Optimization of Distribution Overhead Powerline Design Using Genetic Algorithm with Memory

by

Graeme Andrew Vanderstar

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Department of Electrical and Computer Engineering
University of Alberta

Abstract

The increasingly heavy standardization of distribution overhead powerline installations presents an opportunity for the automated design of distribution overhead powerline pole structures, attachments and conductor spans. A successful design automation algorithm must be capable of generating distribution overhead powerline designs that meet all relevant code requirements and utility company standards, be capable of producing a design that is ideally more cost effective than that of a typical human-created design and be able to perform the optimization process within a reasonable amount of computing time.

A genetic algorithm optimization tool is developed for use by a distribution facility operator whose service area includes powerline in rural Alberta, Canada. The optimization tool can interpret a survey comma separated value file along with limited user input and then using the supplied data to carry out the economic optimization of a distribution powerline design subject to constraints such as pole structure force loading, conductor span vertical clearance, conductor uplift, grounding and span-tension continuity. The resulting output from the tool contains a completed design in the form of several design documents that comprise a substantial component of a construction design package which is intended for use by the distribution facility operator's design department.

Upon testing the optimization tool on a 10 pole, 15 pole and 40 pole three phase distribution overhead powerline new extension, it is found that the tool can produce designs that not only comply with all code requirements and standards but can also result in fewer design omissions compared to the corresponding human-created de-

signs. The overall cost efficiency of the optimized designs either meet or exceed the human created designs by a slight margin. Finally, the total optimization time for the 40-pole structure powerline design using a high-performance desktop computer is found to be almost three hours.

Preface

This thesis is an original work by Graeme Andrew Vanderstar. No part of this thesis has been previously published.

This thesis is dedicated to my wife, Nicole. Your support and love give me the courage to persevere and to face life's challenges.

Acknowledgements

I would like to express gratitude to my supervisor, Dr. Petr Musilek, for his support and assistance during the development of this thesis. If it were not for his direction and guidance, this thesis would not have been possible.

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Abbreviations

ACSR Aluminum conductor steel reinforced powerline conductor.

CSV Comma Separated Value.

DFO Distribution Facility Operator. In the context of the thesis, DFO refers to the parent electric utility with service area in Alberta, Canada for which AutoDesigner is developed for.

DOP Distribution Overhead Powerline.

DUP Distribution Underground Powerline.

FEA Finite Elements Analysis.

GIS Geographic information system.

HOA Height of Attachment.

HOC Height of Conductor.

MGN Multi-Grounded Neutral.

TOP Transmission Overhead Powerline.

Glossary of Terms

Anchor Normally a screw-type metallic rod that is drilled into the soil at an appropriate angle and depth to provide downhaul support for a tensioned guy wire.

Chromosome A vector of genes which contains the encoded data for all the un-optimized design parameters associated with a DOP design.

Compatible Unit The reference name for a pole-top structure attachment as per the DFO's Construction Standards Manual [5].

Conductor Uplift Is a measure of the net upward force exerted on a structure attachment of a pole by the tensions of an incoming and outgoing span resolved into a single upward pulling force vector on the structure.

Conductor Tension The near-horizontal force (in Newton's) that a tensioned powerline conductor exerts on the structure attachments of the conductor's supporting structures.

Conductor Sag Conductor sag or maximum sag is the height in meters between the lowest conductor elevation along a span and the attachment height of the lowest supporting powerline structure for the span.

Constraint Violation In the context of AutoDesigner a constraint violation refers to a failure of a given DOP design to comply with one of the constraint modules during optimization. A constraint violation is represented as a cost adder with a minimum value that is not less than $1 000 000 and which gets added to the total construction labour and material cost of the DOP design. A constraint violation makes a design ineligible from being considered as a candidate for the final design.

Dead-End A DOP structure attachment that terminates overhead conductor with no additional overhead carry-on spans or tap-offs. A dead-end structure attachment is usually accompanied by an equipment structure such as a pole-mounted transformer or a riser structure that provides an electrical service to a customer or a means of transitioning the conductor to a high voltage underground cable.

Deep Set The additional depth at which a power pole is set in the ground beyond its nominal set depth. Deep sets of 0.0m 0.5m 1.0m and 1.5m are considered in the thesis [23].

Deflection Refers to a left or rightward change in direction of the outgoing powerline conductor span with respect to the incoming span. A deflection of zero degrees corresponds to a perfectly straight profile of the incoming and outgoing conductor spans where the two span attachments are oriented 180 degrees apart on the pole structure.

Fitness The suitability of an individual in obtaining a low material and construction labour cost as well as being free from constraint violations.

Fitness Function The function to be minimized by the genetic algorithm optimization. The fitness function contains the sum of two objective functions where the first objective function is the construction material cost and the second is the construction labour cost. The fitness function also includes as part of the summation a penalty factor which is represented by the total number of constraint violations multiplied by a $1 000 000 scalar.

Gene An integer valued between 0 and 99 which represents the encoded details of a single optimizable design parameter for a DOP design.

Generation A group of individuals that are generated by a genetic algorithm optimization process whose fitness is evaluated prior to the application of any crossover or mutation operations. The most suitable individuals from within the generation are selected as candidates for crossover for the next generation of individuals to be created using the characteristics of the individuals in the current generation.

Guy Wire A downhaul high tension steel wire that is attached near the top of a pole structure to provide force-bearing support and is connected to an anchor rod that is fastened into the ground at an appropriately designed distance away from the parent pole structure.

Heavy Loading Condition where powerline conductor is assumed to be coated with an 18 mm layer of ice. Heavy Loading is only present in certain regions of Alberta based on a CSA-supplied map as well as empirical analysis of the DFO [4] [5].

Height of Attachment The height (in meters) from ground level measured at the base of a pole structure to the structure attachment mounting point near the top of the pole.

