Qualitative and Quantitative Risk Analysis of Unmanned Aerial Vehicle Flights over Construction Job Sites

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***Abstract*—Unmanned Aerial Vehicles (UAVs) have been used on construction job sites for a variety of purposes for more than a decade. But the risks and hazards of flying UAVs on construction job sites has never been quantitatively or qualitatively evaluated. While the general aviation industry has been using sophisticated analysis techniques to quantitatively assess the risks of general aviation industry flights over the general population for decades, the risks of UAV flights over this group has never been quantitatively assessed. UAVs are being used in construction activities on a regularly without proper risk assessment. There is no action plan in place, by either construction managers or safety officers, to design UAV flights based on safety measures. This paper presents the first known quantitative and qualitative analyses of UAV flight risks for construction job sites. A quantitative model for UAV flight risk assessment is presented and tested, using the Monte Carlo simulation technique, for an actual construction job site. A qualitative risk assessment of UAV flights is also presented by combining the Federal Aviation Administration (FAA) rules, regulations and guidelines concerning UAV flights, with the safety needs and specifications of UAV flights on a construction job site. The techniques introduced in this paper can be used by construction managers and safety officers to take safety into account when planning UAV flights over construction job sites. This paper further argues that using techniques and methods introduced in this research paper could potentially make UAV flights in any environment safer and more reliable.**

Keywords-Unmanned Aerial Vehicle, UAV, Monte Carlo Simulation, Risk Assessment, UAV flight risk

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have been used in the construction industry for over ten years [1]–[3]. The versatility of UAVs enables users to capture different types of data (typically visual) easily from angles which might not be possible without such a device. The relatively low cost of new generations of UAVs along with the possibility of having different sensors attached to them, such as high resolution and thermal cameras, RFID readers, and laser scanners, have played a crucial role in their proliferation in construction research and practice. The applications explored for using UAVs in construction includes construction progress monitoring [4], [5], overall site monitoring [6], structural health inspection [7]–[11], surveying job sites and building 3D models [12], infrastructure asset management [13]–[16], urban monitoring [17], material tracking [18], sustainable energy production management [19], and construction safety [20]. The applications and use of UAVs have increased exponentially while the safety risks associated with UAV flights have not been studied thoroughly.

As a general approach, the risks associated with flying UAVs over a job site can be divided into two categories:

1. *direct hazards*, such as the falling of the UAV and falling debris from a collision of a UAV with other objects [21][22]; and
2. *indirect hazards*, such as the invasion of personal space [23][24], diverting the attention of workers due to the UAVs' sound and motion (thereby increasing their cognitive load while performing their tasks [25]–[27]), and invasion of a workers' personal space [28].

The construction industry is often critiqued for its high rate of fatalities and poor safety record. The total number of work-related fatalities in the United States in 2015 was 4,836, 20% of which occurred within construction (more than any other industry). From construction, falls, slips and trips are the highest cause of fatal incidents, with 364 cases. Transportation incidents were the second highest cause (with 226 cases) and contact with objects came third (with 159 cases) [29]. These statistics show the importance of the role of equipment in construction safety and establish the need for better monitoring and regulation of their use. Safe use of construction equipment, such as excavators, loaders, and cranes has been thoroughly regulated due to prolong use in construction. In contrast, new equipment introduced to the job sites, such as UAVs, do not have specific regulations in place for managing their safety in use. Flying UAVs can be challenging in any environment. Construction job sites are dynamic systems that are constantly changing. These constant changes could make flying UAVs even more challenging, potentially introducing more hazards to construction activity. The lack of a comprehensive qualitative and quantitative methodology for risk assessment of UAVs on construction sites coupled with a rapid increase in their use poses a new safety threat that requires attention. This paper proposes and evaluates quantitative and qualitative approaches for modeling the safety risks related to UAV flights over construction job sites. The method is applied to a case study from a building project at the University of Florida to demonstrate the methods application and significance.

This paper is organized as follow. In Section 2, rules and regulations regarding UAV flights in the United States are presented. Section 3 discusses the risks of UAV flights. Section 4 introduces the use of Monte-Carlo simulation for modeling uncertainty in the flight path environment. Section 5 presents a quantitative application of risk assessment of UAV flights in a case study. The last section concludes the study with a discussion of the results and of a simple qualitative approach to UAV flights risks within construction.

II. RULES AND REGULATIONS GOVERNING UAV FLIGHTS IN THE UNITED STATES

In the US, the Federal Aviation Industry (FAA) is the main agency for managing civil aviation. The FAA regulates the Unmanned Aerial Systems (UASs) (a broader category for UAVs) flights by dividing the UAV uses into the following two main categories: (1) fly for hobby purposes and (2) fly for commercial use. UAS Flight rules issued by FAA are as follow [30][31]:

A. *Fly under the Special Rule for Model Aircraft (Section 336)*

- Only used for entertainment or hobby purposes.
- The model aircraft need to be registered.
- Follow community-based safety guidelines and fly within the programming of a national community-based organization.
- The weight limit of the aircraft is 55 lbs., unless certified by a community-based organization.
- Flying range cannot exceed visual line-of-sight.
- Never fly near other aircraft.
- The airport and air traffic control tower must be notified in advance if a model aircraft is flying within 5 miles of an airport.
- Never fly near emergency response efforts.

