

A HYBRID MODEL FOR SELECTING LOCATION OF MOBILE CRANES
IN BRIDGE CONSTRUCTION PROJECTSMohamed Marzouk¹✉, Mohamed Hisham²*Dept of Structural Engineering, Cairo University, 12613 Giza, Egypt*
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Abstract. Mobile cranes are considered one of main equipment in bridge construction projects. Choosing the best locations for mobile cranes in bridge construction sites is an important task that must be done efficiently. This paper presents a hybrid model that integrates Genetic Algorithms and Bridge Information Modeling to choose the best locations of mobile cranes in bridges construction sites, taking into account different constraints related to: safety, clearance, existing site conditions, construction schedule, and duration of erecting structural members. The proposed model is novel since it explores more features of Bridge Information Modeling such as decision making including location of mobile cranes and less boom maneuvers.

Keywords: Genetic Algorithms (GAs), Building Information Modeling (BrIM), 3D modeling, construction equipment.

1. Introduction

Optimum locations of equipment and other facilities is a main concern in bridges projects. This task is considered complex due to the presence of many variables and constraints which lead to decisions that are not guaranteed to be the best decisions regarding time, cost, and safety. Using optimization techniques in construction helps in solving many problems including the site layout problem, and equipment locations. The optimization technique used in this paper is Genetic Algorithms (GAs). GAs are search algorithms that are based on the natural selection and genetics to search through decision space for optimum solutions. They employ a random yet directed search for locating the globally optimal solution (Sanad *et al.* 2008). GAs have many advantages such as: optimization with continuous or discrete variables; dealing with a large number of variables; providing a list of optimum variables, not just a single solution; and working with numerically generated data, experimental data, or analytical functions (Haupt, Haupt 2004).

GAs have been applied in several applications. Zouein *et al.* (2002) used GAs for solving site layout problem with unequal size and constrained facilities. Sanad *et al.* (2008) used GAs to obtain optimal construction site layout considering safety and environmental aspects. Elbeltagi *et al.* (2004) uses GAs in optimization of temporary facilities locations in integration with a scheduling tool. Ning *et al.* (2010) developed a method that uses continuous dynamic searching scheme to guide the max-min ant

colony optimization algorithm to solve the dynamic site layout planning problem under the two congruent objective functions of minimizing safety concerns and reducing construction cost. Gholizadeh *et al.* (2010) used harmony search algorithm to solve the problem of assigning a set of predetermined facilities to a set of pre-allocated locations within a construction site.

Mobile cranes are considered main type of equipment that is used in bridges construction sites. Choosing the suitable mobile cranes and their positions in bridges construction sites is a very important task that must be done accurately. Any failure in achieving this task in an efficient manner leads to excessive losses related to safety and costs. A lot of efforts have been made to generate 3D models in different applications. Raynar (1990) used artificial intelligence techniques to find the minimum number of crane positions necessary to erect structural steel. Al-Husseini *et al.* (2005) developed optimization algorithm for selection and on site location of mobile cranes. Tam and Leung (2002) integrated GAs with 3D visualization for optimum positioning of tower cranes. Tantisevi and Akinci (2009) presented an approach for automatically generating motions of mobile cranes to support conflict detection by extending existing approaches in product and process modeling and visualization of construction operations. Behzadan and Kamat (2010) presented augmented reality that employs graphical visualization to plan and design construction operations. Realistic visual outputs are created and translated into three-dimensional (3D) virtual

contents (CAD model engineering) of the animated scenes. Tantisevi and Akinci (2007) presented an approach for generating workspaces that encapsulate spaces occupied by mobile cranes moving during an operation. Hasan *et al.* (2010) presented an automated system which is designed to assist practitioners in calculating the mobile crane's support reactions and in designing the supporting system. Wu *et al.* (2011) presented an algorithm for selecting mobile cranes on construction sites which takes into account the lifting capacity, the geometrical characteristics of the crane, the dimensions of equipments and riggings, and the ground bearing pressure. Tantisevi and Akinci (2008) presented an approach that determines possible locations of mobile cranes based on discrete-event simulation of crane operations incorporating dynamic behaviors of cranes.

