NORTHERN ARIZONA UNIVERSITY | College of Engineering, Forestry, and Natural Sciences

Final Proposal

PCI Big Beam Competition

CENE 476

12/14/17

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List of Abbreviations

ASTM	American Society for Testing and Materials
PCI	Precast Concrete Institute
SCM	Supplementary Cementitious Material

1.0 Project Understanding

The purpose of this project is to design a precast/prestressed concrete beam for the annual PCI Big Beam competition. This project will bring forth and challenge the structural analysis skills that have been developed through undergraduate studies to design a beam that is strong, light, flexible, and several other qualities described in the PCI Big Beam Competition brochure [1]. Upon project completion, a report will be submitted as well as the final testing results to PCI headquarters to be entered into the competition. The sections below define and describe the project with regards to background, scope, scheduling, and staffing.

1.1.0 Technical Considerations

The following sections describe the technical considerations that must be addressed to properly accomplish this project.

1.1.1.0 Concrete Mix

Concrete is made up of a mixture of cement, aggregate, water, and admixtures. Adjusting the proportions of these items in the mix can have an effect on the strength, workability, and ductility of the concrete. The competition committee has established ASTM standards that each concrete constituent must follow in order to be used in the concrete beam. In order to succeed in this competition, it is vital that the ASTM standards are understood and implemented correctly.

1.1.1.1 Portland Cement

The Portland cement used in the mix design must conform to ASTM C150. This standard covers eight types of Portland cement [1]. In order to meet this standard, Portland cement shall only include Portland cement clinker, water or calcium sulfate, or both; limestone; processing additions; and air-entraining addition for air-entraining Portland cement [1]. Aggregates in the mix design must conform to ASTM C33 or C330. These standards specify requirements for grading and quality of fine and coarse aggregate [1]. ASTM C330 applies solely to lightweight concrete [1]. Chemical Admixtures in the mix must conform to ASTM D98, C494, C260, or C1017. ASTM D98 covers technical grade calcium chloride typically used for dust control, stabilizations, ice and snow removal, shorten curing time, etc [1]. ASTM C494 covers seven different types of admixtures that involve water reducing admixtures and/ or accelerating/retarding admixtures [1]. ASTM standard C260 pertains to air-entraining admixtures and ASTM C1017 specifies requirements for producing flowing concrete [1].

1.1.1.2 Supplementary Cementitious Materials

In this competition, the use of supplementary cementitious materials (SCM's) are allowed as long as they meet their respective applicable ASTM standards. The addition of silica fume into the mix must conform to ASTM C1240. Class C of F Fly Ash and Class N Metakaolin must conform to ASTM C618. Ground granulated blast-furnace slag or grade 100 or 120 must conform to ASTM C989. Each of these ASTM standards call for the required properties of the material in order for these supplementary cementitious materials (SCM's) to be used in a concrete mixture. These standards contain literature for various parts of the project, such as testing methods and physical properties to ensure that the material is appropriate to be classified as an SCM.

1.1.2.0 Structural Considerations

When designing the concrete beam, beam dimensions and reinforcement must be considered for the intended loading. Additionally, characteristics of precast-prestressed concrete must be researched, as these differ from the structural characteristics of non-prestressed reinforced concrete.

1.1.2.1 Precast-Prestressed Concrete

Precast-Prestressed concrete is used in structures to reduce the effect of external forces by introducing internal forces prior to loading. These internal forces then help negate the tension experienced by the concrete, which is a characteristic weakness of concrete structural members. To do this, a high tensile force is introduced by pulling on the strands within the beam, creating an internal compressive force within the beam prior to loading. This is different than a traditional reinforced concrete member, which has no internal forces prior to loading. With this method, concrete beams can attain the structural capacity of high-strength concrete in compression while also possessing the ductility of steel in tension. This method and its subsequent characteristics must be considered in the beam design.

1.1.2.2 Cross-Section

The cross section must be designed such that the concrete beam is strong enough to support the intended loading without failure. This is done by using the compressive strength of the concrete mix, which is a deciding factor in the design mix selection, and is determined from the concrete mix testing. The cross section will also be designed such that the beam has an optimal weight and deflection. The PCI Big Beam Competition brochure calls for beams to be designed for the largest deflection, which would require a lower moment of inertia, and thus a smaller cross-sectional area. This, in addition to the previously mentioned considerations, shall be considered for the design of the cross section of the beam.

