From the Point of a Tower Crane Operator’s View: Use of an Eye-Tracker in Construction Sites

Berna H. Ulutas (bhaktan@ogu.edu.tr), N.Firat Ozkan (fozkan@ogu.edu.tr)

Department of Industrial Engineering, Eskisehir Osmangazi University, Seoul, 445-743

ABSTRACT

The need for high-rise building constructions, large-scale apartment blocks, or construction in urban areas raised the number of tower crane use. For safe and efficient activities in construction sites; tower crane type selection, decision of tower crane location, decision of load type, load location, specified area, and their supply, securing equipment, also the work schedules and maintenance should carefully be planned. This study proposes a methodology to support accident management in construction sites where a single tower crane is used. Aim is to identify the risks during operations and rank the severity levels of the activities to avoid property damage and bodily injuries. Up to best knowledge, a mobile type eye-tracker is used for the first time to record the view of tower crane operator during operations. In the first step, operator is asked to wear the eye-tracker as a regular glasses and climb the operating cabin that is attached to the structure of the tower crane. Based on the video records, it is possible assess not only the guiderails, handholds, steps, and trap door but also the operating cabin interior design in terms of control unit locations, window panels. In the second step, the data collected during material handling operations is used to assess the location of loads, potential risks for the slinger who is responsible for attaching and detaching the load to and from the crane and the signaler who is responsible for relaying the signal from the slinger to the crane operator and directing the safe movement of the crane. The visual attention of the tower crane operator and working postures are evaluated. In the third step, the records when tower crane operator is descending the ladder of the tower are considered. Obtained data is interpreted as indicators of fatigue such as duration of fixation, number of fixation, and pupil size change. Data obtained from two construction sites (one constructed near the single building construction site and other between two buildings construction site) where one tower crane is used to test the hypothesis. Results illustrate that the location of tower crane have a significant effect on safe operations for the crane operator. Further comments are made based on the possible impacts of communication system, high visibility clothing, and weather conditions for an efficient accident management.

Keywords: construction, tower crane, material handling, safety, eye-tracker

1. Introduction

The use of lifting equipment such as cranes, elevators, or hoist lifts is inevitable for lifting materials on construction sites (Shapira et al., 2007). Cranes are a commonly used form of lifting equipment and tower cranes are typically used in construction of projects such as high-rise or large-scale apartment buildings (Hollister, 2011; Park et al., 2013). Tower crane is the key material handling equipment for vertical transportation, especially for the heavy prefabrication units and large panel formwork. Safe and efficient activities in construction sites rely on the tower crane type selection, decision of tower crane location, decision of load type, load location, specified area, and their supply, securing equipment, also the work schedules and maintenance should carefully be planned. Tam et al. (2001) attract attention of the difficulty of site layout planning and a site layout genetic algorithm model is developed along with a practical example. The optimization results of the example are very promising and demonstrate the application value of the model. Tam and Tong (2003) use artificial neural networks to model the non-linear operations of a key site facility. Then genetic algorithms are used to determine the locations of the tower crane, supply points and demand points by optimizing the transportation time and costs.

Jaffar et al. (2011) provide definitions of awkward posture, force, repetition, vibration, static loading, contact stress and extreme temperature when designing a workplace. Construction workers are exposed to various physical factors at work. Lee and Han (2013) use OWAS to analyze working postures and evaluate the risk for occupational musculoskeletal injuries for construction workers.
Smallwood (2015) states that designers influence construction ergonomics directly (i.e., details and method of fixing, and depending upon the type of procurement system, supervisory and administrative interventions) and indirectly (i.e., the type of procurement system used, pre-qualification, project duration, partnering, and the facilitating of pre-planning). The survey results conducted to architectural technologists in South Africa illustrates that cost, quality, and time are more important rather than construction ergonomics and project health and safety.

The studies in the literature does not directly provide solutions for the fatigue of the crane operators. Although interior design of cranes are optimized in terms of accessibility, it is crucial to identify the measures of cognitive load. Second section summarizes eye tracking technology. The comments on the questionnaire results in a real-life application are provided in the third section. Last section concludes the study and discusses the directions for future studies.

2. Method

Eye tracking is the process of measuring either the point of gaze (where one is looking) or the motion of an eye relative to the head. An eye tracker is a device for measuring eye positions and eye movement. Applications of eye tracking technologies include web usability, advertising, sponsorship, package design, and automotive engineering. In general, commercial eye tracking studies function by presenting a target stimulus to a sample of consumers while an eye tracker is used to record the activity of the eye. Examples of target stimuli may include websites, television programs, sporting events, films, commercials, magazines, newspapers, packages, shelf displays, consumer systems (ATMs, checkout systems, kiosks), and software. The resulting data can be statistically analyzed and graphically rendered to provide evidence of specific visual patterns. By examining fixations, saccades, pupil dilation, blinks and a variety of other behaviors researchers can determine a great deal about the effectiveness of a given medium or product.

