Final Project:

Title: Choosing the best "Follow-Me" Drone Camera System for the outdoor sports enthusiast.

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1.0 Executive Summary

2016 was termed as the year of the drones. Since 2012 this technology market has grown tremendously with 1.9 Billion in sales last year. [1] Most of the electronic components have been driven by low prices with high capabilities such as GPS and accelerometers. One of the amazing technology product is a "Follow-Me drone camera system". This autonomous drone system will change professional photographers, hobbyists, commercial industry such as survey, construction, agriculture as well as those people who just want to capture video of themselves without the hassle of controlling the device. Every idea, every groundbreaking leap that changes our world starts with a decision, and making the right decision is the foundation to success and happiness in life.

This study aims to assess different follow-me drones manufacturers using a decision-making process of buying an autonomous "Follow-Me" drone systems by utilizing a hierarchical decision model (HDM). Focusing on the active sports enthusiast customer this model will evaluate which of the six autonomous drone systems the customer should purchase based on a set of evaluation criteria. The criteria contained in the model were based on interviews with subject matter experts in both photography and remote sensing as well as consumer reports and literature review. Two panels were used for this model, panel two was the subject matter experts on just the products and they scored the products against each other in each of the criteria. Once that was finished the model was developed so the consumer only had to fill out level two and level three to find out what drone is best for them based on their priority of the evaluation criteria. After the application of the model, analysis is made concerning the main results and also concerning the importance of each objective and criteria.

2.0 Introduction

"Three years ago, this technology was so expensive, so unattainable, that only the professional cinematographer could afford it," said International Drone Racing Association CEO Charles Zablan in an interview with The New York Times [2]. Now, full drone racing kits with cameras are available on google for about $1,000 USD. Drones, also known as unmanned aerial vehicles (UAV), are pilotless and non-crewed aircraft that are capable of flight either by remote control or through the use of on-board computers [3]. Initially, drones were commonly used for military purposes, but now are widely used for search and rescue operations, civil applications such as policing, firefighting and so forth. Other than civil and military purposes, the technology is attracting hobbyists and enthusiasts to operate drones on relatively smaller scales [3]. In only few years, drones have evolved quickly into tools to create and enjoy new experiences. As a result of rapidly increasing popularity of drones, nearly 4 million commercial drones are expected to sell this year, rising 16 million a year by 2020, according to new report by Juniper Research [2]. Like several new technologies that become affordable and widely available, these flying robots are proving to be useful as well as entertaining. While drones bring stunning aerial video perspectives on life, they're also inspiring people to create art and invent games that never existed before. They have become flying extensions of the human desire to innovate, help people and have fun [2].

2.1 History of Drones

The concept of Unmanned Vehicles (UAV) is not new. The idea of flying the first UAV was implemented on August 22, 1849, when Austria attacked the Italian city of Venice. The first pilotless aircraft, "Aerial Target," was developed in 1916 during World War I but never used. In November 1917, the Automatic Airplane was demonstrated for the US Army. Upon the success of this demonstration, several UAV s were developed during WWI and WWII. In WWII, drones were used to train anti-aircraft gunners and to carry aerial attacks. Besides WWII, US UAVs came into the picture when the US Air Force, concerned about losing pilots over hostile territory, began planning for unmanned flights. By 1973, the US had been utilizing UAV technology in Vietnam, stating that during the war, more than 3,435 UAV missions were flown, of which about 554 were lost in combat. The UAV technology started growing fast in the 1980s and 1990s, during the Persian Gulf War in 1991, when technology became cheaper and more capable. While UAVs were mainly used by military before, the technology was commissioned by CIA after 9/11 attack which allowed intelligence gathering operations in 2004 to use UAVs to be flown over Afghanistan, Pakistan, Yemen, and Somalia. As of 2008, The USAF has employed 5,331 UAVs, which is twice the number of manned planes. It was stated in 2013 that UAVs were used by at least 50 countries, many of them made their own including Iran, China, and Israel. Recently, UAVs are not limited for military and government purposes, and became popular in hobbyists and outdoor enthusiasts by moving from a fixed wing to a quadcopter drone. Use of UAVs has become increasingly popular in commercial and private market. Largest retailer, Amazon also started to develop its own drones for fast deliveries [3].

Rapidly increasing innovation in drone technology and administrative support by regulatory bodies like FAA have motivated many established companies and new entrants to develop wide variety of drones during the last 3 years. The technology has already created large market segments in private and commercial sectors including photography, sports, agriculture, insurance and safety, just to name a few. Due to ease of access to drone technology and low entry barriers, many manufacturer have entered the drone market and many of them are already established with wide range of drone products for different market segments. Companies like DJI, Parrot, Yuneec, Hubsan, Ehang are some major players in drone market giving strong competition to each other within their product lines [7] [8].

2.2 Follow-me Drones Technology and benefits

With the increasing popularity and technological innovations in drones, there are many different features that users can pick from within the technology. A follow-me drone system is one of them. A Follow-Me drone is a UAV which allows a bit more freedom in the creative realm of the user. It has the ability to use very high technology to fixate on a moving object, so the pilot does not have to spend time and effort worrying about the navigation or operation of the aircraft. The subject being followed could be a person, plane, biker, runner, pet having fun, or athlete in training or performance [4].

2.3 How does the technology work?

Follow-Me is an intelligent fight mode which turns the drone into a hands-free aerial camera crew. The earliest versions of "Follow Me" actually weren't actually following an object. They were following the GPS signal thrown off by remote control or smartphone [4]. There are two types of Follow Me technology in use right now. One is GSC with Follow Me GPS transmitter technology and the latest is using recognition software such as DJI Active Track. Many follow me mode drones use a GPS enabled device such as a mobile phone, tablet or a Ground Station Controller (GSC) along with a transmitter (wearable transmitter or mobile phone). The drone is programmed to follow the transmitter and to keep the subject in the picture at all times. The device sends its location to the drone, and as the object moves, the drone tracks the coordinates of the object. Follow me technology creates a virtual connection between the drone and a GPS-equipped mobile device which allows the drone to track the person or another subject in motion. Most Follow me UAVs, can also remain stationary and track the subject by rotating, or it can move along with the subject. The point of "Follow Me" is to make capturing footage of moving objects easier [4].

The technology operates when the device sends its location to the drone, and as the object begins to move, the drone closely tracks the object's coordinates. The technology using GPS tracking which is still used by many companies like Yuneec, 3DR, is not meant to truly see an object, it is just following according to map coordinates that it was given, but software like 'Active Track' from DJI can really see the object. The tracking algorithm is smart enough to recognize a human shape and keep it in center-frame of the camera [6]. An average speed of an auto follow drone is around 25 MPH. For few systems, it is clocked, where other units will vary slightly [4].

2.4 Benefits

For professionals and hobbyists in filming and videography, having a drone camera that follows you is a special feature, the pilot can lock the drone's direction on a very specific moving target [2]. After the pilot selects this function, the drone will then follow the target without needing to use the pilot's input for control, by use of sensors, and software that allows the device to lock in on certain objects. While this feature is activated, the individual operator can focus on their own choice of creative photo and video elements, not having to worry about the duties of stabilizing flight. Some of the other benefits of a self-following drone are for easier filming of action sports. A subject such as a mountain biker or skateboarder can be followed with this feature and having the perspective from overhead will really add to the richness of the clip. When a drone follows a person from overhead, everything from jumps he is taking, marathon steps he is running through, or obstacles he is grinding on, or flying over with a skateboard will really come to life [4].

2.5 Market Numbers

The number of drones sold increased 224% from April of 2015 to April of 2016, according to a report from The NPD Group's Retail Tracking Service. And U.S. officials' estimate that nearly one million consumer drones were sold in the U.S. during the 2015 holiday season [1]. The 2015 holiday season was a big driver within that period, with drone unit sales increasing 445% from the prior holiday season in 2014. Research firm, Markets and Markets, estimates that the global drone market will grow at a compound annual growth rate (CAGR) of 32% between 2015 and 2020 into a $5.6 billion industry. The firm estimates that among applications, precision agricultural drones will enjoy the highest demand with a CAGR of 42% during that period. Other popular applications will include law enforcement, media production, retail, inspection, mapping services, and education.

In terms of geographic growth, the firm estimates that demand for drones will be the strongest in the Asia-Pacific region, which could post a CAGR of 38% between 2015 and 2020. The top players in this market are Chinese drone maker DJI Innovations, French company Parrot, and American firms 3D Robotics and Precision Hawk. [5]

In 2016, the U.S. FAA forecast used of 1.9 million potential annual sales and that number could increase to 4.3 million units sold annually by 2020.as shown in Figure 1.

