Using UAV-generated Visual Contents to Assess the Risk Perception of Safety Managers on a Construction Site

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Abstract

To avoid accidents on site, safety planning plays a crucial role in the construction domain. It consists of risk identification and making proper decisions about the safety measures required to be implemented during the construction phase. This safety planning process heavily relies on safety managers' risk perception capabilities. These capabilities would help safety managers to anticipate the accidents or incidents before they occur on the job site. Safety managers' risk perception capabilities are affected by variables such as years of safety experience, professional safety training, and more importantly the site information and the visual content used for safety planning (e.g., schedules, 2D drawings). One of the technologies employed for gathering visual information of the project sites is the Unmanned Aerial Vehicle (UAV), which is a generic type of aircraft designed to operate without a human pilot onboard. UAV can be deployed to send visual information (e.g., photos and videos) of the job site and specifically inaccessible, hard-to-reach, or unsafe locations on the site to the safety managers, faster and more efficiently. These types of visual information can be transformed through a photogrammetry process into point cloud data (PCD) and then be used to generate an accurate 3D model of a site that provides very detailed and comprehensive view of a project site. In this case study project, we focus on how visual content generated by UAVs (including photos, videos, PCDs, and 3D models) can affect the risk perception of safety managers. A comparison between the UAV-based safety monitoring process vs. the traditional one (using conventional information) was conducted in a case study in Chile and risk perception of safety managers under both methods were evaluated. The study concluded that the use of UAV allows to identify more hazards and increases the safety managers' perception of severity, probability, and risk level of hazards on site.

Keywords: unmanned Aerial Vehicle (UAV), Safety, Risk Perception, Construction

1. Introduction

The number of accidents and deaths continues being a problem that needs to be eradicated from the industries around the world. One of the sectors that present the highest rate of accidents is construction (M. Zhang et al. 2013). Approximately, the accident rate in this industry is four-time higher than the average of other sectors. Because of that, safety has become one of the essential aspects of many construction projects. In Chile, a study conducted by the Superintendencia de Seguridad Social (2017) suggested that during 2017, the rate of accidents in the construction industry was 4.1 per every 100 workers. In the same year, 44 workers died on the job; this represents 20% of all the deaths occurring across different industries. The leading causes of workers' deaths were falls (36%), struck by objects (8%), electrocution (7%) and caught-in/between (6%) (Superintendencia de Seguridad Social, 2017). These hazards led to an average of 23.4 working days lost for each accident during the year (Superintendencia de Seguridad Social, 2017).

The construction industry is characterized for generating low-severity accidents with higher frequency, and additionally, have several sources of risk (Zhou et al. 2015). Because of that, several construction companies consider safety management as one of the main factors associated with reducing costs for work-related accidents and injuries (Hinze, 2002). It consists of a series of steps such as hazard identification, risk assessment, and risk management, each one considered key for the success of the projects. Beside of this, hazard identification activities are carried out to identify and localize the sources of hazards et al. 2013), risk assessment provides indexes that support decisions about how to manage (Lee et al., 2012) and risk management combines efforts to manage risk through risk estimation, risk evaluation, and risk-based decision making and design improvement (Khan et al. 2015).

A factor that directly affects the hazard identification and safety monitoring is the safety manager's risk perception capabilities (Zuluaga et al. 2016). Gürcanli et al. (2015) defined it as a subjective judgment that people make about the frequency and severity of risks. The perception is usually measured by surveys that are applied individually to professionals and workers in order to evaluate scenarios with specific risks. Improving the perception is essential due to several injuries have been linked to poor hazard recognition and safety planning (Khan et al. 2015).

The risk perception depends on variables such as experience, training, and the quantity and, quality of visual information available, among others (Namian et al. 2016). Generally, the safety manager use project technical information such as 2D plans, schedules, and photos to identify and assess the potential risks and its consequences, in other words, traditional method (Zhang et al. 2015).

One of the technologies employed for gathering visual information on the site is the unmanned aerial vehicle (UAV), which is a generic type of aircraft designed to operate without a human pilot onboard. A UAV can be deployed to send visual information (e.g., photos and videos) of the job site as well as inaccessible, remote, unsafe, or hard-to-reach locations to the safety manager faster and more efficiently and help with safety-related data collection and decision-making processes. The job site photos and videos captured by a UAV can also be transformed through a photogrammetry process into point cloud data (PCD) and then be used to generate a 3D model that offers a complete view of the job site from different visual perspectives.