Height of Conductor The height (in meters) from ground level measured at a pole structure to the conductor attachment height near the top of the pole.

High Voltage In the context of DOP high voltage refers to distribution class operating voltages that range from 750 V to 35 kV line-to-line [6].

Hyperparameter A setting pertaining to the genetic algorithm that is defined prior to the optimization process. Examples of hyperparameters studied in the thesis include the population size crossover rate and mutation rate..

Individual In the context of the genetic algorithm optimization stage an individual refers to a chromosome that contains the encoded design parameters that specify q a single possible DOP design whose fitness is evaluated by the genetic algorithm for potential crossover with other individuals of the same generation.

Longitudinal Loading A force load on a structure that has a vector oriented outward radially in the direction of the incoming or outgoing conductor span. Longitudinal loading is generally the result of the tensile force exerted by tensioned conductor on a structure.

Low Voltage In the context of DOP low voltage refers to customer service voltages generally at or below 600V line-to-line [6].

Medium Loading Condition where powerline conductor is assumed to be coated with a 6.5 mm layer of frost or ice [4].

New Extension A new DOP that taps-off of an existing DOP mainline for the purposes of delivering power to a customer that powerline does not currently reach.

Overhead Neutral Conductor a second or fourth wire can be observed on the DOP which is usually located about two meters below the lowest phase conductors and is grounded in at least two locations. The neutral conductor serves the purpose of providing a return path for unbalanced return current as well as bringing the electrical potential of any metallic components that are connected to it to earth potential.

Pole Class Refers to a range of allowable utility pole circumferences that are measured a set distance from the butt of the pole. Pole class is analogous to the thickness of the pole. Pole classes of 1 are the thickest poles considered in the thesis while pole classes of 7 are the thinnest [23].

Pole Height The height of a wooden power pole measured from pole butt to pole top. Pole heights are measured feet and typically range from 30 feet to 65 feet increasing in 5-foot increments for a typical distribution utility application [23].

Powerline Conductor Bare metallic stranded wire that is strung between structures and is the means by which electrical energy is conducted along DOP.

Set Depth Refers to the depth at which a power pole is buried in the ground after installation. Set depth varies based on pole height as well as the presence of a deep-set. The nominal set depth for a 40 ft. pole is 6 feet or 1.8m [23].

Slack Span A short span of powerline conductor that must be less than 35.0m in length and which is hand-tensioned by powerline technicians such that the maximum sag of the conductor is sagged to 1.5m for smaller conductor sizes and 2.5m for larger conductor sizes. Slack spans do not require anchors and guy wire to support unbalanced loading at the pole provided that the pole is deep-set [23].

Structure Pattern A data string that represents the combination of all pole-top attachments on a pole structure where the compatible unit for each attachment is delineated by a comma.

Structure Attachment Utility pole accessories that are mounted near the top of a pole structure for the purposes of supporting or terminating electrical conductor mounting electrical equipment or anchoring unbalanced forces.

Tap-Off A DOP structure that contains incoming and outgoing mainline attachment points as well either one or two additional outgoing spans that branch the powerline off from the mainline to form new circuits for radial delivery of power to customers.

Tight Span A normal span of conductor that is fully tensioned using a tensiometer as per the required tension for the conductor type. Tight spans whose load on the pole is not cancelled by an adjoining span must have an anchor and guy wire to support the load [23].

Transverse Loading A force load on a pole structure that is horizontal and perpendicular to the incoming outgoing conductor spans or the mounting orientation of pole-mounted electrical equipment. Transverse loading is generally the result of wind loading forces.

Vertical Loading A downward force load on a structure. The downward force is generally the result of conductor weight structure attachment weight or electrical equipment weight.

Weight Span A measurement utilized by the FloaterCheck algorithm to assess the degree of uplift reported as a span length in meters where a negative value indicates an upward force contribution from the span. Weight span for the two supporting spans on a pole attachment must sum to a value that is greater than zero for an uplift condition to be avoided.

Chapter 1

Introduction

1.1 Motivation

The design of overhead distribution powerline (DOP) in the 21st century remains relevant to rural electric utilities and affords significant opportunities for design automation. Increasingly, the design of DOP must achieve a safe and reliable installation while not exceeding the lean engineering budgets allotted to distribution powerline projects [1]. To meet both objectives, many distribution electric utilities opt to heavily standardize their distribution design practices limiting designs to use a small number of pre-engineered pole-top structures, pole heights and maximal span lengths. Furthermore, pole placement for new DOP and the determination of conductor sizes are generally not regarded as core design activities as routes are often determined prior to design by land-owner consultants, poles are placed by surveyors while conductor sizes are determined prior to design by system planners. As a result, in contrast to the immeasurable complexity of high voltage transmission overhead powerline (TOP) design where significant portions of the design is custom engineered and routes are custom selected [2][3], the heavy standardization of DOP design practices allows for a state space of design variables that is small enough to be traversed by contemporary optimization techniques such as the genetic algorithm using modern computational power. The possibility of being able to fully automate and optimize the design of DOP for electric utilities offers the potential for enormous cost savings in terms of design labour, construction labour, construction material costs as well as the opportunity for savings on change orders due to fewer design errors being made.

1.2 Problem Statement

The thesis sets out to achieve three specific goals in the design automation of DOP. The first goal is to automate the design of DOP for an electric utility company in Alberta, Canada (referred herein as the Distribution Facility Operator or DFO) for new DOP extensions as well rebuilds or relocations of existing DOP such that a near-final design package can be produced that complies with all applicable electric utility code requirements, design standards and best practices of the DFO [4][5][6]. The second goal is, using automation, to produce an optimized DOP design that can achieve construction material, construction labour and design labour cost savings that are not realizable in a human-designed DOP project. Finally, the third goal is to carry out the design automation requirements of the first two goals for a 40 pole DOP design in approximately two hours of computation time using a modern desktop workstation.