Sales Forecast Summary
Million sUAS Units

	2016	2017	2018	2019	2020
Hobbyist (model aircraft)	1.9	2.3	2.9	3.5	4.3
Commercial (non-model aircraft)	0.6	2.5	2.6	2.6	2.7
	2.5	4.8	5.5	6.1	7.0

Note: Numbers may not add due to rounding

Figure 1: US FAA Sale forecast summary

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3.0 Problem Definition

What is the best drone camera system on the market today? This can only be answered by first understanding what the camera system will be used for, what the customer needs are and lastly which product matches most closely to those needs. The market numbers show that drone cameras are flying off the shelves in the United States at an aggressively increased pace and this trend looks to continue into the future. This means, that the number of manufactures of drone camera systems are already high and will continue to grow. Meanwhile many manufactures on the market will equate to products with many different features. Which will result in more difficult decisions for the consumers when trying to choose the right drone camera system that best suits their needs. At first, one would have to identify their need and which features best support their needs, then weigh the importance of these different needs (i.e. criteria), such as price, speed, control, compatibility, and many other factors in order to purchase the best product. When a customer is looking to invest between $500.00 and $1,500 for a sports action flying camera system using a decision making process will help steer their choice for the best investment. Our model was built to address this problem in order to answer the question of: What is the best "Follow-Me" drone camera system for filming action sports?

4.0 Alternative Products

Before building Hierarchical Decision Model (HDM), the team decided to think about only a few (five to six) products for comparison which are close competitors in terms of price, value, features etc. But, after searching for alternative products in the market, we came to know that there are multiple products available with wide range of price. Some of the companies have wide product line where some are providing similar features at lower price. Also, some providers allows enough variety between respective alternatives, such as DJI, 3DR, and Hubsan etc. Hence, instead of just picking five to six close competitors, we considered all 11 products for comparison and then screened out a few of them according to our selection criteria. DJI, Hubsan, Yuneec, 3DR, AirDog, Ehang, Lily are the providers we considered for comparison, and some of them provided more than one product in the category of 'Follow-Me' Drone Camera system [8] [4].

4.1 DJI Phantom 3

Phantom 3 is one of the most successful commercial drones in the market and naturally, one of the most popular drones that follow you. It has 4K (or 2.7K) video at 30fps camera with 12MP for photos, placed on a 3-Axis remotely controlled gimbal. The camera also has a professional f/2.8 lens with 94º field of view. Phantom 3, features an awesome set of features such as GPS-Assisted Hover, Vision Positioning System, and Automatic Flight logs, Following Mode, Altitude Set Height, Return-to-Home, Auto-pilot and First Person View. DJI Phantom 3 can be controlled via a DJI Devo remote controller or a tablet through a free application available for both Android and iOS. Besides all of this top notch quality, Phantom 3 has an outstanding flight time of 23 minutes (powered by a smart battery) and a control range of 2Km to 5 Km [8].

4.2 DJI Phantom 4

DJI Phantom 4 has already become a global success, mainly due to its advanced functions and ease of use. Phantom 4 aims to be a fully autonomously quadcopter, with a high-end camera and powerful innovative features. Phantom 4 excels with its new upgraded camera Aa12MP photo, 4K and HD video, 94º FOV camera, installed on a 3-Axis gimbal. Capable of competing with GoPro Hero 4, this DJI camera has great quality for photography and videography. Besides Follow-Me feature, Phantom 4 features obstacle sensors (drone will autonomously avoid obstacles), Tap Fly (tap the screen of the tablet on a map and the drone will fly towards that position by itself), Visual Tracking, Smart Return Home (when goes out of range or runs out of battery, safely returns to pilot automatically), Dual Satellite Positioning System, Vision Positioning System and of course Auto-Pilot system. Phantom 4 also has foldable arms (a first for Phantom series) making it very easy to carry, fit it easily in a backpack. Phantom 4 includes all the latest high-quality drone hardware and software, and updates are constantly being made [8].

4.3 DJI Phantom 4 Pro

With longer flight time, better camera and more sensors, Phantom 4 Professional is like a solid upgrade over the standard version. The design has remained exactly the same with the only real differences appearing within features and specifications. Instead of 25 minutes, the Pro version can last 3 minutes longer in the air. It has improved 20mpx camera that not only has a better sensor but is equipped with more features than the one on its predecessor [8].

4.4 DJI Mavic
Mavic Pro is the first premium selfie drone available on the market. It's incredibly small and folds quite easily making it rather mobile and easy to carry. It is able to capture silk smooth aerial footage and doesn't have that jittery feel to it that seems to be the case with some of its competition. Its 4K camera is equipped with awesome features such as Active Track, Tap Fly and more [8].

4.5 Hubsan 501S

Follow-Me feature along with a longer flight time of 20 minutes for $219, undoubtedly make Hubsan 501S interesting drone at lower price tag. 1080P, 5.8GHZ FPV, Headless mode, One Key Automatic Return, GPS Hold, Altitude Hold, are some of the rich features of Hubsan H501S X4 FPV. H501S was an instant hit, as soon as it announced due to its lower price compared to all other competitive products. Along with the build quality, the brushless motors and the integrated 4.3 FPV screen, are the two most important features Hubsan 501S provides [10].

4.6 3DR Solo

3DR Solo is a powerful drone manufactured by the renowned 3DR Robotics Company. 3DR Solo features a top speed of 89 km/h. This speed can be very useful when combined with the Follow Me Mode feature. As it allows the person to lock and record on very fast moving objects,

such as cars and boats. It also features useful photography and videography features such as Selfie Mode, Orbit Mode and, Follow Me mode, as well as innovative Pixhawk 2 Auto-Pilot function. Though, 3DR Solo original package does not come with a camera, however, it is compatible with all new GoPro cameras such as GoPro HERO3, 3+ and 4. The drone has its 3-axis stabilized gimbal as well. Flight time is around 20 to 25 minutes and control distance is 800 meters [8].

4.7. 3DR IRIS+

3DR Iris is an all-in-one autonomous aerial vehicle with a compact and durable design. Stylish and powerful, Iris runs on the innovative Pixhawk autopilot system. Iris features Copter autonomous capabilities, including automatic takeoff and landing, custom mission planning with GPS waypoint navigation, stabilized loitering, return to launch, circling mode, and more. This quadcopter with camera mount (Camera is not included) features a 5100mAh 3S battery capable of providing 15-20 minutes of flight time [10][11].

4.8 Yuneec Typhoon H
Yuneec Typhoon H is a very powerful six motor drone (hexacopter) developed for photography and videography. To make the most out of its Follow Me feature, Typhoon H includes a 4K UHD 30fps, HD 1080p 120fps video / 12.4MP still camera and a 3-axis anti-vibration gimbal camera with full 360° rotation. It features integrated autonomous flight modes, Team Mode, ST16 All-in-one-controller, Orbit Me, Point of Interest Mode, Journey Mode (Selfie mode), Dynamic Home Return, collision avoidance which works perfectly with Follow Me mode. Typhoon H has a long control range of 1600 meters and a flight time of 25 minutes [8].

4.9 AirDog

AirDog was specially designed for autonomous follow me mode flights for all sporting needs. AirDog is a quadcopter which automatically follows AirLeash device (can be used for skate, surf, football) and captures high-quality footage using a GoPro camera. AirDog does not come with a remote controller, instead it follows and can be controlled by this AirLeash, attached to our arm or wrist, is a standalone device which can be used to adjust altitude, angle etc. AirDog is also very easy to carry, due to its retractable arms and lightweight, however it does not come with a camera.   Advanced features such as Lap or Track recording can be configured and uploaded from a smartphone application. Powered by a 14.8V 5600mAh lithium polymer battery, AirDog has a flight time of 10 to 18 minutes. AirDog has the maximum control range of 250 meters [8]

4.10 Ehang GhostDrone 2.0

Ehang Ghost Drone 2.0 is known as the easiest drone to fly due to the reliance on an easy to use Android or iOS application. It comes with 4K camera, a 3-axis gimbal, VR Google camera control, a smartphone tilt control as well as some cool boilerplate autopilot algorithms. It can fly for up to 25 minutes on a single charge with over a half mile range. Waypoint Mode, Companion Mode, Avatar Mode, and Flight Planning Mode are all available with a single tap on the screen with the free EHANG Play App, making it easy to use. Warranty coverage provides hassle free repair or total replacement protection for up to three events and covers shipping costs both ways [9].

4.11 Lily

Lily had been one of the best Drone Camera systems advertising in the market with fully autonomous mode (follow-me mode). Lily is extremely portable and lightweight. Its waterproof function makes it a good fit for outdoor events in the water. The built in camera of HD 1080p recording at 60fps and 720p 120fps slow motion recording makes it interesting. Unfortunately, this drone is not available in the market today [8].

5.0 Methodology

5.1 Hierarchical Decision Model (HDM)

5.1.1 HDM history:

Engineers and managers frequently face the problem of multi-level decision making under conflicting goals and criteria, or making decisions without all the information. They develop strategies, allocate resources, but when it comes to evaluation of results, and strategies, it becomes difficult to measure efficiency of managerial decisions. HDM is an approach to provide solution to such complex analysis and evaluations. The HDM is a MCDM (Multi-Criteria Decision Making) method and was developed in the 1980's by Dr. Kocaoglu. Approach of HDM is to make complex problems simpler by breaking it down into various sub-problems. This tool is used to evaluate and rank alternatives/choices and choose the best one. It can be categorized into decision under certainty, decision under uncertainty, and decision under risk. Hierarchical Decision Model, by Dr. Kocaoglu, is refining the analytic hierarchy process (AHP), developed in 1970 by Thomas Saaty, to elicit and evaluate judgements from two or more elements including generate criteria, classify criteria, and screen decision alternatives [13],[14], and [15].

