

# Unmanned Aerial Vehicles in the Construction Industry

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Technology advances in recent years have resulted in Unmanned Aerial Vehicle (UAV) designs that are more reliable, less expensive, and easier to control. This research looked at the current use of UAVs within the construction industry. Areas of focus included risks associated with using UAVs on construction sites, in-house versus outsourced resources, and a look at the future of UAV applications in construction. Data was collected with a survey distributed to members of the US construction industry and from the online database of Federal Aviation Administration (FAA) Section 333 exemptions granted. Survey results indicated many companies use UAVs on their sites with the majority of applications replacing traditional still photo and video acquisition. The results showed that in-house operation of UAVs is more common than outsourcing. A review of the FAA database revealed that less than 10% of Section 333 exemptions, as of the Summer of 2016, were for construction applications.

**Key words:** Unmanned Aerial Vehicle, UAV, Construction, Drones

## Introduction

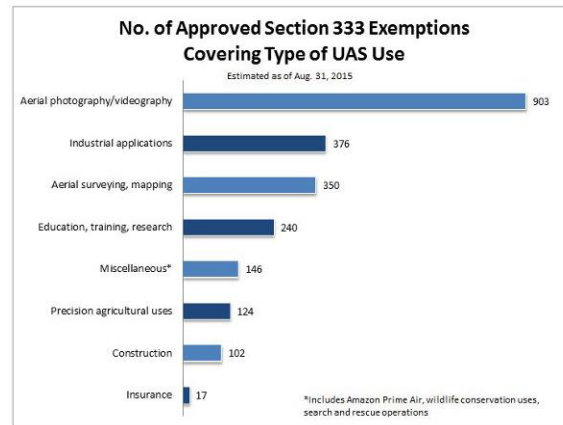
Various forms of Unmanned Aerial Vehicles (UAVs) often referred to as drones, have been used in the US since the Civil War. UAVs are aircraft without an onboard pilot including the ground based, or operator, equipment as well as the data link connecting the two. The term drone, more specifically, refers to the aircraft itself and also includes equipment operated independent of human control (Grayson, 2015). Initial uses for UAVs were primarily aimed at military purposes, and military research has been a major driver for advancing UAV technology. The wide use of transistors in the 1960's allowed electronic equipment to shrink in size, and the civilian hobby of radio controlled aircraft began to develop in parallel to military UAV advances. More recently in the 2000's, 2.4 GHz spread spectrum technology was introduced, which allows multiple UAV operators' to use their equipment without interfering with each other. The introduction of Lithium Polymer (LiPo) batteries provided another advance by providing more voltage and amperage per cell than previous technologies. And the advancement of GPS technology has allowed both military and civilian UAVs to be navigated by satellite (Carrison, 2015).

Today, a boom of UAV use is being seen across many industries as the technology has reached a maturity level that makes it both user-friendly and inexpensive (Joyce, 2015). Innovators are discovering a multitude of uses for UAVs. Advances in cameras, sensing, aeronautics, and navigation technologies have helped make UAVs affordable, reliable and easy to operate. Small multi-propeller helicopters (called quadcopters) can be equipped with almost any sensing technology (Snider & Welch, 2015). In the United States, UAVs can qualify as model aircraft if the operator adheres to the Federal Aviation Administration's (FAA) model-aircraft guidelines and the operation is "purely for recreational or hobby purposes". However, commercial applications for UAVs in the U.S. require an exemption from the FAA known as a Section 333 Exemption (Perlman, 2015). The FAA describes the Section 333 Exemption as follows:

"By law, any aircraft operation in the national airspace requires a certificated and registered aircraft, a licensed pilot, and operational approval. Section 333 of the FAA Modernization and Reform Act of 2012 (FMRA) (PDF) grants

the Secretary of Transportation the authority to determine whether an airworthiness certificate is required for a UAS to operate safely in the National Airspace System (NAS). This authority is being leveraged to grant case-by-case authorization for certain unmanned aircraft to perform commercial operations prior to the finalization of the Small UAS Rule, which will be the primary method for authorizing small UAS operations once it is complete.”

