to document relevant technical competence in relation to the relevant systems operated by the undertaking. The quality manager shall ensure that the undertaking's quality assurance systems are upheld[57].