5.1.2 HDM structure:

Basic structure of HDM varies according to its applications and uses. But, as shown in figure 2, a hierarchical decision model is a tree starting with your mission and having an objective, the goals or criteria than alternatives drawn as nodes. Each criterion is evaluated according to its importance to the objective. The alternatives are evaluated according to their preference with respect to each criterion or goal. The objectives and the criteria are factors in the decision issue, and their lines which connect the objective to its criteria mean that each criterion should be compared to the alternative based on preference for specific objectives. Likewise, the alternatives lines connecting with the more preference for the criterion. based on the book by Baird, Bruce F.; Managerial Decisions Under Uncertainty, HDM is a software, including matrix, that has options to create the three main elements which are the objectives the criteria and alternatives which allow a decision maker to enter his inputs, then, send it to the experts as a link to enter a weight from 100 points for each elements in order to evaluate a final decision [25]. Lastly, any decision maker should follow these steps to implement HDM which are defining the problem, gathering information, collecting data, developing and weighing the options, choosing best possible option, plan and execute, then take follow up action [16].
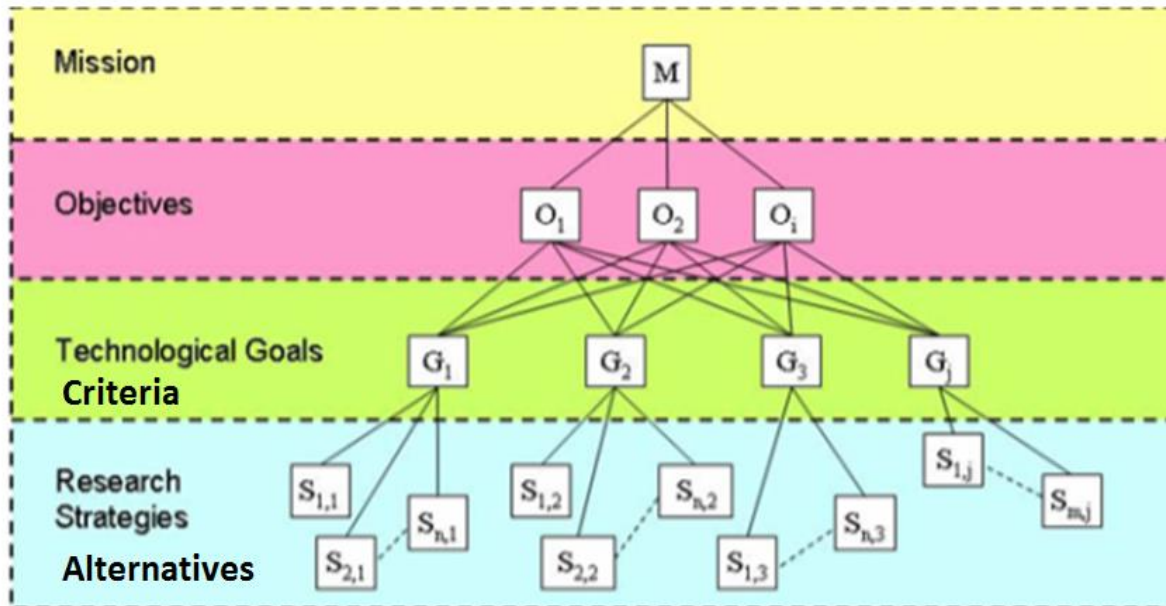
Figure 2: HDM Basic Structure [27]

Application areas: HDM is used in several areas in public and private sectors [17] and [25]. Relative priorities for police calls, allocation of patrol resources to all precincts, high school selection, evaluation of R&D programs, personnel allocation, medical care evaluation, higher education scenarios, transportation planning, evaluating and scheduling alternatives for material requirements planning (MRP), choosing software components from different software retailers, estimating the research or investment proposals quality, and energy policies. Also, it's used to evaluate price, counts, or subjective judgment which inputs into a numerical matrix.

Weaknesses and Strengths of HDM: HDM is criticized for not providing sufficient direction for structuring the issue to be resolved, forming the scale of the hierarchy for options and criteria, and gathering group judgments when a team is geographically distributed with a short time [17]. When applying HDM, it is required to have access to experts to provide evaluations. But it can narrow the results diversity if we rely on experts only in particular research field. Furthermore, the effectiveness of method declines because the analysis depend on pairwise comparisons. This is due to the fact that it is time-consuming for the experts to give their judgments according to the comparison, thus, they might lose their focus, grow tired and not complete the process. The more comparisons the experts do the more lose in concentration especially in the accuracy of the comparison. On the other hand, HDM has several strengths and advantages. The result will be strongly trustworthy because the analysis rely on the experts opinions. Because it is challenging to translate the decision-making process from qualitative to quantitative data, which is easier to evaluate, HDM is a great method to do so. This methodology can be developed to

examine the HDM robustness by using some sensitivity analysis algorithms, thus, the decision makers can change or adjust whenever necessary [18].

5.2 Criteria Selection and Model Building

In order to evaluate the differences between the "Follow-Me" camera drones that are on the market today Figure 3 represent the full list of criteria created by the team. There are many similarities in all the products available that did not allow us to see large differences in product, however there are some slight differences and some very distinctive differences. We brainstormed and researched the products in order to create a very long list of 29 criteria

#	Name	Definition	Used as
1	Battery Life	How long the unit can fly	Evaluation Criteria = Performance
2	Battery Charging time	Down time between flights	Irrelevant due to all units have swappable batteries
3	Camera Resolutions	scored by mega pixels	Evaluation Criteria = Performance
4	Durability	will it withstand a hard landing	Evaluation Criteria = Value
5	Altitude Tracking	Can the unit adjust altitude with the object being filled.	Screening criteria (Must have it)
6	Anti-Collision Technology	Can the unit avoid trees and obstacles while flying	Evaluation Criteria = Feature
7	Down Time for charging	Down time between flights	Irrelevant due to all units have swappable batteries
8	Night flight	can the drone be flown and film at night	Irrelevant due to FAA regulations and line of sight
9	Price	Cost of the unit in US dollars	Evaluation Criteria = Value
10	Flight Time	Number of minutes the unit can fly and film	Evaluation Criteria = Performance
11	360 Degree camera angle	Can the unit film in 360 degrees w/o rotating the drone	Evaluation Criteria = Feature
12	Control Range	Measured in feet from the person controlling the unit	Evaluation Criteria = Performance
13	Water Proof	Can the unit be submersed in water	Merged with Water resistant
14	Speed of Travel	how fat the unit will travel up, down and forward	Evaluation Criteria = Performance
15	Altitude / position hold	Can the drone hold position and continue filming	Irrelevant all the units can do this
16	Water Resistant	is the unit able to resist water such as light rain	Evaluation Criteria = Feature
17	Weight of unit	The lighter the unit the longer it can fly	Merged with flight time.
18	Global Positioning System	Does the unit have built in GPS	Irrelevant all units have GPS
19	Built in Camera	is the camera a add on purchase	Screening criteria (Must have it)
20	Compactness	easy to store and carry to sporting event	Merged with satisfaction = Value
21	Ascend time	Sped in which the unit will ascend	Merged with speed = Performance
22	Descend time	Speed in which the unit will descend	Merged with speed = Performance
23	Availability	is the unit for sale today and available	Screening criteria (Must have it)
24	Maintenance / Warranty	does the unit come with maintenance / warranty	Evaluation criteria Satisfaction = Value
25	Different filming actions	Can the unit do multiple types of sports	Irrelevant all drones will film all sports
26	Application compatibility	Can the unit connect to smart phones	Screening Criteria (Must have it)
27	Ease of use	set up and learning to operate the unit	Merged with user satisfaction = Value

Figure 3: Criteria Definition

We conducted market research and found 11 different products on the market that claimed to do follow me aerial photography. From the list of criteria we found four items to use as screening criteria, seven items that were irrelevant to the study, five that were merged with other criteria for a total of 11 criteria that we finally used to evaluate the products.

Screening criteria was used as a Yes or No answer and something the product MUST have. 1) Does the product have altitude tracking, and for both 3DR products the answer was no, so that product was also removed from our list. 2) Is the device compatible with a cell phone app, and for the Hubsan H 501S the answer was no, that product was removed from our list. 3) Was

the product actually a drone and camera system, in other words, would you have to purchase the camera separately, and for the AirDog, and the 3DR the answer was no, it did not come with a camera, so those products were removed from our list. 4) And lastly, is the product currently available on the market and for the Lily it is not, so that product was removed from future research. If leaving these five products on the list as well as these four criteria then a customer would probably never get to the decision of purchasing one of these five since the model would not connect a feature to a product and therefore not end up selecting the product. Also if leaving all 11 products and all 15 criteria on the model the time required for our panel of experts would be much too long to get a good response, and therefore the model would be disliked and not used.