1.1.2.3 Steel Reinforcement

Steel reinforcement is used to increase the tensile strength of the beam. As concrete is very weak in tension, these reinforcing bars (rebar) allow the beam to carry a higher load, capable of higher moments, because of the internal moment created by the variance in compression of concrete and tension of steel. Additionally, this steel reinforcement is implemented into the design so that the beam fails in tension rather than compression. This is done because a beam which fails in tension is slower to fail all together, and gives signs of failure well in advance, so that there is time to address the issue before failure. A beam which fails in compression typically fails suddenly, with little to no warning of failure. These considerations, as well as those previously mentioned in Section 1.1.2.1 will be considered in the structural design of the beam.

1.2 Potential Challenges

The potential challenges that have been identified for the big beam project consist of, concrete mix testing and selection as well as transportation of the beam. The creation of the concrete mix designs and testing can be difficult to get accomplished in the timeline allotted for this project. Strength testing should take place 3 and 28 days after molding the concrete, meaning that the concrete molds will need to settle and cure in a 28 day period and broken at the conclusion of this period. This can be a challenge, not only because of the rigorous schedule of this project, but also because the molds must remain unhindered during that time. The testing follows ASTM standards and must be adhered to carefully, such as ASTM C39 for compressive strength testing, and ASTM C496 for tensile strength testing. Another potential challenge of the competition is the transportation of the fabricated beam from Phoenix, Arizona to Flagstaff, Arizona. Flagstaff, Arizona has iced over roads for most of the year and the accessibility of vehicles that are able to transport the beam are limited. However, Tpac will provide the transportation of the beam.

1.3 Stakeholders

There are several stakeholders for this project, as it involves multiple parties with varying interests these stakeholders are Tpac, PCI, Dr. Tuchscherer, Northern Arizona University, and project members.

Tpac, an architectural and structural precast concrete company, is one of the primary stakeholders, as they are sponsoring this project and will be responsible for fabricating and shipping the concrete beam. They will be impacted by this project because their name will be on the report that gets reviewed by PCI judges. Therefore, this can affect their relationship with this institute and other companies that review the report submissions.PCI will also be affected by this competition. The more people to hear of precast/prestressed concrete beam competition, it will have an affect an impact on them socially and economically. Robin Tuchscherer plays a major role in this project because his knowledge and experience provides guidance to the project. This project has a social impact on Dr. Tuchscherer, as it has the potential to affect his relationship with Tpac, as well as other PCI members, positively or negatively. The biggest stakeholders for this project would be members of this project, as they are the ones who must agree with each other on each aspect and make sure everyone is on aboard with project decisions and that they are doing what they think is best for the project. This project has a social impact for each team member, as their relationships with each other, their peers, Robin Tuchscherer, and the sponsor is at play.

2.0 Scope

The following scope of work defines the individual tasks necessary to complete the PCI Big Beam project. The objective of this project is to design a prestressed concrete beam which scores the highest for the PCI Big Beam competition judging criteria, while satisfying all of the competition regulations.

2.1.0 Mix Design

For this project, several concrete mix designs will be developed and tested. These will be compared to the pre-existing designs provided by Tpac and the best design will be selected for the beam competition. To do this, the following steps will be taken.

2.1.1 Concrete Mix Development

The project will begin with the concrete design process, through the development of several concrete mix designs for testing and analysis. Research will also be used to better understand standards for concrete mix design, including typical proportions for aggregates and pozzolans in the overall materials used in the concrete mix. To assist with this, a spreadsheet will be created using Microsoft Excel, to normalize concrete mix designs for comparison and analysis. Four unique designs will be selected to continue for testing and analysis. Two concrete designs from the sponsor Tpac will also be incorporated, totaling six concrete designs for testing and analysis in this project.

2.1.2 Mix Testing

Once concrete mixes are developed and six designs are selected, the testing process will being in order to determine the strengths of each design in compression and tension, and to determine the modulus of elasticity for each, as this will determine the concrete's deflection potential. Before testing, the team will request the necessary materials from nearby concrete plants and construction companies, as well as cylinders for testing from the NAU Engineering Lab Manager, Adam Bringhurst.