Bridge Information Modeling (BrIM) is considered a big innovation in bridge engineering and construction industry. It is not just a geometrical representation of bridges, but it is an intelligent representation of bridges since it contains all information needed about bridges through their whole lifecycle. Bridge information modeling goes beyond traditional bridge design by fostering data reuse in different processes. Thus, 3D model of the bridge serves as a window into the vast information asset, and organizations begin to optimize business processes that cross the bridge lifecycle by more flexible access to information about the bridge (Peters 2009). BrIM has great effect on the improvements of the three main concerns of bridges stakeholders which are quality, schedule, and cost and it is needed for bridges since it creates consistency in information in different phases from design to maintenance (Marzouk *et al.* 2010). The paper presents a hybrid model that integrates BrIM and GAs to select best mobile cranes positions in bridge construction site to meet erection requirements and site constraints in order to minimize the time of erection.

2. Proposed hybrid model

The proposed hybrid model integrates different commercial software packages. First, 3D BrIM module is developed taking into consideration site boundaries and conditions. The coordinates of erection locations and site boundaries are then exported to the GAs module which determines the mobile crane locations that satisfy the safety, clearance, and site boundaries constraints. These locations are then exported to the BrIM module. The mobile crane model and other site conditions are visualized in the BrIM module while the locations that are selected by GAs module and contradict with these conditions are excluded. The erection process is simulated by using the animation feature of BrIM. This simulation is done at the locations that previously selected by the GAs model and don't contradict with site conditions. The best location for the crane is then chosen based on simulation results, where the location that provides minimum erection time is selected. Fig. 1 shows the connectivity between different software

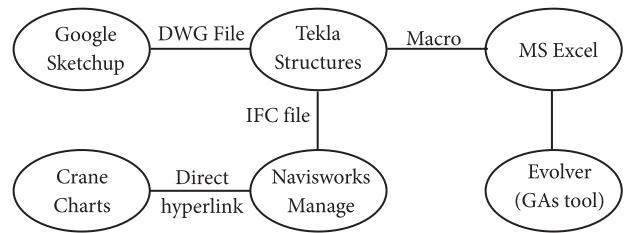


Fig. 1. Connectivity between different components

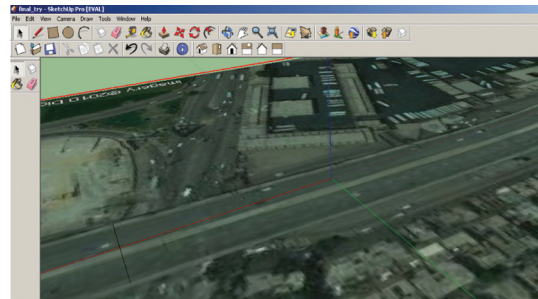


Fig. 2. Capturing construction site by Google Sketchup

packages and methods to achieve the required integration. A detailed description of the methodology is presented in the below sections.

3. Developing 3D BrIM module

The 3D bridge information module is developed using several commercial software packages. In the proposed framework, Tekla structures software is utilized. The developed module is an intelligent module that has several attributes. Although this module is used in several purposes such as cost estimation, 4D modeling, and drawings creation; this module is needed to be integrated with the construction site conditions in order to choose the suitable mobile crane equipment positions and plan their movement in the construction site, therefore, the construction site is needed to be represented accurately to achieve the required task. Google Sketchup software is proposed to be used in representing the construction site. This software is used to capture the construction site location from Google Earth as shown in Fig. 2. The site boundaries and surrounding conditions are then be drawn and highlighted as shown in Fig. 3. The drawn site boundaries and surrounding buildings are then exported from Google Sketchup to Tekla Structures software as a reference model of extension DWG. This reference model assists in modeling surrounding buildings and conditions, and shows the site boundaries and the original 3D BrIM model together. Fig. 4 depicts the 3D BrIM model, site boundaries, and surrounding buildings models.