Figure 4 shows how we screened out 5 of the 11 products

Products / criteria	Screening Criteria			
	Altittude tracking Y/N	App Compatibility w/ smartphone	Camera included Y/N	Available today Y/N
DJI phantom 4 pro	YES	YES	YES	YES
DJI mavic	YES	YES	YES	YES
DJI phantom 4	YES	YES	YES	YES
Yuneec Typhoon H	YES	YES	YES	YES
DJI phantom 3	YES	YES	YES	YES
Ehang Ghostdrone 2.0	YES	YES	YES	YES
Airdog auto follow	YES	NO	NO	YES
3DR IRIS	NO	YES	NO	YES
HUBSAN H 501S	YES	NO	YES	YES
3DR solo	NO	YES	NO	YES
Lily				NO

Figure 4: Products screening criteria

Other items on our long list of criteria were removed from evaluation due to the fact that all remaining units either has the same feature, or none of the units have this feature, and therefore found to be irrelevant. This list is as follows:

1) Down time and 2) battery charging time was not needed as evaluations since all remaining units had a spare battery option allowing the user to have a charged battery ready, and be back to filming in less than a minute. 3) Night flight operations were removed due to federal regulations on flying drones at night and not having clear line of sight with your drone. 4) Altitude/position hold and 5) Guilt in GPS were both found on all remaining drones and removed. 6) Lastly we found all to have built in GPS systems so we removed that criteria from the list.

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Another issue with our long list of criteria were some items needed to be merged. We used expert panel two to help review this list and merged the following:
1) Weight of the unit was merged with flight-time since the weight had a direct effect on the time the drone could fly. 2) Compactness and 3) Ease of use were merged and used to evaluate customer satisfaction since reading the reviews, most customers liked the ability to pack up the drone to take hiking and how easy it was to use. 4) Ascend and 5) descend time both merged with speed since all three of these criteria all address the speed at which the drone can fly in different directions. 6) We found that all the drones camera systems where listed as water resistant but only one was actually waterproof. We originally kept this as an evaluation criteria but during testing found that a Y/N answer to only one device is problematic to our model. We still combined water resistant to waterproof but gave the product that was waterproof a higher rate of scale in comparison to the other products that were just water resistant.

The next step was to look at the remaining criteria and determine the best way to use them as evaluation criteria, in order to compare and select the best product. We divided our evaluation criteria now down to three objectives, 1) Value, 2) Performance and 3) Features. In order to weigh the following criteria we used expert panel 2, a group of five EMT students to do the deep dive research on all remaining products.

5.2.1 Value

Three items fell under the evaluation objective for Value. Price, was easy it's based on the price of the product from online vendors listed in US Dollars. Next was durability, this was given a rating between one and 100, one being low durability and 100 being high durability. These numbers were based on consumer reports talking about hard landing or crashes and our panel 2 subject matter experts looking at items like plastic rotors vs. titanium rotors. The third item under value was satisfaction. This category actually combined three of the original list of criteria 1) ease of use, 2) compactness to carry in a backpack or carry to your sporting event and finally 3) the warranty and customer support. We rated this category between one and 100. One being the lowest and 100 being the highest. We gave scores based on the 5 star rating schema on consumer reports, discussion on product and customer satisfaction and whether the product carried a limited or an extended warrantee.

5.2.2 Performance

Five evaluation criteria fell under the objective of performance. Speed in which the device can travel. At first this was just a question of how fast can the device travel and can it follow a motorbike, Jet Ski, etc. After we learned that all our remaining products also had descend and ascend speed that were all very compatible we combined this evaluation criteria just down to one item called speed. Controller range is based on how far can the drone be away from the person controlling the drone, this distance is distinctly different within the remaining units and is measured in Miles. Flight time is very important as is measured in how long the unit can maintain flight while filming. Weight of the unit was also factored into this criteria since the lighter the unit the longer the flight time. Stability of the drone and camera is important and was ranked on a scale from one to 100. One being the lowest and 100 being the highest. Items we used in order to rate stability criteria was customer feedback, and manufactures limitation to flying under windy conditions. Camera resolution was based on the mega pixels for the camera.

5.2.3 Features

Three evaluation criteria fell under the objective of features, anti-collision, water-resistant and 360 degree camera rotation. Anti-collision detection system was ranked on a scale from one to 100. One being a low rating and 100 being the highest rating. This data was collected by several different types of technology. LiDAr will allow the drone to track what is beneath the device and adjust altitude to fly over. Sonar is used to track front, side or rear and fly left or right in order to avoid a collision. Some devices had only one, some had two and others had three showing a very sophisticated software application. Water resistant was measured as how long a drone can fly in the rain, how heavy of a rain storm and is the device submersible. This criteria was scored between 1 and 100 with one being the lowest and 100 being the highest. The last criteria was the ability to rotate the camera angle 360 degree without rotating the drone. Some devices were capable of 70 degrees and others were fixed and not able to rotate any direction relying 100% on the rotation of the drone. This was scored directly by the degree in which the camera can rotate.

5.3 Summary of Alternatives with selected criteria

After screening out five of the products for not meeting the team's minimum screening criteria we were left with six "follow me" drone camera systems to evaluate based on the definitions listed in the above section. Figure 5 shows the criteria ranking of these 6 units, with scores based on the definitions, explanations and subject matter experts on each of these drone systems.

Products/13 criteria	Value-Ranking			Performance-Ranking					Features-Ranking		
	Price Scale in USD	Durability Scale (1-100)	Satisfaction Scale (1-100)	Speed Scale In MPH	Control Range Scale In miles	Flight Time Scale In Min	Stability Scale (1-100)	Resolution Scale In MPs	Anti-collision Scale (1-100)	Water Resistant Scale (1-100)	360 Camera Scale in Degrees
DJI Phantom 3	$415	80	60	45	3 miles	23 min	80	1080P & 12MP	0	40	95
DJI Phantom 4	$998	100	100	45	3 miles	28 min	80	1080P & 12MP	60	60	95
DJI Phantom 4 PRO	$1,330	100	80	45	4.3 miles	30 min	80	1080P & 20MP	100	60	360
DJI Mavic	$1,299	60	80	40	4.3 miles	27 min	60	1080P & 12.7MP	60	80	75
Yuneec Typhoon H	$996	80	80	43	1 miles	25 min	60	720P & 12.4 MP	80	80	360
Ehang Ghostdrone 2.0	$399	60	80	25	0.6 miles	25 min	60	720P & 12 MP	0	100	95

Figure 5: Products criteria ranking

5.4 HDM Model

The model has 4 levels. The intent of the model is to link objectives to criteria and get details on the factors that are weighed more than others in decision making in order to choose the best follow me drone camera system. The details of the model and nodes at each level is provided below in Figure 6
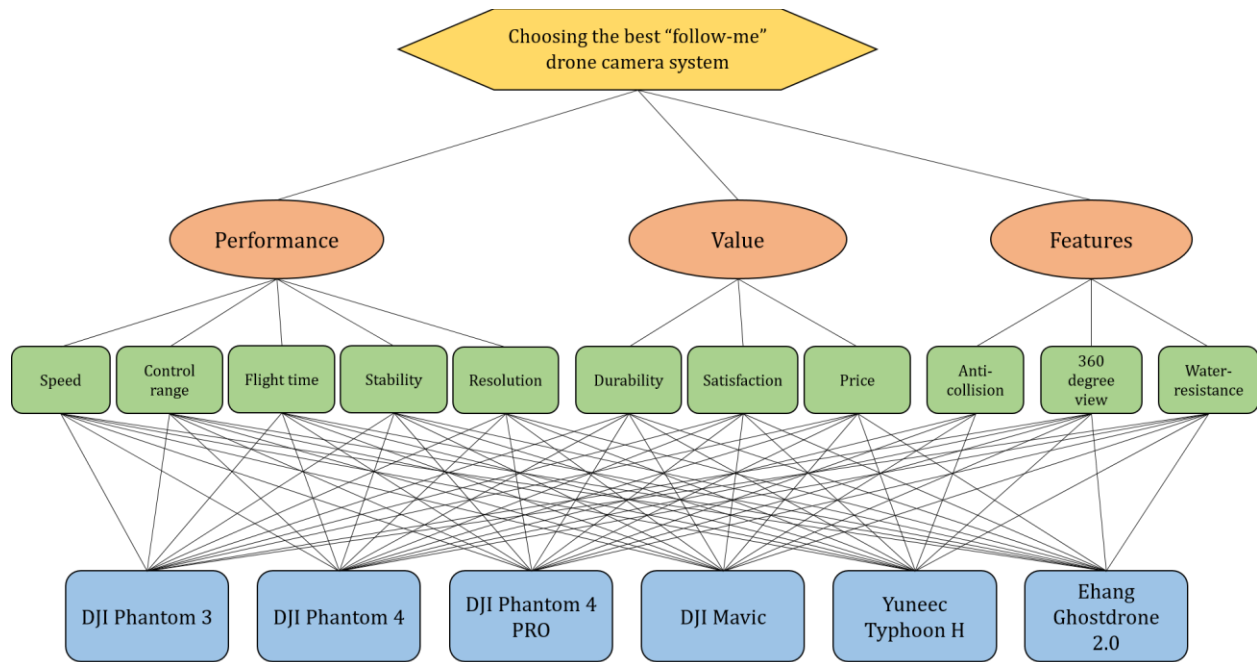
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Figure 6: The Final HDM

1ˢᵗ level: This represents the mission of the model, "choosing the best Camera Drone system" between given number of alternative providers.

