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COST FACTORS AFFECTING DECISIONS FOR RECYCLING AND REUSE OF CONCRETE RESIDUALS IN NORTH CAROLINA

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Abstract: Highway infrastructure construction and rehabilitation operations such as hydrodemolition, diamond grinding and diamond grooving generate a large amount of concrete residuals. These residuals consist of wastewater, wet sand, chips and chunks of concrete, and slurry water. The North Carolina Department of Environmental Quality (NCDEQ) classifies these residuals as "Class A," and they are therefore treated as "inert debris," allowing them to be reused instead of disposing them in facilities such as Publicly Owned Treatment Works (POTW) and Municipal Solid Waste (MSW) sites. The North Carolina Department of Transportation (NCDOT) would like to encourage beneficial reuse methods for these concrete residuals, and requested an investigation of the costs associated with the following end uses: land application, water reclamation, beneficial fill, alternative daily cover, and soil modification within roadways. The aim of the study was to provide information that could encourage contractors to opt in favor of these recycling and reuse methods, and to allow the NCDOT to better estimate costs. In this study the costs associated with these methods were identified, and data was collected and analyzed. A model was developed, using @Risk and Monte Carlo simulations, to facilitate comparison of the different disposal and reuse methods and to provide insight into the relative costs of specific options for projects within different regions of North Carolina. Ultimately, this model can be used to facilitate the decision making process for NCDOT and contractors, potentially providing cost savings to stakeholders and enabling more frequent selection of beneficial reuse options for concrete residuals

Keywords: diamond grinding, diamond grooving, hydrodemolition, slurry, concrete residuals.

1 Introduction

Infrastructure projects undertaken in North Carolina often require the removal of concrete through the processes of hydrodemolition, diamond grinding, and diamond grooving. Hydrodemolition involves the removal of unsound concrete material from concrete structures through the use of high-pressure water jets. These jets are mounted on a mechanical hydrodemolition robots, or this type of removal is accomplished via a worker spraying specific areas with a handheld lance. The process of diamond grinding is used to improve smoothness and skid resistance to in-situ concrete roadway structures, and can be used to improve surface characteristics of new roadways. The process involves using a large diamond studded circular saw blade in conjunction with continuous water flow to grind the surface of a roadway, in a parallel direction, to improve ride-ability characteristics. Diamond grooving is used as a treatment technique on portland cement concrete pavements, using a diamond studded saw blade to cut parallel or perpendicular grooves into a pavement surface to improve drainage characteristics. The cuts in a grooved section of road can be up to six times the size of the cuts on a grinded section, and the cuts are spaced much further apart.

The four waste products associated with these processes are wastewater, wet sand, chips/chunks of concrete, and concrete slurry water (ICRI 2014). These waste products, often called concrete residuals, require time and resources to adequately manage.

In recent years, lack of appropriate guidance for handling and disposal of these residuals has been causing confusion to contractors, resulting in change orders, additional costs, and project delays until disposal or reuse methods suitable for specific project conditions are identified. Often, changes in handling and/or disposal methods (and associated delays) had been caused by contractor's lack of knowledge of how to manage these residual materials in a way that is not detrimental to the environment or be financially risky. To address this situation, NCDOT personnel developed a streamlined process to guide management of concrete residuals in hopes of promoting beneficial reuse and realizing cost savings. Supporting this effort, NCDOT has performed research on appropriate means of disposal and beneficial reuse for concrete slurry water and residuals (Line and Smyth 2015; Line 2016). Additionally, the authors of this paper were tasked with developing a Benefit-Cost Model (BCM) using Multi-Criteria Analysis that would enable the estimation of the costs of disposing and/or reusing concrete residual material that is produced by the hydrodemolition and diamond grinding/grooving processes. This model would provide contractors bidding on NCDOT projects guidance to assist them in identifying available options for concrete residuals based on project locations.

The permitted methods in North Carolina by the NCDOT and available to contractors for the disposal of liquid (water) waste are: disposal at wastewater treatment plants (WWTP), disposal at publicly owned treatment works (POTW), or reuse of the water via land application. The permitted methods by the NCDOT and available to contactors for solid disposal are: disposal at municipal solid waste (MSW) landfills, disposal at construction & demolition (C&D) landfills, and disposal at land clearing and inert debris (LCID) landfill. The permitted methods for solid waste reuse are beneficial fill onsite/offsite. This paper outlines the methodology with which the costs associated with the disposal of these residuals were analyzed and modeled using a Monte Carlo simulation (MCM).