As of September 1, 2015, the FAA had granted over 1,400 exemptions in total, with more than 1,000 in review and more being submitted every day (Figure-1). The first exemptions were granted to companies in the film and television industries (Dillow, 2015) which fits in the category of aerial photography and videography, the largest category of exemptions granted thus far (McGowan et al, 2015).



*Figure 1: Categorical Breakdown of Section 333 Exemptions (McGowan et al, 2015)*

Industrial applications for UAVs is the second most popular category. Some of these applications include inspection of critical linear infrastructure such as oil and gas pipelines or electrical transmission lines (Miller, 2015), inspection of wind turbine blades by UAVs with higher-resolution imaging (compared to the traditional method of scaling the masts or using binoculars to conduct inspections)(NAW Staff, 2015). The real estate industry has begun to take advantage of UAVs to conduct aerial surveys and mapping of planned developments or to document transactions (Naylor, 2015). Though not the greatest number of exemptions, precision agriculture applications are becoming a valuable tool for 21st Century farms. UAVs are being used to determine whether crops need to be watered and when and where to apply fertilizer in order to increase crop yields and decrease farming expenses (Naylor, 2015).

The construction industry has not been immune to the popular draw of UAVs. Construction companies have primarily been using UAVs to provide real-time reconnaissance of their jobsites and to provide high-definition (HD) video and still images for publicity and documentation of progress Schriener &\* Doherty, 2015). These uses are only scratching the surface of the possibilities of UAV applications in the construction industry, and the coming years are sure to see expanding innovations Perlman (2015).

The aim of this research is to explore the current and potential utilization of unmanned aerial vehicles within the construction industry, study the extent of in-house versus subcontracted UAV services being utilized by contractors, and identify potential risks associated with UAV uses on construction sites.

## Literature Review

Numerous articles have recently been published on the subject of commercial UAV applications, including use in areas of construction. This literature review presents the information found among various publications in terms of

the UAV uses currently being implemented on construction sites, and uses being contemplated for the future related to construction projects.

### Aerial Photography

Construction companies have long known the value added in having photos and video of their construction sites from a bird's-eye-view. Whether taken from a crane, airplane, or helicopter, the unique perspective not only allows the contractor's to demonstrate the progress achieved on their projects; it also allows them to attract future business by using the aerial views in advertising materials.

Because of their small size and maneuverability, UAVs have added the ability to collect views of construction projects starting from ground level, sweeping through the project at various heights and viewpoints, on up to fly-over views above the site. The results can be seen in minutes and at a fraction of the cost of using an airplane or helicopter. Aerial images produced by UAVs can be taken daily in order to plan the placement of stored materials, the flow of workers and vehicles in and around the site, and to identify potential issues with installed construction or the constructability of planned installations (Molla, 2015).

UAVs with GPS technology are being used to capture images from the same aerial perspective over time in order to track actual construction progress against planned progress. Routes are preprogrammed so that the UAV can follow predetermined routes independently (Schriener & Doherty, 2015). Planning software allows specific routes, speeds, altitudes, and hover times to be entered, and landing can be accomplished automatically with some UAVs (Willis, 2015).

### Surveying

Equipped with appropriate sensors and camera technologies, UAVs provide an economical platform for obtaining survey data. Surveying services providers use GPS enabled UAVs that automatically follow a GPS controlled flight path planned in advance. Using photographic systems which can provide high resolution images, overlapping photos taken by the UAV are put together in mosaic fashion which are then transformed into high resolution 3D surface models that can be used for topographic mapping, volumetric calculations, or three dimensional representations of job sites (Height Tech, 2015). Also, UAVs equipped with thermal imaging can be used to discover energy leaks by conducting building envelope surveys (Height Tech, 2015).

Photogrammetry, which converts two-dimensional images to three-dimensional models through the use of triangulation and high quality photographs, is also being achieved with UAVs. Combining the photogrammetry with Lidar (Light Detection and Ranging) technology, photos captured by UAVs allow the production of 3D building models, contour maps, volumetric surveys, and various other products (Corrigan, 2015).