2ⁿᵈ level: This level represents the major objectives of our decision making process. It consists of Performance, Value and Features which are further divided into multiple criteria in level 3. This level comprises of combination of three objectives, decision makers would consider before choosing the product.
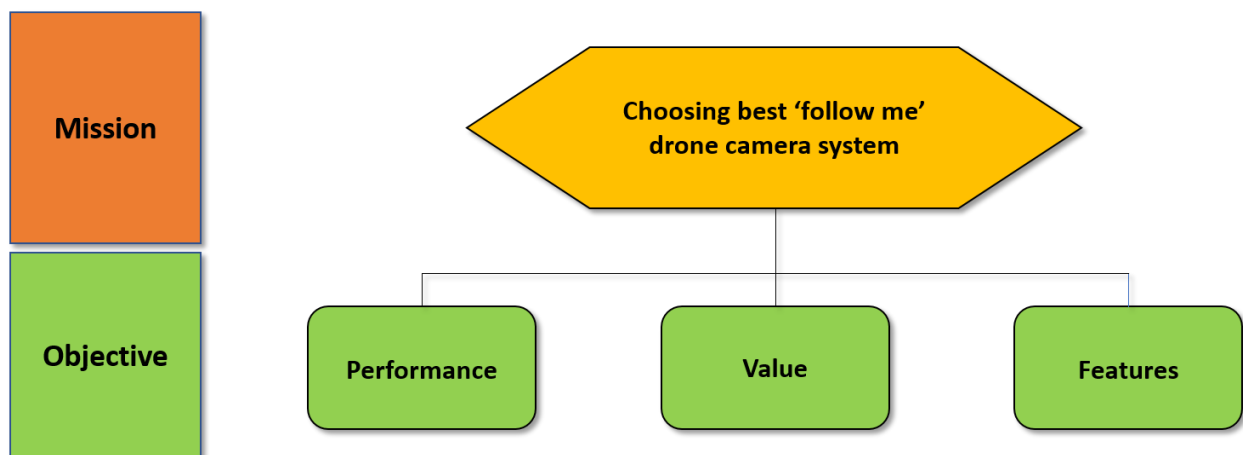

Figure 7: First and second level

3rd level: Among large number of criteria, our team came up with 11 major screening criteria for the comparison between different products. This level represents these 11 criteria for selection under 3 objectives are shown in figure 8 below.
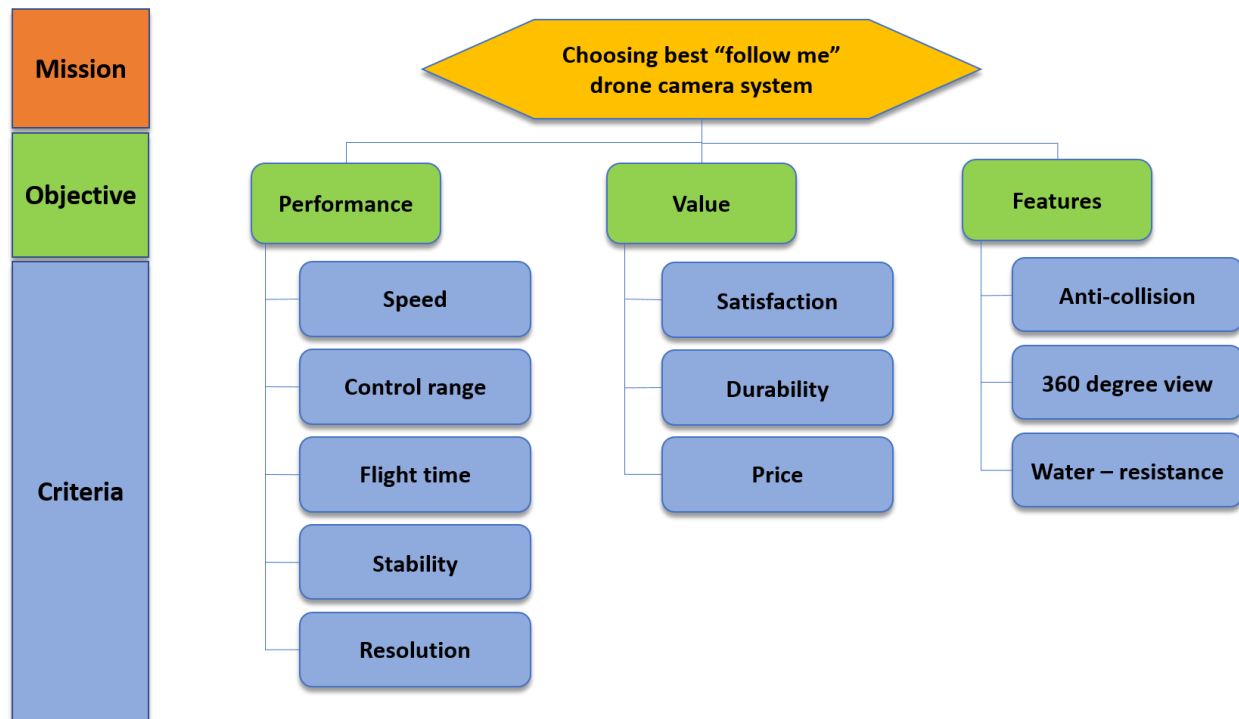

Figure 8: Third level

4th level: This level comprises of 6 different products/alternatives which provide similar products in terms of criteria mentioned above. The 6 alternatives that are evaluated and compared with each other against the criteria listed in level shown in figure 9 below.
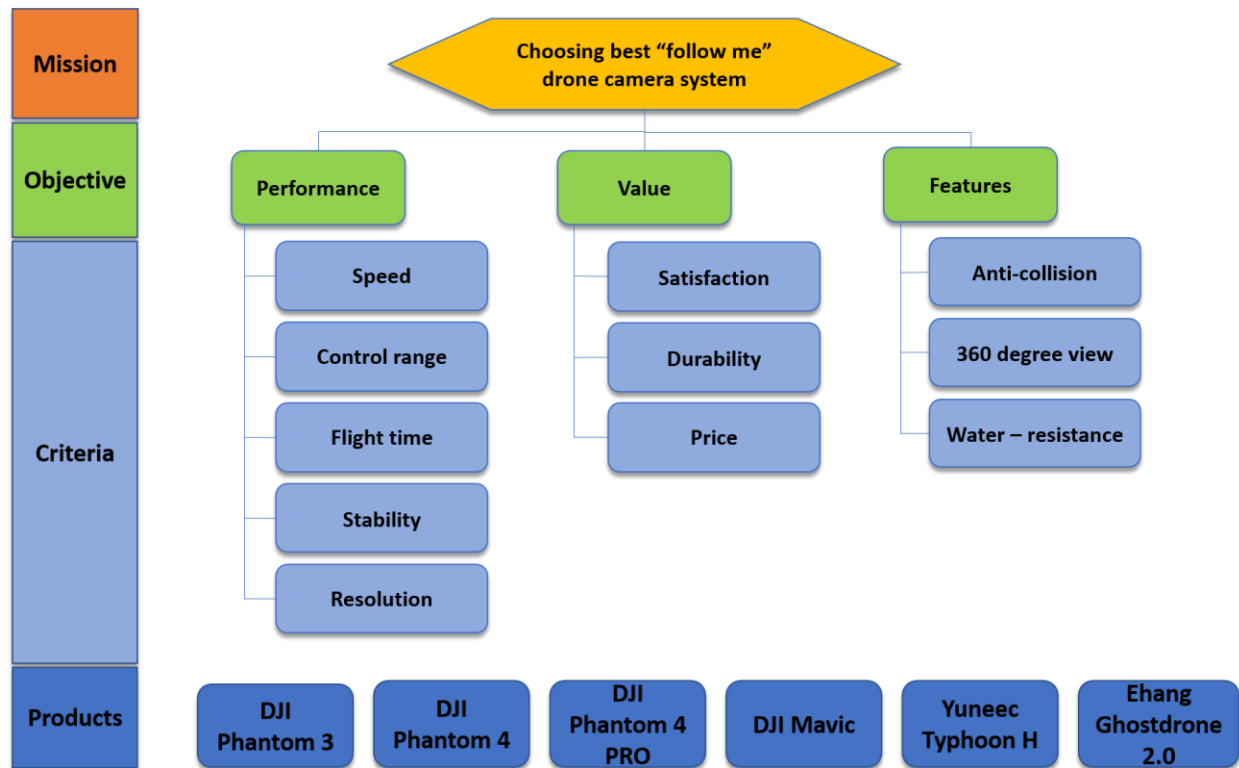
Figure 9: Overall HDM

5.5 Expert Panels

5.5.1 Expert panel 1:

As we know, from last few years, Drone Camera systems are quite popular in consumer market. The number of enthusiasts and hobbyists are growing, and so does the popularity of drones. To choose between multiple drone providers, we took help from 10 experts, majority of them are active in the field of photography and sports. Some of them are technically sound and have knowledge about the drone technology. All of these experts are asked to give feedback on all selected criteria and rate all criteria relative to each other. In other words, all experts answered the question of, 'what is more important' when it comes to comparison between two criteria. Though, these experts were unaware of the products we chose to compare. They simply rated the value of each criterion over others.

