Comparison of the supervisory cost of using an unmanned aerial system and conventional methods in construction projects

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Abstract. Unmanned Aerial Systems (UAS) are a growing aircraft technology being used in all sorts of industries. Despite studies exploring the potential applications of UAS, such as photographs or video collected by UAS, its benefits for the supervisory job on construction sites is not well understood. This paper presents a comparison of the supervisory cost generated using UAS and that from the conventional method. In this study, both five projects applying UASs and another five using the conventional supervisory method participated voluntarily. The survey used questionnaires targeted to people working in a supervisory job within the five projects. The results showed that most potential applications were particularly suited for tracking and monitoring job progress, evaluating safety monitoring and support, and inspecting difficult areas. In comparison, it was found that applying UAS was more cost-effective than the conventional supervisory method. The average supervisory cost to total wage generated from the project supervisory job by applying UAS and conventional methods were 0.212% and 0.450% respectively. Despite insignificant differences, the study provided a picture that, by applying UAS properly, it would be able to have a potential cost saving in the supervisory job in construction.

1. Introduction
In the rapidly changing world, technology has played an important and increasing role in the working environment of the people across the globe. The commercial goals of new technology development are to improve the cost-effectiveness of projects. In terms of commercial business, new technology can prove effective in a process or task by meeting the project objective. An example of a new commercially available technology popular both for work and entertainment is unmanned aerial vehicles (UAVs), well-known as a drone. The construction industry has used a drone to gain benefits in work supervision during the execution phase. A study by The Boston Consulting Group [1] reported that the construction industry represented one of the largest income generating sectors in the world.

Additionally, the study reported that drones have the potential to reduce costs and time for the inspection of large areas of construction sites, as evidenced by several cases mentioned in the study. In addition to the inspection, drone use has the potential to improve efficiency in a wide variety of other construction site jobs, including surveying, digital mapping, and volumetric analysis, as shown in several separate case studies [2]. Despite the limited use of drones in these projects, it could help...
decrease costs, increase productivity and efficiency at inspection or monitoring in the case of a live report, and would ultimately lead to higher profitability for construction companies [2].

The emerging technology known as unmanned aerial systems (UAS) is commonly used in the military, currently used as a toy for children, and functioning as a working device in construction [3]. The potential use of UAS as devices in working environments has been of interest in many businesses such as agriculture, archaeology, architecture, construction, forestry, and transportation. Indeed, government bodies, such as federal and state agencies in the United States, have operated UAS for security and surveillance purposes.

This study focuses on UAS (drone) as a supervisory device to compare the effectiveness of drone application and traditional methods in monitoring and inspection. The study aimed at 1) evaluating the current application of UAS in construction projects; 2) analysing the factors influencing supervising and monitoring a project using UAS, and 3) comparing the cost of monitoring and supervising using UAS and conventional (traditional) methods.

2. Literature review

2.1. Robotics applied in construction
The innovative business-oriented and competitive construction industry today requires automated and robotized system technology. The technology is needed for streamlining industrialized processes such as material production while constructing and installing prefabricated building components; on-site activities; building maintenance, renovation and retrofitting; and processing solid waste disposal. According to several sources in robotic technology, one popular use of robots in construction is the UAS, commonly known as a drone. This device is used to conduct monitoring and inspection during the construction process and also has flex time in working on site. In term of data collection, drones can work faster than either surveyors or aircraft, and also provide the same or better detail when the drone fly without disturbance or interruption in executing construction work. The advantages of using drones were that it made direct observations of the intended observed location. See Braunl [4]; Yukio [5]; and also Fassbender et.al [2]

2.2. The UAS (drone) vehicle
The drone is a type of intelligent machine that functions at a high level of autonomy, and while it appears attractive in operation, it combines technologies packed into its lightweight design. A drone typically consists of four, six or eight motors. Each motor has its own propeller, as well as several other components. A drone with four motors is known as a quad-copter, six motors is a hexacopter, and eight motors is an octocopter [6]. In general, a drone contains an on board GPS, so it allows the user to recognize the drone altitude and location, and it even logs the spot in case the drone needs to land unassisted [7].