2 Background

Residual concrete materials (solids, liquids, and slurries) are generated by several construction processes during the construction or repair of concrete infrastructure. However, the construction processes that were of interest to the NCDOT for this investigation were hydrodemolition, diamond grinding, and diamond grooving.

2.1 Hydrodemolition

Since its development in Europe in the 1970's hydrodemolition has become one of the go-to methods for concrete bridge deck removal (Nittinger 2001). The emergence of hydrodemolition as a favorable technology can be attributed to the following (ICRI 2014):

- Consistent results on a project-to-project basis,
- Guaranteed total removal of degraded material,
- No damage to existing reinforcing steel or adjacent concrete,
- Creation of a rough surface for easy bonding to new concrete,
- No impacts, vibrations, dust, or fumes, and
- A rapid rate of work.

Hydrodemolition equipment typically utilized for bridge deck removal consists of a motorized vehicle that slowly drives on a concrete surface, spraying a constant stream of water at very high pressures. The pressures, flow, and motion of the water jets are controlled to ensure a continuous demolition process of the concrete it is driving over. This method is shown in Figure 1 (left). Upon completion of the process, the contractor is responsible for cleaning up the area and removal of the wastewater. The residual material, which is a combination of wastewater, wet sand, chips/chunks of concrete, and concrete slurry (ICRI 2004), is collected and treated until the criteria for disposal set by the state are met. Hydrodemolition is unique because it can be controlled in a manner that will demolish sound and unsound concrete to a desired depth, while also creating an appropriately roughened bonding surface for new concrete (Nasvik 2001). The residuals produced during hydrodemolition can be seen in Figure 1 (right).

Figure 1: Hydrodemolition Equipment (left) and Post-Hydrodemolition Surface (right)

2.2 Diamond Grinding

The process of diamond grinding is used to rehabilitate a pavement surface texture to a condition that is often as smooth as a new pavement. Diamond grinding is also used to reduce road noise while increasing surface macro texture and skid-resistance. The process uses closely spaced diamond equipped saw blades attached to a truck bottom and run longitudinally across a pavement surface. The saw requires a constant stream of water, which is provided to the machine by a separate truck run in conjunction with the diamond grinding equipment. A vacuum is attached around the saw blade in a fashion that picks up the water, concrete residuals, and slurry, and sends these materials to a separate holding tank within the water holding truck (Caltrans 2008).The grinding equipment and water truck used can be seen in Figure 2. A picture of the saw blade can be seen in Figure 3 (left) and a typical grinded section can be seen in Figure 3 (right).

Figure 2: Diamond Grinding Machine (left) and Water Supply Tank (right)

The residual materials created from the diamond grinding process consist of waste water, hardened concrete fines, and concrete slurry, and are referred to as Concrete Grinding Residue (CGR). The CGR is collected by the vacuuming process, to be held, treated, and disposed of at a later time. The International Grooving & Grinding Association (IGGA) states that grinding slurry is an inert, nonhazardous byproduct of diamond grinding portland cement concrete pavement. Many tests have been done to ensure that the residual material is nonhazardous (IGGA 2013a). The CGR is a highly alkaline material (pH of 11-12.5+)

containing many suspended solids, which may cause problems for existing roadside vegetation and nearby waters. Some slurries may contain sulfates, chlorides, hydrocarbons, or other materials derived from concrete admixtures. However according to a characterization of the CGR by DeSutter et al. (2011), it was found that:

- Slurry samples displayed non-hazardous characteristics according to EPA hazardous waste standards.
- Slurry samples passed the 96-Hour Acute Toxicity testing, showing no toxic characteristics.

Figure 3: Diamond Grinding Saw (left) and Typical Grinded Section (right)

Additional field and laboratory testing assessing the impact of land application of diamond grinding slurry was performed for NCDOT by Line (2016), with application of diamond grinding slurry and HRW to the field application areas not presenting "significant concern to the soil or vegetation of the application area or adjacent surface waters."

2.3 Diamond Grooving

Diamond grooving of portland cement concrete pavement is a treatment for increasing tire traction and decreasing the possibility of vehicular accidents caused by inclement weather. A study by IGGA showed that after grooving operations have been completed declines in wet pavement vehicular accidents of up to 70% have been reported (IGGA 2013c).

