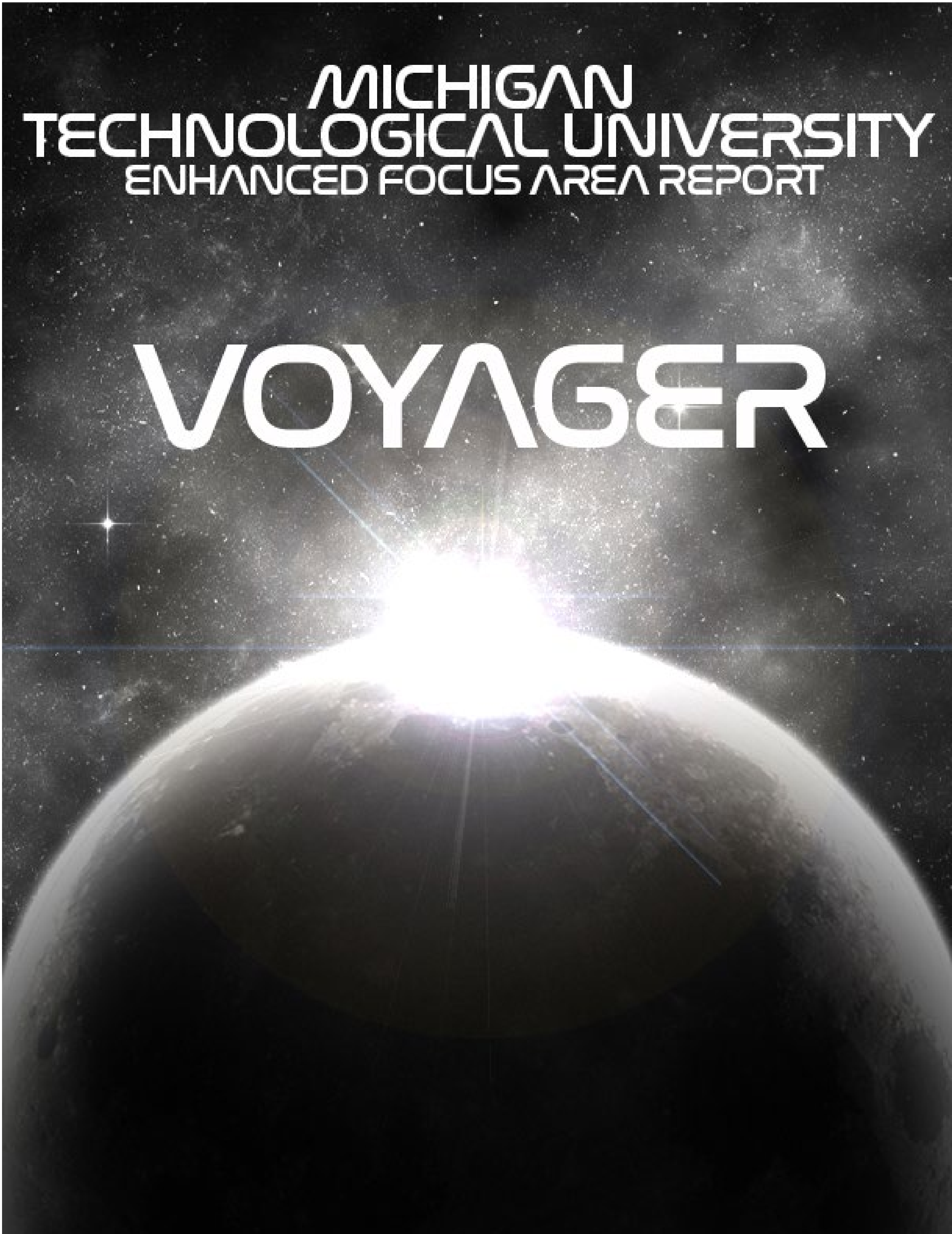
MICHIGAN TECHNOLOGICAL UNIVERSITY

ENHANCED FOCUS AREA REPORT

VOYAGER



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Introduction

The 2021 Michigan Technological University (Michigan Tech) Concrete Canoe Team was inspired by the unknowns of space this season and thought that the perseverance and pragmatism demonstrated by the aerospace industry was especially important to uphold during the COVID-19 pandemic. The team not only applied this outlook to the season, but specifically to the enhanced focus areas (EFAs). With there being unknowns throughout the year regarding lab access and knowledge transfer, it was important that the Michigan Tech Concrete Canoe Team chose EFAs that not only addressed these unknowns, but also explored new areas of research. The team was further encouraged to investigate areas of research not typically done in a competition year, as the 2021 competition does not require a physical prototype to compete, meaning that if an EFA proved unsuccessful, the team would face minimal consequences at competition. Through these new research areas, it was of the utmost importance that they promoted the longevity of the team via providing opportunities for knowledge transfer and knowledge application. Therefore, throughout the EFA selection process, knowledge transfer was at the forefront of decisions.

Selection Process

There were two EFA selection criteria, with the first regarding an EFA's ability to be accomplished virtually, as the ability to normally access the lab throughout the year was unknown due to COVID-19. This criterion resulted in the majority of proposed EFAs being software based, specifically with software taught in undergraduate classes at Michigan Tech. Through considering software that each student has been exposed to, it was guaranteed that a majority of time spent on developing the EFA was dedicated toward researching rather than teaching the software. The second criterion required an EFA to be multifaceted; this allowed the team to understand the theories and background of the EFA, and then apply that knowledge to testing results. Presenting an opportunity for students to be involved with the process from the initial model to final testing results not only encouraged participation, but retention of knowledge. Performing validation tests for each selected EFA in the 2021 season was optimal, but given the uncertainties of lab access, the second criterion only required that the EFA possess the ability to be validated in future seasons. Therefore, the proposed software from the first criterion needed to have the ability to be validated through testing to fulfill criterion number two.