5.5.2 Expert panel 2:

As, not every expert in the panel 1 can be aware of all drones available in the market and also their related features. Hence, to choose 'the best Drone Camera System', we as a team formed expert panel 2 and selected the best product amongst all with the help of feedback given by

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expert panel 1. We, as expert panel 2 searched and studied all competitive products. After close inspection of customer reviews, market numbers, and specifications of each product, we came up with detail information about each product relative to each other for each criteria. Finally, with the help of expert panel 1 evaluations, we compared each product in HDM and came up with the best amongst all.

6.0 Data Analysis and Results

6.1 Level 2 Results

Level 2 of the model includes 3 objectives:
   1. Performance
   2. Value
   3. Features

Choosing the best 'follow-me' drone camera system	Performance	Value	Features	Inconsistency
Expert 1	0.51	0.3	0.19	0.01
Expert 2	0.54	0.3	0.16	0
Expert 3	0.54	0.3	0.16	0
Expert 4	0.54	0.31	0.16	0
Expert 5	0.55	0.29	0.16	0.01
Expert 6	0.51	0.3	0.19	0.01
Expert 7	0.51	0.32	0.17	0
Expert 8	0.54	0.3	0.17	0
Expert 9	0.58	0.28	0.14	0
Expert 10	0.5	0.32	0.19	0.01
Mean	0.53	0.3	0.17	
Minimum	0.5	0.28	0.14	
Maximum	0.58	0.32	0.19	
Std. Deviation	0.02	0.01	0.02	
Disagreement				0.015
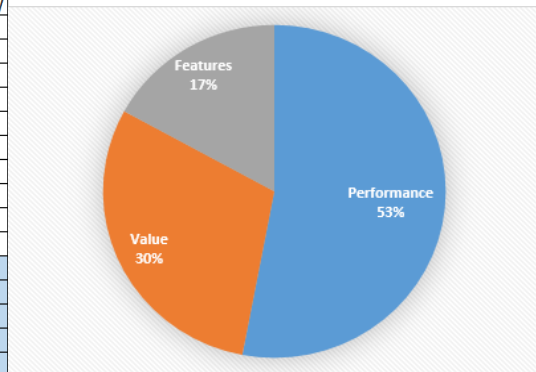
Figure 10: Evaluation of Level 2 (Objectives)

Analysis

It can be observed from the table and graph above, (Fig 10) all experts rated Performance higher over Value and Features of the product. According to evaluations by each experts, almost all experts want the product with high performance and medium value. As, we can see from the average rating of the objective of Feature which is 17%, product with distinctive features is not accepted by majority of the customers if its performance specifications and value is low.

6.2 Level 3 Results

Level 3 of the model contains 11 criteria connected to the respective 3 objectives.

Performance
There are total 5 criteria under Performance objective.
The criteria under Performance are:
1. Speed scale
2. Control range scale
3. Flight time
4. Stability on the scale from 1 to 100
5. Resolution

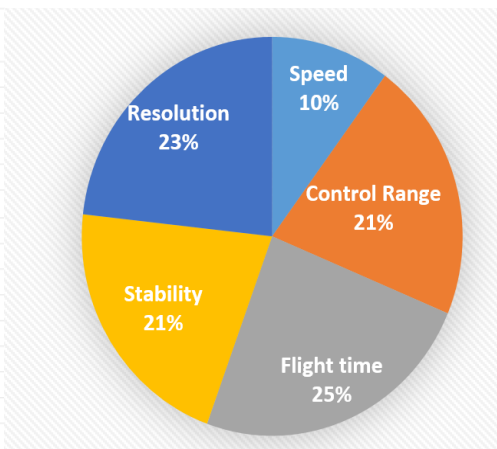| Experts	Speed	Control Range	Flight time	Stability	Resolution	Inconsistency
Expert 1	0.09	0.21	0.27	0.22	0.2	0.07
Expert 2	0.06	0.28	0.36	0.15	0.15	0.03
Expert 3	0.11	0.23	0.37	0.12	0.17	0.01
Expert 4	0.07	0.21	0.28	0.25	0.18	0
Expert 5	0.15	0.2	0.24	0.27	0.14	0
Expert 6	0.11	0.25	0.27	0.18	0.19	0.01
Expert 7	0.04	0.23	0.08	0.26	0.39	0.06
Expert 8	0.12	0.13	0.22	0.2	0.31	0.02
Expert 9	0.06	0.12	0.12	0.3	0.4	0.02
Expert 10	0.23	0.22	0.18	0.18	0.18	0
Mean	0.1	0.21	0.24	0.21	0.23	
Minimum	0.04	0.12	0.08	0.12	0.14	
Maximum	0.23	0.28	0.37	0.3	0.4	
Std. Deviation	0.05	0.05	0.09	0.05	0.09	
Disagreement						0.064

Figure 11: Evaluation of Performance Sub-Criteria

Analysis
Overall, it can be seen in the pie chart, in Figure 11, that the Flight Time criterion is the highest selection, 25%, compared to Speed, 10%, the lowest one. However, Stability and Control Range criteria have the same ranking which is 21%. Also, the Resolution is the second favorite criterion after the Flight Time criterion with ranking 23%.

Furthermore, in term of expert's results, it can be seen in the performance sub-criteria evaluation data table, in Figure 8, that five experts ranked the Speed criterion less than 10%, between 0.04 to 0.09, compared to the four experts ranked it more than 10%, between 0.11 to 15. However, the gap her in the last expert who ranked this criterion at 23% which is the highest weight. Therefore, it can observed that the speed is not a popular feature in drone camera according to the experts ranking, and the average preferences is 10%. In the Control Range criterion, six experts give it a weight less than 26%, between 0.21 to 0.25, compared to two experts ranked this criterion in 13% and 12%, however, one expert gives a very low weight in

2% and the highest weight made by one expert in 28%. Therefore, this criterion shows a gap in the experts preferences between 2% to 28%, but most of preferences are above 20% with average 21%. The Flight Time criterion shows that the most majority of experts, five experts, ranked it between 18% to 28% compared to the lowest weight 8% made by just one expert. However, the highest weights are 36% and 37% made by two experts. Therefore, the average among these experts weight is 24%. Stability criterion shows that four experts give it from 22% to 27% compared to other four experts from 12% to 18%. However, the lowest weight made by two experts in 2% and 3%. Thus, it can be observed that the most preferences is above 20% with average 21%. Resolution criterion shows that six experts give it a weight between 12% to 19%. However, the highest weight made by two experts with 31% and 39% compared to the lowest one made by two experts with 2% and 4%. Therefore, it can observed that even though there is a gap in ranking this criterion between the experts and most of them between 12% to 19%, the highest weight made the two experts impact the overall average and increase it to be 23%. As a result, the average in Flight Time Resolution criteria are the highest weight among the other criteria in in term of performance with 24% and 23% respectively compared to the Speed which is lowest criterion in 10%. Also, these two criteria have the highest Sat. Deviation with 0.09 compared to the other three criteria in 0.05., however, the percentage of the disagreement between the experts is 0.064.

Value
The criteria under Value are:
1. Satisfaction
2. Durability
3. Price

Analysis
On the average, all sub-criteria under the objective of value are almost equally rated with 33% for Satisfaction, 29% for Price and 38% which is maximum amongst all for Durability. (As show in Figure 12 pie chart below) But, if we observe the table of evaluations, it can be seen that there is considerable difference between average maximum and minimum weight given to each sub-criteria. e.g. for Price, minimum weight given is 13% where maximum is 45%, where for Satisfaction, minimum is 22% and maximum is 63%. Average maximum weight for Durability is 24% where maximum is 49%. (As shown in figure 12 table)

| Experts	Satisfaction	Durability	Price	Inconsistency
Expert 1	0.35	0.47	0.18	0
Expert 2	0.23	0.38	0.4	0.03
Expert 3	0.25	0.4	0.35	0
Expert 4	0.35	0.4	0.25	0
Expert 5	0.22	0.33	0.45	0.01
Expert 6	0.33	0.33	0.33	0
Expert 7	0.63	0.24	0.13	0.03
Expert 8	0.25	0.49	0.26	0
Expert 9	0.32	0.43	0.25	0
Expert 10	0.33	0.36	0.31	0
Mean	0.33	0.38	0.29	
Minimum	0.22	0.24	0.13	
Maximum	0.63	0.49	0.45	
Std. Deviation	0.11	0.07	0.09	
Disagreement				0.075
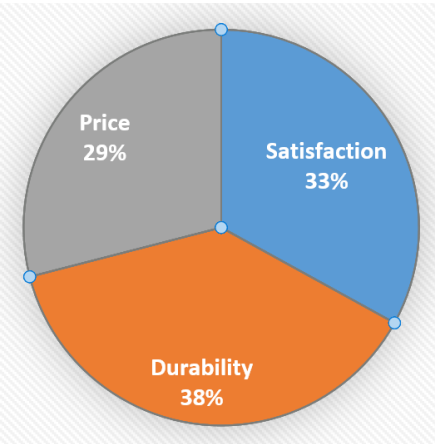
Figure 12: Evaluation of Value sub-criteria

In case of satisfaction, average rating is improved because of only one expert which is Expert 7, otherwise this criteria has almost average rating from all other experts. Overall, for all experts in this panel, Durability of the product is the important criteria over Price and Satisfaction.

