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STUDY ON STRUCTURAL EFFECTIVE LIFE OF TOWER CRANE AND MONITORING SYSTEM FOR TOWER CRANE FLEET BASED ON SYSTEMS ENGINEERING

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ABSTRACT

The success of construction projects depends on proper use of construction equipment and machinery to a great extent. Thus, appropriate planning and control of the activities that rely on construction equipment could have significant effects on improving the efficiency of project operations. Cranes are the largest and most conspicuous construction equipment, widely used in typical construction sites. They play a major role in relocation of materials in horizontal and vertical directions on construction sites. Given the nature of activities relying on construction cranes in various stages of a project, cranes normally have control over the critical path of the project with the potential to create schedule bottlenecks and delaying the completion of the project. This dissertation intends to improve crane operations efficiency by developing a new framework for optimizing crane service sequence schedule. The crane service sequence problem is mathematically formulated as an NP-complete optimization problem based on the well-known Travel Salesman Problem (TSP) and is solved using different optimization techniques depending on the problem's size and complexity. The proposed framework sets the basis for developing near-real time decision support tools for on-site optimization of crane operations sequence. To underline the value of the proposed crane sequence optimization methods, these methods are employed to solve several numerical examples. Results show that the proposed method can create a travel time saving of 28% on average in comparison with conventional scheduling methods such as First in First out (FIFO), Shortest Job First (SJF), and Earliest Deadline First (EDF).

Introduction

The restriction of service life due to age of a crane appears to have originated in the Asian Pacific where there had been no prior restrictions on used cranes brought in from various countries. It was the most obvious issue addressed by CICA in that Australia was basically a "dumping ground" for old and worn out cranes which had exceeded their economic life and for counterfeit cranes. In prior years, maintenance and testing records were not required, resulting in thousands of cranes being imported into their country at the expense of safety. When records were supplied for cranes from other countries, language barriers limited document review regarding proper testing and maintenance. It is well documented that Singapore has progressed in the development of new local crane manufacturers, and the protection and support of those companies may be at least one underlying motive for implementing age limits on imported cranes. However, like Australia, Singapore is a growing country with what appears to be limited control of crane imports until the mid-2000s when the new regulations were implemented which addressed a more controlled and regimented layout, design and erection of tower cranes. Singapore further enhanced their new standards by requiring personnel involved in the erection and use of a tower crane to sign the layout plan demonstrating their understanding of their respective responsibilities. New York has improved crane safety during the past decade by

implementing necessary inspection procedures for various tower crane procedures. However, New York also has included a new nuance by imposing a new requirement for load cycle counters. New and more sophisticated technology on cranes appears to be the position of the Ontario MoL for safer crane operations. This is a simple and logical conclusion, but will more technologically savvy cranes be safer?

Proper maintenance, documentation and ongoing inspection and testing of cranes, remains the foundation for crane longevity as noted by Singapore, Australia, Cal-OSHA, and the City of New York. The alternative to allowing insufficient maintenance and inspection/testing is limiting the age of a crane; however, abuse and improper operation of any mechanical equipment has no age limit and can cause severe damage over a short period of time. Certainly structural, mechanical, hydraulic, pneumatic, and electrical degradation is inevitable as a crane ages. Crane maintenance is more intense with an aged crane since components naturally wear with use, because metal fatigue develops with repeated severe cycles, and because systems become inoperable, break due to impact or misuse, and deteriorate from environmental conditions.

With aged cranes, the original crane manufacturer often discontinues support a series or line of cranes. With mergers and acquisitions, the acquiring company often refuses legal responsibility for the design of cranes manufactured by an acquired company even though they will fabricate spare parts according to drawings contained in the purchased assets. Knowledgeable maintenance personnel for components of aged cranes also may become hard to find, and at some point, the crane may require complete overhaul. These issues and conditions increase maintenance costs and reduce the economic service life of a crane.

Component replacements, system modifications, and continued aging of the crane, at some point may dictate a risk assessment before allowing continued crane operation. Risk assessment should be conducted on a crane by crane basis.

However, as with any manufactured item, specific maintenance requirements must be met to achieve the ultimate service life of that piece of equipment. Proactive maintenance of cranes and crane systems can eliminate component and system failures. Preventative maintenance needs to be performed routinely per manufacturer schedules. Preventative maintenance inevitably increases the service life of a crane. Manufacturer maintenance schedules should be followed as standard practice since preventive maintenance produces the desired results of maximized component life, reduced component failure and reduced overall cost. Failure to follow manufacturer maintenance requirements will reduce the service life of any equipment.

Inspection requirements and maintenance schedules vary widely for the various crane components. For example, manufacturers require that maintenance personnel regularly perform.