Multiple EFAs were considered, most of which stemmed from research initiatives started in previous years but were either unsuccessful or simply not investigated further. The first EFA considered was one relating to the team's sustainability, with goals to develop a process to purify snow for use in the structural mix. However, because there was no obvious software that the team could use to complete a majority of this EFA, and it mainly required in-person development, it was not considered further. Another proposed EFA was the use of a convex mold for casting the canoe, rather than the traditional concave mold used by the team. If the convex mold proved unsuccessful in a mock-cast, there would be no point-deductions because a physical prototype was not required. This EFA was ideal as it was a project that involved the entire team, from designing a new mold for the mock-cast, developing a new casting procedure, to investigating the use of tension ties throughout the hull of the canoe. However, this EFA had a significant time constraint, as the team would have to schedule for a fall cast, something never done before, and it was not guaranteed that the information learned from this EFA would be used in future projects, as the mock-cast could prove unsuccessful. Additionally, with the mock-cast occurring at the end of the semester, it was especially unknown if the team would be allowed to construct the prototype in-person. For these reasons, the EFA was not further developed. The third EFA considered was a finite element analysis (FEA). In years past, when FEAs were permitted as part of the structural analysis portion of competition, Michigan Tech utilized them. However, since FEAs have been disallowed at competitions, the team's knowledge and understanding of them diminished. Developing an FEA model for this EFA satisfied the requirement of the EFA being majorly software-based. To satisfy the second selection criterion, Michigan Tech planned to use their completed 2020 prototype, *Dozer*, to verify the FEA model through deformation testing. Therefore, with an FEA satisfying both criteria, it was selected as the first EFA. The final EFA considered and selected, was one that introduced a statistical analysis software to the research and development committees. Historically, the mixture design committee utilized a trial-and-error process for developing the structural and finishing mix, with each week designated to improving one aspect of the design, such as binders, fibers, or aggregates. Although this always proved successful at competitions, nothing was implemented to cross-check the decisions made each week. This proposed EFA was to use the software Minitab to generate a design of experiments (DOE) for each constituent of the design and analyze the results synchronously with the traditional trial and error process. Unfortunately, lab access was lost before both the FEA model and DOE were finalized, meaning that both chosen EFAs were reduced to their software. However, because the second decision criterion guaranteed that in-person testing could be done in the future to fully integrate the EFAs into the team, the two EFAs remained and their modeling proceeded.