### Inspections

It has been validated by the oil industry that using UAVs can quicken pipeline inspection process, and enhance safety by reducing worker exposure to harsh conditions in extreme climates. In term of commercial construction, a CEO of UAV services company describes a scenario in which a fifteen story building has a water leak on one of the higher floors. A window frame is suspected to be the source of the leak. The building is bordered by a busy highway, making access even more difficult. A UAV is able to capture numerous photos from various angles and zoom settings in a matter of minutes. The entire operation is conducted without road closures, at greatly lower cost than alternative inspection techniques, and with very little safety risk (Pritchard, 2015).

Wind turbine inspections have traditionally been accomplished through the use of binoculars or by technicians that are required to climb to great heights. The introduction of UAVs has provided a much safer option for these inspections and with higher resolution than that offered by binoculars. (NAW Staff, 2015)

### Safety/Security Monitoring

A construction safety manager's efficiency can be increased greatly with the aid of UAVs on his construction site. Using a UAV to provide real-time two-way communication allows the safety manager to communicate with employees anywhere within the construction site. Images and video captured by the UAV gives the safety manager valuable documentation of jobsite conditions in cases where accidents do occur, and the UAV provides him a tool to cover a larger area of the construction site in a shorter amount of time (Schriener & Doherty, 2015).

Security of construction sites can also be enhanced through the use of UAVs. A UAV integrated into the security alarm system can dock on rooftop station that provides a continuous charge to the battery. When an alert is received, the UAV is deployed and hovers above the construction site to capture video of what's happening. The high definition camera will have the capability to identify individuals or vehicles within its view, and the video can be viewed from a smartphone. The UAV will also have the ability to be programmed for periodic security sweeps, and it will return to its rooftop station automatically (Ingenious, 2015).

### Automated Assembly

Automated assembly of structures is one of the more prominent future uses of UAVs being speculated. Small scale projects have been completed to prove that UAVs are capable of assembling structures. Architects have created an exhibit to demonstrate the capability of UAVs to transport and assemble a structure made of modular units. They termed the exhibit Flight Assembled Architecture. The project used a team of drones to construct a 20-ft tower made of 1,500 foam bricks. The UAVs communicated with each other during the assembly and were operated semi-autonomously. The General Robotics, Automation, Sensing and Perception (GRASP) Lab at the University of Pennsylvania similarly used a team of UAVs to assemble a structure made of beams and columns. The beams and columns were mated together by magnetic connections. It is thought that both of these demonstrations of UAV capabilities can one day be scaled up to automate assembly of structures. (Jones, 2015)

## **Methodology**

In order to meet the objectives of this research, quantitative methods were used which included the collection of both primary and secondary data. The primary data was collected through the use of an online survey, while the secondary data was collected from a database that exists in the public domain on the Federal Aviation Administration's (FAA) website.

An online survey questionnaire was designed and distributed through [www.SurveyMonkey.com](http://www.SurveyMonkey.com) to a list of four hundred and fifty-two (452) individuals in the construction industry in the US. In order to maintain anonymity among respondents, the survey did not record respondents' names or their company names in connection with their survey responses.

The FAA publishes a list of Section 333 Exemptions granted on their website for the public to view. The information posted includes:

- The date the exemption was granted
- The petitioner's name (individual or company name)
- A brief description of the operation or mission for which the petitioner intends to operate UAVs

- Links to both the petition and the grant of exemption documents.

The data was current through October 31, 2015 as the time of this research. A search of the data was conducted for the word “construction” in the Operation/Mission field to find the number of current exemptions granted to companies overtly petitioning for construction related uses. The remaining exemptions were examined to find companies that are petitioning for other uses that could be construed as construction related, such as surveying, mapping, or inspections. Once collected, the data was reviewed to identify the percentage of FAA Section 333 Exemption grantees that intend operate their UAVs for construction related uses.

## Data Analysis and Discussion

The questionnaire survey posted on [www.SurveyMonkey.com](http://www.SurveyMonkey.com) was distributed through email to four hundred and fifty-two (452) individuals in the construction industry. Responses were received from one hundred and thirteen (113) individuals for a response rate of 25%.