1.3 Thesis Statement

The thesis seeks to develop a non-commercial software package (referred herein as AutoDesigner) for use by the DFO that is capable of fully automating the design of DOP by taking as input a comma-separated value (CSV) file produced by the DFO's survey department that contains pole and crossing locations along with accepting limited user input, performing design optimization using genetic algorithm, and producing a near-complete construction design package on the output.

1.4 Outline of Thesis Deliverables

Note that Figure 1.1 is a representation of the distinct modules that comprise the AutoDesigner software package with the flow of data moving from input to output being denoted by arrows. Each module of the process flow is introduced in the following sections as they relate to the three objectives of the problem statement.

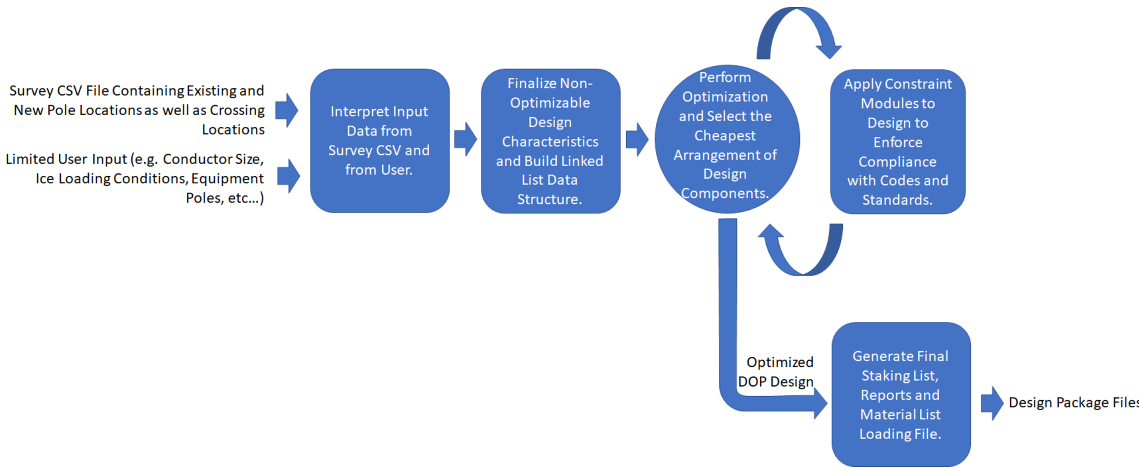

Figure 1.1: Flow of DOP Design Automation Process.

1.4.1 Interpreting Input Data from Survey CSV File and from User

AutoDesigner is developed to conform as much as possible to the existing processes and documentation practices of the DFO in order to help reduce the engineering effort hours spent on data entry and to impose minimal changes on the DFO's existing design practices. Minimal time spent on data entry aids in the minimization of project design costs. The decision to use a CSV file is made due to the file being a standard design document that is produced by the DFO's survey department and so AutoDesigner directly utilizing the file introduces minimal data entry time on top of what a typical DOP project already incurs.

The CSV file lists new and existing pole locations, elevations and crossing locations. The CSV file's original purpose is to be used as a loading file for the DFO's geographic information system (GIS) database as well as to provide the design engineer with some additional details about existing powerline structures related to the project work. Accurately interpreting the CSV file and handling the variability in the file's formatting is an essential capability that AutoDesigner must have to be able to produce an accurate and compliant design.

1.4.2 Determining Non-Optimizable Components of the Design and Modelling Design with a Data Structure

In large part due to the heavy standardization of modern DOP design, AutoDesigner can finalize a significant level of detail about the design of a new DOP using rule-based analysis before the optimization via genetic algorithm is performed. Details that can be determined prior to optimization include design elements such as pole locations for new and existing power poles, conductor tap-off locations, potential anchor locations, potential span locations for low-tension slack spans, pole locations that will have equipment such as transformers installed, the possible set of pole-top structures that are feasible at each pole as well as the set of existing poles that can potentially be replaced or upgraded to accommodate the new DOP design.

The finalization of preliminary details is critical not only in achieving an accurate design but also in terms of speeding up the optimization process. For example, with significant amounts of the design's physical characteristics determined from rule-based analysis, the remaining unknown components of the design can be reduced to a vector of discrete variables with a limited state-space of possible values which becomes very convenient to formulate into a chromosome for genetic algorithm optimization. Constraining many of the physical characteristics of the DOP design prior to optimization also allows for the construction of a linked list data structure which compliments the physical reality of the powerline and allows for convenient and fast data retrieval during optimization.

1.4.3 Optimization Using Genetic Algorithm with Memory

Once the chromosome is constructed, genetic algorithm is applied with the objective of minimizing the sum of material and construction labour costs for a DOP design. The genetic algorithm performs optimization by selecting design characteristics such as: pole height of each pole in the design, pole class of each pole in the design, the set depth of each pole, whether short spans are slack-spans or tight-spans, and whether an existing power pole should be replaced or upgraded to accommodate the new DOP design. The optimization terminates only after the total project and construction cost of the best performing individuals in a generation falls under $1,000,000 and no further cost savings can be realized.

Furthermore, the evaluation of individuals, or candidate designs, by the genetic algorithm optimization is enhanced with the capability of remembering past outputs. The memory is applied specifically to the computationally intensive constraint modules discussed in the next section that are referred to as PoleCheck and ClearanceCalc. When the genetic algorithm encounters a pole or span segment within a DOP design whose characteristics are identical to a pole or span segment from a past individual, the PoleCheck and ClearanceCalc results are retrieved from a look-up table instead of being re-calculated. The constraint module memory capabilities of the optimization stage dramatically speed up the optimization process.