Enhanced Focus Area 1: Finite Element Analysis

After finite element analysis was disallowed from the structural analysis portion of competition, the Michigan Tech Concrete Canoe Team evaluated their hull design in one-inch segments and used an Excel spreadsheet to calculate stress states. However, this process proved complicated and yielded inaccurate results; therefore, the goal of finite element analysis EFA was to not only improve the structural analysis process, but to ensure that in future years, structural analysis will not be a weak spot of the team. To begin, a 3D model of the hull was designed in a modeling software; historically, this was done via AutoCAD, but to make this EFA more accessible to the entire team, the hull was modeled in NX, a software taught in first-year classes. The hull modeled was that of Michigan Tech's 2020 boat, *Dozer*, as the 2021 hull was not finalized, and *Dozer* was fully completed and available for modeling. Once the NX model was complete, it was imported into Ansys, an engineering simulation software also taught at Michigan Tech. In Ansys, entities of the model can be assigned specific materials that are either within an Ansys database or that have been input by the user. For the simplicity of the model, the hull was assumed as one entity, with the selected material as the 2020 composite structural mix, *Backfill*. Only yield strength is required to run the simulation, but Ansys accepts supplemental properties, such as compression strength and ductility; material parameters entered were those gathered from three-point bend tests (ASTM C1341-13). A limitation to this design was the inability to model the gunnels as their own entity, as their composite strength was not the same as the hull's due to differing reinforcement schemes.

The Ansys model proved useful in two areas of structural analysis, with the first being the visual graphic. Given specific load cases and constraints, this visual graphic displayed where the boat will initially fail and that corresponding critical stress. In the future, this portion of the model can be evaluated synchronously with the mixture and reinforcement design, such that the committees can immediately gauge the performance of their designs. Ansys also exports a graph that displays stresses undergone at specific locations along the hull; this proved useful as, historically, after racing, Michigan Tech's boats develop micro-cracks along the gunnels. Although the initiation of micro-cracks along the gunnels are typically not as critical as the initiation of cracks in the hull, their propagation led the 2019 Michigan Tech concrete canoe to break in half. In *Dozer*, a steel cable was placed throughout the gunnels to act as a tension tie that restricted the propagation of these micro-cracks, but because there was no 2020 competition, the cable's efficacy was not evaluated. Therefore, once gunnels are modeled as their own entity in Ansys, the graph feature will allow the team to efficiently evaluate the effectiveness of various tension ties throughout the gunnels.

As mentioned, lab access was lost during the finalization of the FEA model, and therefore, no in-person testing was completed to validate the model and its assumptions. In future years, *Dozer* can be tested to validate the FEA model; however, it is important to ensure that the testing of *Dozer* yields the correct property exported by Ansys. For example, if the model exports the critical compressive strength of *Dozer*, tensile testing should not be conducted. It is also important that the specimen geometry taken from *Dozer* is acceptable for each test, as failure to do so would result in incorrect results and a waste of limited resources. In future years, the model can be refined to include layering of the reinforcement, finishing mixture, and gunnels to improve the accuracy of model results. Although it is unknown whether or not FEAs will be permitted in future competitions, its development as an EFA will continue to aid Michigan Tech Concrete Canoe Teams through providing convenient, accessible, and once validated through *Dozer*, reliable supplemental structural analysis information for years to come.

Enhanced Focused Area 2: Statistical Analysis

Minitab is a statistical analysis software used to generate various types of DOEs and evaluate the statistical significance of design factors on chosen responses. It can be used to generate p-values, contour plots, matrix plots, evaluate the normality of data, and perform gage repeatability and reproducibility tests. Before lab access was lost, the initial EFA planned to evaluate each constituent of the mix, meaning that all binders, aggregates, and cementitious materials would be factors in the DOE. Responses were to be the mixes' respective unit weight and compressive strength, as the mix committee's goals typically involve altering these properties. However, with no way to test the strength of mixes and investigate the use of new materials, the EFA was reduced to evaluating the effects of previously used aggregates on the unit weight of mixes. Aggregates investigated were those used in the 2020 structural mix, *Backfill*, that met the microsphere requirement.

