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EVALUATION OF SMALL UAS ACQUISITION COSTS FOR CONSTRUCTION APPLICATIONS

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Abstract: Unmanned Aerial System (UAS) technologies have rapidly evolved since the 1990's. It is estimated that the 2016 market for such systems ($2.6 billion) will quadruple ($10.9 billion) by the year 2025 (Teal Group Corporation 2016). New technological advancements in UAS design, battery duration, GPS navigation capabilities and control reliability, have made possible the development of new low-cost, lightweight aerial systems. These advancements have also generated tremendous interest by academia and industry in the construction domain for different applications such as surveying, safety, and quality, and inspection and documentation. With hundreds of UAS manufacturers available in today's market, it is difficult to evaluate the life-cycle cost metrics of the such aerial systems. Wide differences regarding metrics such as aircraft weight, payload capabilities, and battery autonomy, make an objective assessment of expenses a daunting task. This pilot study explores the acquisition cost factors for the comparison of small UASs in the construction domain. As a result, a parametric model is presented to estimate the acquisition costs of small UASs for construction applications.

Keywords: Small UAS, Acquisition Cost, Parametric Modeling, Construction Industry.

1 INTRODUCTION – UAS COST ANALYSIS

Economic aspects of unmanned aerial system (UAS) technologies are largely unexplored in the Architecture, Engineering, and Construction (AEC) domains. The study of these new technologies is of importance to aid professionals to make decisions regarding the acquisition, the employment, and maintenance of these systems, making their use sustainable in time. Efforts have been done outside these fields to evaluate the Total Cost of Ownership (TCO) of such systems. Papadales and Downing (2015) approached the cost and business model for civilian missions for unmanned small to medium aircrafts. UAS classified as small to medium aircrafts by the Federal Aviation Administration (FAA) contemplates aircrafts that weight 1320 pounds to 41000 pounds. (U.S. Department of Transportation, 2013). Papadales and Downing (2015) evaluated UAS flight services for NASA funded science missions with a TCO model on cost per-flight-hour and per-mission basis. It was determined that the UAS civil science operation were to remain a niche market due to the elevated TCO within market sector. Valerdi (2005) also explored the cost metrics for UASs in military operations (unmanned small to medium aircrafts). This research reviewed the estimation methods used on the aeronautic industry, established cost metrics that could be used to evaluate the TCO of UASs, and defined a model based on cost per-pound-hour.

Papadales and Downing (2007) examined the cost analysis for UASs focused on commercial flight services. In this study, the elements of the annual mission cost were compared by breaking down into baseline characteristic of unmanned small to medium sized aircrafts. The UASs were studied for surveillance missions on large extension of terrain

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(approximately 1600 square miles). It was found that for this type of operations, it was more economically feasible to employ larger unmanned aircrafts. Furthermore, Malone et al. (2013) identified some of the unique cost estimating parameters requirements of UASs. The key elements that defined the costs of a UAS for unmanned small to medium aircrafts were reported and it was observed that the main considerations for estimating the cost of the aircraft, the software employed, and the ground operations and communications required to operate the aerial vehicle.

More recently, Valerdi and Ryan (2016) evaluated the TCO for Unmanned Automated Systems (UMAS) based on US Department of Defence (DoD) reports. Here, the UMAS costs were approached by creating a Product Breakdown Structure (PBS) and by the establishment of the cost drivers for estimating the development, operations and support through parametric models. It was identified that PBS, comparisons with historical data, and utilization of parametric models provide a reliable estimation for UMAS TCO.

2 UAS Cost Analysis in the Construction Industry

With the advent of UAS technology and recently bursting market growth, unmanned aircrafts has been increasingly introduced into the construction market sector for a variety of possible operations. Vascik and Jung (2015) performed a projection of the UAS market for the year 2020, cataloguing the construction industry as the second largest economic market sector, behind cropland precision agriculture, with a capability of recovering revenue for the client surrounding the 500 million US dollars. Research have been conducted utilizing UAS in the construction industry for a wide range of applications. Most of the research performed falls into the construction operations suggested by Vascik and Jung (2015): airborne surveying, safety and quality inspection, and documenting of build progress or the ones proposed by Irizarry and Costa (2016): project and work progress, jobsite logistics, safety conditions, and work quality inspection.

