Design Optimization of Lifting Mechanisms

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Abstract. The design of the lifting device (mobile crane vs tower crane) has big influence on construction efficiency and the whole building process. That is why we made this design optimization of lifting mechanisms for many types of building site. Basic algorithm of this methodology was made with respect to structure of the area, time and technology. Construction, shape and dimensions of the designed building are also necessary be taken into consideration, as well as shape and weight of the load. We also included building site characteristics and required deadline. The decision between two basic types of lifting devices, i.e. mobile crane or tower crane, also depends on economy, ecology, time and spatial demands. After collecting information from many building sites, we made computer software, which could be accessible for layman and even for specialists in building engineering. This software is also approachable for smartphones, what makes it more accessible. Every user inputs basic information (building site location and characteristics, area, building construction, deadlines and load). Very important are deadlines of particular procedures - foundation construction, vertical support constructions, horizontal support constructions, staircase and roof. The choice between mobile and tower crane will be made by this software after imputing all this information. The lifting devices are also compared in compliance with economy and ecology and subsequently sort from the most suitable to the most inconvenient. This methodology and software should help with selection of the most suitable lifting device for every specific construction and solve problems with building material transport as well. These problems can result in project delay, what often means cost increase.

1. Introduction
Tower cranes and mobile cranes rank among the most commonly used machines employed by the construction industry. They are usually the most expensive pieces of equipment on the building site, even though they are often just rented to the company building the structure. The selection of cranes and the manner in which they are deployed has a fundamental influence on the smoothness of the workflow onsite, the construction time and the costs involved in realizing the building project. This is not being given sufficient attention at the present time.

The article concerns the proposal of a method for selecting suitable lifting equipment for a specific construction project. The selection of lifting machinery with required technical parameters is optimized on the basis of the evaluation of boundary conditions. The choice will be made between tower cranes and mobile cranes. The proposed method is being prepared for implementation in computer software which will be used by professionals and the lay public in construction industry practice.

2. Proposal of a method for the selection of lifting equipment
The proposal of lifting equipment has a key influence on the rational and economically effective course of the construction of primarily the shell of the structure, as well as on the plan for equipping the
construction site. A method for use in the selection of the most suitable lifting machinery (tower crane or mobile crane) for a specific construction project is proposed.

The following algorithm describes a procedure for selecting suitable lifting equipment (Figure 1). The individual parts of the algorithm are described below. The comparison will be performed with regard to spatial, technical and time structure. Lifting machinery that is appropriate from the perspective of technical parameters and boundary conditions will subsequently be compared from the financial and ecological points of view. [1]

Figure 1. Algorithm for the proposed method

Certain realities which markedly influence the selection of lifting equipment have been classified as boundary conditions of the solution. They are:

1. building site location;
2. the shape and dimensions of the structure;
3. the shape and weight of the elements to be lifted;
4. the character of the building site;
5. the required construction speed (the period needed for each process stage, or the total construction time)

The first four initial boundary conditions (characteristics) will be used to determine the most appropriate group of lifting devices and possibly the amount to be deployed. The intersection of the sets of results from the individual initial boundary conditions will give rise to a subset of suitable preliminarily selected lifting devices. The chosen suitable lifting devices will then be subjected to economic and ecological evaluation with consideration given to the required speed of construction.

2.1. Building site location
The correct selection of lifting equipment is influenced by the location of the building site. It must be possible to convey the lifting equipment to the site, i.e. the public roads leading to the place where the crane will be assembled must allow it to be transported there. Another limiting factor is the site entrance itself, which may restrict access by certain crane types to the site.
2.2. Shape and dimensions of the structure

It is necessary to have data on the dimensions of the footprint of the structure, its height and number of floors, so that the most suitable lifting machinery can be selected on the basis of these parameters and correctly placed. The parameters are also necessary when determining the number of lifting devices to be deployed. This will be based on standard spatial situations, taking into account the structure’s footprint and height, and the reach of the crane.

The selection of a lifting device, with consideration given to the required maximum hook height, is clearly shown below in Figure 3 Maximum crane hook height. The needed crane hook height $H$ is determined by the relation [7]:

$$H = h_1 - h_2 - h_3 - h_4$$  \hfill (1)

where:
- $H$ is the necessary crane hook height,
- $h_1$ is the highest surface upon which elements will be mounted or materials placed,
- $h_2$ is the clearance height,
- $h_3$ is the height of the conveyed load,
- $h_4$ is the height of the sling on the crane hook.
2.3. Shape and weight of lifted objects
Critical loads will be chosen that are decisive for the selection of the lifting device. The most adverse loads that may be conveyed during the movement of material by the lifting equipment are considered, e.g.:

- the heaviest lifted load;
- the most distant lifted load;
- the closest lifted load;
- the load that could result in the most adverse loading moment.