This study presents a case study conducted in Chile where we compare the traditional method with the UAV-based method of conducting safety planning and monitoring on a construction site in Chile and evaluate the risk perception of safety managers using both methods. It is envisioned that a UAV-based approach might allow the safety managers to improve their risk identification process and reduce the manual efforts to capture data that are utilized to measure hazard indicators during the construction phase

2. Research Method

For this research project, a case study strategy was adopted. It consists of detailed observation of a case subject to identify practical problems and situations. Using this methodology, it is possible to capture the complexity of a single case and potentially generalize the results to other conditions or circumstances (Rolf Johansson, 2003; Yin, 2009). The research was conducted in a residential location in Santiago, Chile. This project was a high-rise residential building which included four 23-story and two 6-story buildings with a land area of 16,850 m^2. This project was selected because of its safety monitoring complexities and challenges due to work conducted at a high altitude and a congested area with a very limited number of safety managers on board. Two safety planning approaches were used in this case study, and safety managers' risk perception was assessed and compared under each method. The research method consisted of the following three steps:

(1) The Traditional Method consists of developing the safety planning process using project and job site information such as plans, schedules, and photos. Safety managers use such information to determine possible risks and assess their probabilities and consequences. For the research purpose, technical plans, and weekly schedule that were implemented during the construction stage were used. The safety managers used these contents to evaluate the possible risks and assess their probabilities and consequences on the same site.

(2) The UAV-based Method consists of developing the safety planning process using project and job site information that was previously used in the traditional method together with visual content captured by UAVs such as photos, videos and generated 3D models. Then, safety managers use the data generated by UAVs to determine the possible risks and assess their probabilities and consequences on the same site. The 3D models generated are part of the data set used to evaluate the safety managers risk perception, together with photos and videos captured by the UAV. During the data collection, the job site was photographed to obtain horizontals and oblique photos and after that transforming into job site 3D models through photogrammetry technique using the software Drone Deploy. These processes were conducted during the five job site visits. The parameters used to process the 3D models are also elaborated in Table 1

(3) Traditional vs. UAV-based Comparison: Traditional based method and the UAV-based method were compared to determine the safety manager risk perception in both scenarios. The variables evaluated and analyzed for the comparison were as following:

- **Severity** indicates the level of consequence generated by an accident measured in scale of no injured to fatal injured were evaluated using a scale from one to five, where five in the case of accident severity is No Injury, and one is Fatal.
- **Probability** of occurrence refers to the possibility that an unwanted event occurs and can produce consequences. It is measured in the scale of infrequent to frequent
- **Risk level** is the multiplication of the probability that occurs an unwanted event and the severity level. It is measured in the scale of very low to very high-risk level was implemented.

3. Data Collection

A total of five visits were conducted for both traditional and UAV-based methods. Figure 1 shows the project status during each visit.

Site Visit #1	Site Visit #2	Site Visit #3	Site Visit #4	Site Visit #5

Figure 1: Site Visits

For the data collection process, the project team followed the flight regulations established by the Dirección General de Aeronáutica Civil (DGAC) that control UAV flights in Chile. Under the standard DAN 151, the general requirements indicated are the following (Dirección General de Aeronáutica Civil, 2015):

(1) UAV should be registered in the DGAC portal,
(2) UAV pilot should be licensed to operate the vehicle for professional purposes,

(3) the maximum allowable altitude is 130 meters above ground level, and
(4) the maximum allowable operating horizontal distance between the UAV and the pilot is 500 meters.

To collect the data a DJI Phantom 4 Pro UAV was selected. It was chosen due to the quality of its camera, its battery life and included sensors that allow for making safer flights near objects such as cranes, trucks, scaffolds, and guardrails on the project site. This UAV has a camera lens with an 84° field-of-view and with a 1-inch 20-megapixel sensor capable of shooting 4K/60 fps video at 100 Mbps (DJI, 2017).