B. *Fly under the FAA's small UAS Rule (Part 107)*

- Fly for recreational or business use.
- The drone must be registered.
- Require a remote pilot certificate issued by the FAA.
- Weight of drone under 55 lbs.
- Flight speed at or under 100 mph.
- Flying range cannot exceed visual line-of-sight.
- Never fly near other aircraft or over people.
- Do not fly in controlled airspace near airports until you get the permission from FAA.
- Fly only during daylight or civil twilight.
- Flying height limit is 400 feet.
- Never fly from a moving vehicle, unless in a sparsely populated area.

Generally, to simplify the most critical aspects of these rules, this paper makes the following assumptions: (1) the construction site used as the case study is not close to the 5-mile radius of any airport; (2) all UAV flying regulations are being followed; (3) UAV flights are taking place within the line-of-sight of the pilot; (4) UAV specifications comply with FAA regulations, and more importantly (5) UAVs are not flying through the space over people's heads for safety consideration. These assumptions are specifically highlighted in the qualitative risk analysis that is provided in the discussion and conclusion sections.

III. RISKS OF UAV FLIGHTS

A. *Quantifying Risks of UAV Flights*

Quantifying risks associated with UAV flights over construction job sites is a crucial factor in determining the safety of UAVs flights over construction project zones. By having a quantifiable analysis of UAV flight risks, construction managers and superintendents and in general decision makers in this industry, based on reliable metrics, are able to assess the extent of risks related to UAV flights. Also, a quantifiable risks analysis of UAV flights will give insurance companies a better insight into the value, extent and severity of risks associated with UAV flights on construction job sites. In this paper, based on the Clothier and Walker [22] approach, the authors define a model to measure and describe ground fatality expectation. The model only measures and enumerates the risk of expected ground fatalities based on falling UAVs or falling debris.

While this model quantifies the direct risks of falling UAVs, or debris, it does not consider the indirect risks associated with UAV flights. Some of the indirect risks that are not considered in this model but could have a significant impact on the general risks of UAV flights are: (1) threatening workers' personal space, (2) threatening privacy of workers and (3) potential distraction of workers due to noise and motion.

Clothier and Walker [22] formalized the ground fatality expectation model as below:

$$SO = MR * \varphi * AL \qquad (1)$$

where: SO is the safety objective in terms of the number of fatalities per flight hours; φ is the population density of the area under the flight path of the UAV; AL is the lethal area, which is determined by the circular area of the maximum length of UAV diameter plus a (safety) buffer; and MR is the mishap rate, calculated according to (2).

$$MR = SFR + MC\mathit{Debris} + Other \qquad (2)$$

where: SFR is the system failure rate per flight hour; MC*Debris* is the quantity of debris from a possible midair collision per flight hour, and *Other* is the other hazards that might result in fatality risks.

Based on [1], the fatality rate, which is expected in the industry of common air travels, is generally bounded to $1*10^{-06}$ or in other words one casualty for every million flight hours. However, due to a lack of data about the causalities, fatalities and injuries caused by UAVs around the world, it is not possible for the authors to establish a fatality rate for UAV flights. For this reason, the same safe rate of fatality as the general aviation industry (one in a million flight hours) was adopted.

B. *Qualitative Risks of UAV Flights*

As discussed in Section 2, FAA established a series of general rules and regulations for UAV flights within the national air space. Two of these rules and regulations are specifically important for the construction industry: (1) never fly a UAV out of the pilot's line of sight and (2) never fly a UAV over a populated area, which means that it is illegal to fly a UAV over people's heads. Based on these specific regulations, the authors developed a qualitative safety map for UAV flights over the job site that has been used as a case study in this research and is presented in the analysis section.