Note that the thesis performs a hyper parameter search in order to determine appropriate cross-over rates, mutation rates and population sizes for the genetic algorithm optimization based on three different sample DOP design samples of various sizes and characteristics. The preferred hyper-parameters are determined based on minimum construction labour and material cost, the ability for the optimization algorithm to remove all constraint violations produced by the constraint modules, as well as the total computation time needed to arrive at a final design.

1.4.4 Constraint Module Evaluation with Graded Penalty Factors

In the genetic algorithm optimization stage, AutoDesigner focuses primarily on the reduction of material and construction labour costs, however, in the constraint module stage the objective is to reinforce design compliance during optimization. Constraint modules are the means by which AutoDesigner selects optimizable parameters in a DOP design that complies with all applicable utility codes, DFO standards and best practices. Five distinct constraint modules are applied to a proposed DOP design during optimization where each module enforces a specific key utility code or DFO standard practice that is needed for a compliant design and which cannot be finalized during the pre-optimization stage. The constraint modules are called whenever the total material and construction cost is computed by the genetic algorithm in evaluating the fitness of an individual representing a potential DOP design. Each constraint module determines whether a violation is present for the specific requirement that the module is responsible for enforcing in the design. If the constraint modules find a violation, a minimum of a $1,000,000 penalty factor is added to the total project cost per constraint violation. Several of the constraint modules make use of a graded penalty factor where violations that are further away from compliance are punished with a more heavily weighted penalty that exceeds the minimum $1,000,000 adder. Because the genetic algorithm optimization will not terminate until the objective function of the best performing individual falls under $1,000,000, it is therefore required that all constraint violations be eliminated before optimization is terminated.

Three of the five constraint modules are used to enforce DOP design compliance with specific electric utility code rules. The first constraint module, referred to herein as PoleCheck, ensures that all power poles pass a finite element analysis (FEA) check of the forces that are acting on the pole [4]. The second constraint module, referred to as ClearanceCalc, is responsible for maintaining clearances of conductor spans over land that is traversed by vehicles or pedestrians [6]. The third constraint module, FloaterCheck, is responsible for evaluating and flagging conductor uplift conditions on poles that have pin-type insulators [4]. Note that the ClearanceCalc and FloaterCheck constraint modules are Excel-based design tools that are currently in use by the DFO and that have been adapted for use within AutoDesigner with minimal modification. PoleCheck, on the other hand, is a custom-created set of look-up tables created using PLS-POLE[7]. Note that the PoleCheck constraint module contains two submodules: PoleCheck1.0 and PoleCheck2.0. PoleCheck1.0 is designed by the DFO for use by its designers, however, the thesis develops a replacement tool referred to as PoleCheck2.0 that is more suitable for use in AutoDesigner while also having the capability to replace PoleCheck1.0 for use by the DFO for manual DOP designs. At the time of design evaluation of AutoDesigner for the thesis, both PoleCheck1.0 and PoleCheck2.0 coexist for use within AutoDesigner as the lookup table generation for PoleCheck2.0 is not yet complete.

Note that the final two constraint modules are implemented to enforce DFO standards and best-practices which are not directly derived from a utility code rule requirement. The fourth module flags any poles which have unanchored, low-tension spans (slack-spans) but that do not have an appropriate deep-set as per empirical practices established by the DFO. The final module ensures that overhead neutral wire and pole-top equipment have an appropriate number and spacing of ground rods installed as per DFO standards and best practices.

1.4.5 Generation of Output Files

Once the DOP design is optimized and a final design is determined, AutoDesigner's final stage generates a battery of output files and reports which comprise a significant portion of a final design package currently used by the DFO. The output reports generated by AutoDesigner are intended to be usable by the DFO's design engineer requiring minimal modification, formatting or data-entry, enabling significant savings in terms of data entry time over conventionally designed DOP projects.

AutoDesigner produces six main outputs after optimizing a design. The first output is a final staking list which is an excel sheet that is formatted as per DFO standards and contains information on pole heights, classes, set-depths, pole-top structures, anchors, span types and grounding. The second document generated by AutoDesigner is a loading file for the DFO's material management software and summarizes all material items such as poles, attachment structures, guy wires and grounding structures associated with the optimized DOP design. Next, AutoDesigner generates output summary reports for the PoleCheck2.0, ClearanceCalc and FloaterCheck constraint modules for each pole or span within the DOP design. The constraint module reports are in the same format as the tools currently used by the DFO and are intended to provide the design engineer with a complete justification of the compliance of the DOP design produced by the optimization. The final document generated by AutoDesigner is a text file which succinctly summarizes the PoleCheck, ClearanceCalc, and FloaterCheck output results without requiring the user to open individual excel files.

1.5 Evaluation of Performance

1.5.1 Evaluation of AutoDesigner

After the hyper parameter search for the genetic algorithm parameters is complete, the thesis studies three new DOP designs that already have designs specified by a human designer. The thesis evaluation utilizes AutoDesigner to suggest its own design and AutoDesigner's final designs are then evaluated qualitatively for technical compliance against the human-designed outputs. For example, specific differences in design decisions between the human and automated designs are noted. Note that remarkable design decisions made by AutoDesigner that are novel or innovative in nature are also identified and explored in this section. Next, the optimized designs from AutoDesigner and human-designed outputs are compared for overall construction and material costs. Finally, the optimization time for a 40-pole design is measured to assess how well AutoDesigner complies with the two-hour targeted optimization time set out in the thesis problem statement.

1.5.2 Evaluation of PoleCheck2.0

The PoleCheck2.0 constraint module is evaluated separately from AutoDesigner. Since PoleCheck2.0 is a lookup table-based design tool, it is evaluated by comparing samples from the tables against a known reference. The known reference used for evaluating PoleCheck2.0 is the existing PoleCheck1.0 tool that is currently in use by the DFO. A sufficiently large number of sample comparisons are made between PoleCheck2.0 and the original PoleCheck to verify the technical compliance of PoleCheck2.0.