Features

Criteria under Features

1. Anti-Collision
2. 360 Degree View
3. Water resistant

Analysis

It can be observed from the graph and table below (Fig 13), criteria of Anti-Collision was rated high by majority of the experts. On the average, Anti-collision was rated as 53%, where criteria

Experts	Anti-Collision	360 Degree View	Water-Resistant	Inconsistency
Expert 1	0.34	0.32	0.33	0.04
Expert 2	0.7	0.17	0.13	0
Expert 3	0.7	0.12	0.18	0
Expert 4	0.54	0.18	0.28	0.02
Expert 5	0.37	0.21	0.42	0
Expert 6	0.48	0.31	0.22	0.06
Expert 7	0.84	0.12	0.04	0.04
Expert 8	0.53	0.28	0.19	0.01
Expert 9	0.46	0.29	0.24	0
Expert 10	0.41	0.27	0.32	0
Mean	0.54	0.23	0.24	
Minimum	0.34	0.12	0.04	
Maximum	0.84	0.32	0.42	
Std. Deviation	0.15	0.07	0.1	
Disagreement				0.102

Figure 13: Evaluation of Feature sub-criteria

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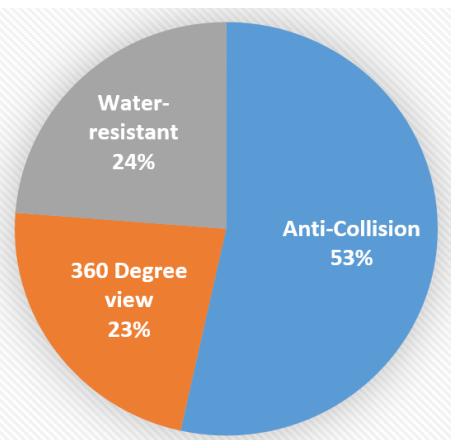Team Final Project

of Water-Resistant and 360 degree view were rated almost same, that is 24% and 23% respectively. Also, it is seen from the table that there is considerable difference between average minimum and maximum value for each criteria; the maximum difference is for Anti-collision which is 34 and 84%. But still Anti-collision was given higher weights by many experts. Hence, it is identified that, for the Follow-Me Drone Technology this is the most important feature. For Expert 7, Anti-collision is the most important factor in the drone with 84% of the weight given to it, even all other experts rated it high as well compared to other two criteria. It can be seen from the table that average minimum value of Anti-collision is higher than average maximum value of other two criteria or collective sum of them too.

It can be seen from figure 13 above, there is disagreement of 0.102 in 10 evaluations. As by convention, tolerance threshold is 10%, and 0.102 was in the same range, we didn't necessarily ask all experts to evaluate again.

6.3 Final Results

According to all evaluations by Expert Panel 1, it was clear which objective is more important and which criteria should be rated high to choose the Best Drone. Expert Panel 2 after studying each product, summarized all details including performance, feature and value criteria for each product which are shown in Figure 14. All products are then compared and rated relative to each other with the help of expert panel 1 evaluations.

Product/Criteria	DJI Phantom 3	DJI Phantom 4	DJI Phantom 4 PRO	DJI Mavic	Yuneec Typhoon H	Ehang GhostDrone 2.0	Inconsistency
Speed	0.19	0.19	0.19	0.16	0.18	0.08	0
Control Range	0.19	0.17	0.27	0.27	0.06	0.04	0
Flight time	0.15	0.18	0.19	0.17	0.16	0.16	0
Stability	0.2	0.2	0.2	0.13	0.13	0.13	0
Resolution	0.15	0.15	0.15	0.15	0.23	0.15	0
Satisfaction	0.11	0.26	0.17	0.17	0.17	0.11	0
Durability	0.16	0.24	0.24	0.1	0.16	0.1	0
Price	0.28	0.12	0.09	0.09	0.12	0.3	0
Anti-Collision	0	0.21	0.32	0.21	0.26	0	0
360 view	0.09	0.09	0.33	0.07	0.33	0.09	0
Water-resistant	0.08	0.12	0.12	0.19	0.19	0.29	0

Figure 14: Expert Panel 2 Results

Analysis

As it can be observed from figure 5, DJI Phantom 4 PRO and DJI Phantom 4 were high on Anti-Collision, Flight Time, Durability, 360 degree view and Speed as well. And these criteria were rated high by Expert Panel 1, especially Anti-Collision was the highest among all. Also, Performance factor of DJI Phantom 4 PRO is high amongst all and this objective is rated high by all experts (see Figure 10), while Yuneec Typhoon H is high on resolution, Anti-collision and speed which added to make them(Phantom 4, Phantom 4 PRO & Yuneec Typhoon H) top 3 high ranked products (See Figure 15).

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Product	Average Rating
DJI Phantom 3	0.16
DJI Phantom 4	0.18
DJI Phantom 4 PRO	0.21
DJI Mavic	0.16
Yuneec Typhoon H	0.17
Ehang GhostDrone 2.0	0.12
Inconsistency	0

AVERAGE RATING FOR EACH DRONE

Ehang GhostDrone 2.0 12%
DJI Phantom 3 16%
Yuneec Typhoon H 17%
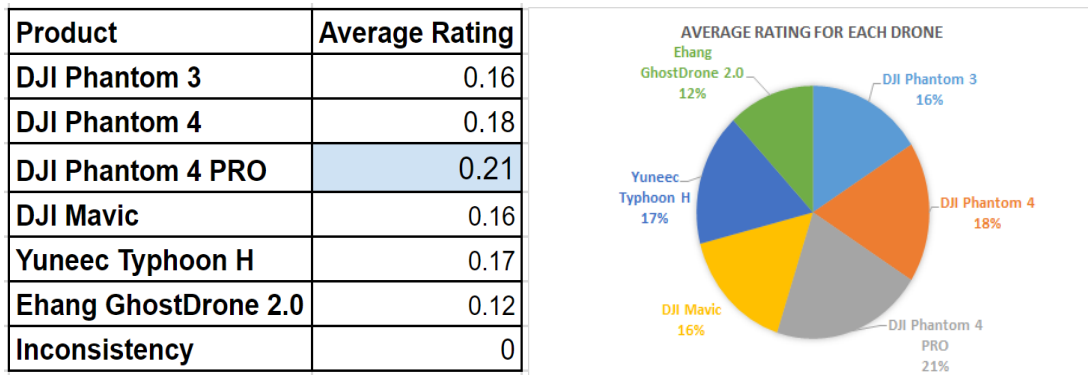DJI Phantom 4 18%
DJI Mavic 16%
DJI Phantom 4 PRO 21%

Figure 15: Choosing the Best Drone

The final results by Expert Panel 2 are shown in (Fig 15). It can be analyzed that there is no large difference between all these ratings, but, DJI Phantom 4, Yuneec Typhoon H and Phantom 4 PRO were high on average ratings. While, DJI Phantom 4 PRO was rated highest as 21% among all. This is mainly because of Anti-collision feature, which is the most important criteria for many experts (can be seen in Figure 16) and Phantom 4 PRO is high on that (Figure 5). Also, Performance was rated as the highest objective by all experts and counts for 53% in the model. DJI Phantom 4 PRO proves to be highest in Performance Category, which made him be ahead of all other alternative products.

Figure 16: Summary of Final results in HDM

When we analyze average rating of each sub-criteria, that is Flight time (27%), Control

Range(26%) under Performance, Durability(40%) under Value & Anti-collision(48%) and 360 degree view(31%) under Features are the most important criteria for all experts as their average values are high among all sub-criteria, under particular objective (See Figure 16). And, DJI Phantom 4 proves to be the best in class for all these sub-criteria. Hence, average value of all rankings by Expert Panel 2 added to make it the "Best Drone" in the comparison with 21% of average rating.

7.0 Limitations and future Research

7.1 Limitation:

The products were all very similar and we struggled with some of the criteria. Durability, satisfaction, and stability. When testing the model we found our results to all be the same in these three categories, Going back to Panel 2 expert's definitions and ranking we determined we needed to not rank them between 1 and 5 but between 1 and 100. This then gave us a point spread in which we were able to differentiate between the different products. Also in these three categories the rating is very subjective by the expert panel, making it more difficult to get clear separation based on raw data and statistics.

Since we used screening criteria in order to reduce our alternative from 11 products down to six product this will limit our model to only certain types of drones. It removes the options of less expensive but still good products that do not have a built in camera. Some customers might be looking for this type of Follow-Me drone camera system however we limited our model to exclude them.