Components of cranes that endure regular movement through crane operations, cylinders, winches, motors, pumps, and other components, wear with use. Typically, these components operate for long periods before either rebuilding or replacement becomes necessary. These components have a combination of bearings, bushings, seals, and/or piston (wear) rings that require replacement. Winch brake systems have brake linings and/or friction discs that also need replacement. Excessive wear of these crane components causes losses in performance and efficiency. In other

words, these components lose responsiveness and tend to develop sluggish movements, sloppy movements, slower speeds, increased vibrations, and slippage during crane operation. These are indications that crane component maintenance is needed. Manufacturer service manuals address these performance inefficiencies within the trouble-shooting sections of their manual, as well as

required actions to eliminate ineffectiveness of these components. Following these manufacturer

recommendations will maximize component life. Manufacturers usually provide lists of replacement parts within their manuals to facilitate regular maintenance practices. If some component is worn excessively and cannot be rebuilt, replacement of the Original Equipment Manufacturer (OEM) component will not reduce overall service life of the crane.

Structural deterioration is very long term issue. Design codes and historical performance typically result in structures being exceedingly robust. American Welding Society (AWS) design criteria assume that welded connections are flawed from the onset of fabrication and that fatigue crack initiation life is gone from first use. (Total fatigue life is the sum of initiation life plus propagation life.) These design criteria for dynamic structures assume that fatigue cracks evolve from entrained flaws and that service life is governed solely by crack propagation. Inspection criteria usually are defined such that multiple inspections are done during that period.

while crack growth is in the subcritical region. That is, if an existing structural crack is not detected during one inspection, there will be several subsequent inspections at later dates which should detect the crack long before it

becomes catastrophic. Often, no catastrophic failure occurs even with a sizable crack present within a structure. Fatigue cracks which form in structural members should be visually obvious during routine inspections. In critical applications, inspection intervals are specified such that multiple inspections occur prior to the crack growing to critical

size. Likewise, large structural displacements during operation should alert crane personnel that a structure is failing. Large deflections and progressive buckling symptoms often occur prior to catastrophic collapse.

Common commercial inspection techniques (mag particle, fluorescent particle, dye penetrant) readily detect surface cracks at sizes much smaller than critical size. However, quality inspections cannot be conducted on structures encrusted with dirt, grime and thick layers of paint. Inadequate inspection procedures and improper surface cleaning are the greatest causes of cracks reaching critical size and causing structural failures. Even when inspection practices are inadequate, opening, closing and rubbing of crack surfaces causes spalling or cracking of the paint, dislodges grime and forms readily visible rust stains.

Inspection requirements can increase due to environmental conditions. Cranes operated in coastal regions, even for short durations, can experience deleterious corrosion attack. Chlorine from salt water and fog is particularly insidious to structural components. Cranes close to the shoreline need more frequent inspections of its structural components. Corrosion rates for metals increase the closer metals are to the shoreline, since the amount of salt in the air is greatest near the ocean. Winds carry salt air and moisture inland and provide an environment in which salt accumulations form on metal surfaces of cranes. Salt accumulation on metal surfaces, along with high humidity, accelerates the reactions which cause corrosion. Corrosion rates are higher when high humidity keeps the surfaces damp longer. Over time, and even beneath paint films, chlorine corrosion will degrade steel members into dust. Therefore, more frequent periodic inspections and regular maintenance of crane structural components are necessary to prolong the service lives of these cranes operating near a shoreline.

Existing method

A tower crane not manufactured in Singapore whose existing certificate is 8 or more years old shall undergo a third-party inspection before each installation.

If the tower crane is 15 years or older, it will not be allowed to be used unless the owner obtained a letter from the manufacturer certifying that the crane can be safely used for a longer period of time.

Tower cranes 20 years or older will not be allowed for use.

Non-destructive tests shall be carried out by an accredited testing company in accordancewiththeSingapore

Accreditation Council, SINGLAS (Singapore Laboratory Accreditation Scheme) guidelines for the particular scope of testing.

Proposed method

This dissertation intends to improve crane operations efficiency by developing a new framework for optimizing crane service sequence schedule. The crane service sequence problem is mathematically

formulated as an NP-complete optimization problem based on the well-known Travel Salesman Problem (TSP)

and is solved using different optimization techniques depending on the problem's size and complexity. The proposed framework sets the basis for developing near-real time decision support tools for on-site optimization of crane operations sequence.