It should be noted that the surrounding buildings are modeled as building blocks with low level of detail because the purpose of modeling these buildings is to determine and visualize the surrounding constraints that may affect choosing the cranes' positions. The erection locations of bridge beams or segments, and the site boundaries are

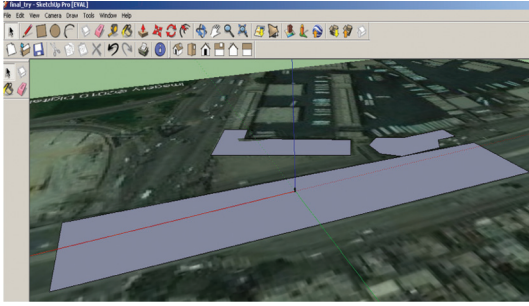


Fig. 3. Highlighting site boundaries and surrounding buildings

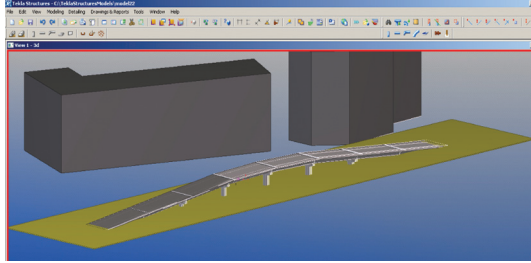


Fig. 4. Site boundaries representation in Tekla structures

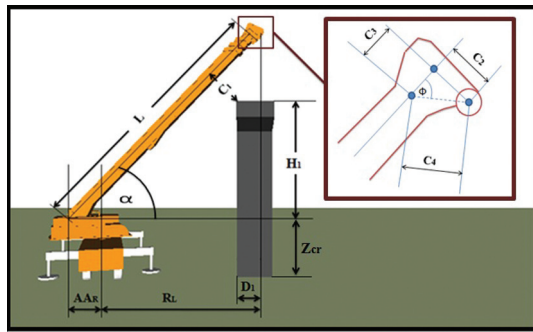


Fig. 5. Parameters of GA module

essentially the main inputs in the GAs module. Tekla Structures layout manager is used to extract these positions by choosing the erection locations and the site boundaries. The extracted points are opened in *Microsoft Excel* sheet; consequently, it is easy to link the extracted coordinates with the GAs model which is developed in *Microsoft Excel* sheet.

4. Genetic algorithm module

GA module is used to obtain the possible locations of a mobile crane in a bridge construction site during erection of beams on the bridge piers. The obtained positions are then inserted to Bridge Information Modeling software to perform animation and simulation for erection process, and then choose the position that minimize the erection time. The utilized optimization technique takes into account two erection locations (at both edges of bridge pier). This is done while the effective pier widths related to the two erection locations are calculated automatically by the module. In addition, site boundaries, safety during lifting and erection, and clearance constraints are considered in GA module. The safety is achieved by choosing a crane that affords lifting the load, and not exceeding the limited

lifting radii and boom lengths. All constraints and equations used in developing the GA module are listed below. Fig. 5 shows a mobile crane model and the parameters used in deriving the equations that are used in the optimization process.

$$R_L = \sqrt{(X_{er} - X_{cr})^2 + (Y_{er} - Y_{cr})^2}, \quad (1)$$

where R_L – the lifting radius, m; X_{er} and Y_{er} – the plan coordinates of erection location, m, while X_{cr} and Y_{cr} – the plan coordinates of the centre of the crane, m.

$$L = \frac{R_L \pm AA_R - C_3 \cos \alpha}{\cos \alpha}, \quad (2)$$

where L – the main boom length, m; C_3 – sheave offset, m.