IV. USING MONTE CARLO SIMULATION AS A RISK ASSESSMENT METHOD

Risk and uncertainty are prevalent throughout every construction project [32]. It is necessary to conduct quantitative risk analysis to evaluate failure and safety risks to provide a platform as a means of decision making. A dichotomy of risk assessment techniques is into deterministic and probabilistic methods [33]. Deterministic methods ignore uncertainty, while probabilistic methods are able to take into account unexplained variances in factors as diverse as time, weather, spatial demands, and labor performance [34]. Due to the fact that in this study, several uncertainty elements including behavior of the UAVs and the work area conditions are part of the assumptions, a probabilistic method was adopted. The Monte-Carlo method is a commonly adopted probabilistic technique in the construction industry due to the high levels of uncertainty and the large financial investments in this type of work [35]. Mooney [36] defines Monte-Carlo simulation as a computerized mathematical approach that enables researchers to perform quantitative risk analysis through a decision making process. The approach replaces point estimates with random variables drawn from representative probability density functions [37], refining the results through a large sampling of possible outcomes [38]. Occupational safety and health risks and associated hazards can be modeled using Monte-Carlo by considering the stochastic nature of the problems[39]. Baudry [40] suggested using a range-based Multi-Actor Multi-Criteria Analysis as a scenario that addresses the group decision making under high uncertainty, to consider different viewpoints of the stakeholders. Later, the binocular optical axis parallel detection method was used by Ying [41] to analyze the error factors and establish a model based on Monte-Carlo simulation. Applying this method, and given different values for corresponding coordinates, the analysis is conducted [41]. Podgorny [42], using a Monte-Carlo based model, examined three-dimensional radiative transfer over inhomogeneous surface albedo including open water, sea ice, and melt ponds by flying UAVs over these areas The goal of this study was to investigate the influence of surface feature erraticism on the energy budget of the lower troposphere ice–ocean system. Also, Monte-Carlo simulation has been used to determine and examine the active relationship between the factors leading to an accident and the recompense paid for it [42]-[44]. In a real-time location-based Monte Carlo simulation, Li et al. [45] used historical data to forecast the safety hazard level on a separate level based on time and position. On construction job sites, small UAVs require safety consideration due to uncertain operational conditions, such as their weak structural shape that may cause instability and failure in windy weather, their potential for operational errors, as well as their high maneuverability and potential for mechanical failures. Recently, Plioutsias et al. [46] concluded in a research paper that current commercial UAVs are far from being able to meet safety requirements. To simulate collision and other hazards between one or multiple UAVs operating on construction sites and their bordering area, the Monte-Carlo simulation method offers both flexibility and potential accuracy in modeling. This method is playing an important role in modeling uncertainties, such as the movement of different kinds of object on a construction site and environmental factors, such as wind [47]-[50].

V. ANALYSIS OF THE CASE STUDY

A. *Analysis of Quantifying Risks of UAV Flights*

In this section, a Monte Carlo Simulation is used to assess the risk of flying UAVs over construction job sites, which is referred to as the Safety Objective (SO) as described by (1) above. Mishap Rate (MR), the Lethal Area (A_L) and the density of population (φ) are needed to find the SO in each area. MR is the variable with the least empirical data as there is not much information recorded on the MR of UAVs. In this analysis, it is assumed that the UAV lifetime, or the duration over which the possibility of a crash exists, is normally distributed, with a range between 100 hours and 10,000 hours, a mean of 5,050 hours, and standard deviation of 1,650 hours. MR is referred to as the rate of failed UAV flights in a given flight hour lifetime for a UAV. In this case, the normal productive life of a UAV is estimated to be in this range. As a result, MR is calculated as one crash in a UAV's lifetime: 1 / (lifetime of UAV in flight hours).

A_L is the area that has the potential for lethal impact from the UAV or debris if the UAV crashes. Typically, it is calculated by using the longest dimension of a UAV. In this case, considering the fact that most of the UAVs flying over construction job sites are commercially available, it is presumed that A_L can assume a value between 0.3 m and 1.8 m. Thus, an even distribution across a diameter with a minimum of 0.3 m and maximum of 1.8 m is used in the simulation. The density (φ) represents the number of personnel on the site divided by the area of the location that a UAV flies over. In this study, it is assumed that only construction workers are present at the job site. Due to a lack of empirical data it is estimated that the number of construction personnel on the job site varies between 2 and 14 with a normal distribution (a mean of 8, a standard deviation of 2). The density is calculated for Area 1 to Area 4 by dividing the sampled number of construction workers for each zone by its area. The area of each location that a UAV can fly over is calculated and shown in Figures 1 and 2. The area surrounding the job site is divided into Area 1 through Area 4 using the logic of FAA regulations regarding safe UAV flights, which prohibits UAV flights over head of people, in this case construction personnel.

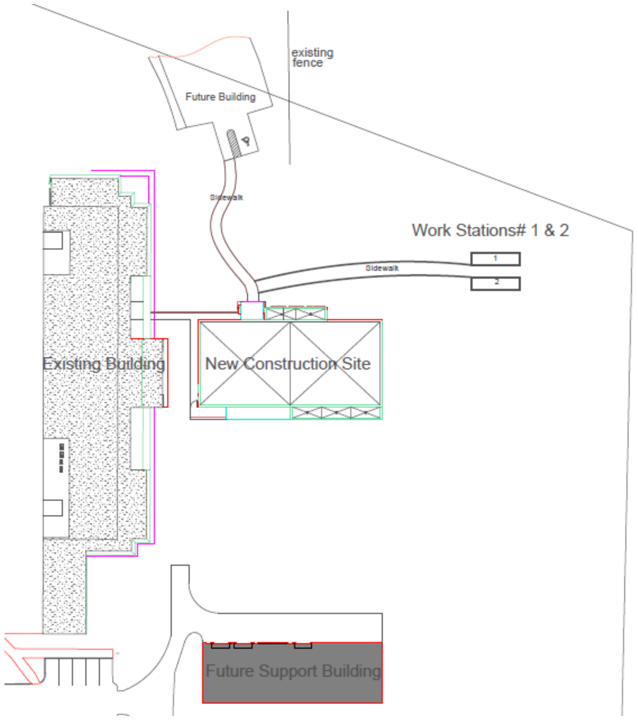

Figure 1. General layout of the construction site

Thus, considering the pathways that construction personnel routinely commute between work stations and the job site, four separate areas are drawn as separate areas that UAVs can fly over. Due to these regulations, UAVs cannot fly from one of these areas to another because they need to fly over a construction personnel pathway, which is prohibited by FAA regulations. A Monte Carlo simulation was run using the Palisade @Risk 7.5. The number of simulation iterations was controlled for convergence of the mean and standard deviation of the SO (safety objective) results for each area. The simulation was run until it reached convergence with 95% confidence and 5% tolerance. The convergence was checked every 600 iterations. The simulation reached convergence at 174,000 iterations. The results of the Monte Carlo simulation are summarized as follows:

- Area 1 (Figures 3 and 4):
    - Mean: 2.746E-006
    - Mode: 2.634E-007
    - Median: 1.900E-006
    - Standard deviation: 2.716E-005

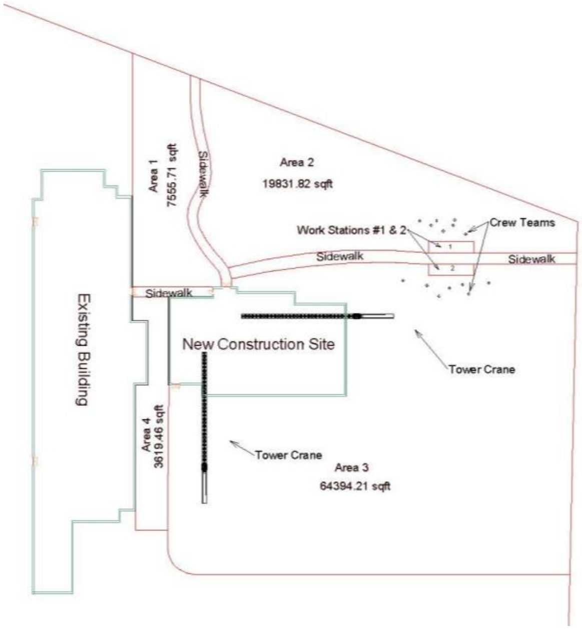

Figure 2. Simplified layout for analysis

- Area 2 (Figures 5 and 6):
    - Mean: 1.042E-006
    - Mode: 8.349E-008
    - Median: 7.248E-007
    - Standard deviation: 1.029E-005
- Area 3 (Figures 7 and 8):
    - Mean: 3.217E-007
    - Mode: 3.078E-008
    - Median: 2.232E-007
    - Standard deviation: 3.414E-006
- Area 4 (Figures 9 and 10):
    - Mean: 5.670E-006
    - Mode: 5.512E-007
    - Median: 3.972E-006
    - Standard deviation: 5.328E-005