2.1.2.1 Compressive Strength Test

The compressive strength of concrete is a critical point of information, as this value helps determine the cracking and ultimate capacities of the concrete. Compressive strength tests will only be performed for the four concrete mix designs developed by the team, as the compressive strength is already provided for the designs from the sponsor. Compressive strength tests will be performed in accordance with ASTM C39 *Compressive Strength of Cylindrical Concrete Specimens* standards. It is important to note that, for compressive strength tests, two values will be determined; the stress at release (fci), which is measured 3 days after release, and the stress at 28 days (f'c), which is the compressive strength of the concrete, to be used for analysis.

2.1.2.2 Tensile Strength Test

The tensile strength will be determined in accordance with ASTM C496 *Splitting Tensile Strength of Cylindrical Concrete*. For this test, three cylinders will be tested for each concrete design, including the sponsor's concrete mixes, as the tensile strength is not provided by Tpac. This means that 18 concrete cylinders are required for testing for this test.

2.1.2.3 Strain Test

Six additional cylinders must be developed for testing to determine the Modulus of Elasticity of the concrete mixes provided by the sponsor. This test will be done in accordance with ASTM C469 *Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.*

2.1.3 Analysis of Mix Testing Results

Once all tests have been completed, the results for each concrete mix design will be collected and the information will be compiled into a report for comparison. After this, the results of the test will be analyzed as they relate to the project objectives. The compressive and tensile strengths will be considered for the ultimate and cracking capacities, and the modulus of elasticity will be considered for its effect on beam deflection. Statistics will be evaluated to determine the pros and cons of each design, and that information will be used to advance concrete mix selection.

2.1.4 Mix Selection

Once each design is evaluated for its strengths and weaknesses, a decision matrix will be made with various weighted values, including deflection potential and ultimate and cracking capacities of the concrete. In general, concrete mixes with higher compressive strengths will be able to carry more load, while beams with a lower modulus will allow for more deflection. These and other concrete mix properties will be taken into account to determine the weight values of each quality, and three final concrete mixes will be selected for further consideration.

2.2.0 Beam Design

Another important consideration in concrete beam design is the cross-sectional characteristics of the beam. This section describes how an ideal beam will be designed for the competition objectives.

2.2.1 Develop Beam Designs

To begin, six cross section designs will be developed for consideration. The cross sections will be designed so that they optimize a specific project objective, such as achieving maximum deflection, offering the lowest cost, or carrying the most load per unit weight.

2.2.2 Develop MathCAD Model

Autodesk's MathCAD program will be used to model the cross-sectional designs previously described in section 2.2.1. MathCAD will be used to calculate important structural values including maximum moment and tensile strength experienced by the beam.

2.2.3 Beam Scoring

After being analyzed by the MathCAD model, each beam will be weighted by its ability to achieve the specific project objectives, as mentioned in section 2.1. These designs will be paired with the concrete mix testing data to optimize the specific objectives, so that the beam can maximize its potential for that specific structural attribute.

2.2.4 Beam Selection

By combining the chosen three mix designs and three beam cross sections, nine final designs will be chosen based on the same criteria. The team will then use the PCI Big Beam Competition judging criteria to determine the best beam design. The competition judging criteria for beam design include: maximum applied load, cracking load, cost, weight, and deflection.

2.3.0 Final Beam Design

With the concrete mix and the desired cross section selected for the beam, detailed shop drawings will be developed and used as reference to create beam predictions and for beam fabrication.

2.3.1 Shop Drawings

The shop drawings of beam will be prepared using AutoCAD software. Included in the shop drawings will be a plan view of the beam depicting the length of the beam, an elevation view of the entire beam, and a cross-sectional detail of the final beam design. The plan view of the beam will also include the spacing of the stirrups to be used for shear reinforcement of the beam. The cross-sectional view of the beam will elaborate on the dimensions of the beam including the height and width of the beam along with the positioning of the reinforcement in the beam. This will be sent to the sponsor, Tpac, and will be used in the beam fabrication process.

2.3.2 Concrete Mix Volumes

The previously developed Excel spreadsheet for concrete mix volumes will be used to create a concrete mix volume report. Should a Tpac concrete mix be chosen for the final design, the name of the mix will be included in the final cross-sectional drawing. If one of the experimental mix designs is selected for the concrete mix, a detailed mix report will be provided with the shop drawings.