1.6 Thesis Outline and Contributions

The thesis is divided into seven chapters. Chapter 1 is set aside for the Introduction. Chapter 2 provides a review of related works as well as background on the fundamentals of DOP design. Chapter 3 provides a detailed discussion about the modules that comprise AutoDesigner except for PoleCheck 2.0. Chapter 4 provides a detailed discussion of the PoleCheck2.0 constraint module. Chapter 5 summarizes the results of the hyper-parameter search performed on the genetic algorithm optimization stage within AutoDesigner. Chapter 6 lists the data tables and figures related to the final evaluation of AutoDesigner and PoleCheck2.0, evaluates the performance of AutoDesigner and PoleCheck2.0 and provides concluding thoughts and thoughts for future work.

The key contributions made by the thesis are as follows:

1. Provide a non-commercial software package (AutoDesigner) for use by the DFO that automates and optimizes the design process enabling considerable savings in design labour cost, construction labour cost and material cost,

2. Provide a FEA pole-loading look-up table database (PoleCheck2.0) for the DFO that can be used in conjunction with AutoDesigner or as a standalone tool,

3. Propose a genetic algorithm optimization approach that utilizes memory in the context of DOP design to dramatically speed up the rate of optimization,

4. Gather insight into the unique design practices suggested by AutoDesigner that stand apart from the normal design practices contained within a human-designed DOP.

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Chapter 2

Background

The Background Chapter of the thesis focuses on first reviewing the available literature and existing commercial software offerings that are relevant to the task of DOP design automation. Next, the chapter covers a review of basic DOP design concepts that are necessary in understanding the operation of AutoDesigner.

2.1 Related Works

The investigation of related works includes an examination of available literature as well as a study of the available commercial software options that currently exist for automating the design of DOP.

2.1.1 Literature Review

A large body of literature exists that focuses on the challenge of optimizing the design of overhead transmission and distribution powerline. Given the highly specialized nature of AutoDesigner, however, there is significant challenge in finding existing literature that deals with the design of DOP at the specific scale of complexity being considered in the thesis. Except for Cicconi, et. al [12], much of the related literature deals specifically with TOP Design [13][14][2][15][16][17] or considers DOP design in the context of high level planning that abstracts above the scope of the design objectives considered in the thesis[18]. When considering high level planning criteria such as routing of feeders [13][18], pole locations [13][16], minimization of energy losses [13][17], conductor thermal limits [13][18], life cycle costs [15], and location of normally-open points [18][17], it becomes infeasible to consider all of the factors needed for generating a final DOP design package such as structure-loading, conductor clearances over roadways and pole-specific attachment information. Alternatively, the existing literature may forego the design of a complete powerline in favor of focusing in on the optimization of a specific powerline structure enabling a very detailed and custom structural design [2], in which case the complexity is brought down to a feasible level but again where a final, optimized design package for a complete powerline extension is not attainable.

Sauhats, et. al. proposes a TOP optimization method that considers design cost as a parameter within the overall life-cycle cost of the powerline [13]. The paper makes use of PLS-CAD in its evaluation of design cost which has the capability to optimize structure heights as well as performing FEA loading analysis of structures [13].

Kishore and Singal perform an extensive literature review on available articles pertaining to the economic optimization of TOP and groups literature based on mathematical optimization methods, searching algorithms and iterative searching algorithms which include the genetic algorithm as used by AutoDesigner [14]. The paper recognizes the benefits of methods such as genetic algorithm in being able to significantly reduce the computational complexity of an optimization task while still being able to arrive at a good minimum.

Mohammed and Taysi make use of genetic algorithm to perform FEA optimization of a single transmission steel-lattice structure [2]. While AutoDesigner deals specifically with the optimization of wood pole distribution structures, Mohammed and Taysi perform FEA using a technique implemented in FORTRAN as opposed to making use of commercial software such as PLS-POLE which is used for performing FEA computations for the PoleCheck2.0 constraint module used by AutoDesigner [7]. Future work with AutoDesigner includes plans to develop an internal FEA solution that does not require the use of commercial software for pole-loading calculations and is discussed further in Chapter 6.

Jordaan, proposes a method for the planning and design of TOP that considers cost factors such as land-routes, thermal rating, and voltage range violations and captures socioeconomic considerations in the planning of the powerline route [15]. Avidar suggests a method that can tweak pole locations, heights and routes using a trial and error algorithm based on terrain imagery and limited survey data points [16]. Avidar's automatic placement of poles based on terrain analysis may represent possible future work for consideration in AutoDesigner where the use of LIDAR data can be used to substitute the survey CSV file and where pole locations can be modified slightly without massively increasing the state space of the variables under optimization.

Ciconi et al., provides a very relevant paper that performs design automation of DOP by combining a structural analysis tool with a CAD modelling tool and validating the results using a commercial FEA tool [12]. The algorithm developed by Ciconi et al. has significant similarities with AutoDesigner such as:

1. performing cost optimization on a DOP design and selecting design parameters such as pole heights, pole classes, and pole attachments;

2. accepting input data that specifies pole locations, crossing locations, conductor types, number of phases, etc.;

3. performing FEA on pole structures using data extracted from commercial software;

4. referring to a database to determine acceptable pole loading configurations.

That being said, the method proposed by Ciconi et al. differs from AutoDesigner's implementation in that it makes use of commercial powerline design software (ProLED 2.0) to perform the design automation process of selecting poles and attachments [12]. As a result, the method suggested by Ciconi et al. is likely to share many of the common advantages and drawbacks with that of the commercial DOP design automation software discussed in the following subsection.