The drone is also equipped with both “transmitter and receiver,” and “remote control” using radio frequency. While many drones provide manuals to control the operation, it is for a certain type of drone. Recently, more companies have also begun using apps on smartphones or tablets, which wirelessly connect to the drone via Bluetooth [7]. Regardless of the controllers, all drones are typically equipped with the same main pitch, yaw and roll controls. The yaw command can make the drone rotate (turn) left or right, the pitch command can order the drone to fly forward or backward, and the roll command can direct the drone from side to side [6]. Various functions of drones are able to perform complex tasks and contribute to the versatility of drone applications on sites in construction projects, see also Zack at Navigant.com [8].

2.3. Legal requirements in Indonesia related to the use of the drone
Recently, the use of drones become famous for entertainment and communication, not only as a toy for young people but also for children. On the other hand, the use of this tool can disturb aviation. Therefore, the Minister of Transportation of Indonesia established regulation no. 90 of 2015 as a guideline for using
drones [9]. The regulation aimed at 1) limiting drone operation in the flight area to only 150 meters, which can be increased by asking permission from relevant agencies such as the local police office, district government, and the transportation agency; 2) forbidding drone operation within the aviation safety operation area located near airports for aeroplane operations; 3) forbidding drone operation in the prohibited area, known as ring one of the airspace areas that can endanger aeroplane flight and 4) prohibiting a drone user from entering restricted airspace or areas. In addition, for international regulation practice, the certified flights granted for users must follow rules such as 1) remaining out of specific areas that affect air flight; 2) providing a secured ground area for society; 3) refrain from flying above individual property within urban areas; and 4) stay within the line of sight of a safety pilot of aeroplanes. See Canis [10].

2.4. The effective use of drones
According to Banik [11], contractors and consultants react unfavourably to spending additional money on providing drones. Simple drones would typically cost in the range of $100 or less and can complete some work. While these drones have a very favourable purchase price, they have significantly limited features. Complete drones features would cost around $1000. Drones require maintenance with spare parts due to items simply wearing out, crashes due to the operator error, mechanical failure, or fuel/battery issues. Another problem with drones is that their capabilities have limitations on flight-time, low payload issues and environmental issues. To be more useful, the drone needs the capability to carry a payload consisting of a camera, thermography detection unit, and other tools. Cheaper drones do not have this capability since it is severely constrained such that its camera payload is limited to producing low-quality photos.

2.5. Cost of UAS application
The application of UAS associated with its cost was vary since its legal requirement and the ability of the device to contribute many tasks in a construction project. According to Irizarry and Costa [12], several aspects associated with application cost should be considered, such as obtaining the required authorization for use, the price of UAS itself, training the UAS operator, paying a service to operate the UAS and insurance. Since UAS application was not only commonly spread in construction, but also be greatly varied from project to project. A detailed estimate of the costs that would apply to all projects has not been established. If UAS regulations were established and in place, the application related costs could cause change and perhaps some items of the cost would likely decrease. For example, the process of obtaining authorization for UAS application would be simpler under the proposed regulations and the operation cost would decrease. If the capability of operators were tested in a simple manner, such as only to take a written exam, would reduce the cost of obtaining a pilot’s license.

2.6. Common UAS applications in construction
The research reported by Opfer and Shields [13] stated that the contractors used UAVs also used other tools for the project applications. Additionally, UAS application was restricted since it can only see an item from its bird-eye perspective. While it could not practically replace a worker for every relevant task with a camera, it could supply much information about the progress of the construction project. In practice, the UAS can provide a multiplier in saving time for the inspection and supervision of a project and allowing work to be carried out with a remote-control camera. UAS applications could provide not only standard aerial photography but also include several important construction tasks such as inspection, productivity surveys and interference documentation related to the construction claims, see also Opfer and Shields [13] and Eschmann et al. [14]. For a company to implement the UAS supervisory concept in the project, it requires experience and education to implement. UAS supervision assisted a construction company in executing aerial supervision of a project, especially during the on-going stage. The supervisor role is to control the process of construction carried out by operatives and to determine the necessary action to overcome malfunctions generated by the devices, see Irizarry and Johnson [15] and Aerogeosurveyindonesia [16].
3. Methodology
A literature study was used to get as detailed information as possible about the use of drones in the construction world; the authors found five sources as benchmarks for this study. Research conducted by Yukio [5], Irizarry et.al [15], Zack [8] and Irizarry and Costa [12]. From these five studies, the authors developed an overview of the use of drones in the construction industry, as well as a reference in looking for data related to this research.