Figure 5: Grooving Machine (left), and Typical Grooved Pavement Section (right)

Grooving of pavement can be either parallel or perpendicular to the lane, and is used to create paths to remove water from the surface of roadways to improve drainage characteristics. The grooving process is similar to that of grinding; however, grooving uses a vehicle with a mounted saw that uses cooling water while grooving, a source water tank, and a vacuum to pick up grooving residue. A picture of a grooving machine can be seen in Figure 5 (left). Grooving produces larger and deeper cuts that are spaced further apart than with grinding (IGGA 2013b). At typical grooved section can be seen in Figure 5 (right).

2.4 Residual Products and Disposal Methods

Current best management practices for the handling and disposal of the slurry material have been developed by IGGA, who suggests that in rural areas with vegetated slopes adjacent to the roadway, the slurry can be spread on these side-slopes as the grinding operation moves along the road. This is not the case when the work is conducted adjacent to wetlands or other sensitive or protected areas, where the IGGA suggests that the slurry be vacuumed, picked up, and disposed (IGGA 2013a). According to the Environmental Protection Agency (EPA), the wastewater from the process should be filtered to remove both coarse and fine solids and treated to lower the pH to acceptable levels and hauled to a publicly owned treatment works (POTW) or waste water treatment plant (WWTP). Another method for disposal is containing the slurry in a decanting pond, allowing the water to evaporate away leaving only the solids behind for disposal (EPA 2012). Solids can then be directed for solid disposal at landfills, or used as beneficial fill in construction sites. No matter what method is used, solids and liquids need to be separated, and disposed/reused in different locations.

The disposal/reuse methods for concrete residuals that are acceptable for use in North Carolina are the following:

- For wastewater: Disposal via waste water treatment plant (WWTP) and publically owned treatment works (POTW), and Reuse via land application.
- For solid waste: Disposal via municipal solid waste (MSW) landfill, construction & demolition (C&D) landfill, and land clearing and inert debris (LCID) landfill, and reuse via beneficial fill onsite/offsite

Acceptable methods by the NCDOT for separation of the liquids and solids include the use of frac tanks, and the use of a decanting pond. When considering all of this information, the available combinations for the disposal and reuse of waste material are as follows:

- Initial waste handling: frac tank, decanting pond (2 options)
- Wastewater disposal/reuse: WWTP/POTW and land Application (2 options)
- Solid Disposal: MSW, C&D, LCID, beneficial fill on site, beneficial fill off site (5 options)

This results to 20 possible combinations ($2 \times 2 \times 5 = 20$).

2.5 Monte Carlo Method

The MCM is used to obtain numerical solutions in situations where solving analytically is too complicated (Rubinstein et al. 2013; Palisade-Corporation 2016). The MCM uses computerized mathematical techniques to simulate an outcome through the use of information related to that outcome, in the form of probability distribution functions. In practice, the MCM can be used to create a model to solve a given question that has many variables with differing probabilistic values. By running many hundreds, or even thousands, of iterations, a sample average may be considered acceptable by the probabilistic theory of the law of large numbers (Renze 2016). The final values in a model created using the MCM will be a distribution of values from high to low, allowing the user to get a range that is most likely to occur for that outcome based on the input values (Takeshi 2013).

The MCM holds advantage over deterministic models because it shows not only what could happen, but how likely that result is to happen, in a clear graphical manner. The MCM also allows for the quick determination of the factors that would have the largest impact on the final outcome, identifying the ones that should be most closely monitored to decrease risk. By using data that has been gathered directly by means of survey or other direct data collection methods, the range of values for each factor can be reasonably assumed to represent likely values that may occur in practice. Data gathering is therefore a very important part in creating a MCM Simulation (Rubinstein et al. 2013).

3 Methodology

Information to build the MCM model was obtained from various sources, which included surveys and interviews for recording the methods for disposal/reuse of concrete residuals, and the identification of costs and production rates using valid cost estimation techniques. Additional construction industry references were used for estimates on productivity and equipment costs. These reference included R.S. Means (R.S. Means 2009), the US Army Corps of Engineers Construction Equipment Handbook (USACE 2014), and the Davis-Bacon Wage determination website (NTIS 2016). The information gathered for each variable was compiled into probability definition functions (PDF), which were utilized in the MCM model. The interaction of the PDF in the MCM simulation produces the anticipated results.

3.1 Surveys

A survey was developed to interview contractors about their chosen methods of disposal/reuse. The information provided by the contractors was used to highlight the factors that influence cost on a project. Based on the literature review and the goals of this project, the survey concentrated on the following areas:

- Types and quantities of materials generated,
- Environmental tests required,
- Disposal/reuse options,
- Contractual obligations
- Quantities of residuals generated, and
- Unforeseen cost variables.