The feasibility of the use of UAS for construction management was studied by Blinn and Issa (2015). A survey was conducted to consult with construction experts, assessing the current state of UAS in the industry. It was found that UAS was less costly than the traditional methods employed to obtain aerial imaging, indicating that it is financially feasible. The authors set a word of caution due to legal constraints at the time of the survey in the publication. At that time, it was required to hold a traditional manned aircraft pilot license (sport, recreational, private, transport, or commercial) under the Federal Aviation Regulation: Part 61, and applying for a Section 333 Exemption of the FAA Modernization and Reform Act of 2012. In 2016, the FAA passed the new regulations of the operational rules for routine commercial use of small UASs. This allows operators to obtain a commercial pilot certification for all types of small UASs aerial operations, including those performed in the construction industry. The FAA defines "*small unmanned aircraft*" as "*an unmanned aircraft weighing less than 55 pounds including everything that is on board the aircraft (total take-off weight)*" and "*small unmanned aircraft system*" as "*a small unmanned aircraft and its associated elements (including communication links and the components that control the small unmanned aircraft) that are required for the safe and efficient operation of the small unmanned aircraft in the national airspace system*". Analogously, the European Aviation Safety Agency (EASA) have only proposed a framework for the operation of UAVs under the A-NPA-2015 (European Aviation Safety Agency 2015), classifying small UAS as "*Low-risk operation – 'open' category*" which encompasses "*small drones under direct visual line of sight with a Maximum Take-Off Mass (MTOM) of less than 25 kg operated within safe distance from persons on the ground and separated from other airspace users*". The EASA definition is equivalent to the FAA definition including its weight restrictions (25kg ≈

55 pounds); nevertheless, the EASA is still on the process of review and has not presented a final publication with the general ruling as December of 2016.

Employing the United States regulations, the Federal Aviation Regulation: Part 107 (U.S. Department of Transportation 2016) addresses the basic regulation required to safely operate a UAS commercially, and established that the applicant must approve an aeronautical knowledge test in addition to the Part 107 training course content. The direct consequence of this is that under Part 107, a traditional manned aircraft pilot license is no longer required, significantly lowering initial professional costs and making it easier to get required documentation to fly a small UAS for commercial applications. As a result, the acquisition of small UASs has become increasingly attractive for applications in the construction domain. A wide market is available for commercial small UASs but it is difficult to contrast device options with cost metrics that relate into expenses that are large unexplored. Additionally, it is difficult to assess the costs associated to UASs due to is the shortage of studies about the current state of small UAS life cycle assessment and its associated practices within the construction industry today. This translates in a necessity to examine the acquisition cost factors in the standards of life cycle assessment for small UAS.

3 Life Cycle Assessment Metrics for UAS in the Construction Industry

The life cycle assessment evaluates all the cost associated with a product from its inception to its disposal. It includes the overall costs incurred during the expected life of the product, and particularly in the aircraft industry it includes: research and development, production and construction, operations and management, and retirement and disposal (Praveen 2009). The life cycle assessment become relevant for decision making through the contrast of products that are similar. Nevertheless, this model is not directly applicable to the construction industry since the two initial phases are not currently within the reach of the industry; instead, a procurement and acquisition phases are required to replace those phases (Figure 1). It is noteworthy, that from the construction industry perspective the life cycle cost is based on a single owner (e.g. a general contractor).

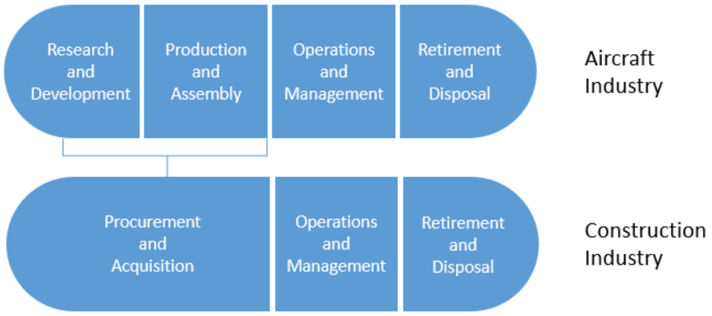

Figure 1: Aircraft Life Cycle Assessment (adapted from Praveen 2009).