Gantovnik et al. utilizes genetic algorithm in the design of composite cylinders with lattice reinforcement where the objective is to minimize the structure weight [17]. While the paper does not deal with the optimization of DOP design, it presents a modified genetic algorithm that makes use of memory that remembers past design computations to reduce the number calculations needed in determining the fitness of future individuals. The memory technique presented by Gantovnik et al., makes use of a decision tree for storing past outputs and is capable of reducing the number of calculations by up to 67%. The memory used by AutoDesigner's genetic algorithm makes use of a sparse data table which is similar in function to that of the decision tree used by Gantovnik et al. where results of past constraint module outputs are directly addressable and do not require the use of an intensive searching algorithm.

Finally, Patil and Pawar perform a literature review investigating optimal values for crossover and mutation rates for use in genetic algorithm optimization [3]. The range of common values for crossover and mutation rates cited by Patil and Pawar serve as a useful guide in selecting the minimum and maximum values in the hyperparameter search performed in Chapter 5.

2.1.2 Review of Commercial Software Offerings

A substantial selection of commercial software products is available that carry out the task of automating DOP design.

Automated Utility Design^{tm} is a software offered by Spatial Business Systems, Inc. and Power Lines Pro is a software product offered by LineSoft Pty. Ltd [19][20]. Both software packages are capable of semi-automating the design process where users will still manually place poles, however, the process is made largely seamless with the aid of a convenient 3D interface. Both software packages have the ability to model conductor sags, pole loading calculations, integrate the DFO's standards libraries as well as the capability to accept rule-based design criteria (such as ruling span lengths) that may be specific to a given DFO. The software platforms can also generate output staking reports and bill of material files.

PLS-CADD is DOP design software developed by Power Line Systems, Inc. that is the most well-established commercial DOP design software in the market as well as the most widely used by DFO's across North America [21][22]. PLS-CADD primarily aids design engineers in the manual construction of DOP through the placement of poles in a 3D interface, however, the software also boasts significant design automation capabilities through the use of its Optimum Spotting module [22]. Optimum Spotting allows for poles to be placed optimally in a right-of-way as well specifying pole heights that meet required clearances, avoiding uplift conditions on pole attachments and specifying pole classes that most cost-effectively satisfy the FEA analysis check generated by PLS-Pole [7]. Note that AutoDesigner also makes use of the FEA analysis from PLS-Pole in the construction of the PoleCheck2.0 constraint module look-up tables.

Utilizing commercial software for DOP design automation can yield designs that effectively comply with code rules and can easily optimize the selection of pole heights and pole classes while ensuring that applicable structure loadings and clearances are complied with. Furthermore, commercial DOP automation software may be capable of selecting appropriate pole-top attachments provided that the DFO's standards library is fully integrated into the software's database. Additionally, some commercial software packages may even allow for custom DFO-specific rules to be added to the optimization such as ruling span lengths and guy wire requirements all of which allows for increased potential for design optimization [3]. That being said, commercial software will invariably fall short of being able to fully consider all of the practices and empirical rules used by a specific DFO in the design optimization procedure and this inhibits a truly optimal design from being realized without user assistance in making design decisions. In the case of the DFO that AutoDesigner is developed for use by, some of the rules that are difficult for commercial DOP software to fully model in the optimization process include:

1. the ability for short spans to have normal tight wire tension or to be low-tension, hand-strung slack-spans that do not require guy wires;

2. utilizing empirically-derived pole deep-set depths to support poles with unanchored low-tension slack spans without site specific soil composition data;

3. ensuring that pole-top transformer equipment has a minimum of two ground rods either on the same pole structure or different structures connected via a neutral wire and where the number of optimal spans that the neutral should run before being terminated may vary based on factors such as nearby road crossings and nearby poles with existing anchors;

4. determining when it is best to replace an existing pole's structural attachments, when it is best to replace the complete pole or when it is best to leave the existing pole unmodified.

Furthermore, commercial DOP automation software generally lacks the versatility to be able to automatically accept the complete set of input data needed to complete a DOP design in the native format used by a specific DFO as well as to produce the properly formatted output files. For example, even if commercial software is capable of reading in pole location survey data in a CSV file format, the software will generally not be capable of recognizing the more customized content contained in a specific DFO's CSV file format such as height of attachment, height of cross arm data points for existing poles as well as types of existing pole-top structures. Height of attachment and type of existing pole top structure data is especially critical for re-build projects where new DOP is tied in with a large number of existing tap-offs and where each tap-off has its own unique height of conductor attachment that is field determined by survey. Furthermore, output data produced by commercial DOP automation software also generally lacks the capability to produce all of the specific output files needed in a design package in the precise format required. While the limitations described above do not make it impossible for commercial DOP design automation software to automate a design, they do introduce additional design time needed for manual data-entry and formatting which in some cases may even outweigh the cost savings made possible by DOP design automation.

Overall, commercial software options offer impressive benefits that allows for significant portions of DOP designs to be automated. That said, highly customized software developed for a specific DFO, such as AutoDesigner, remains the most feasible way to fully automate the DOP design process to such a degree where human design intervention is not required and where the optimized design considers all aspects of the DFO's design practices.

2.2 Review of Distribution Overhead Powerline Design Concepts

In order to be able to fully grasp the methodology of AutoDesigner and its component modules, it is first essential to establish a basic understanding of DOP design as carried out by the designers working for the DFO. The section begins with a high-level review discussing the two primary classes of DOP designs that AutoDesigner endeavors to optimize with minimal human input. Next, a review of the individual powerline supporting structures is provided including details on the wood pole structures, pole heights, classes, pole-top structures and guy wires. Afterwards, a review of the types of conductor spans that are attached to the poles is provided as well as a review of design considerations such as conductor clearance and conductor uplift that must be considered in a DOP design. Finally, a short introduction to DOP grounding is presented.