3.2 Disposal Facilities

To identify the costs associated with the disposal of materials, disposal facilities within the state of North Carolina were contacted to determine whether or not they would accept the residual material, and at what price. A sample from all the facility types was contacted (WWTP/POTW, MSW, C&D, LCID). The directories for these facilities were obtained on the North Carolina Department of Environmental Quality (NCDEQ) website (NCDEQ 2016). These facilities were then grouped and organized based on region and type, then selected at random to be contacted in order to identify the level of quality at which they would accept waste material, if they required pre-treatment, and cost of tipping fees. The cost data was then utilized in the MCM to better estimate the price at which the residual materials would be disposed once generated. The costs varied based on location and type of facility. To support this work, 205 facilities were contacted, with responses received from 97 facilities (a 47.3% response rate).

3.3 Information from other Sources

The R.S. Means Manual (R.S. Means 2009) was used to identify types of equipment used on projects, and their estimated productivity values. The typical crews for each piece of equipment were also noted from the R.S. Means Manual, however within the MCM it is possible to select different crew sizes. Information presented in the R.S. Means manual was also used to find the information associated with the activities involved in choosing the decanting pond option for slurry handling. The activities involved in the decanting pond method of slurry handling are: excavation, geosynthetic layering, backfilling, and compaction.

Hourly costs for equipment necessary to perform the necessary operations for the disposal or reuse of the concrete residuals, the Construction Equipment Ownership and Operating Expense Schedule for Region III (USACE 2014) was used. The USACE manual was used to estimate the costs of:

- Hydraulic excavators,
- Front-end loaders,
- Compaction equipment,
- Transportation trucks,
- Water tank attachments for transportation trucks, and
- Solid waste transportation vehicles.

The Davis Bacon Wage Act website was used to determine the minimum hourly wages of workers on the jobsite for government projects (NTIS 2016). It is possible that labor costs associated with the activities for disposal and reuse of concrete residuals might be higher than the rates obtained from the Davis Bacon Act website. However, since that information is proprietary to the contractors and is generally not shared, the Davis Bacon Act values were determined to be a good approximation. The website was used to find the hourly costs of laborers and equipment operators. The wages were generated using Mecklenburg County as a baseline, and included the necessary fringes and benefits.

3.4 Monte Carlo Model Flowchart

The logic built into the model follows the flowchart shown in Figure 6. In order to produce a range of possible costs, multiple simulations of the model were performed, calculating numerous possible outcomes. For this simulation, 5000 iterations were performed. The process starts with the identification of the construction operation that takes place: either hydrodemolition, concrete grinding, or concrete grooving. Each of these operations produces waste products in the forms of slurry, liquids and solids. The quantities of the slurry, liquid, and solid waste products for the selected operation are determined by the probability definition functions that were generated from the contractor interviews. When the simulation is performed using the @Risk add on, the PDFs incorporated into the model, along with the supporting calculations, multiple possible solutions from the variables discussed previously are generated.