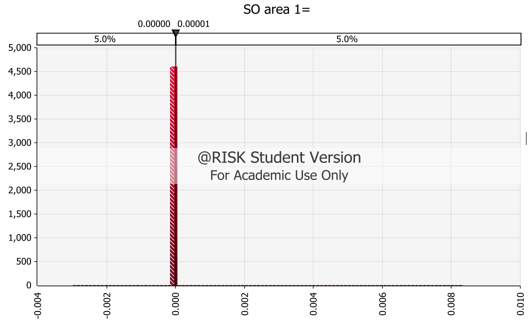

Figure 3. SO result of area 1 from simulation

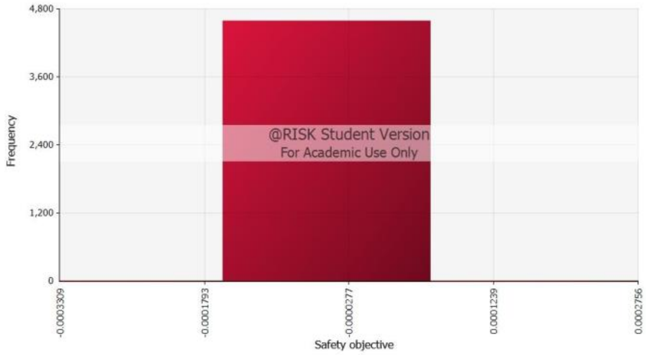

Figure 4. Zoomed in SO result of area 1 from simulation

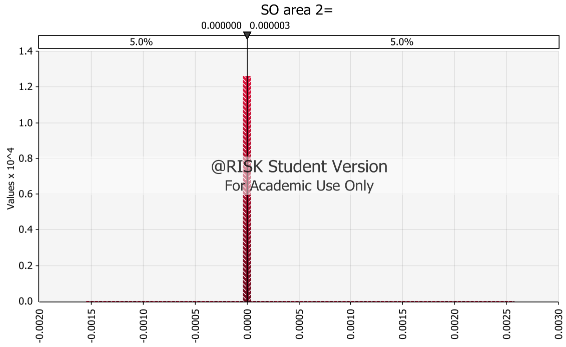

Figure 5. SO result of area 2 from simulation

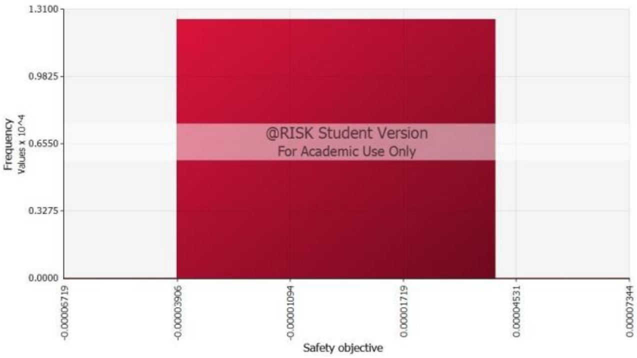

Figure 6. Zoomed in SO result of area 2 from simulation

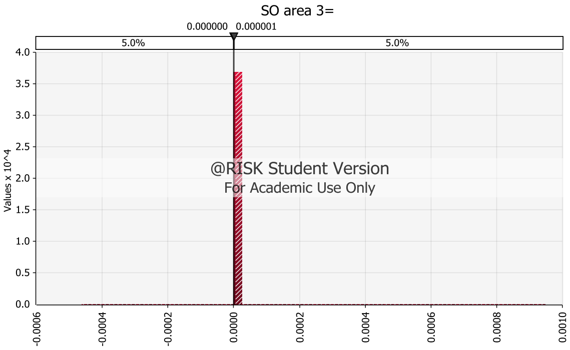

Figure 7. SO result of area 3 from simulation

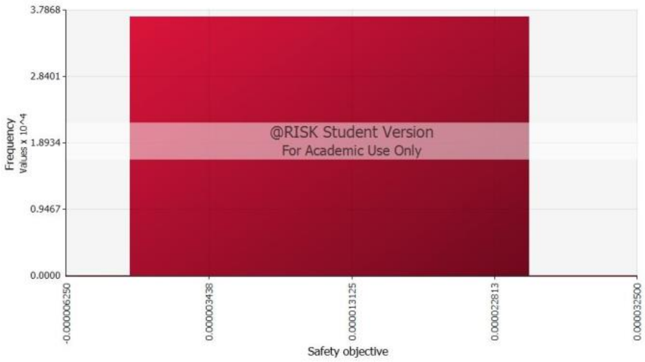

Figure 8. Zoomed in SO result of area 3 from simulation

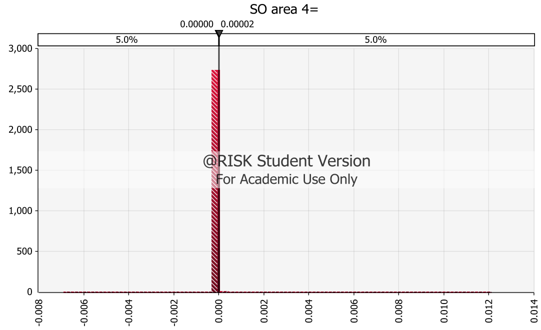

Figure 9. SO result of area 4 from simulation

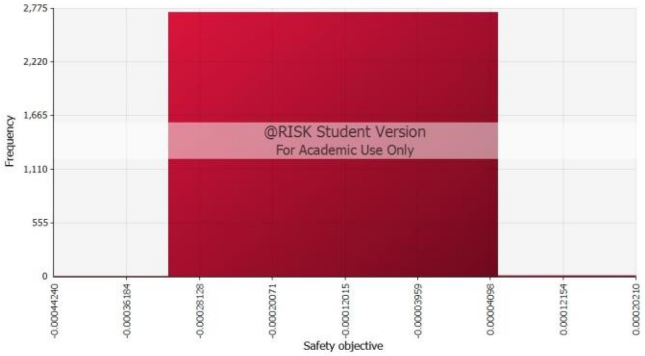

Figure 10. Zoomed in SO result of area 4 from simulation

B. Analysis of Qualititative Risks of UAV Flights

The FAA regulations prohibit flying over head of peoples' heads. Thus, in Figure 1, we need to restrict the areas that are safe for UAV flights. This logic leads to Figure 2, where each area is restricted by the workers' pathways that act as borders between each area. Taking FAA regulations into account, the following issues need to be considered in developing a qualitative risk assessment color-coded map for UAV flights:

- UAV no-fly zone areas are shown in red. These are the areas that are absolutely forbidden for UAVs to fly over/on due to federal rules.
- The area immediately adjacent to the red areas are shown in orange as it is risky to fly close to a no-fly zone.

- Any existing construction equipment is shown with orange as it is risky to fly over, on or adjacent to moving objects.
- In this example, there are two tower cranes which, by nature, are constantly moving in three dimensions.

Considering these facts, a color-coded safety map using green for safe to fly areas, orange for risky to fly areas, and red for no-fly zones, is constructed and shown in Figure 11. Authors believe that this is the first UAV safety heat map for construction that qualitatively categorizes the relative risks of UAV flights over job sites.