### Introductory Questions

In order to understand the makeup of respondents, the first four questions of the survey requested information about the respondents’ companies and their background information. The results show that overwhelming majority of respondents, 71%, were from the commercial/industrial general contractor category. The remaining 29% of respondents were from four other categories, including specialty trade contractor (11%), residential general contractor (10%), design/build architectural and/or engineering & construction firm (6%), and civil/heavy works general contractor (2%).

In term of the respondents’ positions in their companies, an almost even percentage of executives (43%) and project managers (44%) chose to participate in the survey. The remaining 13% of respondents consists of individuals in the engineering (4%), quality control (4%), site superintendent (4%), and site safety categories (1%).

As shown in Figure-2 for the sizes of the various companies responding to the survey and Figure-3 for the revenue ranges of the responding companies, a majority of respondents are from medium or large construction companies.

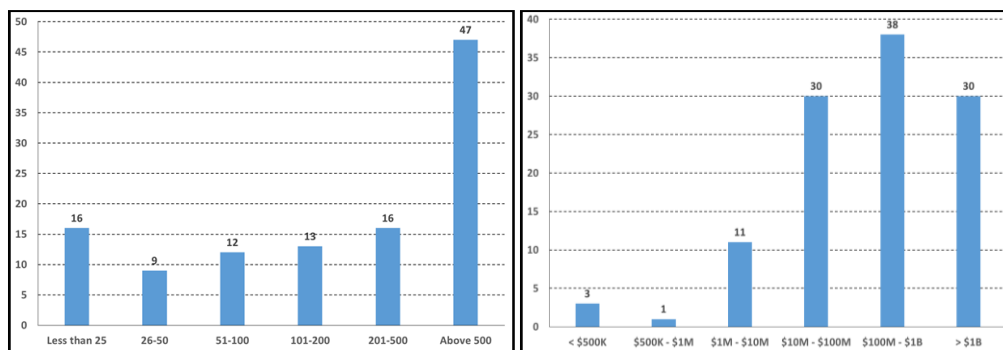
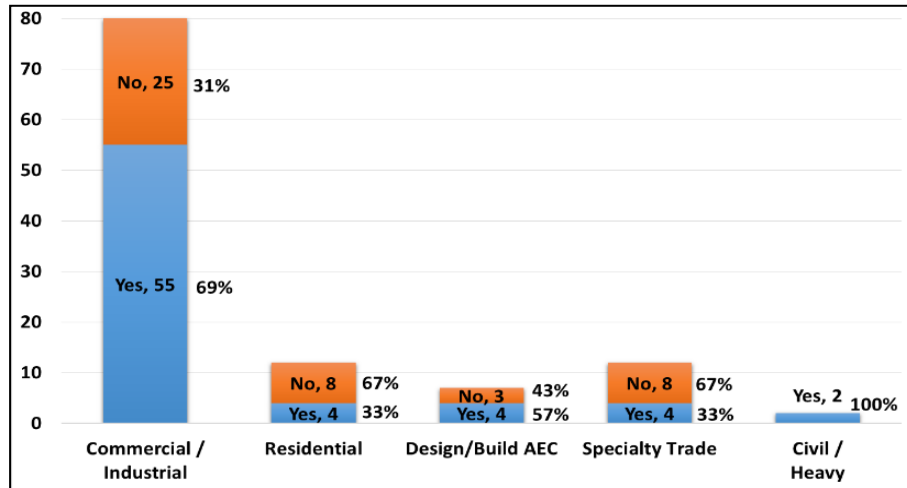


Figure 2 and 3: Survey Responses per Employee Population and Revenue Range

### Usages and Impacts of UAVs

The second group of questions in the survey collected data about the usages of UAVs by construction companies. Out of the 113 respondents, 69 respondents (or 61%) affirmed that their companies do use UAVs, while 44 respondents (39%) said that their companies do not use UAVs. The numbers are broken down by construction industry segment in Figure-4.