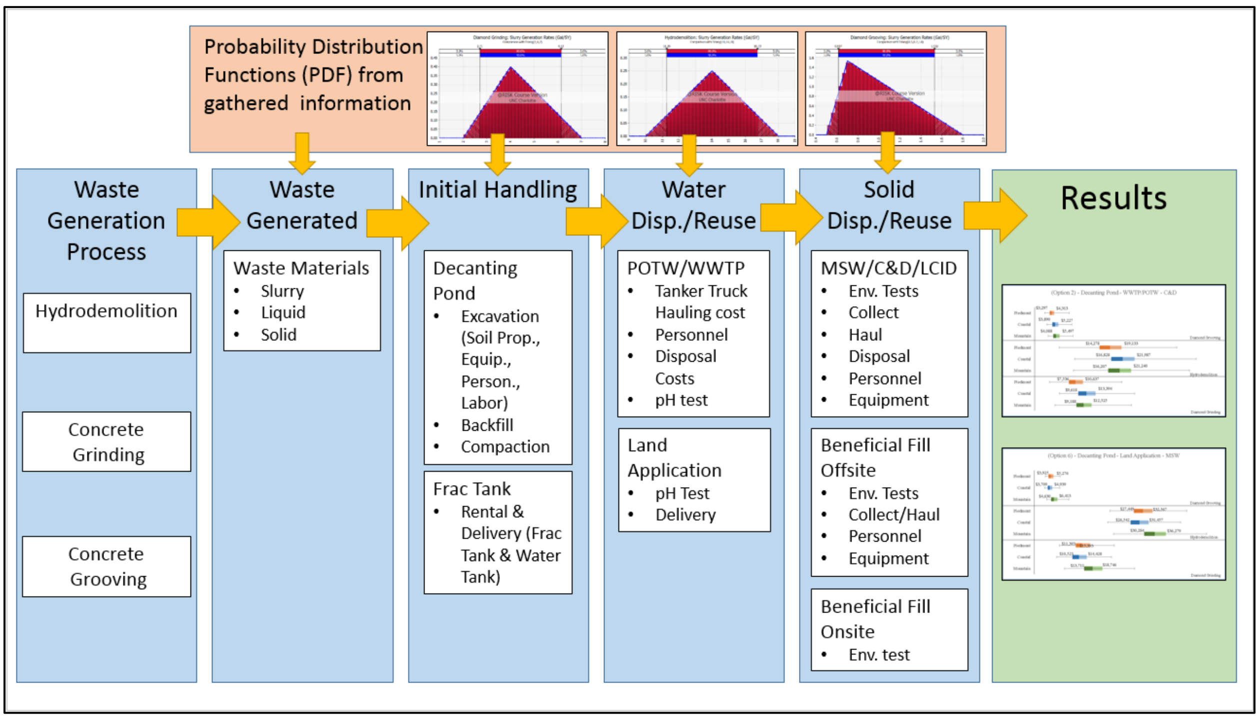

Figure 6: Monte Carlo Model Flowchart

After ranges for the quantities of the waste products are generated by the model, information is directed to the "Initial Handling" calculations. The two possible options for initial handling include decanting pond and frac tank. The costs associated with the decanting pond option include equipment, personnel and materials associated with the following activities: excavation of the pond, placement of lining, backfill, and compaction. Costs associated with the frac tank option include rental and delivery of the tanks.

The model then calculates the cost of water disposal/reuse, where two different options are possible: POTW/WWTP and land application. Costs associated with the POTW/WWTP option include labor, personnel and equipment associated with the following operations: tanker truck hauling, disposal fees, and environmental tests. Costs associated with the land application option include environmental tests and delivery of the waste water.

The model then proceeds to calculate the costs for disposing the solids according to the five options mentioned previously. Disposal at MSW, C&D, and LCID facilities is treated similarly and the costs associated with this option include: environmental tests, collection of the material, hauling, disposal fees, personnel, and equipment. The costs associated with beneficial fill offsite, include the required environmental tests, collection of material, hauling, personnel and equipment. For disposal onsite, only the environmental tests were considered.

Once each of the costs have been calculated by the model for the project characteristics, they are added together, and ranges for possible costs for multiple scenarios are generated.

4 Results

Sample simulations were performed using characteristics of a theoretical project that had a diamond grinding, diamond grooving or hydrodemolition area of 10,000 square yards. The model output provided ranges of costs displayed in a box plot format, an example of which is shown in Figure 7, where the box represents the range of cost values between the 25th and the 75th percentile. The mean (50% value) is in the middle of the plot, at the point where the color changes from darker to lighter. The "whiskers" of the box plots indicate the two extreme cost values of 0% and 100%. For comparison purposes box plots were generated for each of the 20 combinations for the three regions of North Carolina (Mountain, Piedmont, and Coastal). It is not possible to show all combinations in this paper, but the summary of all the results will be discussed instead. It is important to remember that due to the probabilistic nature of the Monte Carlo analytical method supporting the model, the results of the simulation will be different each time it is run. Therefore, these plots can be used to compare the relative differences of the options when compared to each other.