An extreme-vertices mixture DOE was designed, as this does not require the factors of the DOE to have uniform levels and allows the factors to sum to a single total. For this EFA, the single total of aggregates was 100, to represent 100% of the total aggregate volume. Aggregates levels, or volume fraction ranges, were determined based on past research and mixture designs

(Table 1). Volume fractions of individual binders and cementitious materials were held constant at their values within *Backfill.*

Table 1. *Mixture DOE Design for Aggregates*

Factors (X's)	Levels	Design: Mixture Single Total: 100	Responses (Y's)
Elemix (%)	10-40	Replicates: 1	Unit Weight (pcf)
Haydite (%)	20-50	Center Point: Yes	
Crushed Concrete (%)	20-65	# Runs: 13	

Once a DOE is designed, it outputs numerous runs that are required to complete, such that Minitab can accurately perform statistical analysis. The response of unit weight was calculated for each run in an Excel spreadsheet the mix committee uses during their research and development stages. The total mass and volume of the mix is calculated using each constituent's respective volume fraction and bulk specific gravity; volume fraction and water-to-cement ratio are user-inputted. To calculate unit weight, total mass is divided by total volume, total volume must equate to a cubic yard, 27 ft^3, for the unit weight to be accurate. From this DOE, a contour plot was generated. The contour plot displayed unit weight contour-lines as a function of the three aggregates, with the grey outline separating gathered data and extrapolated data (Figure 1); all data outside of the grey box is extrapolated.

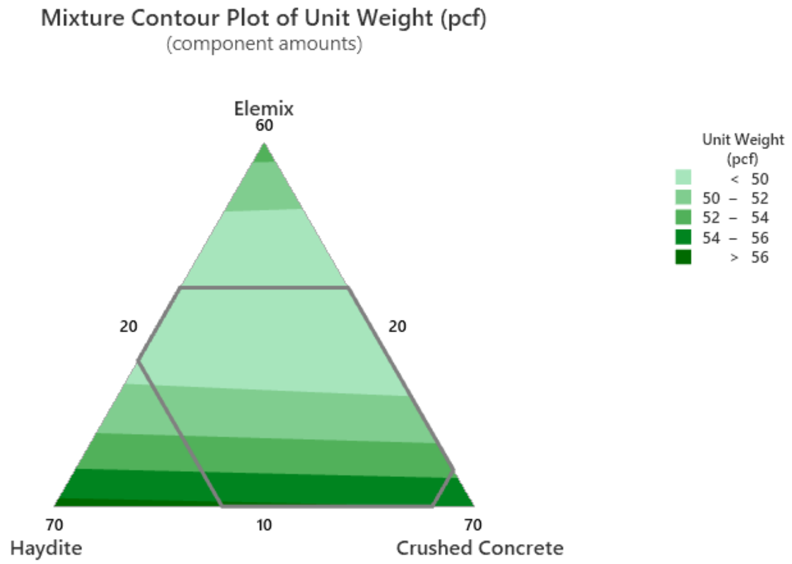

Figure 1. *The contour plot generated for the mixture DOE, with factors of Haydite, Elemix, and Crushed Concrete. The data outside of the grey box is extrapolated.*

Minitab's response optimizer feature was also utilized, as the user can specify whether they want to minimize, maximize, or target a specific response value, and Minitab outputs the corresponding factor-values needed to achieve that response. When the team attempted to minimize the unit weight, Minitab resulted with a mix of 37.2727% Elemix, 42.7273% Haydite, and 20% Crushed Concrete (Figure 2), with a predicted unit weight of 24.8282 pcf. Comparing these values to Figure 1, the contour line representing the lightest mix contained 37.2727% Elemix, 42.7273% Haydite, and 20% Crushed Concrete. However, when cross-referenced with the Excel sheet, the resultant unit weight was 48.62 pcf; therefore, it is important to understand that Minitab's minimize feature generates the factors' values based on extrapolated data and is not entirely accurate. Additionally, 48.62 pcf is not a realistic unit weight for a mix. Subsequently, when using Minitab to design the 2021 structural mix, *Moon Dust*, the team targeted a specific low unit weight mix of 63.0 pcf.