The metrics to perform the cost analysis of UAS for construction are intrinsically related to the life cycle phases. The procurement and acquisition phase relates to the initial cost of obtaining the UAS depending on the project particular needs. These are incurred at the time of procurement and acquisition of the aircraft. Such costs are: Battery Autonomy, Payload Capacity, and Cameras/Sensors. Operations and management is associated with the inherent costs that are incurred to perform the manoeuvres of the UAS; they are experienced in regular intervals of time and per operation. This may include: Propeller Lifespan, Battery Lifespan, Software Adaptability, Insurance, Operating Crew, among others. Finally, retirement and disposal phase evaluates what capital can be recuperated at the end of the lifespan of the vessel. This study will be concerned exclusively with the first phase of the three for the life cycle assessment process.

4 Procurement and Acquisition of UAS

4.1 Research Methodology

A comprehensive methodology was used to collect small UAS relevant data. First, a world-wide-web search was based on unconstrained and unstructured iterative searches to explore commercially available small UASs. The investigation exclusively focused on small UAS with a weight equal or lower that 55 pounds and any aircraft with a higher weight was not considered. The objective from these searches was to systematically review the web using iterations to perform the aircraft selection based on the information collected and progressively define categories. As there are no standards defined on small UASs for construction usage different than the FAA regulations, aircrafts with sufficient photography/videography quality (720p or more) capabilities were considered as the majority of the applications in the construction domains rely on the capture aerial data for imaging in the form of photo and video (JBKnowledge 2016).

Only commercially available small UAS available up to December 2016 were studied to assure that the information contained was recent. Three categories of small UAS were defined depending on their acquisition cost. This cost is tightly related to the small UAS specifications and capabilities as described in the following chapters. As a result, twelve aircrafts were simply random sampled from each category from the data obtained from the web search and the AUVSI 2015 Buyer's Guide (Association for Unmanned Vehicle Systems International 2015), totalling 36 data points. Hill (1998) suggests that samples of 30 or more are recommended in experimental research in order to obtain representative statistical samples. Only rotary wing UAS were selected for this study because of their innate hovering capabilities and its flexibility to operate in confined spaces (Siebert and Teizer 2014), facilitating traditional built environment AEC operations. Finally, the evaluation of the cost assessments was based parametric models, which is a representation of mathematical relationships between dependent and independent variables. These allow visual representation of the data collected and the associations between them in a simple and intuitive display.

4.2 Cost Metrics

Small UAS acquisition is defined by a series of parameters that help determine the overall expenses incurred to obtain a system. Aircraft specification data was collected for 36 commercially available UAS, to observe for factors that affected the acquisition cost. Previous studies (Valerdi 2005, Papadales and Downing 2007) have proposed to use weight and endurance to assess the cost of the UAS and provide a predictive parametric model. Similarly, this study proposes to use four parameters related to the small UAS hardware to develop the model as follows:

- **Weight:** Mass of the aircraft in pounds including frame, flight controllers, motors, propellers, and battery; in other words, any element necessary for the take-off of the aircraft.
- **Payload Capability:** The additional take-off power linked to the modularity in payload presents an increase of the overall cost of the aircraft, calling for more demanding motors and higher energetic consumption. This metric is measured in pounds, and if often composed of a gimbal, and a camera or other sensors.

- **Total Take-off Weight:** As defined by the FAA, it encompasses the aircraft weight and payload capability in a single metric. This variable is the maximum mass at which the aircraft can regularly take-off expressed as weight plus payload capability.
- **Endurance:** Battery autonomy of the aircraft measured in minutes. This is a variable metric, depending on the aircraft's payload distribution, aircraft configuration, and environmental conditions. Because of this, the manufacture's given endurance for the worst case scenario; that is fully loaded and non-ideal weather, is used as the total endurance of the small UAS.