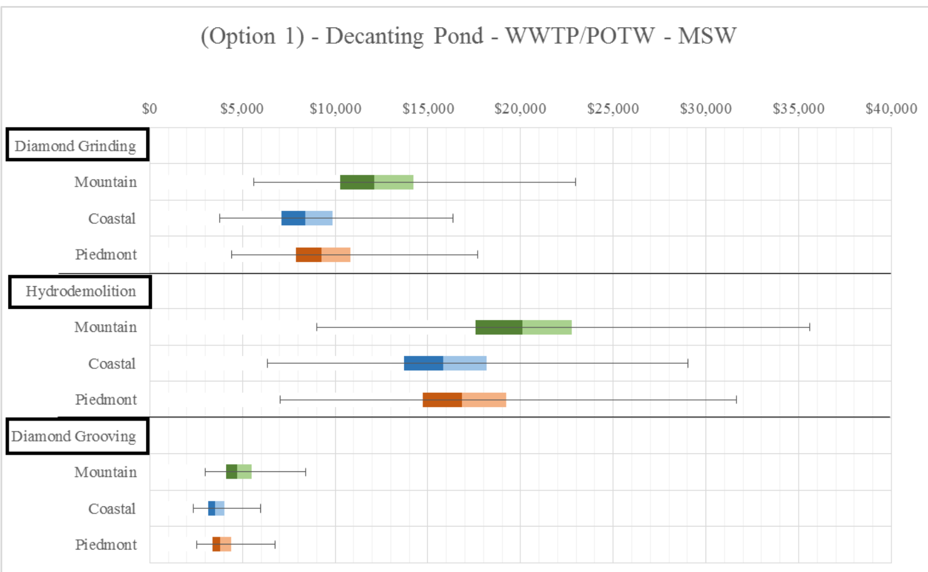

Figure 7: Example of results – Decanting Pond – WWTP/POTW – MSW

The MCM model was validated by industry professionals undertaking similar projects in North Carolina. Additional information on validation is presented in Tymvios et al. (2017). After the model's validation, it was determined that costs associated with handling, disposal, and reuse of concrete residuals can be reasonably predicted for the 20 different disposal/reuse combinations for hydrodemolition, diamond grinding, and diamond grooving debris. The results of the simulations using the model allowed for the identification of the following trends:

Options involving decanting ponds (instead of a frac tank) were less costly, and difference is more evident in operations that produced less amounts of liquid slurry, such as in diamond grinding/grooving. In hydrodemolition operations where the quantity of liquid slurry produced is high, the cost comparisons between options that utilize a frac tank and a decanting pond are less obvious. The use of frac tanks allows contractors to limit the amount of work and workers necessary to manage and operate the slurry handling, thus reducing the possibility of worker error and lowering risk.

The MCM results showed that disposing of liquid residuals at POTW/WWTP facilities is more cost effective than land application for hydrodemolition and diamond grinding operations, and vice versa when diamond grooving is performed. This is likely due to the cost of sending the water to the land application facility. The costs on a per gallon basis obtained during this investigation were reasonable according to experts who validated the model, but experts did comment that costs tended to be on the higher end of the range of expected values. It is possible that a lower price per gallon disposal fee might be possible at land application facilities in the future, eventually making that type of disposal more effective. Based on feedback from NCDOT personnel and environmental consultants, land application is also perceived to be the less risky and more environmentally responsible option of liquid residual management.

Regarding solid residual disposal, it was observed that for all regions (Mountain, Piedmont and Coastal), beneficial fill onsite is the most cost effective, least risky, and likely the most environmentally responsible option available for solid residual management. When the other options are compared, some regional differences arise. C&D facilities in the Coastal Region have higher tipping fees, while that is also the case for MSW facilities in the Mountain Region. These higher costs make the use of options involving C&D facilities in the Coastal Region, and MSW facilities in the Mountain Region, more expensive. In the Piedmont Region, LCID facilities were seen to have lower tipping fees and as a result options involving LCID in that region are less expensive.

5 Conclusions

The MCM model was observed to be an acceptable method to obtain a range of possible costs for the 20 different combinations for disposal or reuse of concrete residuals. Since a different range is generated every time the simulation is run, the exact numbers of the simulation should not be compared, but the trends should be compared instead. The MC allowed the comparison of the 20 different options, through the generation of cost ranges, which can be applied to a project of any size. Since contractors are not always forthcoming with cost information, the MC can be used by project owners during the planning of a project to better estimate project costs, while at the same time incorporating risk factors into the decision for the disposal option.

The trends described in the results have been validated by industry experts, and expressed that in general they seemed to be accurate with minor exceptions. The industry experts suggested that the Davis Bacon Act labor rates are generally under estimated, but due to the reluctance of contractor to company proprietary information, that can serve as a good approximation.

There were some limitations in the model as well. First, evaporation from decanting ponds was not considered in the model, since that highly variable process would unnecessarily complicate the investigation. The decanting pond utilized in the model is a lined, single-pond system. A more complex decanting pond design, or a multi-pond design, would increase the cost. The need for additional safety measures around a decanting pond would also increase the cost of this option. Such alternatives were not utilized since they would dramatically increase the complexity of the MCM model.

It should also be noted that this model is only applicable within the state of North Carolina. Other states may have different regulations that could alter costs, affect the risks in the projects, and change any possible environmental benefits.

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