C_1 is the boom clearance, m, as reported by Al-Husseini *et al.* (2005) in Eq (3):

$$C_1 = \frac{\left[L - \frac{D_1 - C_4 \cos(\varphi - \alpha)}{\cos \alpha} - \frac{H_1}{\sin \alpha} \right]}{\left[\text{tg} \alpha + \frac{1}{\text{tg} \alpha} \right]}, \quad (3)$$

where D_1 – the effective width that affects the erection or the load placing process, m. It is the distance between the edge of the building (or bridge pier) and the point of the load placing or erection. For the work presented in this paper, D_1 is calculated for two erection locations of beams which are at the edges of a bridge pier. The work presented in this paper assumes that the beams erection is done by two cranes, so, the point of carrying the load is near the beam edge. The calculations are done for one crane and repeated for the other crane by the same methodology. Calculation of D_1 is done based on the orientation of the bridge pier. For example, for the case shown in Fig. 6, two effective widths are considered $D_{1(1)}$ and $D_{1(2)}$ as per Equations.

$$\theta_1 = \text{tg}^{-1} \left| \frac{Y_{er1} - Y_{cr}}{X_{er1} - X_{cr}} \right|, \quad (4)$$

$$\beta_1 = \gamma + \theta_1 - 90^\circ, \quad (5)$$

$$D_{1(1)} = \frac{B}{\cos \beta_1}, \quad (6)$$

$$\theta_2 = \text{tg}^{-1} \left| \frac{Y_{er2} - Y_{cr}}{X_{er2} - X_{cr}} \right|, \quad (7)$$

$$\beta_2 = 90^\circ - \gamma, \quad (8)$$

$$D_{1(2)} = \frac{B}{\cos(\theta_2 + \beta_2)}. \quad (9)$$

The GA module was developed using evolver software which is MS Excel Add-In. All variables and equations are modeled in an excel sheet where the optimization process

is to be applied. The genes of the developed GA module are: X_{cr} , Y_{cr} , α_1 and α_2 . The first two genes represent the location of the center of the crane, while the last two genes represent the inclination angle between the boom and the ground for the two erection locations. The objective function is maximization, and minimization of Eq (1) for the two erection locations. This is achieved by maximizing and minimizing the radius at the first erection location and then checking that the resulted location of the crane satisfies safety and clearance requirements for the second erection location, and then maximizing and minimizing radius at second erection location and then checking that the resulted location of the crane satisfies safety and clearance requirements for the first erection location. Therefore, optimization process will be performed for four cases.

Safety constraints are satisfied by keeping the lifting radius and the boom length within their limits which are defined in mobile crane charts. Representing safety constraints in the GA module is done by inserting the lifting radii, and boom lengths ranges that achieve safety for lifting a certain load. The limits for the first two genes (X_{cr} and Y_{cr}) are obtained from the values extracted by the Tekla Layout manager software as discussed before. The GA module calculates the lifting radii from Eq (1), and calculates the boom lengths from Eq (2). The erection locations (X_{er} and Y_{er}) are also extracted by the Tekla Layout manager software. The module calculates the effective widths for the two erection locations based on the different cases of pier orientation by inserting the number of the case, and the angle of rotation between the pier axis and X axis. The model requires specific parameters related to each crane to be inserted by the user based on mobile crane geometry such as sheave offsets (C_3 , and C_4), Z_{cr} (height from ground to boom pin), and AAR (distance between boom pin to rotation centre).

5. Choosing best cranes' locations

The GA module provides several feasible solutions. The GA module doesn't take into consideration other site conditions such as the presence of utilities (such as pipes) at shallow depths, and the available spaces in site based on the schedule. This is attributed to the fact that GA module is designated to consider final position at placing the load without considering these site conditions, and without considering erection time minimization. BrIM module is an effective tool in choosing the best crane location based on the results retrieved from the GA module. Representing resulted crane locations is be done using Tekla Structures software by inserting the resulted locations as IFC components as shown in Fig. 7. 4D modeling is an effective feature in BrIM. It depends on linking a time schedule to the components of the BrIM model, thus, the project team visualizes what is to be constructed at a specific date, the achieved work at this date, and compare actual work with planned work. This feature has an important role in choosing crane location because it represents the available spaces and the restricted spaces in the site at time of erection. Fig. 8 shows 4D modeling in Tekla Structures