Results

During July 2014, we published the results of a study of crane accidents that dates

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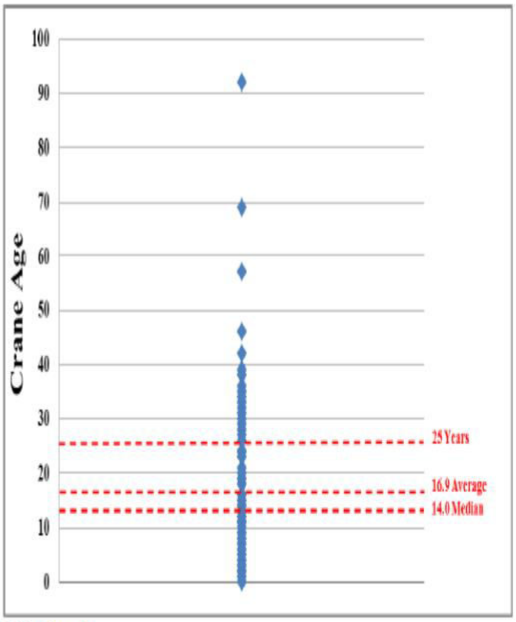
back to 1983. Our analysis and experience was based on the evaluation of over 800 crane accidents since 1987. The study involved complete analysis of 507 crane accidents at the time of publication. As part of our study, we identified the manufacturing date of the crane for each incident, as well as the age of the crane at the time of the incident in order to determine if there was a correlation. Of the accidents included in our study, we were able to identify the exact age of the crane 125 times.

Our study indicated a range of crane ages from 0 to 92 years with the average age of 16.9 years and a median of 14 years. A total of 78.4% of the cranes involved in incidents were less than 25 years old, and we found no discernable pattern to indicate calendar age of the cranes was a contributing factor. We did identify several accidents associated with condition of the crane, although the circumstances had resulted from severe abuse or neglect, including one that had only two annual inspections in 15 years and little or no maintenance. Site supervision is required to confirm that all cranes brought onto a construction site have undergone current inspection requirements. Many construction companies require a complete annual before a crane is brought onto the site or have an independent inspection company perform the inspection for the company.



Incident Crane Age

We considered the factors associated with calendar age that can cause or contribute to crane incidents. These include wear, metal fatigue, material degradation and operational abuse. All crane manufacturers have inspection requirements to verify that wear and materials degradation are within specific limits. However, metal fatigue does not always present itself in a manner easily observable during a typical inspection. New York City, recognizing this, previously instituted stringent inspection requirements for critical crane components.

We also considered safety improvements through operational aids in newer cranes compared to 25-plus year old cranes. Our study examined the use of more advanced technologies and particularly, operational aids to assist operators during lifting operations. A lift is successful when the process is thought out and planned. A lift will not be successful because a crane is new. A lift is successful because all parties thought through the process, provided accurate information, and used a crane capable of performing the lift. It has been our experience that lifts become dangerous when the lift director or operator rely on the crane (computer) itself to ensure limits are not exceeded rather than conducting a proper and thorough analysis and devising a plan to ensure limits are not exceeded.

Conclusion

The temporary aspect of construction projects and the involved dynamics might prevent efficient operations. Equipment operations and efficiency of individual pieces of equipment are major players in

determining the overall project productivity and cost, and improper planning of them will lead to wasting the project resources. Cranes, by far, are one of the most expensive pieces of equipment in many construction projects as well as freight terminal operations. Since cranes play a major role in construction operations, expediting their operations would have direct impact on the operation efficiency. The main motivation of this research was to overcome the existing problem in crane operation scheduling.

Conventional scheduling in fleet management, including cranes, is manual, and very dependent to human judgment. Since human judgment combined with his/her ability to decision making can result in sub-optimal decisions, a decision support system (DSS) was developed to help the on-site scheduler or directly the crane operator in his/her routine operation. Limitations and Future Research Similar to any other modeling study, this study had some limitations and simplifying assumptions that can be addressed in future studies. A general variant of the CSSP is when each supply material has several alternative locations. However, this research dealt only with a simplified version of the problem in which there is only one supply location for each material. Future studies can address this simplifying assumption. In the travel time prediction model, the travel time between two nodes was considered to be deterministic while travel time can vary in practice. Future studies can consider stochastic travel times. Given that the time savings increase with increased travel time resulting from elevation differences, future studies can investigate the effects of larger elevation differences (more than 10 meters) on travel time. This study assumed that each loaded bucket can be sent to one target location only, i.e., the crane hook cannot visit multiple demand nodes after being loaded. Future studies might relax this assumption. While in this study travel time was assumed to be independent of the load, future studies can evaluate the effects of material weight on travel time.

Future scope

Similar to any other modelling study, this study had some limitations and simplifying assumptions that can be addressed in future studies. A general variant of the CSSP is when each supply material has several alternative locations. However, this research dealt only with a simplified version of the problem in which there is only one supply location for each material. Future studies can address this simplifying assumption. In the travel time prediction model, the travel time between two nodes was considered to be deterministic while travel time can vary in practice. Future studies can consider stochastic travel times. Given that the time savings increase with increased travel time resulting from elevation differences, future studies can investigate the effects of larger elevation differences (more than 10 meters) on travel time. This study assumed that each loaded bucket can be sent to one target location only, i.e., the crane hook cannot visit multiple demand nodes after being loaded. Future studies might relax this assumption. While in this study travel time was assumed to be independent of the load, future studies can evaluate the effects of material weight on travel time.

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