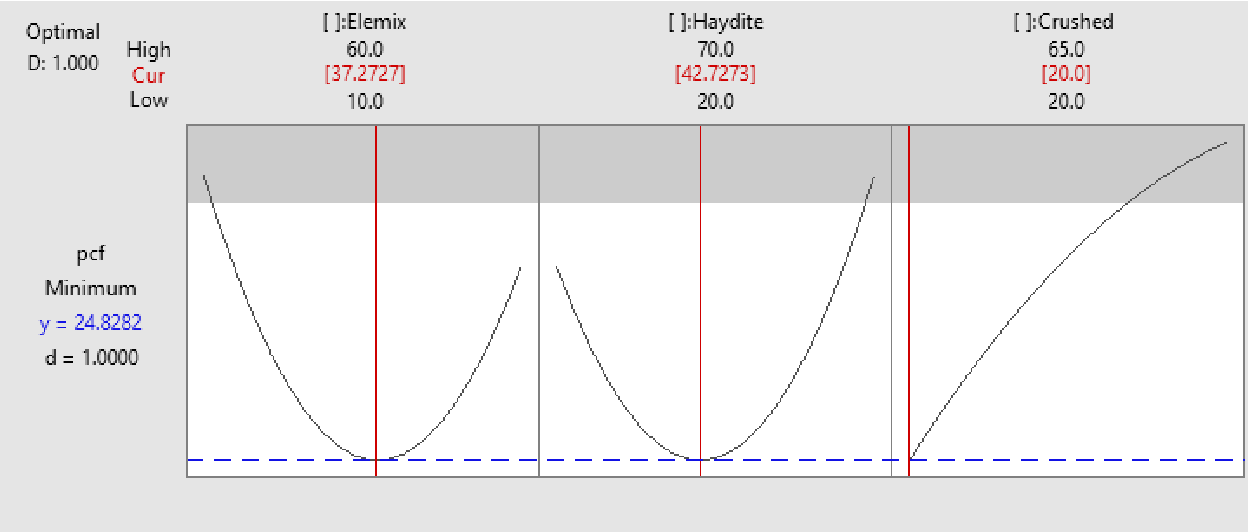

Figure 2. *Response optimization results that minimized the unit weight (pcf) in red. D is the combined desirability of the unit weight and d indicates how optimized unit weight was; 1 indicated the most desirable result.*

In future years, the mixture committee will use Minitab to validate their traditional trial and error mixture design process. Specifically, Minitab can be utilized in one of two ways, with the first using Minitab as a complementary analysis to the trial-and-error data. Or Minitab could be used to eliminate specific concentrations each week; this option will not only improve the team's sustainability by reducing the number of mixes made each year, but it will also shorten the time required to design and finalize any structural and finishing mixes. However, this would result in a loss of the specific knowledge of each aspect of the mix. Nonetheless, the contribution of Minitab's statistical analysis of mix design to the qualitative trial and error process will ensure successful developments of future mixture designs.

Conclusions

With the main focus of Michigan Tech's Concrete Canoe Team's 2021 season being knowledge transfer, it was important that the enhanced focus areas both improved the team and contributed toward its longevity. To ensure this, there were two important criteria used in selecting the EFAs, with the first requiring that, if needed, the EFA could be completed entirely virtual through software taught at Michigan Tech. The second criterion required the EFA to be multifaceted, such that it encouraged member engagement throughout the entire process. The first EFA was a finite element analysis of the completed 2020 boat, *Dozer*, through the software

Ansys. To verify the model, deformation testing of the boat will be performed at some point in the future when the lab is more freely accessible. The EFA will be further improved with the addition of layering to the model. The second EFA included the usage of Minitab to aid in the development process of the 2021 structural mix *Moon Dust.* Through Minitab, the significance of each of the three aggregate materials was evaluated and a low-unit weight mix was produced. In future years, the accuracy of Minitab's predictability will be verified. By taking inspiration from the aerospace industry, the 2021 Michigan Tech Concrete Canoe Team was able to persevere and pragmatically navigate through the many unknowns of the 2021 season.

References

Ansys. Computer Software. Ansys, Inc., Canonsburg, PA

ASCE/NCCC. (2021). 2020 ASCE National Concrete Canoe Competition™ Request for Proposals. ASCE. (September 10, 2020).

AutoCAD 2018. Computer Software. Autodesk, Inc., San Rafael, CA.

Michigan Tech Concrete Canoe Team. (2020). Dozer: Michigan Technological University Design Report. Houghton, MI.

Michigan Tech Concrete Canoe Team. (2019). Driftwood: Michigan Technological University Design Report. Houghton, MI.

Microsoft Excel. Computer Software. Microsoft, Redmond, WA.

Minitab. Computer Software. Minitab, LLC, University Park, PA.

NX. Computer Software. Siemens PLM Software, Plano, TX.