2.2.1 Introduction to Distribution Overhead Powerline Design and Explanation of Design Categories

A DOP, in the context of the type designed by the DFO, is a series of wood pole structures that is used to safely suspend one or more open-air metallic conductors that provide a reliable conductive pathway for transmitting electrical power from a source to an electrical load. The source of the electrical supply for a DOP is typically either a mainline DOP or a transmission substation. Power is transmitted along the DOP conductor from the source to the electrical load at a voltage that can range from 2.4kV to 14.4kV line-to-ground. The electrical load served by the DOP is typically one or more residential, commercial or industrial customers. DOP is regarded as the preferred means of supplying power to customers who are located in rural areas due to the low population density and the relatively low installation cost of DOP. Note that the main alternative to DOP is the use of distribution underground powerline (DUP), which is preferred in urban areas due to its higher reliability, safety and aesthetic benefits but which comes with a substantially higher cost of installation labour [5]. Note that AutoDesigner is intended to be able to automate two main categories of DOP designs while requiring minimal human intervention and where each category is reviewed below.

The first category is the new extension of DOP. New extension designs specify new DOP where the objective is to tap-off of an existing mainline DOP and install new powerline to serve a customer at a location where no DOP currently feeds. New extension designs are generally free from interactions with existing powerline infrastructure after the first pole, where the first pole is either an existing pole on a mainline that is converted to a tap-off structure, a new tap-off pole that is installed in the same location as an existing pole of an existing mainline that is being salvaged, or a completely new pole in a new location that is set mid-span along an existing DOP alignment for the purposes of tapping off. New extensions are normally constructed radially which means that a single DOP is extended to feed the customer with no second path for redundancy. New extensions often terminate inside the customer's premises at a pole-top transformer structure that is designed to step down the high voltage to a lower level that is directly usable by a consumer. That being said, it is also often the case for industrial and commercial customers that new extensions terminate at a riser pole outside of the customer premises from which the DOP transitions to a DUP which then supplies power to a pad mounted or side-wall mounted transformer within the underground network [5]. Note that figures 2.1 and 2.2 illustrate a sample of a new DOP extension denoted with red conductor and with the existing mainline DOP shown with black conductor.

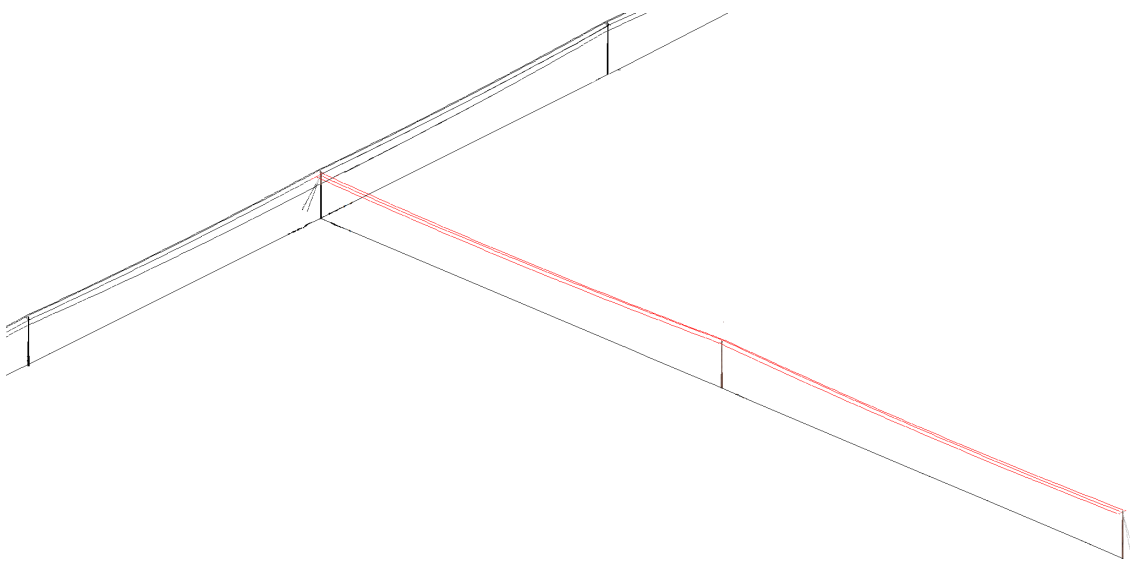


Figure 2.1: 3D View of a Sample DOP New Extension.

The second category of DOP design that is considered by AutoDesigner is the rebuild of existing DOP. Rebuilds are DOP designs where existing DOP mainline is either replaced, relocated or upgraded. Of particular interest to AutoDesigner are rebuilds that involve the complete removal of existing structures along a particular segment of DOP and where the installation of new poles occurs in the same or a nearby alignment. Rebuilds may occur as the result of powerline needing to be moved to accommodate the expansion of road allowance boundaries, single phase powerline

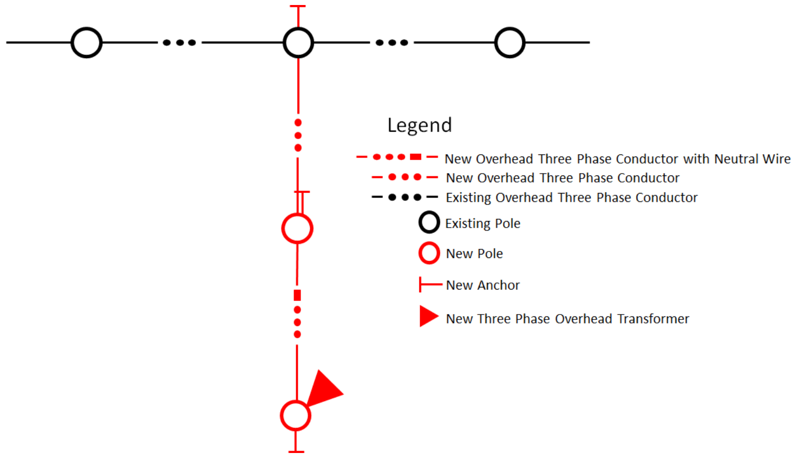


Figure 2.2: Design View of a Sample DOP New Extension.