DJI Phantom 4 Pro

Pilot conducting the flight Data Collection

DJI Phantom 4 Pro on the site

Figure 2: UAV Platform and Data Collection on Site

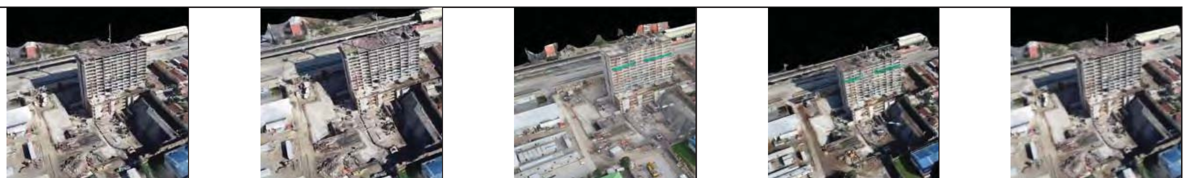
The next table show the amount of data collected during this process:

Table 1: Data collection

Parameters (Unit)	Site Visits				
	#1	#2	#3	#4	#5
Building height (meters)	60	63	66	66	66
Flight height (meters)	76	75	73	73	73
Flight start time (24 hr)	12	14	10:30	10:30	10:30
Flight duration, for taking pictures only (min:sec)	8:42	10:18	15:03	15:03	15:03
Frontal overlapping (%)	79	79	82	82	82
Lateral overlapping (%)	84	84	82	82	82
GSD resolution (centimeters/pixel)	2.3	2.2	2.0	2.0	2.0
Flight speed (meters/second)	15	15	15	15	15
Number of photos	122	161	267	267	267
Number of additional vertical photos	15	15	15	15	15

Parameters (Unit)	Site Visits				
	#1	#2	#3	#4	#5
Flight duration, for taking videos only (min:sec)	34:34	42:12	45:45	42:23	38:21
Weather conditions	Cloudy	Sunny	Sunny	Sunny	Cloudy

A total of 46 video clips and 1159 photos were captured throughout the five site visits to generate the 3D point clouds using Drone Deploy's ® photogrammetric capabilities. Drone Deploy is a cloud-based system that allows for sharing its outcomes with other groups involved through the web and allows for the development of point cloud data through a cloud-based photogrammetry process. To improve the quality of the generated 3D model, fifteen frontal and vertical photos were added to the photogrammetry process to increase the visual content overlap on the sides of the building. The models created were carefully reviewed to minimize visual inconsistencies produced by insufficient horizontal and vertical overlapping, photo set quality or moving objects. Because of that, these models offered an accurate representation of the job site and, provides a complete view from different visual perspectives of them. In total, five 3D models were generated after the end of each site visit (see Figure 3).



Site Visit #1	Site Visit #2	Site Visit #3	Site Visit #4	Site Visit #5

Figure 3: 3D models developed after each site visit

4. Comparative Results and Discussion

Two safety managers with nine and seven years of on-site risk prevention experience were in charge of safety inspection and monitoring for this project. At the end of each week of data collection, the safety managers were asked to examine construction documents (plans and schedule) and a set of photos, videos, and 3D model took at the job site. First, the traditional method was evaluated, and then after around thirty minutes, UAV-based method was assessed. The risk perception evaluation of each method took around one hour. As a first step of the research, the number of hazards identified was determined using the traditional method and then the UAV method. After this, the severities, probabilities of occurrence, and the risk levels of the identified hazards were determined, and these quantities were averaged utilizing both methods. The following table shows the results consolidated:

Table 2: Risk perception data analysis.

Variables	Site Visit #1		Site Visit #2		Site Visit #3		Site Visit #4		Site Visit #5		Average	
	Traditional	AV	Traditional	AV	Traditional	AV	Traditional	AV	Traditional	AV	Traditional	AV
Hazards identified (#)	19	22	16	18	22	26	15	19	17	21	17.8	21.2
Severity	3.3	3.5	2.9	3.1	3.7	3.6	3.2	3.3	2.8	2.9	3.18	3.28
Probability	3.8	4.1	3.3	3.6	4.1	4.2	3.5	3.7	3.2	3.5	3.58	3.82
Risk level	3.7	3.9	3.6	3.7	3.9	3.8	3.4	3.8	3.1	3.6	3.54	3.76

Regarding identified hazards, the use of UAV-based methods allowed for the identification of more hazards than the traditional method. On average, using this method, it was possible to increase the number of identified by up to 19% hazards in the workplace. Figure 4 shows some examples of the identified hazards in the UAV-based method.