2.4.0 Beam Manufacturing

Tpac will receive the final design report for the PCI Big Beam Competition, which will include the project description, the concrete mix design, the beam's final structural design, and the previously specified drawings. Subject to scheduling, it is expected to visit the sponsor before mix selection to collect pictures of the manufacturing process, as well as take advantage of a learning opportunity regarding prestressed concrete production.

2.5.0 Predictions

Mathcad will be used to base predictions off of. Within Mathcad, multiple potential beam shapes will be introduced in order to meet the needs of the competition and better understand how changing cross-sectional areas can affect the concrete's behavior.

2.6.0 Testing

The following steps will be taken for the loading and testing of the designed concrete beam, to be used submitted in the PCI Big Beam Competition.

2.6.1 Transportation

With fabrication completed by Tpac down in Phoenix, Arizona, there is an issue with transporting the beam up to Flagstaff, Arizona. The beam should be shipped out in mid-March which makes driving conditions along the interstate-17 and within flagstaff harsh since it is winter season and flagstaff is known for its snowy winter. Another issue is dealing through traffic on Northern Arizona University's campus, since this is where the beam shall be shipped to be tested. During the afternoon, traffic on campus is really busy. A plan will be created to successfully ship the beam to the testing facility on campus.

2.6.2 Testing Prep

The acquisition of the fabricated prestressed beam will be a task that all group members must be involved in. The team must plan where the beam will be placed upon arrival and prepare so that the group can place the beam into its appropriate location as simply as possible. It is also important to ensure the equipment that will be used to analyze the loading and deflection of the beam are working properly prior to the final testing of the beam.

2.6.3 Testing

The beam will be tested using a hydraulic press in the testing room within the engineering building on Northern Arizona University's campus. There will be video recording of the load applied to the beam as well as measuring the deflection of the beam.

2.6.4 Video

The loading and failure of the beam will be recorded and sent entered into the competition for consideration as "best video". This will be done by having a unique theme as well as providing clear representation and audio of the testing of the beam. The video shall include a representation of the beam as well as a representation of the load that is being applied at all times. The video shall be enjoyable to watch not just for testing analysis but as well as entertaining the audience.

2.7.0 Report

Three reports will be required in this project. A 50% report to NAU will be submitted to ensure progress is being made and a route to completion is feasible. Two final reports will be created, which will be largely similar but slightly modified to address the requirements of each final report.

2.7.1 50% Complete Report to NAU

The 50% report to NAU will act as a preliminary draft of the final report and will be reviewed by the NAU grading instructor. The purpose of this report is to ensure that it is written in reference to the scope included within this proposal.

2.7.2 Final Report to PCI

The report will be created with respect to the competition guidelines and will be modified in order to be submitted as the Capstone report. The report will largely be a discussion of how the mix design and structural design was determined through testing and theory. The reasoning behind final mix and structural design selected will be adequately explained in order to offer support for the decisions made by the team.

2.7.3 Final Report to NAU

The final report turned into NAU faculty will meet the requirements put forth by the final Capstone report guidelines. The final report to NAU will be a modified version of the final report entered to the competition committee to include any relevant or required information that was not required in the PCI final report.

3.0 Schedule

This project is expected to take one hundred and eighty days to completion, starting on October 4th, 2017 and ending on April 2nd, 2018. The tasks defined in the scope section above are further explained in the table below, which identifies the durations as well as start and end dates for each task. For clarity, these tasks have been outlined so that they are identical to the scope outlined above.

Table 3-1: Scheduled Tasks

Task Number	Task Name	Duration	Start Date	End Date	Dependencies
1	2.1.1 Concrete Mix Development	11 days	Wed 10/4/17	Wed 10/18/17	
2	2.1.2 Mix Testing	22 days	Thu 10/19/17	Fri 11/17/17	1