The technology of eye tracking has improved and mobile devices enable to conduct real-life applications. Figure 1 illustrates the eye-tracker used in this study. Crane operator is asked to wear the eye-tracker as a regular glasses and climb the operating cabin that is attached to the structure of the tower crane. Based on the video records, it was possible to assess how he behaves during climbing, and performing operations.

Based on the records, ideal locations of materials and construction workers on site are discussed for safe materials handling.

3. Results

Two construction sites are examined for the scope of the study. A crane that has 62 m boom length and maximum capacity of 8 ton is located on the site where a five store hospital building is being constructed. The location of the crane is determined based on previous experiences. Crane is capable of 35 m lifting. Two apartment building is being constructed in the second construction site. Crane is located between the building bases. Crane has 65 m boom length with 8 ton lifting capacity and 35 m lifting height.

It is observed that crane operator at the age 20 is capable to climb crane faster than 50 years old operator. Also, fitness of the operators is a critical issue since they need to climb the stairs in a limited area. The safety platforms are used three times by the aged operator for resting. Both cranes in concern are rather new. The operators stated that cabin interior of both cranes are designed well in terms of control unit locations, window panels. There was no complaint about the material and use of control units. Aged operator also compared the previous crane designs and stated that new cranes require less force and enables to work longer periods without physical strain. However, when there is a lifting or lowering duty that require visual attention, operator may need to stand up or lower the body working postures.

3.1 Visual attention during operation

The data collected during material handling operations is used to assess the location of loads, potential risks for the slinger who is responsible for attaching and detaching the load to and from the crane and the signaler who is responsible for relaying the signal from the slinger to the crane operator and directing the safe movement of the crane. Figure 1 illustrates the location of materials to be handled on the construction site along with the engineering facilities. Figure 2 represents the workers on the construction floor. It is obvious that clothing of workers is important for visibility. Lumber stock on the floor is presented in Figure 3.
3.2 Assessing material handling duration

Construction material located on the ground is lifted by the crane. Duration of the operations (attaching and detaching the load) performed by the slinger is summarized in Table 1. Based on the video records, it can be stated that crane operators’ visual attention is higher when the load is being lifted. Duration of fixation, number of fixation, and pupil size change can be used as indicators of fatigue. However, it is not easy to define an Area of Interest (AOI) for the study.

| Duty            | Time (sec) | Total time (sec) |
|-----------------|------------|------------------|
| Tying fitting   | 77.0       | 172.9            |
| Handling fitting| 55.9       |                  |
| Untying fitting | 40.0       |                  |
| Empty travel    | 36.4       | 36.4             |
| Tying fitting   | 100.4      | 191.6            |
| Handling fitting| 52.0       |                  |
| Untying fitting | 39.2       |                  |
| Empty travel    | 41.2       | 41.2             |
| Tying fitting   | 107.9      |                  |
| Handling fitting| 49.5       | 197.8            |
| Untying fitting | 40.4       |                  |
| Empty travel    | 26.1       | 26.1             |
| Tying fitting   | 244.3      | 313.3            |
| Handling fitting| 40.7       |                  |
| Untying fitting | 28.8       |                  |
| Empty travel    | 29.5       | 29.5             |
| Tying fitting   | 115.5      | 240.7            |
| Handling fitting| 64.2       |                  |
| Untying fitting | 60.7       |                  |

Figure 4 is drawn based on the observations of the construction site. It is not always possible for the crane operator to see the signaler. Therefore, communication between the workers on site, signaler, and the crane operator is enabled by use of walkie-talkie.

Only panels for molding are lowered from the floor of the building. All other materials are used in the floors during to the construction. Duration of the handling is analyzed and lifting the loads from ground to the fourth floor and lowering from fourth floor to ground is measured as 12 seconds. On the other hand, loads (i.e., fitting, molding panels, etc.) that are about 2 ton require more attention and need to be handled in longer period of time. Since panels have a wide area, they are also prone to be affected from wind. Panels may swing and cause severe risk not only for the construction workers
but also for the property damage. Figure 5 represents the top view of the construction site. Analysis results support the difficulty of the homogenous and heterogeneous load movement vertically. As the building rise, crane operator require to bend the crane window and try to see the load and other people in the construction site.

![Figure 5. Vertical load move](image)

Figure 6 represents horizontal moves of crane. Analysis illustrate that crane operators are more comfortable in load handling within the same floor especially for homogenous loads.

![Figure 6. Horizontal load move](image)

4. Conclusion

This study aims to attract attention to the use of eye-tracker systems during visual workload in construction. Up to best knowledges, eye tracking technology is not used to assess crane operators before. This study illustrates promising application of a mobile eye tracker during the activities of crane operators. Besides the location of control and display units in the crane cabin, it is also important where and when the materials should be carried. Based on the indicators of cognitive workloads, actions (i.e., work schedules, rest periods, etc.) to improve the performance of the crane operators and take actions for occupational health and safety can be defined. On the other hand, virtual crane simulators must be used to train crane operators for several handling duties with various unexpected cases. Better design of crane interior, control and display locations have helped to reduce physical work load. However, there are still open issues to be solved for comfortable climbing and descending.

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