The primary data were delivered to the respondent office either directly or using email, while the secondary data, such as detailed workers, costs and current application type, obtained from the project. To examine the problem, the authors used questionnaires and interviews with several parties that participated in the construction sector. The data obtained from the questionnaire was the primary data. The instrument used in this research was adopted by Irizarry et al. [15, 17]. To identify the data, several steps were taken. After the questionnaire was filled out by the respondent, the completeness was checked. 1. Questionnaire completeness. 2. Relevance between the answer and the measurement standard to anticipate the misunderstanding toward the question prompt. 3. The data that categorized into valid conditions were identified using a spreadsheet. The data identification was conducted based on the group that already categorized in the questionnaire to make the analysis process easier.

In conclusion, the researcher would compare drone and conventional (traditional) supervision and monitoring, which can differentiate UASs and conventional (traditional) methods, perspective, current visual assets, cost, and time of construction project? The researcher also will suggest which supervision is preferred for the contractor or consultant, especially for a high rise building project in terms of reducing cost and time.

4. Result and discussion
4.1. General information
The number of questionnaires that were distributed is 30. They were sent to several construction companies that have a project on Yogyakarta, Makassar, and Jakarta. From the total surveys distributed, 14 questionnaires were returned and ten were required for this study. The ten questionnaires consisted of 10 construction companies. Distribution and collection of the questionnaire required approximately two months. Some of the companies rejected and did not respond to the questionnaire due to: i.e., company privacy, busy on their project, etc. There were ten cases, five that implemented the UAS partially, and another five that applied purely conventional (traditional) supervision. The respondents were placed in four groups based on their work experience. The respondents with the largest percentage were respondents with work experiences <5, 5 to 10 and > 15 years—30% for each group. Next, respondents with 10–15 years of work experience is 10%. The analysis of ten projects shows that most of the projects have five similar salary projects with costs from 3–6 Million Rupiahs for UAS Supervision, and the rest of the projects with the same salary had 3–6 Million Rupiahs. Some of the chief engineers were interviewed and reported that the salary for the UASs supervisor is the same as the conventional because the duty is the same, but there is an additional charge due to the ability operator obtain a Remote Pilot Airman Certification from FAA (Federal Aviation Administration) worldwide, but the Indonesia regulation is Indonesian Ministry of Transportation no 180: 2015 [9]. In addition to the regulation, the Indonesian Air Force also restricts the open flight area.

4.2. Current and future use of UAS
UAS application in a construction company varies. Each construction project has a specific method and function. The respondents show “does have” or “does not have” experience using UASs in their construction project, as shown below in table 1.

Drones have proven themselves to be a useful tool on the construction site had only one respondent. Fifty per cent of those surveyed who reported that they had used drones on projects reported it to be a success and very satisfied with both the experience of using a drone and obtaining quality results.
4.3. Comparison analysis of the cost of monitoring and supervision

The study of ten projects showed whether most of the projects had a similar salary range, five projects paid 3–6 Million Rupiahs for UASs Supervision, the other 5 projects with the same pay were 3–6 Million Rupiahs. From both methods, there was no difference in salary for supervisors or inspectors in term of UASs and conventional monitoring. Referring to the cost for supervision, some of the chief engineers interviewed said that the salary for the UASs supervisor is the same as the conventional because the duty is similar, but there is an additional in charge fee because the ability operator can operate and obtain a Remote Pilot Airman Certification from FAA (Federal Aviation Administration).