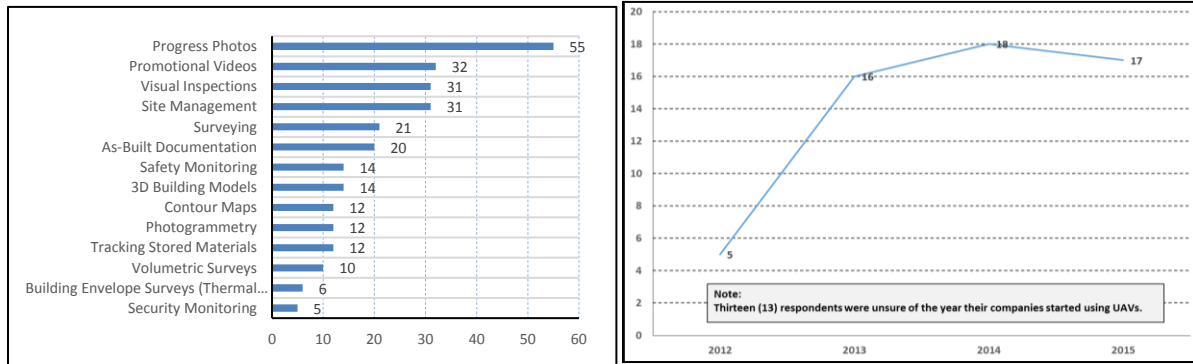
*Figure 4: Breakdown of Companies Using UAVs by Industry Segment*

In a follow-on question which was only posed to those who responded “No” to having used UAVs on their construction sites. Of the 44 responding “No” to having used UAVs, roughly half, 21, responded that their company had contemplated their use. 22 of the 44 have neither used UAVs nor contemplated using them on their construction sites. Thus, it was concluded that 90 of the 113 respondents, 80%, have either used UAVs on their construction sites or contemplated their use.

Of the 69 respondents that affirmed that their companies had used UAVs, 49 responded that in-house personnel are used to operate the UAVs (71%). According to current FAA regulations discussed earlier, construction companies using in-house personnel to operate UAVs would require a Section 333 Exemption granted by the FAA. However, the survey result shows that only 8 of the 49 respondents (16%) using in-house UAV operators knew for certain that their company had been granted an exemption. The other 84% either knew their company had not been granted an exemption or didn’t know for certain. This could indicate that either the FAA regulations are not widely known within the construction industry or construction companies are accepting the risk of FAA fines in order to use UAVs on their sites.

Construction companies have the option of subcontracting UAV services they desire rather than using in-house UAV operators, thereby shifting the risk of FAA fines for not having an exemption. According to the survey results, 34 respondents said that their companies use subcontracted UAV services. Reviewing the raw data for these 34 respondents reveals that 18 of them were among those that also use in-house UAV operators. This means that 16 respondents totally rely on subcontracted UAV services out of the 69 that use UAVs on their construction sites (28%).

Survey participants were asked to select their uses of UAVs from numerous options within the construction industry. Respondents were allowed to select as many uses that applied, plus they were allowed to respond with other uses if those uses were not, provided as choices. As seen in Figures-5, the most popular uses of UAVs on construction sites are capturing progress photos, then followed by taking promotional videos, conducting visual inspections, and enhancing site management.



*Figures 5&6: UAV Uses across all Sectors of the Construction Industry & Distribution of Year-of-UAV-Adoption*

Figure-6 presents the distribution of responses related to the year in which respondents' companies first used UAVs on their construction sites. The earliest known uses among survey participants occurred in the year 2012, when five respondents indicated that their companies started using UAVs. The next year, 16 respondents' companies started using UAVs. Little change was seen in the number of companies starting to use UAVs in the years 2014 and 2015, as the numbers were 18 and 17 respectively. The introduction of FAA rules related to small UAVs may have resulted in the slowdown of the adoption of UAVs from 2014 to 2015, but as companies become more familiar with the exemption process and the FAA rules, the trend of UAV utilization will likely see an increase.

Those 69 survey participants that answered positively to their companies having used UAVs on their construction sites were asked if using UAVs provided a cost saving or positive schedule impact to their projects.