The selected lifting equipment must be capable of safely conveying all of the above-stated loads. The load curves of each lifting device will be employed in the evaluation of individual lifting device variants.

2.4. Character of the building site
The general character of the building site also influences the choice of crane and particularly the options for its placement at the site. The lifting device must be placed so that the reach of the jib covers the area of the built structure, necessary onsite storage areas and roads intended for the unloading of construction materials.

The entrance to the building site, its radius and the onsite transportation of cranes to the place of assembly, i.e. the characteristics of the roads at the site, are all important evaluated parameters. It is necessary to consider the distance of the deployment point of a mobile crane from the structure to be built. One of the most important reasons for this is that space is needed for crane assembly, whether it is a tower crane or a reinforced deployment point for a mobile crane. When decisions are being made about the placement of lifting machinery, the distance of the crane from all solid parts of the built structure is taken into consideration. These distances are the following – at least 0.5 m from the structure up to a height of 2.0 m; at heights above 2.0 m the distance is 0.1 m. It is necessary to ensure safe distances are maintained from the edge of constructed pits and site equipment structures: see Figure 4.

If two or more cranes have been selected for use at a construction site, and they are operated simultaneously, they must be positioned so that they do not collide. The assembly of the cranes is planned so as to ensure that their jobs are at different heights. The principle which applies is that the minimum distance between any parts of neighbouring cranes is 2.0 m. At the same time, the overlap of the jibs must be planned so that distances \( v_1 \) (the distance of the end of the jib from the mast of the second crane) and \( v_2 \) (the distance of the crane hook from the jib or the cable leading to the apex of the second crane) are no lower than 2.0 m – see Figure 5 Minimum distances between the jibs of simultaneously operating cranes [7].
2.5. Construction time
The time required to build the structure, or the duration of process stages, needs to be known in order to perform the financial evaluation of lifting devices that have been selected as potentially suitable for deployment from the technical standpoint.

The construction time will be taken from the contract schedule and the construction deadlines of each process stage in which the lifting equipment is to be used to the greatest extent. These are the following process stages:

- foundations
- substructure
- building shell
- roofing

If there is no construction schedule, it is necessary to create one; any suitable software can be used. Then, the above-mentioned process stages will be selected from the schedule and time values assigned to them corresponding with the duration of the deployment of lifting equipment at the site.

A proposal will be put forward regarding the number of cranes necessary to build a given structure according to the shape of the structure, its dimensions (in terms of footprint and height), the number of floors, the volume of the enclosed area and the construction time.

2.6. Database of lifting equipment
A database will be used for the preliminary selection of lifting equipment (i.e. tower cranes or mobile cranes) based on construction site location, the shape and dimensions of the structure, the character of the building site and the shape and weight of critical loads. The database of lifting machinery is proposed.

2.7. Determination of costs
Once the preliminary selection of lifting devices has been conducted and their total deployment time determined, the operating costs of the tower cranes and mobile cranes that were preliminarily selected as being suitable with regard to boundary conditions and technical parameters will be compared.

The following costs are evaluated for tower cranes:

- crane selection;
- transportation of the crane to the building site;
- crane assembly;
- construction of crane base, or rails;
- electricity consumption;
- crane rental;
- crane operation;

![Figure 5. Minimum distances between the jibs of simultaneously operating cranes](image-url)
crane disassembly;
transportation of the crane from the site.

The following costs are evaluated for mobile cranes:
- transportation of the mobile crane to the building site;
- fuel consumption;
- mobile crane rental;
- mobile crane operation;
- transportation of the mobile crane from the site.

The total costs connected with the operation of lifting devices and other construction equipment are influenced not only by the type and number of deployed machines, but also by the efficiency with which they are used. Experience shows that expenses generated by the operation of construction machinery account for between 5 and 10% of total construction costs, to which tower cranes usually contribute significantly. This means that it is rather expensive to have tower cranes standing unused at the construction site. Proper consideration should thus be given to the issue of whether to deploy a single crane, or two, or perhaps more. The deployment of each crane must be justified.

2.8. Impact of lifting machinery operation on the environment

When selecting lifting equipment, it is necessary to consider the aspect of ecology, which is included in the proposed method for that reason. The operation of a tower crane or mobile crane has, in our opinion, a marked effect on the environment.