Other factors such as navigation type and flightpath automation were not considered for this study because of their software related nature. Software drives the avionics for the aircraft including control, monitoring, communication and navigation. In addition, ground-based mission critical software for fixed and mobile sites all lie within the operational environment (Malone et al. 2013). These software pieces would be considered as a cost associated with research and development or operations and management which is not within the scope of this study.

4.3 Small UAS Classification

The definition of small UAS provided by the FAA encompasses an extensive range of aircrafts. The main indicators that permit the classification of small UAS is the cost. The cost was used because it correlates directly to other factors such as aircraft weight, payload capability, and sensors installed. Using this factor, small UAS were grouped as Low, Medium, and High performance as shown on Figure 2.

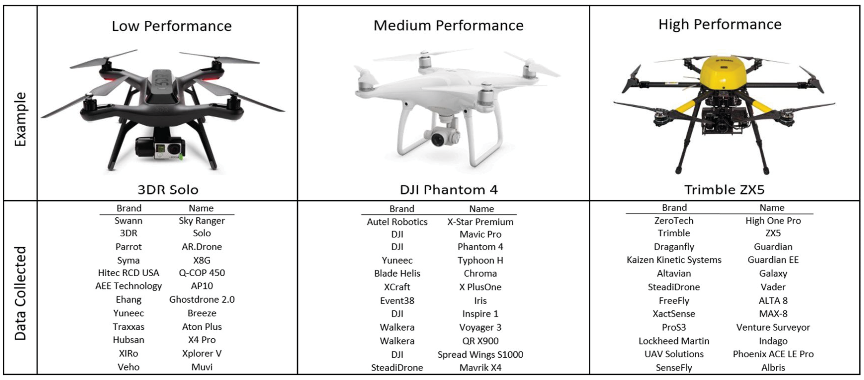

Figure 2: Small UAS Performance Classification.

- **Low Performance:** light-weight, compact quadcopters, with very limited to no payload capabilities. Often, these are equipped with built-in cameras in the body of the UAS (e.g. Syma X8G, Ehang Ghostdrone, Veho Muvi) or only offer very limited, light-weight sensors carrying capabilities (e.g. 3DR Solo, Traxxas Aton Plus, Hubsan X4 Pro).
- **Medium Performance:** average sized quadcopters, with some payload capabilities. Frequently, allow to carry small payload of under a pound (Autel Robotics X-Star Premium, Yuneec Typhoon H, StediDrone Mavrik X4) or have built-in sensors (DJI Phantom 4, Walkera Voyager 3, Blade Helis Chroma).
- **High Performance:** heavy-weight, large quad/hexa/octo-copters, with wide range payload capabilities. Regularly, permit the usage of payloads of over two pounds for carrying extra batteries to extend its endurance or employ any kind of sensor required (Altavian Galaxy, FreeFly ALTA 8, Trimble ZX5).

Each group was examined in detail, employing the cost metrics previously defined along with the associated commercially available cost. Table 1 displays the cost metrics: average take-off weight, average endurance, and the range of cost for each category.

Table 1. Average Cost Metrics for Performance Groups

Performance Group	Average Take-off Weight (pounds)	Average Endurance (minutes)	Average Cost (dollars)	Cost Range (dollars)
Low	2.4	20	$380	$180 – $500
Medium	7.2	21	$2250	$700 – $5,000
High	20.5	29	$19500	$7,000 – $33,000

4.4 Parametric Model

The Office of the Secretary of Defense UAV Roadmap (2005) proposed weight and endurance, or pound-hour as the main metric to estimate the cost of large UAV systems. This approach encompasses complex technologies that do not follow the linear relationships. Analogously, this approach was used in this pilot study to evaluate small UAS parametric modeling for its acquisition. It is noteworthy, that the endurance for small UAS becomes scaled down from hour to minutes because of the nature of the systems. The small UAS cost metric employs total weight of take-off (in pounds) (1) multiplied by the endurance (in mins) versus the cost (in dollars) (2). That is:

$$total\ weight\ of\ take-off = weight\ (lb) + payload\ capabilities (lb) \quad (1)$$

$$cost\ metric\ (lb * \text{min}) = total\ weight\ of\ takeoff\ (lb) * endurance\ (min) \quad (2)$$