3	2.1.3 Analysis of Mix Testing Results	5 days	Mon 1/15/18	Fri 1/19/18	2
4	2.1.4 Mix Selection	5 days	Mon 1/22/18	Fri 1/26/18	3
5	2.2.1 Develop Beam Designs	33 days	Wed 11/1/17	Fri 12/15/17	
6	2.2.2 Develop MathCAD Model	50 days	Mon 11/20/17	Fri 1/26/18	
7	2.2.3 Beam Scoring	1 day	Mon 1/29/18	Mon 1/29/18	3,6
8	2.2.4 Beam Selection	1 day	Wed 1/31/18	Wed 1/31/18	7
9	2.3.1 Shop Drawings	10 days	Thu 2/1/18	Wed 2/14/18	5,4,8
10	2.3.2 Concrete Mix Volumes	10 days	Thu 2/1/18	Wed 2/14/18	4,8
11	2.4.0 Beam Manufacturing	16 days	Thu 2/15/18	Thu 3/8/18	9,10
12	2.5.0 Predictions	10 days	Thu 2/1/18	Wed 2/14/18	3,8
13	2.6.1 Transportation	5 days	Mon 3/12/18	Fri 3/16/18	11
14	2.6.2 Testing Prep	5 days	Fri 3/9/18	Thu 3/15/18	
15	2.6.3 Testing	1 day	Mon 3/19/18	Mon 3/19/18	13,14
16	2.6.4 Video	5 days	Fri 3/16/18	Thu 3/22/18	14
17	2.7.1 50% Complete Report to NAU	5 days	Mon 3/26/18	Fri 3/30/18	15
18	2.7.2 Final Report to PCI	5 days	Mon 4/2/18	Fri 4/6/18	15,12
19	2.7.3 Final Report to NAU	1 day	Mon 4/2/18	Mon 4/2/18	15

The tasks listed in the table above are further illustrated in Figure 3-1 below.

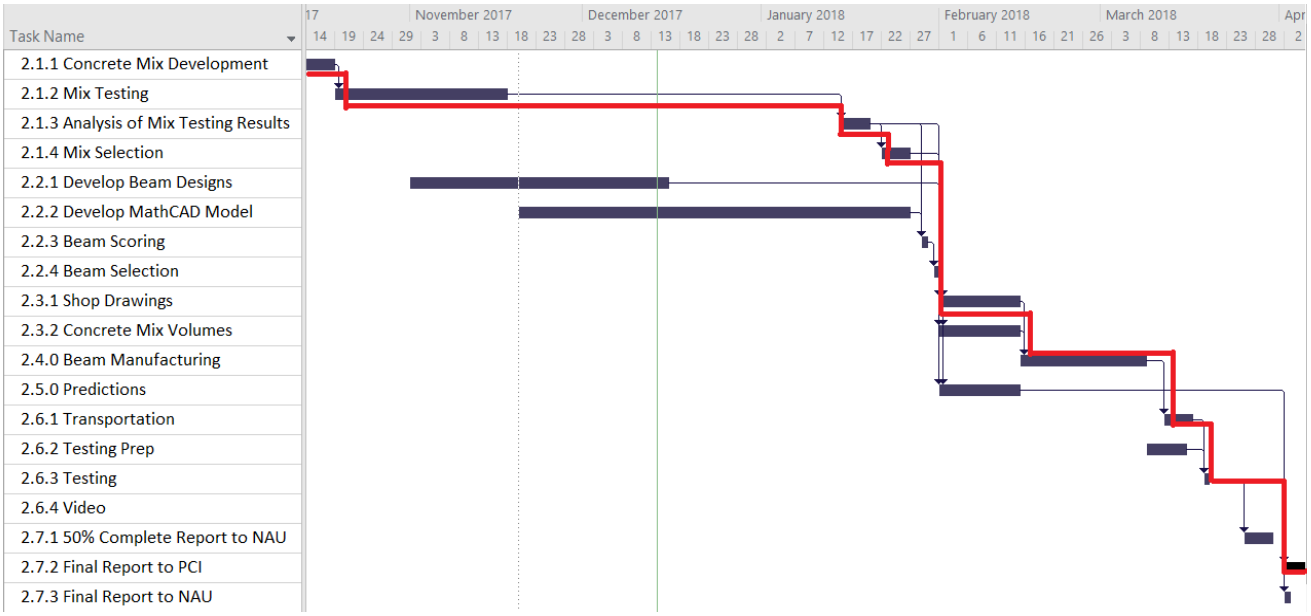

Figure X: Gantt Chart with Critical Path

This figure illustrates in red the critical path for this project, which includes the tasks that are essential to the project timeline. If one of these tasks were delayed, it would cause further delays throughout the project. This is why managing the tasks identified within the critical path is essential for finishing the project within the time scheduled. This will be done by ensuring focus and effort are directed towards these tasks specifically, to avoid large project delays. Additionally, extra time has been added to the schedule in case one of these tasks were delayed, in order to avoid project delays.