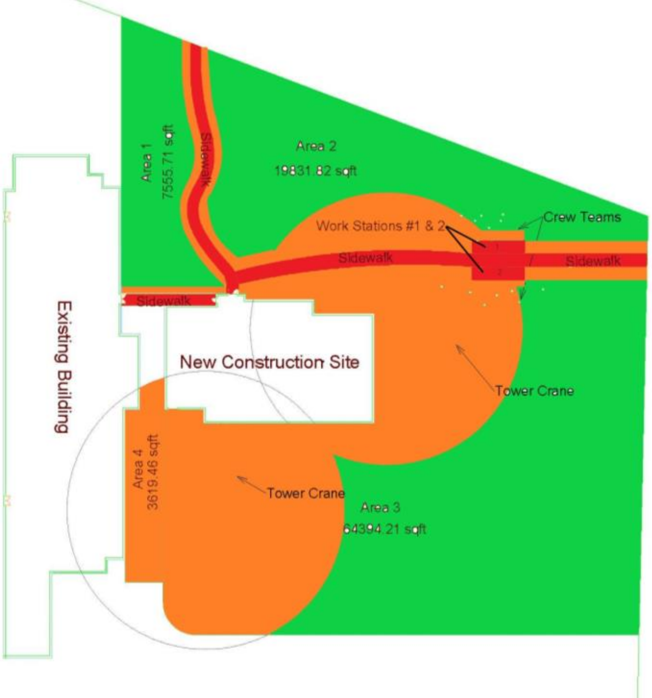

Figure 11. A color-coded map showing the qualitative risks of flying UAVs in a construction job site, where green represents the minimum risk, orange represents the medium risk and red represents high risk or no-fly zones.

VI. DISCUSSION AND CONCLUSION

This paper presents qualitative and quantitative risk analyses of UAVs flights over construction job site environments. It is the first known study discussing risks of UAVs flights over construction job sites using a Monte-Carlo simulation as a well-known qualitative analysis and also a quantitative analysis based on FAA rules and regulations.

By using Monte-Carlo simulation, it is shown that the risks of flying a UAV (with a given probability of UAV size, over an active construction job site, with a given probability of construction crew presence) the mean risk of a fatality incident varies from 5.670E-006. In other words, this predicts more than five fatalities in a million flight hours, to 1.042E-006 (almost one fatality in a million flight hours). Based on Clothier and Walker [22], the general aviation industry fatality rate is restricted to *one fatal incident in one million flight hours*. While it is not truly accurate to propagate the fatality rate of the general aviation industry to the UAV industry, authors use the general aviation industry as a reference to compare the risks due to the lack of data on qualitative risks of UAV flights. By comparing the simulation results to the general aviation industry restricted fatality rate, which is one fatality in a million flight hours, it is seen in the case study that most areas have higher than normal fatality risks of flights. Thus, it is up to construction managers or safety officer to decide on the appropriateness of UAV flights on this construction site.

So far, a quantitative method has been presented that provides a specific number for expected fatalities per million UAV flight hours. Using this quantitative method, it is straightforward for anyone (whether or not they have knowledge of risk assessment and/or expertise in UAV flights) to determine whether it is safe to fly a UAV within specific zone. This provides safety managers, project managers, owners and insurance companies with valuable insight on the safety of proposed UAV flights.

The FAA rules and regulations prohibit UAVs to fly over peoples' heads, over or close to airports and set a series of specific guidelines regarding UAVs operations. Combing these FAA guidelines with safety specification of UAVs flights in construction job site environments, such as higher risk of UAV collision in proximity of tower cranes, a qualitative color-coded safety map is generated that shows the relatively safer areas for UAV flights, using green, compare to medium UAV flight risks areas, with orange color, and no-fly zones, or the highest risks of UAV flights zones with red. Figure 11 presents this qualitative safety map. Areas above sidewalks, pathways and construction personnel work stations are shaded as red, as it is not safe to fly a UAV over these areas. The work radius of tower cranes is marked with two distinct circles. Areas in proximity of tower cranes are shaded in orange, as it is risky to fly UAVs in close proximity to tower cranes. The areas that are shaded green are the ones without any known safety hazards. This simple map can be used when no data is available regarding the number of workers present on site and/or when general assessment of safe-fly-zones and no-fly-zones are being performed.

These two analyses, qualitative and quantitative, enable construction managers, safety officers and insurance companies to detect, explore and address the risks of UAV flights in construction job site environments, which will help the construction industry to better manage the safety concerns of UAV flights.

REFERENCES

[1] Y. Ham, K. K. Han, J. J. Lin, and M. Golparvar-Fard, "Visual monitoring of civil infrastructure systems via camera-equipped Unmanned Aerial Vehicles (UAVs): a review of related works," Vis. Eng., vol. 4, no. 1, p. 1, 2016.

[2] P. Liu et al., "A review of rotorcraft unmanned aerial vehicle (UAV) developments and applications in civil engineering," Smart Struct. Syst., vol. 13, no. 6, pp. 1065–1094, 2014.

[3] M. Zucchi, "Drones: A Gateway Technology to Full Site Automation | 2015-06-10 | ENR." [Online]. Available: https://www.enr.com/articles/9040-drones-a-gateway-technology-to-full-site-automation?v=preview. [Accessed: May 30th 2018].

[4] K. Han, J. Lin, and M. Golparvar-Fard, "A formalism for utilization of autonomous vision-based systems and integrated project models for construction progress monitoring," in Proceedings of 2015 Conference on autonomous and robotic construction of infrastructure, 2015, pp. 118–131.

[5] J. J. Lin, K. K. Han, and M. Golparvar-Fard, "A framework for model-driven acquisition and analytics of visual data using UAVs for automated construction progress monitoring," in Computing in Civil Engineering 2015, 2015, pp. 156–164.