For each data point obtained for each category the metric was calculated and plotted against its cost. Figure 3 displays the scatterplot obtained from the relation between the cost of the small UASs in dollars ($) and the cost metric in pounds-minutes (lb*min). A regression analysis was performed to evaluate the best fit possible though the use of least square means on the data obtained. It was found that the power function presents the best fit for the data set and it validated with a coefficient of determination (R2) of 0.6297.

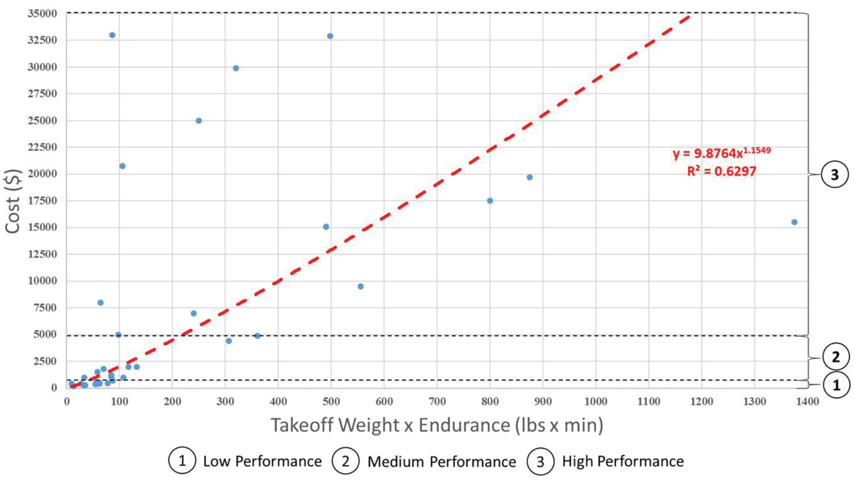

Figure 3: Small USA Acquisition Cost Parametric Model

The fitted parametric model is sensitive to performance category. The low performance categorization presents a projected cost on average of 100% over the original cost, shifting the estimation average for small UAS cost from $380 to $760, or an increment of $380. This is due data distribution gap in performance between the low and medium/high performances, as it is displayed on Figure 3, where low performance category is clustered on the very low end of the plot. The medium and high performance categorizations present a projected estimation cost that is on average 8% over the original cost. This signifies that the average for medium performance category increases from $2250 to $2430 (rising the cost $180) and for the high performance category increases from $19500 to 21060 (rising the cost $1560). The dramatic decrease of the estimation error is due to the distribution of the data in these two categories, displaying a more evenly spread around their respective means, reducing the overall measure on the least of squares means fitting process.

5 Summary and Further Study

Small UASs usage in the construction industry has been rapidly growing and recently facilitated by the new FAA regulations. Evaluating life cycle of such systems is of uttermost importance in order to make their use sustainable in time. This study focused on the assessment of the procurement and acquisition section of the overall life-cycle assessment model. Data was collected through web search (36 small UASs) and analysed to obtain a parametric model that would describe the cost metrics of the aircrafts. Using total weight of take-off and endurance as cost metrics, a regression analysis was performed to find a mathematical relationship between the cost and the cost metrics. It was found that the power function describes the data set with a coefficient of determination (R2) of 0.6297. For the overall model, the error in the estimation for the low performance small UAS duplicates the projected cost, but the medium and high performance are only increased by an 8%.