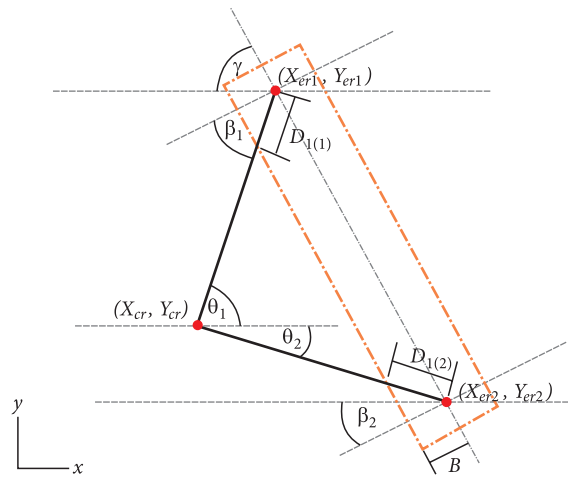


Fig. 6. Estimation of effective widths

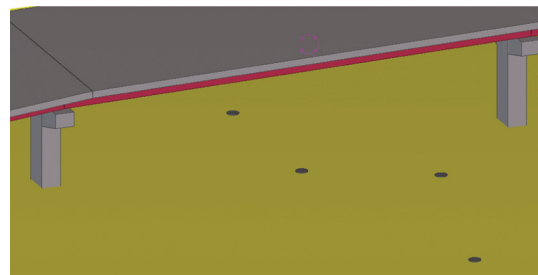


Fig. 7. Exporting GA feasible solutions to Tekla structures

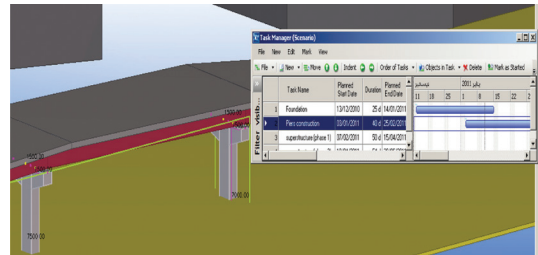


Fig. 8. Generating 4D modeling

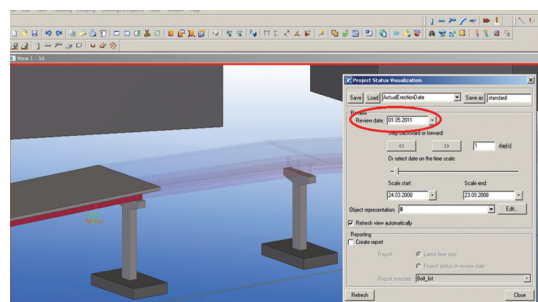


Fig. 9. Demonstrating project status at a specific date

software, while Fig. 9 shows the project status at a specific erection date. The next step is exporting the 4D model, generated by BrIM module, including site boundaries, surrounding buildings, and represented crane locations from Tekla Structures software to Navisworks Manage software. The extension of the exported file is to be IFC. The model of the existing utilities such as cables, water pipes, or