Table 1. Knowledge and experience of using a drone.

| No | Response                                      | Answer | (%) |
|----|-----------------------------------------------|--------|-----|
| A  | I know very well, and I have the experience to use it | 1      | 10% |
| B  | I know but do not have the experience to use it | 4      | 40% |
| C  | I am interested and studying it now           | 4      | 40% |
| D  | I only know the word UASs (drone)             | 1      | 10% |
| E  | No, I do not know it all                      | 0      | 0%  |
|    | Total                                         | 10     | 100%|

Regulations issued by Air Force Authority in Indonesia needed to be considered such as open area that restricted or prohibited for a flight for drone in open area. The operator must comply with regulations so as to not be fined due to operation of a drone in the project, see Aerogeosurvey Indonesia [16].

Table 2 shows that the number of respondents that answer questions about the number of staffs to implement UASs (drone) supervision: 2 to 4 staffs in projects is two (40%), 5 to 7 staffs are 3 answers (60%). For conventional supervision staff, four (80%) answered from 8 to 10 staffs, and only one project answered with more than 11 staffs.

Table 2. Total employees acquired for supervisory of two methods.

| No | Staff   | Partial UASs | Conventional |
|----|---------|--------------|--------------|
| 1  | 2−4     | 2 (40%)      |              |
| 2  | 5−7     | 3 (60%)      |              |
| 3  | 8−10    | 4 (80%)      |              |
| 4  | >11     | 1 (20%)      |              |
|    | Total   | 5 (100%)     | 5 (100%)     |

It was found that the need for conventional labour in the field of supervision is more than seven staff, as respondents in the conventional method did not often use any technological monitoring. On the other hand, for partial UASs supervision use, total staff of two (2) to four (4) is two answers (40%), five (5) to seven (7) is three answers (60%). Therefore, it can be inferred from this information that projects that applied a partial UASs method did not staff more than 5 to 7 people, mostly about 2 to 7 staff with this method. In the other hand, the projects that applied a solely conventional method usually had staff for supervision that could be more than eight people for monitoring. It can be concluded a project that already applied UASs technology could use much less staff than a project that still applied solely conventional monitoring.

4.4. Analysis of worker wage (total staff)

The total per cent mean supervisory cost of both methods was based on the planned and specified budget, see table 3. The highest total workers wage supervision was 0.853%, obtained from the total cost in Project 5. This project applied the conventional supervisory method and, from the data obtained, total
conventional workers for supervision in each Project 5 was 6 staff with the same 1095 working days. Then the lowest total for both mean percentages is 0.087% in Project 7, having 4 staff with the planned and specified budget working day of 365 days.

4.5. Comparison of cost between two methods

Supervision cost for both methods were based on the working experience of the respondents. The respondent who applied UAS were being aware of the cost components when applied to supervision such as to: 1) train the staffs, 2) conduct a study of UAS implementation in the company, 3) purchase UAS and obtaining license; and 4) establish the company’s UASs procedures or manuals in operation and maintenance. In the light of these awareness, respondents provided the supervision cost as shown in Table 3. It shows the comparison the total wage staff to determine which method is issuing more cost-effective financing. Calculating both supervisory wages showed that the average costs were 0.212%, and 0.450% for using drones and conventional, respectively. Note that the projects using drones should also be partially applied to conventional since the nature of building projects in interior works are difficult to access by the drones. From the result of the calculation shown in table 3, it also shows the difference in the total staff wages based on the planned and specified budget. Despite there were found different of average supervision cost for both methods, a test was carried out using independent samples t-test for comparing UASs and conventional supervision. Result obtained a probability of 0.113 from t-test indicating that there was no significant difference between the two methods.

Table 3. Comparison of worker wages cost using drones and conventional methods.

| No | Cases     | UASs (%) | Conventional (%) | Total Wage |
|----|-----------|----------|------------------|------------|
| 1  | Project 1 | 0.040%   | 0.117%           | 0.157%     |
| 2  | Project 4 | 0.054%   | 0.163%           | 0.217%     |
| 3  | Project 7 | 0.022%   | 0.065%           | 0.087%     |
| 4  | Project 8 | 0.034%   | 0.171%           | 0.203%     |
| 5  | Project 9 | 0.066%   | 0.329%           | 0.394%     |
|    | Average   | 0.339%   |                  | 0.610%     |
| 6  | Project 2 |          |                  | 0.196%     |
| 7  | Project 3 |          |                  | 0.164%     |
| 8  | Project 5 |          |                  | 0.711%     |
| 9  | Project 6 |          |                  | 0.196%     |
| 10 | Project 10|          |                  | 0.295%     |
|    | Average   |          |                  | 0.450%     |