[6] M.-C. Wen and S.-C. Kang, "Augmented reality and unmanned aerial vehicle assist in construction management," in Computing in Civil and Building Engineering (2014), 2014, pp. 1570–1577.

[7] C. Eschmann, C.-M. Kuo, and C. Boller, "Unmanned Aircraft Systems for Remote Building Inspection and Monitoring," Proc. 6th Eur. Work. Struct. Heal. Monit. July 3-6, 2012, Dresden, Ger., vol. 2, pp. 1–8, 2012.

[8] N. Kerle, J. Fernandez Galarreta, and M. Gerke, "Urban structural damage assessment with oblique UAV imagery, object-based image analysis and semantic reasoning," in Proc., 35th Asian conference on remote sensing, 2014.

[9] N. Michael et al., "Collaborative mapping of an earthquake-damaged building via ground and aerial robots," J. F. Robot., vol. 29, no. 5, pp. 832–841, 2012.

[10] G. Morgenthal and N. Hallermann, "Quality Assessment of Unmanned Aerial Vehicle (UAV) Based Visual Inspection of Structures," Adv. Struct. Eng., vol. 17, no. 3, pp. 289–302, 2014.

[11] K. S. Pratt et al. "Use of tethered small unmanned aerial system at Berkman Plaza II collapse," in Safety, Security and Rescue Robotics, 2008. SSRR 2008. IEEE International Workshop on, 2008, pp. 134–139.

[12] S. Siebert and J. Teizer, "Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system," Autom. Constr., vol. 41, pp. 1–14, 2014.

[13] A. Ellenberg, A. Kontsos, F. Moon, and I. Bartoli, "Bridge related damage quantification using unmanned aerial vehicle imagery," Struct. Control Heal. Monit., vol. 23, no. 9, pp. 1168–1179, Sep. 2016.

[14] C. Eschmann, C.-M. Kuo, C.-H. Kuo, and C. Boller, "High-resolution multisensor infrastructure inspection with unmanned aircraft systems," ISPRS-International Arch. Photogramm. Remote Sens. Spat. Inf. Sci., no. 2, pp. 125–129, 2013.

[15] N. Metni and T. Hamel, "A UAV for bridge inspection: Visual servoing control law with orientation limits," Autom. Constr., vol. 17, no. 1, pp. 3–10, 2007.

[16] S. Rathinam, Z. W. Kim, and R. Sengupta, "Vision-based monitoring of locally linear structures using an unmanned aerial vehicle," J. Infrastruct. Syst., vol. 14, no. 1, pp. 52–63, 2008.

[17] R. Qin, "An object-based hierarchical method for change detection using unmanned aerial vehicle images," Remote Sens., vol. 6, no. 9, pp. 7911–7932, 2014.

[18] B. Hubbard et al., "Feasibility study of UAV use for RFID material tracking on construction sites," in Proc. 51st ASC Annu. Int. Conf, 2015.

[19] R. R. Murphy et al., "Use of remotely operated marine vehicles at Minamisanriku and Rikuzentakata Japan for disaster recovery," 9th IEEE Int. Symp. Safety, Secur. Rescue Robot. SSRR 2011, pp. 19–25, 2011.

[20] J. Irizarry, M. Gheisari, and B. N. Walker, "Usability assessment of drone technology as safety inspection tools," J. Inf. Technol. Constr., vol. 17, no. 12, pp. 194–212, 2012.

[21] N. D. Opfer and D. R. S. PE, "Unmanned aerial vehicle applications and issues for construction," in 121st ASEE Annual Conference and Exposition, pp. 1-16, 2014.

[22] R. A. Clothier and R. A. Walker, "Determination and evaluation of UAV safety objectives,". Bristol, United Kingdom: 21st International Unmanned Air Vehicle Systems Conference, 2006.

[23] R. Clarke, "Understanding the drone epidemic," Comput. Law Secur. Rev., vol. 30, no. 3, pp. 230–246, 2014.

[24] R. L. Finn and D. Wright, "Unmanned aircraft systems: Surveillance, ethics and privacy in civil applications," Comput. Law Secur. Rev., vol. 28, no. 2, pp. 184–194, 2012.

[25] F. Christiansen, L. Rojano-Doñate, P. T. Madsen, and L. Bejder, "Noise levels of multi-rotor unmanned aerial vehicles with implications for potential underwater impacts on marine mammals," Front. Mar. Sci., vol. 3, p. 277, 2016.

[26] C. F. Liew and T. Yairi, "Quadrotor or blimp? Noise and appearance considerations in designing social aerial robot," in Human-Robot Interaction (HRI), 2013 8th ACM/IEEE International Conference on, 2013, pp. 183–184.

[27] G. Sinibaldi and L. Marino, "Experimental analysis on the noise of propellers for small UAV," Appl. Acoust., vol. 74, no. 1, pp. 79–88, 2013.

[28] B. A. Duncan and R. R. Murphy, "Comfortable approach distance with small unmanned aerial vehicles," in RO-MAN, 2013 IEEE, 2013, pp. 786–792.

[29] "Census of Fatal Occupational Injuries (CFOI) - Current and Revised Data." [Online]. Available: https://www.bls.gov/iif/oshcfoi1.htm. [Accessed: 20-Apr-2018].