Using UASs is a new and rapidly evolving area in construction, and in-depth research studies are needed not only to study their technical implementation but also to investigate social, legal, and financial factors that constrain their acquisition, construction, or operation in the construction domain (Gheisari and Esmaeili 2016). This investigation provides a glimpse of the factors involved in estimating small UASs acquisition costs for construction applications. However, further investigation of additional factors must be considered before extensive implementation in the industry. Additional research requires the evaluation of different sensors with regards to its impact on the UAS payload capabilities; including the effects the sensors represent for different construction applications, revenue correspondence for each sensor, and the cost time-dependence exert on this rapidly evolving technology. Furthermore, the software employed to control, monitor and interact with the aircraft may be assessed into the acquisition costs, as it is an integral part for certain operations. This indicates that there is still work to be done, but this research provides an initial stepping stone for estimating life-cycle assessments of small UASs for construction management applications.

6 References

Association for Unmanned Vehicle Systems International (2015). *UAS Buyer's Guide*. Web at: < http://w ww.auvsi.org/auvsiresources/uasbuyersguide > (Dec. 7, 2016).

Blinn, N. and Issa, R. R. A. (2015). Feasibility Assessment of Unmanned Aircraft Systems for Construction Management Applications. Construction Research Congress 2016, 2593-2603.

European Aviation Safety Agency (2015). *Civil drones (Unmanned aircraft)*. Accessed from the European Aviation Safety Agency web site at: < https://www.easa.europa.eu/easa-and-you/civil-drones-rpas > (Dec. 12, 2016)

Gheisari, M. and Esmaeili, B. (2016) Unmanned Aerial Systems (UAS) for Construction Safety Applications. Construction Research Congress 2016: pp. 2642-2650, doi: 10.1061/9780784479827.263.

Hill, R. (1998). What sample size is “enough” in internet survey research? Interpersonal Computing and Technology: *An Electronic Journal for the 21st Century*, 6(3-4).

Irizarry, J. and Costa, D. (2016). Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks. *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000422, 05016001.

JBKnowledge (2016). *The 5th Annual Construction Technology Report*. Accessed from JBKnowledge at: < http://jbknowledge.com/2016-construction-technology-report-survey > (Dec. 7, 2016).

Malone P., Apgar H., Stukes S. and Sterk S. (2013). UAV Unique Cost Estimating Requirements. Aerospace Conference, 2013, 1- 8.

Office of the Secretary of Defense (2005). *UAV Roadmap - Unmanned Aircraft Systems Roadmap: 2005-2030.* Accessed from the Federation of American Scientist at: < https://fas.org/irp/program /collect/ uav_roadmap2005.pdf > (Nov. 16, 2016)

Papadales, B. and Downing, M. (2005). UAV Science Missions: A Business Perspective. AIAA Infotech Aerospace 2005 Conference and Exhibit, 1-13.

Papadales, B. and Downing, M. (2005). Cost Analysis of Commercial UAV Flights. AIAA Infotech Aerospace 2007 Conference and Exhibit, 1-9.

Siebert, S. and Teizer, J. (2014). Mobile 3D Mapping for Surveying Earthwork Projects Using an Unmanned Aerial Vehicle (UAV) System. *Automation in Construction*, 41, pp. 1-14.

Teal Group. (2016). *World Civil Unmanned Aerial Systems Market Profile & Forecast 2016 Edition*. Accessed from the Teal Group Corporation at: < http://www.tealgroup.com > (Oct.16, 2016).

U.S. Department of Transportation (2016). *Advisory Circular – Small Unmanned Aircraft Systems AC 107-2.* Accessed from the Federal Register at: < https://federalregister.gov/a/2016-15079 > (Aug. 16, 2016).

U.S. Department of Transportation (2013). *Unmanned Aircraft System (UAS) Service Demand 2015 – 2035.* Accessed from the Federal Register at: < https://fas.org/irp/program/collect/service.pdf > (Dec. 6, 2016).

Valerdi, R. and Ryan, T. R. (2016). *Total Cost of Ownership (TOC): An Approach for Estimating UMAS Costs. Operations Research for Unmanned Systems*, First Edition, Wiley, 207-232.

Vascik, P. D. and Jung, J. (2015). Assessing the Impact of Operational Constraints on the Near-Term Unmanned Aircraft System Traffic Management Supported Market. AIAA Infotech Aerospace 2015 Conference and Exhibit, 1- 17.