As shown in the figure, the task which is scheduled to take the most time is developing the MathCAD model. This is intentional, as extra time and effort spent here should result in a better project overall. With the additional time added to the schedule for developing the MathCAD model, more time is available to determine which cross-section will be most effective for the design.

4.0 Staffing

The following table provides information regarding billing and profit for each of the personnel members involved in this project.

The four staffing positions that were determined to be essential to the completion of the project were a senior engineer (SENG), a lower level engineer (ENG), a lab technician (LA), and an administrative assistant (AA). The senior engineer will be responsible for verifying all work completed by the other members of the team as well as participate in the completion of all major tasks of the project. The lower level engineer will be tasked with creating prospective mix designs and will also be largely involved in the structural design of the beam. The lab technician will largely be involved during the preliminary concrete mix development and the final testing of the concrete beam. The administrative assistant will be involved throughout all tasks of the project to document the results gathered during the project and assist any team members with their duties.

Table 4-1 Staff Pay Rates

Pay Rate					
Personnel	Base Pay ($/hr)	Multipliers (% of Base Pay)			Billing Rate ($/hr)
		Benefits	Overhead	Company Profit	
Senior Engineer	77	20%	35%	10%	130
Engineer	36	20%	60%	10%	70
Lab Technician	20	20%	70%	10%	40
Administrative Assistant	18	20%	60%	10%	35

The base pay rates shown are reflective of the base pay rates used for these job positions in last year's competition. These rates were verified with online sources to ensure they were still applicable. The cost of benefits, overhead, and company profit were determined using multipliers of the hourly base pay per staff member. The benefits and company profit multiplier were held constant for each staff member whereas the overhead multiplier varied based on the specific job of the staff member.

The table below contains the hours expected for each staff member to work on each major task included in the scope and schedule.

Table 4-2 Major Task Staffing Hour Distribution

Task Name	**SENG**	**ENG**	**LAB**	**AA**	**Total**
Mix Design	14	45	45	20	124
Mix Testing	5	20	75	8	108
Beam Design	10	35	5	5	55
Final Beam Design	15	25	3	6	49
Beam Manufacturing	4	8	4	3	19
Predictions	8	12	4	5	29
Testing	10	30	70	8	118

Report	10	30	10	20	70
Total Hours	76	205	216	75	572

5.0 Cost of Engineering Services

The table below shows the anticipated budgeting distribution for this project, according to the information taken from the sections above.

Table 5-1 Projected Cost of Project

Budgeting				
	Personnel	Hours	Billing Rate ($/hr)	Cost
Staffing	SENG	76	130	$9,880
	ENG	205	70	$14,350
	LAB	216	40	$8,640
	AA	75	35	$2,625
Lab Use		48	100	$4,800
Beam Fabrication/Shipping				$3,000
Travel Costs				$400
Total Cost of Project				$43,695

The projected total cost of the project, shown above, is $43,695. The largest cost component of this project is the staffing cost, over 80% of the total cost. The estimated lab use fees, beam fabrication and shipping costs, as well as the cost of two roundtrips from Northern Arizona University to Tpac in southern Phoenix make up the rest of the total cost of the project.

6.1 References

[1] TPAC, "TPAC Official Website," [Online]. Available: tpacaz.com. [Accessed 30 11 2017].

[2] Precast/Prestressed Concrete Institute, "PCI," [Online]. Available: pci.org. [Accessed 30 11 2017].

[3] PCI, "2018 PCI Big Beam Brochure," [Online]. [Accessed 30 11 2017].

6.2 Appendix A – Cover Letter to Client

PCI Big Beam Team 2017-2018

Northern Arizona University | Roy Crouch, Stephen Gergal, Fernando Rojo, and Brandy Wagoner |

Date
Dr. Robin Tuchsherer

Project Understanding Review Request

Date: 9/07/2017

Dear Dr. Robin Tuchsherer:

Attached is a copy of the team's Project Understanding deliverable for CENE 476C. It would be much appreciated if you could kindly review the team's progress so far on the document, and provide feedback on corrections that you see fit to the document. Any corrections suggested to the document will be modified once the suggestions are received. Because of your busy schedule as well as the team's, it would be preferable to have any comments and modification suggestions on or before September 21, 2017. Thank you for your time and we look forward to hearing back from you.

Best Regards,
PCI Big Beam Team 2017-2018