The main negative impacts of the operation of lifting equipment on the environment are emissions, noise, vibrations and the pollution of water and soil. They also consume a great deal of energy gained from the burning of fossil fuels, which are considered to be non-renewable resources from the point of view of sustainable development. Mobile cranes have a negative influence on air quality in particular. This mainly arises due to the imperfect burning of fuel mixtures in their engines. Noise and vibration are other problems. Their source is the mobile crane’s motor, the interaction between the vehicle and the road, and also aerodynamic phenomena related to the body of the vehicle. The limitation of water and soil pollution from a vehicle can only be achieved via a thorough inspection to determine its state. Tower cranes are powered by electricity and the negative effects of the operation of tower cranes on the environment are minimal. They are perhaps limited to air pollution (emissions) from the means of vehicular transport that brought the tower crane to the building site. The noise made by a tower crane during operation is not as great as that produced by a mobile crane. From the perspective of the comparison of the effects of lifting devices on the environment it can be stated that mobile cranes have a significant negative impact compared to tower cranes, whose impact on the environment is minimal. After the full consideration of all of the above-stated factors, the final selection of lifting equipment will take place. The device or devices should fulfil the stipulated boundary conditions as regards technical parameters and should be the financially and ecologically most suitable choice for the given construction project.

3. Implementation of the method in computer software

Preparations are being made for the implementation of the proposed method for the selection of the most suitable lifting device for a specific construction project in an online computer programme (mobile application) [8]. The software is intended to be used both by specialists and by lay members of the public working in the construction industry.

The user’s task will first be to collect basic information about the construction project for use as initial data by the software:
- site location – place (town, district, region);
- shape and size of the structure – footprint shape, number of floors, footprint dimensions, height of structure, enclosed area [m³];
- lifted elements – critical loads for crane selection;
character of the building site – with regard to the transport, assembly and placement of the crane;
contract schedule, possibly the deadlines for process stages.

After starting the application, the user will be asked to create a new project, which will require basic identification data about the structure, i.e. the name of the structure, site location, investor, main contractor, and possibly other data that allows the user to easily find their way around the projects they are dealing with. The user then enters the location of the construction site in question into a map along with the initial position of the lifting device. This is done in order to determine the transportation route to be used when conveying the lifting device to the site, and the distance of this route in km. The location of the structure to be built and the initial location of the lifting equipment have a large influence on the determination of total costs for the equipment, as the cost of transporting a lifting device to a construction site is high. The costs involved in transporting a crane are determined according to the means of transport and the distance travelled.

After this stage, data on the basic shape and dimensions of the structure in question are entered. The user then enters the number of floors and total height of the structure. The basic footprint dimensions of the structure are entered based on standard spatial situations that take into account the structure’s footprint. The result of this part of the programme is a proposal encompassing all suitable cranes from the perspective of horizontal and vertical reach and their number with regard to the spatial layout of the structure to be built. According to the result of the selection of one or more lifting devices, the required data concerning the minimum mutual distances between crane jibs will be prescribed.

Another task for the user will be to stipulate and enter the critical load that will be conveyed by the lifting device. With such loads the weight is entered, along with the horizontal and vertical distances they will be conveyed before placement. The computer programme scans the database of lifting devices and their loading curves in order to select all cranes that are suitable as regards critical load. This produces another set of lifting devices which will be evaluated in connection with their possible use. Figure 6 depicts the evaluation of a lifting device from the perspective of its load capacity.

![Figure 6. Preliminary selection of a lifting device from the perspective of load capacity](image)

This is then followed by the evaluation of the entrance to the building site, its radius, the space available for the assembly of the lifting equipment, onsite transportation of the crane to the place of its assembly and space for a mobile crane deployment point.

In the next step the construction time is entered based on the contract schedule and the construction deadlines for the individual process stages in which the lifting equipment will be used. These are the following process stages:
- foundations
- substructure
- building shell
- roofing

At the end, the programme evaluates all the options and selects the most suitable lifting device from the subset of lifting devices that simultaneously fulfil all four previously stated boundary conditions. This is with consideration given to construction time and the also connected aspects of costs and impact.
on the environment. The result will take the form of information about the proposed lifting device or a
group of them, i.e. type, number, use of load capacity, costs and impact on the environment.

4. Conclusions
The presented method with computer and mobile application has been proposed for the selection of
lifting mechanisms for use in building construction, an area where such machines are decisive for the
workflow and efficiency of the construction project. It can, however, be modified or possibly extended
for other areas of construction such as transportation and utility structures. The programme is freely
available for design and contracting organisations as well as other members of the specialised and lay
public. The aim is not only to contribute a means of achieving the rapid and effective selection of lifting
mechanisms, but also to compare and evaluate other possible offers and alternative solutions, including
those considering the financial perspective.

The proposed method, and in particular the computer software that’s being prepared, with the option
of a mobile application, allow those preparing construction projects, site managers and construction
firms in general to select lifting machinery on the fly and quickly. The choice can be made between
tower and mobile cranes for a specific structure and with consideration given to costs.

The use of this method in practice, or its computer application, is user friendly. We hope that it will
be a truly popular tool that provides useful support.

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