- 36 of them (57%) indicated that using UAVs provided a cost avoidance to their companies, while 20 (29%) indicated no cost avoidance was experienced, and 10 chose not answer the question.
- 29 of them (42%) agreed that using UAVs has provided a positive schedule impact to their projects, while 30 of them (43%) indicated positive schedule impacts were not experienced and again 10 chose not answer the question.

#### Risks Related to Uses of UAVs

Survey respondents were provided an open-ended question asking them to identify any risks that were avoided by their companies through the use of UAVs on their construction sites. Of the 23 participants choosing to answer the question, 10 indicated that the use of UAVs allowed their companies to avoid risks to the safety of their personnel. Six participants said that information obtained through the use of UAVs allowed their companies to make more informed decisions, thereby avoiding the risk of making uninformed decisions. The other risks avoided because of the use of UAVs that were mentioned by the respondents included: loss associated construction cost and schedule (2 responses), losses associated with claims because UAVs provided supporting documentation for their companies (2 responses), and security risks (1 response).

Alternately, survey respondents were provided another open-ended question asking them to identify any risks that they perceived to accompany the use of UAVs on their construction sites. Responses were reviewed individually and separated into the categories shown in Figure-7. 69 participants chose to answer this question versus the 23 responses to the preceding question related to risks avoided. This most likely indicates that more risks are perceived to accompany the use of UAVs than those avoided by their use. 12 of the 69 responses indicated that no risks were perceived, leaving 57 identifying perceived risks. Top four of the identified risks are: 1) the risk of crashing the UAV, 2) the risk of causing personal injuries to employees or civilians, 3) the risk of privacy concerns, and 4) the risk of causing property damage (either on the jobsite or on surrounding properties).

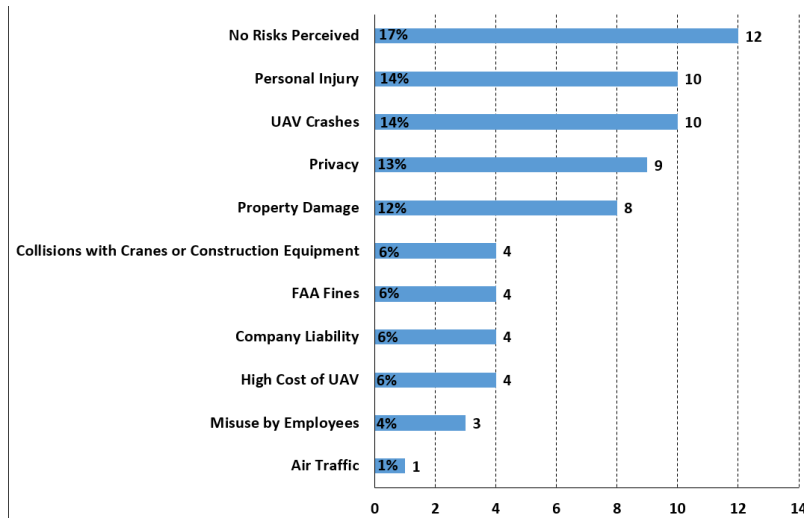


Figure 7: Risks Accompanying the Use of UAVs

#### Future Uses of UAVs

In order to determine potential future uses of UAVs on construction sites, survey participants were asked if their companies were contemplating any UAV uses for which the technology does not yet exist or is not fully developed. 54 participants chose to answer the question with 23 (43%) responding affirmatively. A follow-up open-ended question was then asked to determine the specific future uses being contemplated. Individual responses were reviewed to extract those that provided current uses already identified in the study. Responses providing a unique future application of UAVs were then tallied, as show below:

- Automated employee check-in/check-out
- Automated safety checks
- Scanning RFID tags on materials in laydown areas for inventory
- Material delivery
- Parts delivery
- Remote job walks
- Preview views from a building prior to construction
- Thermal scanning of utility scale PV plants.
- Interior missions

#### FAA Section 333 Exemptions Data and Analysis

The FAA database of Section 333 exemptions granted was downloaded from the FAA website into a Microsoft Excel spreadsheet. As of October 31, 2015, the database had 2,137 granted Section 333 Exemptions. A further search found that 190 granted exemptions were for missions related to the construction industry, which equals to approximately 8% of all exemptions granted.