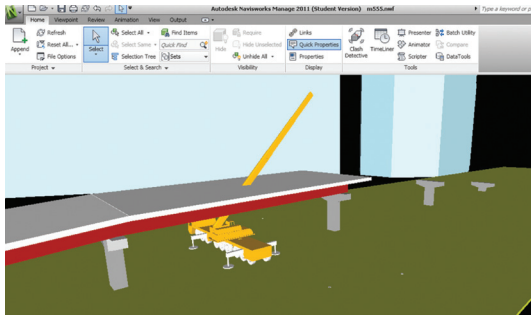


Fig. 10. Excluded location due to clashes

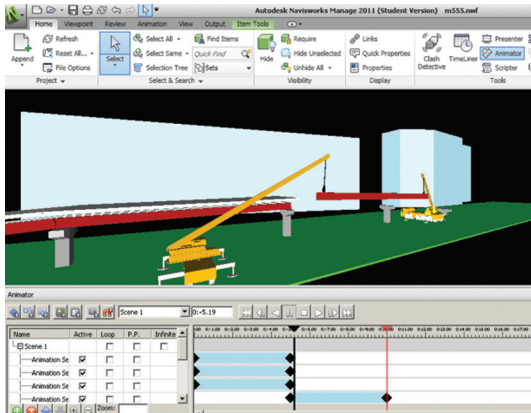


Fig. 11. Simulation and animation of beam erection in BrIM

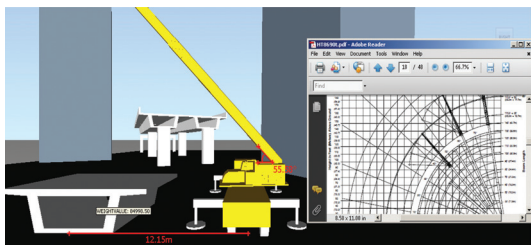


Fig. 12. Checking safety requirement procedure

sewer pipes are also be imported from other BIM software packages to Navisworks manage software. The next step is to import the 3D mobile crane model and exclude the crane locations that contradict with existing utilities or site conditions at the date of erection. Fig. 10 shows a location which is excluded due to the presence of casted slab and beams above this location which prevents the crane from lifting and placing the load in its erection location.

6. Simulation and animation

After the exclusion of contradicting positions, different trials are executed to choose the best crane location. In each trial, a simulation of the erection process is done by inserting the mobile crane to capture the selected location and perform boom movement animation. The animation starts by lifting the beam from the truck (or stored position) and ends with placing the beam in its final position. The position of the truck or the stored position is determined based on site conditions, and safety requirements. The purpose of simulation and animation is to determine the crane

locations that have the least number of boom maneuvers from lifting to placing the load. As the number of boom maneuvers decreases, the erection time decreases, and that achieves the goal of using BrIM with GAs which is to minimize time of erection. Fig. 11 shows a snapshot of animation done by Navisworks software to simulate the erection process. The time used in the animation is obtained from the distances moved by the boom during erection, and the velocity of the boom movement while carrying the load obtained from the crane specifications.

7. Checking safety requirements

BrIM is used to check the safety requirements with respect to carrying loads in the bridge construction site by a specific crane. This is done in three-steps procedure: 1) a hyperlink is created to activate specified crane charts by just clicking on the crane model; 2) visualizing the weight of any beam or structure member which is an attribute of the intelligent components of the BrIM module. This step is achieved in Navisworks Manage software by setting Quick properties to be visualized as IFC for the category, and weight for the attribute, thus, the weight value is visualized by just pointing the component; 3) performing necessary measurements for the boom angle and the lifting radius. Fig. 12 depicts this procedure illustrating; the crane charts, weight of component, and boom angle and lifting radius are all visualized together. As such, the user decides whether the crane is capable to lift the required weight based on its current location or not.

8. Conclusions

The paper presented a hybrid model that integrates GAs and BrIM for choosing the best locations for mobile cranes in bridges' construction sites. The paper illustrated how to represent bridge construction site and surrounding obstacles in BrIM module by integrating different software packages such as Google Sketchup and Tekla Structures. The site boundaries and the coordinates of erection locations are exported from the BrIM module using Tekla Structures layout manager. The paper presented the development made in GA module for optimizing the location of mobile cranes. The GA module was developed using Evolver software (MS Excel Add-In). The developed module takes into consideration two erection locations (at edges of a bridge pier). It also takes into account the change in the effective widths which depends on the orientation of the bridge pier with respect to the site coordinates. Safety and clearance constraints are taken into account in the developed model. The resulted crane locations are exported to BrIM module. By integrating the resulted crane locations, 4D model, site boundaries, mobile crane 3D model, and surrounding buildings in Navisworks Manage software; the infeasible locations are excluded. The best position is chosen from the remaining locations by importing the crane model in these locations and simulating erection process. The chosen location is the one that has minimum boom maneuvering and time of erection. The paper also presented the procedure for checking safety requirements with respect to carrying loads in the bridge construction site by a specific crane.

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Received 9 May 2011; accepted 6 June 2011