7.2 Future Research

As new products enter into the market, new features are added and new technology becomes available research must be conducted in order to update this model. This model is good only for a short time before it would need to be updated.

Other research needed is to understand the different types of customers that would use this model. For example real estate offices are filming the outside of homes to advance marketability of both their firm and well as the listed home. How would this model help that type of customer? Also industrial inspections, agriculture, remote sensing, and search & rescue are all upcoming consumers of these type of drone camera systems. Understanding their needs and how the model would works for these types of customers is needed.

Research in the advancement of Artificial Intelligence, anti-collection and high tech camera systems like infrared for example are things we need to continue to follow and research. Different customer groups, different needs, and different panel groups, such as remote sensing, search and rescue and industrial surveys.

8.0 Key Learning Points

The evaluation criteria cannot be ranked between 1 and 5, you need separation between your values in order to create distance between each product. Testing our model showed us our mistake. It was quickly fixed and we moved forward.

We brought over one criterion that was a Yes or No answer. The model is able to deal with this type of criterion as long more than one product has the feature. However in our case only one item had this one feature, so as soon as expert panel one placed any weight on that feature it automatically came to the top of the list. This single alternative being chosen each time negated the need for a decision making process.

Follow the process of building an HDM model and make sure you clearly define the problem. Do extensive research on all the products, determine what criteria you really need to bring that into the model and test the model before having any expert panels go in and compare the criteria.

Finally we learned that the importance of writing an instruction sheet for your panel is very helpful, the software lets you choose performance over value over feature but without instruction, the expert wouldn't know what is under each objective.

9.0 Conclusion

The goal of this study was to help in the selection of the best "Follow-Me" Drone Camera System for filming action sports. The goal was achieved by using the Hierarchical Decision Model (HDM). The model was built using criteria gathered through a survey and also through literature review. The alternatives considered represent the diversity that currently can be found in the market. After finalizing and running the model, the alternative DJI Phantom 4 Pro considered the best "Follow-Me" Drone Camera System for filming action sports for hobbyists and enthusiast. Taking into consideration the judgment of the experts and the criteria contained in the model. DJI Phantom 4 Pro was the top ranked product, the rest of the alternatives did not fall behind by a big margin. In addition, the results were remarkably tight, and tight differences between competitors come to show that there is not much differentiation within the available products currently on the market today. The drone camera market is very new, unexplored and unknown. Hence, in the near future, when the market is more mature, it should be clearer which products are the best performers and which are the worst performers, it will be clearer who the leader is. Finally, whoever understands better and faster the needs and characteristics of this new market will definitely have more success and lead the way.

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References

[1] S. French, "Drone sales in the U.S. more than doubled in the past year", *MarketWatch*, 2017. [Online]. Available:http://www.marketwatch.com/story/drone-sales-in-the-us-more-than-doubled-in-the-past-year-2016-05-27.

[2] T. Innovation, "5 Awesome Uses for Drone Technology - iQ by Intel", *iQ by Intel*, 2017. [Online]. Available: https://iq.intel.com/5-awesome-uses-for-drone-technology/.

[3] "The History Of Drone Technology - Redorbit", *Redorbit*, 2017. [Online]. Available: http://www.redorbit.com/reference/the-history-of-drone-technology/.

[4] "The 7 Best Follow You Drones - [2017] Follow Me Drone Review", *Dronethusiast*, 2017. [Online]. Available: http://www.dronethusiast.com/drones-that-follow-you/. [Accessed: 17- Mar- 2017].

[5] L. Sun, "Drones in 2016: 4 Numbers Everyone Should Know -- The Motley Fool", *The Motley Fool*, 2017. [Online]. Available: https://www.fool.com/investing/general/2016/02/29/drones-in-2016-4-numbers-everyone-should-know.aspx. [Accessed: 17- Mar- 2017].

[6] N. Majumdar, "The Consumer Drone Market: Trend Analysis", *Emberify Blog*, 2017. [Online]. Available: http://emberify.com/blog/drone-market-analysis/. [Accessed: 17- Mar- 2017].

[7] "Consumer Drone Sales to Increase Tenfold to 67.7 Million Units Annually by 2021 | Tractica", *Tractica.com*, 2017. [Online]. Available: https://www.tractica.com/newsroom/press-releases/consumer-drone-sales-to-increase-tenfold-to-67-7-million-units-annually-by-2021/.

[8] V. Dronelli, "15 Best Drone That Follows You - 2017 Follow Me Drones FROM $261", *Drones Globe*, 2017. [Online]. Available: http://www.dronesglobe.com/guide/follow-me/.

[9] E. Aerial, "Ehang Ghostdrone 2.0 Aerial: Features, Review, Specs, Price, Competitors", *Mydronelab.com*, 2017. [Online]. Available: http://mydronelab.com/reviews/ehang-ghostdrone-2-0-aerial.html.

[10] 3. Rating and 3. Rating, "3D Robotics Iris Plus Drone Review | Sciautonics.com", *Sciautonics.com*, 2017. [Online]. Available: http://www.sciautonics.com/3d-robotics-iris-plus-drone-review/.

[11] A. Industries, "3DR Iris - autonomous multicopter ID: 1546 - $649.99 : Adafruit Industries, Unique & fun DIY electronics and kits", *Adafruit.com*, 2017. [Online]. Available: https://www.adafruit.com/product/1546.

[12] A. Pri, "Hubsan H501S X4 FPV, Follow Me GPS Quadcopter", *Quadcopterflyers.com*, 2017. [Online]. Available: http://www.quadcopterflyers.com/2015/12/hubsan-h501s-x4-fpv-follow-me-gps-quadcopter.html.

[13] D. Kocaoglu, "A participative approach to program evaluation", *IEEE Transactions on Engineering Management*, vol. -30, no. 3, pp. 112-118, 1983.

[14] Munkongsujarit, S., Schweinfort, W., Iskin, I., Colon, R., Tanatammatorn, N., Phopoonsak, N., & Almobarak, A. (2009). Decision model for a place to live at PSU: The

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case of international graduate students. *Management of Engineering & Technology, 2009. PICMET 2009. Portland International Conference on,* 513-534.

[15] Taha, Byung Chul Choi, Chuengparsitporn, Cutar, Qian Gu, & Phan. (2007). Application of Hierarchical Decision Modeling for Selection of Laptop. *Management of Engineering and Technology, Portland International Center for,* 1160-1175.

[16] Phan, K., & Kocaoglu, D. (2014). Innovation measurement framework to determine innovativeness of a company: Case of semiconductor industry. *Management of Engineering & Technology (PICMET), 2014 Portland International Conference on,* 747-757.

[17] M. Alexander, "Decision Making using the Analytic Hierarchy Process (AHP) and SAS/IML", 2017. [Online]. Available: http://analytics.ncsu.edu/sesug/2012/SD-04.pdf.

[18] Chen, H., & Li, J. (2011). A sensitivity analysis algorithm for the constant sum pair-wise comparison judgments in hierarchical decision models. *Technology Management in the Energy Smart World (PICMET), 2011 Proceedings of PICMET '11:,* 1-17.

[19] Commercial Drone Market Analysis - Size, Share, Growth, Trends and Forecasts To 2022: Grand View Research. (2015, August 12). *M2 Presswire*, p. M2 Presswire, August 12, 2015.

[20] De Muniain, J. (2016). 2016: The year of the drone. *Fire and Rescue,* 10.

[21] C. Snow, "Commercial Drone Markets: 2016 Year in Review", *Drone Analyst*, 2017. [Online]. Available: http://droneanalyst.com/2016/12/19/commercial-drone-markets-2016-year-in-review/.

[22] "Commercial Drone Shipments to Surpass 2.6 Million Units Annually by 2025 | Tractica", *Tractica.com*, 2017. [Online]. Available: https://www.tractica.com/newsroom/press-releases/commercial-drone-shipments-to-surpass-2-6-million-units-annually-by-2025-according-to-tractica/.

[23] "Aerotenna Takes Home First Prize at UTM Drone Sense and Avoid Tech Competition The Next Era of Aviation Is Powered by Radar - sUAS News - The Business of Drones", *sUAS News - The Business of Drones*, 2017. [Online]. Available: https://www.suasnews.com/2016/11/aerotenna-takes-home-first-prize-utm-drone-sense-avoid-tech-competition-next-era-aviation-powered-radar/.

[24] Gerdsri, P., & Kocaoglu, D. (2008). HDM for developing national emerging technology strategy and policy supporting sustainable economy: A case study of nanotechnology for Thailand & #x2019;s agriculture. *Management of Engineering & Technology, 2008. PICMET 2008. Portland International Conference on,* 344-350.

[25] Bernhard, R. (1991). A review of: "MANAGERIAL DECISIONS UNDER UNCERTAINTY; AN INTRODUCTION TO THE ANALYSIS OF DECISION MAKING" by Bruce F. Baird, John Wiley and Sons, Inc., New York, 1989, xii + 530 pp., ISBN 0-471-85891-9. *The Engineering Economist, 36*(3), 264.