4.6. Discussion of results

To address the first objective regarding identifying the current application of UASs in the construction projects, it was found that 1) most applications were aerial photography for tracking job progress, and 2) safety monitoring and support for safety and health at work in the construction projects for both Yogyakarta and Jakarta. The result regarding the usefulness of visual assets provided by UASs by most respondents showed that: 1) safety monitoring; 2) tracking job progress; and 3) inspection of difficult or impossible access by contractor areas have a high degree of advantage toward UASs on a construction project. The finding of this study indicates that there are some potential uses of UASs in construction management regarding visual assets including 1) monitoring project progress; 2) evaluating job site logistics plans; 3) monitoring safety conditions; 4) inspecting the quality of work performed among other secondary management tasks.

To address the second objective regarding identifying and comparing the factors influencing monitoring and supervision of the project using conventional and partial UAS tool use. Applying UASs
can be beneficial in reducing the time needed for documenting the progress of works such as 1) photos produced by the drone to be delivered to site; 2) no limit on the number of photos; 3) no limit on angle and elevation of view of the photos; and 4) can produce videos from a perspective and elevation similar to aerial photos. These benefits would need to be quantified financially for a more direct comparison to aerial and ground photography services. Also, UASs can provide flexibility in photography service times compared to traditional photo sessions. With an on-site based UASs, project workers are granted real-time access to on-site generated images and videos from many appropriate angles.

To address the third research objective regarding comparing the cost of supervision by UASs and conventional tools the results of the analysis showed that most projects have a similar salary, supervisory staff for both methods were paid a salary between 3 and 6 Million Rupiahs. From the interviews with some of the chief engineers, the UASs and conventional supervisory personal bore the same duty. Based on the results obtained from observation, the study concludes that UASs (drones) are more cost-effective than conventional supervision. The differences between both methods are significantly high in their expenses, with the total wage amount of Rp852,900.000 (1,187%) and average total wage amount of Rp170,580.000 (0,24%) for conventional and UASs supervisory tasks, respectively.

5. Conclusion and suggestion

5.1. Conclusion
In terms of the data, quality and costs factors are very important in construction project implementation for this study. This study found that UASs and conventional supervision has an effect or impact benefit and outcomes on data, quality, and cost factors due to obtaining visual assets. Specifically, the result means that factors have significantly impacted the project timeline, as well as the project, receive a very high return on investment.

In terms of factors in project implementation construction, the results indicate that UASs and conventional supervisors have effect benefits and outcomes on management aspect factors due to obtaining visual assets. It was found that the management aspect is more beneficial and with fewer outcomes in terms of obtaining visual assets.

The responses of contractors and consultants on usage factors were carried out using independent samples t-test for comparing UASs and conventional supervision. The study shows that there was no significant difference between two methods. These results indicate that UASs have increased benefits and outcomes on usage factors due to obtaining visual assets compared to conventional supervision. The study found that by implementing UASs on construction projects, not only could the contractors can increase the effectiveness of the job they perform but they could also reduce their return on investment for projects, all due to the innovation and usefulness of UASs.

5.2. Suggestions
Base on this study regarding UAS application in construction projects, there are some recommendations as consideration for further studies. 1) Research should focus on evaluating the financial implications in detail to determine what project characteristics could affect the financial feasibility of UASs in inspecting and supervising both for new building, and operation/maintenance. 2). The study would further include the impact of UAS application, the impact of the learning curve in the use of UAS technology by construction personnel, privacy concerns, and safety issues that may be related to the use of UAS technology on job sites. 3) UAS application is not widely used in construction stages and can greatly vary from project to project. Future research should observe supervisors operate a drone in a proper way and assess the performance of UASs for the tasks that may be considered feasible with UAS technology in the field. 4) UAS Applications seem to be more effective in infrastructure projects covering larger areas such as highway and bridge, dam, airport, seaport, and energy projects construction.
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