[30] Federal Aviation Administration. Getting Started: 2 Options for Flying Your Drone. [Online]. Available from:https://www.faa.gov/uas/getting_started/ 2018.04.21

[31] Federal Aviation Administration. Fly under the small UAS Rule. [Online]. Available from:https://www.faa.gov/uas/getting_started/part_107/ 2018.04.21.

[32] P. A. Thompson and J. G. Perry, Engineering Construction Risks: A Guide to Project Risk Analysis and Assessment

Implications for Project Clients and Project Managers. Thomas Telford, 1992.

[33] T. Öberg and B. Bergbäck, “A Review of Probabilistic Risk Assessment of Contaminated Land (12 pp),” J Soils Sediments, vol. 5, no. 4, pp. 213–224, Oct. 2005.

[34] A. S. Akintoye and M. J. MacLeod, “Risk analysis and management in construction,” International Journal of Project Management, vol. 15, no. 1, pp. 31–38, Feb. 1997.

[35] A. S. Akintoye and M. J. MacLeod, “Risk analysis and management in construction,” International journal of project management, vol. 15, no. 1, pp. 31–38, Feb. 1997.

[36] C. Z. Mooney, Monte Carlo Simulation. SAGE Publications, 1997.

[37] E. Gómez-Lázaro et al., “Probability Density Function Characterization for Aggregated Large-Scale Wind Power Based on Weibull Mixtures,” Energies, vol. 9, no. 2, p. 91, Feb. 2016.

[38] J. H. Smid, D. Verloo, G. C. Barker, and A. H. Havelaar, “Strengths and weaknesses of Monte Carlo simulation models and Bayesian belief networks in microbial risk assessment,” International Journal of Food Microbiology, vol. 139, pp. S57–S63, May 2010.

[39] V. Sousa, N. M. Almeida, and L. A. Dias, “Risk-based management of occupational safety and health in the construction industry – Part 2: Quantitative model,” Safety Science, vol. 74, pp. 184–194, Apr. 2015.

[40] G. Baudry, C. Macharis, and T. Vallée, “Range-based Multi-Actor Multi-Criteria Analysis: A combined method of Multi-Actor Multi-Criteria Analysis and Monte Carlo simulation to support participatory decision making under uncertainty,” European Journal of Operational Research, vol. 264, no. 1, pp. 257–269, Jan. 2018.

[41] J. Ying and B. Liu, “Binocular optical axis parallelism detection precision analysis based on Monte Carlo method,” in Fourth Seminar on Novel Optoelectronic Detection Technology and Application, 2018, vol. 10697, p. 1069719.

[42] I. Podgorny, D. Lubin, and D. K. Perovich, “Monte Carlo Study of UAV-Measurable Albedo over Arctic Sea Ice,” Journal of Atmospheric and Oceanic Technology, vol. 35, no. 1, pp. 57–66, Jan. 2018.

[43] R. Y. M. Li, K. W. Chau, and D. C. W. Ho, “Dynamic Panel Analysis of Construction Accidents in Hong Kong,” Asian Journal of Law and Economics, vol. 8, no. 3, pp. 1–9, Dec. 2017.

[44] I. M. Shohet, M. Luzi, and M. Tarshish, “Optimal allocation of resources in construction safety: Analytical-empirical model,” Safety Science, vol. 104, pp. 231–238, Apr. 2018.

[45] H. Li, X. Yang, F. Wang, T. Rose, G. Chan, and S. Dong, “Stochastic state sequence model to predict construction site safety states through Real-Time Location Systems,” Safety science, vol. 84, pp. 78–87, 2016.

[46] A. Plioutsias, N. Karanikas, and M. M. Chatzimihailidou, “Hazard Analysis and Safety Requirements for Small Drone Operations: To What Extent Do Popular Drones Embed Safety?,” Risk Analysis, vol. 38, no. 3, pp. 562–584, Mar. 2018.

[47] D. Alejo, J. A. Cobano, G. Heredia, and A. Ollero, “An Efficient Method for Multi-UAV Conflict Detection and Resolution Under Uncertainties,” in Advances in Intelligent Systems and Computing, vol. 417, L. P. Reis, A. P. Moreira, P. U. Lima, L. Montano, and V. Muñoz-Martinez, Eds. Cham: Springer International Publishing, 2016, pp. 635–647.

[48] S. P. Cook and D. Brooks, “A Quantitative Metric to Enable Unmanned Aircraft Systems to Remain Well Clear,” Air Traffic Control Quarterly, vol. 23, no. 2–3, pp. 137–156, Apr. 2015.

[49] J. A. Douthwaite, A. De Freitas, and L. S. Mihaylova, “An interval approach to multiple unmanned aerial vehicle collision avoidance,” in 2017 Sensor Data Fusion: Trends, Solutions, Applications (SDF), 2017, no. April, pp. 1–8.

[50] A. Mcfadyen, T. Martin, and L. Mejias, “Simulation and modelling tools for quantitative safety assessments of unmanned aircraft systems and operations,” in 2016 IEEE Aerospace Conference, 2016, vol. 2016-June, pp. 1–12.

[51]

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