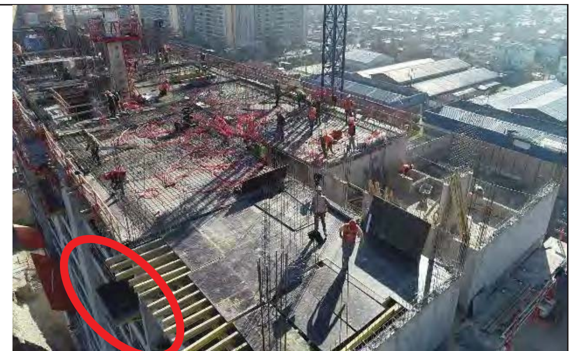
	
A worker in close proximity to openings and edges	Lack of guardrails
	
Worker without safety rope	Lack of guardrails

Figure 4: A few hazards identified in the visual content captured in UAV-method

On the other hand, the severity assessment using the UAV-based method for all the identified hazards increased compared to the traditional method by up to 3%. The probability of occurrence of the identified hazards, as with the other variables, increased by 7% using the UAV-based method due to the safety managers' access to a job site panoramic view using the 3D models generated by the UAV. Finally, the risk level increased by 6% on average using the UAV-based method (except for site visit # 3).

Focusing only on safety hazard types, it was noticed that using UAV-based method; the safety manager could better identify the following unsafe conditions and safety measures:

- Lack of Guardrails (Fall Hazards): The 3D models generated by UAV provided a very precise representation of the job site status and allowed the safety managers identify the presence and assess the proper installation of the guardrails through accurate measurements directly in the captured models.
- Lack of Safety Nets (Fall Hazards): Safety Nets are usually located in hard-to-reach zones (e.g., top of the buildings) where it is hard, unsafe, or impossible for safety managers to visually inspect. The visual contents captured by UAVs (especially videos and images) allowed the safety managers to identify the areas such as unprotected exterior boundaries of slabs or balconies that might be required to be protected by safety nets as well as inspecting the proper installation of current safety nets and their proper coverage of the targeted areas
- Moving/Falling Objects (Struck-by Hazards): The aerial images captured by the UAV allowed the safety managers to see better the moving objects (e.g., tower cranes or machineries) or

objects with potential to fall (e.g., loose or unsecured material at height) that might create potential struck-by hazards on the jobsites.

- Lack of Personal Protective Equipment (PPE): The aerial videos captured by the UAV allowed the safety managers to detect several violations regarding improper or lack of personal protective equipment (PPE) and safety harnesses use on the site including several unsafe acts such as not wearing the hard hats or safety glasses.
- Evacuation Route: The aerial images and the 3D models generated by UAVs allowed the safety managers to identify areas without proper evacuation route demarcation.

5. Conclusions

The primary objective of this study was to compare the risk perception of safety managers using traditional and UAV-based safety monitoring processes considering variables such as the number of risks, severity, probability of occurrence, and risk level using a case study in Chile. The case study results showed that the adoption of this technology as a tool for safety planning and monitoring allows for better identification and evaluation of hazards compared with the traditional method. The case study demonstrated that the use of UAVs allows for the identification of up to 19% more hazards during the safety planning stage. Furthermore, safety monitoring using UAVs automates the efforts of capturing proper onsite information and allows for frequent monitoring and safety challenge measurement on site. To properly apply the technology, the safety manager needs to establish the flight plans to collect the appropriate amount of data required for their safety monitoring process. Currently, fully automating the manual onsite observation with UAVs is difficult due to aviation regulations and limitations, weather conditions, and the limited UAV flight times. Using UAVs for safety monitoring on the job site is at a very early stage of development and implementation, and further studies on the legal, financial, safety, as well as hardware and software development aspects of UAVs, needs to be conducted for the successful implementation of UAVs to facilitate safety monitoring on construction job sites

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