As shown in Figure-8, the first company to be granted an exemption with a mission related to construction received their exemption in December of 2014. The second construction related exemption was granted in March of 2015. Since then, the trend has grown tremendously as the last two months (September and October 2015) have seen 81 exemptions granted for construction related missions.

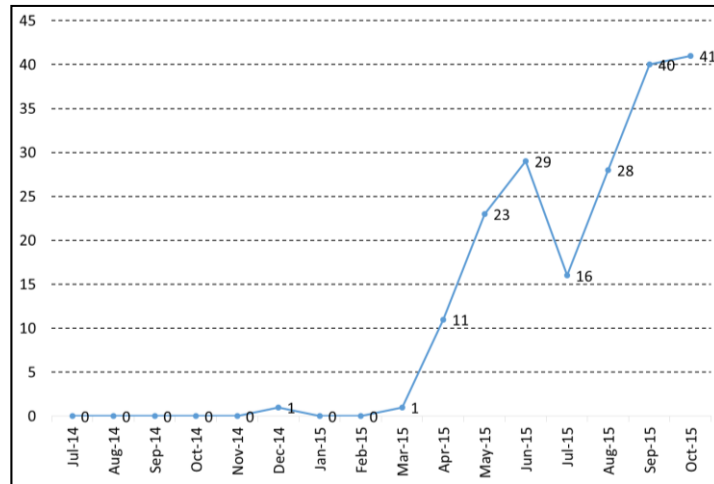


Figure 8: Construction Related FAA Section 333 Exemptions Granted by Month

### Conclusions

Commercial applications for UAVs are being developed across many industries, including building construction. The objectives of this research are to explore current uses of UAVs within the construction industry, to evaluate the extent of in-house versus subcontracted operation of UAVs by construction companies, to identify risks associated with using UAVs on job sites, and to identify future UAVs' uses on construction sites.

This research found that current UAV uses within the construction industry generally fit into four categories: 1) photography/videography, 2) surveying, 3) inspections, and 4) safety/security monitoring. Survey results of this research indicated that roughly 61% of the construction industry have started to use UAVs on their construction sites in some way. When the results were broken down into the various segments of the construction industry, the percentage seemed to hold true for the commercial/industrial segment, as roughly 69% of that segment were shown to have begun using UAVs. Adding those that have contemplated using UAVs on their construction sites to the number that are already using UAVs results in 80% of the industry.

Still photos and video are the main products produced by UAVs for construction sites, and the survey results indicate that these remain the most popular product types. Progress tracking and promotional materials, which are products of both still photos and videos, were the choices most selected by survey participants. Visual inspections and site management also received a high number of selections by survey participants. It also indicated that in-house operations are more prevalent than subcontracted UAV operations, as 71% of responses indicated that in-house personnel were used while 29% totally subcontracted with other companies to provide their UAV services. Data collected through questions in the survey concerning risk indicated that the construction industry perceives that a greater number of risks come with using UAVs than are avoided. Though 57% and 42% of responses indicate that UAVs saved their companies money and time respectively. Interestingly, the most identified risk avoided in the survey was the risk of personal injury, while personal injury was also among the most identified risks perceived to accompany the use of UAVs. Personal injuries avoided most likely involved UAV uses that removed workers from exposure to safety risks, such as replacing inspectors on scaffolding with photos and videos provided by a UAV or a surveying UAV replacing a human surveyor working near construction equipment. Perceived personal injury risks most likely included those caused by an off-course UAV or a UAV causing a distraction to workers on the site. This research found that construction companies are interested in the following areas for the development of future uses of UAVs:

- Automation

- Automated structural assembly
- Automated parts/material delivery

The number of FAA Section 333 Exemptions detailed on the FAA website revealed that only 8% of the more than two thousand companies explicitly describe their UAV missions as being construction related. These percentages and the advantages that UAV technology can offer to the contractors suggest that there is a large market for additional UAV service providers to expand their services into the construction industry.

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