needing to be upgraded to three phase line in order to serve a customer with significant load requirements, or powerline conductor being upgraded to a larger size. Unlike new extensions, rebuilds will interact with existing powerline at least at the beginning and end of the new construction profile, however, the interaction may also include tying in a potentially significant number of existing tap-offs with the new or existing conductor. Because rebuilds present a potentially expansive interaction between new and existing powerline infrastructure, the challenge of automating and optimizing rebuilds is considerably more complex than that of new extensions. For example, while the main optimization problem to be solved in new extension designs is to determine the design characteristics of new structures, re-builds involve designing new structures that are also constrained to maintain safe designs for the existing spans and structures that are impacted by the new line. As a result, when optimizing rebuilds, the question of whether or not it is necessary or financially advantageous to upgrade an existing structure that is close to the new line but is not a part of the original design scope becomes important to consider. The potential to increase the design scope beyond a defined number of new structures presents a very unique optimization challenge that is addressed by AutoDesigner. Note that figure 2.3 illustrates a sample of a DOP rebuild.

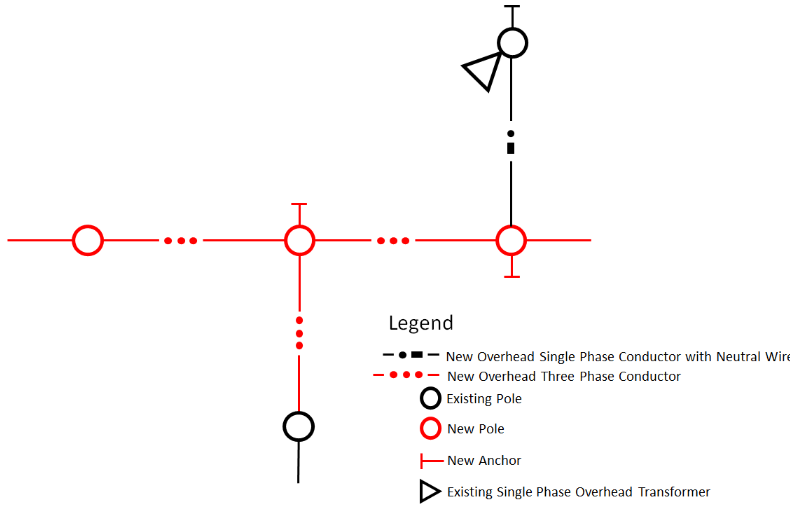


Figure 2.3: Design View of a Sample DOP Rebuild.

2.2.2 Review of Distribution Powerline Structures

The Wood Pole Structure

The powerline structure used by the DFO is usually a single wood utility pole that is set in the ground with pole-top attachments needed to support conductor, equipment or to anchor unbalanced forces. AutoDesigner considers wood pole structures that vary in height from 35 to 60 feet in 5-foot increments which is consistent with the inventory used most commonly by the DFO. Utility wood pole structures are often harvested from trees such as Lodge Pole Pine, Western Red Cedar or Douglass Fir [23]. Pole heights are measured from the base of the pole to the top of the pole, however, once the pole is set in the ground the pole top elevation will be significantly less than the specified pole height. Pole class refers to the thickness of a pole where a class of 1 represents the thickest pole used by the DFO, a class of 5 represents the smallest thickness of pole installed by the DFO and a class of 7 represents the smallest thickness that is most commonly encountered in existing infrastructure in the DFO's service area [5]. Note that for a 40ft pole, a class size of 1 corresponds to a circumference of at least 114cm two meters above the bottom of the pole, while a class 5 pole corresponds to a circumference between 86cm and 93cm two meters above the pole butt [23]. Note that not all pole heights may accommodate the complete range of possible pole classes since the pole must conform to the physical characteristics of the trees harvested. Table 2.1 lists the available pole heights and pole classes along with the typical set depths for each pole height.

Height (ft.)	Height (m)	Nominal Set Depth (m)	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class7
35	9.1	1.83		x	x	x	x	x	x
40	10.7	1.83	x	x	x	x	x	x	
45	12.2	1.98	x	x	x	x	x	x	
50	13.7	2.13	x	x	x	x			
55	15.2	2.29	x	x	x				
60	16.8	2.44	x	x	x				

Table 2.1: Table of Standard Pole Heights, Nominal Set Depths and Classes used by AutoDesigner. Adapted from DFO Distribution Construction Standards Manual [5]

Deep-Setting of Wood Pole Structures

As per the nominal set depth column of Table 2.1, each wood pole has a typical set depth to which the pole butt is buried during installation. In addition to the nominal set depth, the DFO standards allow for additional 0.5m, 1.0m and 1.5m set depths beyond the nominal set depth which are referred to as deep sets. Deep setting a pole provides additional soil holding strengths for poles that are experiencing significant unbalanced force loads which is discussed in more detail later in the section [5].

Pole Top Structure Attachments

Pole top attachments are essential accessories that provide a set utility pole with its functional capabilities to support, dead-end or tap-off conductor, support pole-top equipment or to anchor unbalanced forces. The DFO maintains an extensive standards library of its available pole top attachment structures where each attachment structure serves a specific function such as supporting inline conductor, providing a tap-off attachment, providing a down-hall guy wire, specifying pole-mounted equipment such as transformers or risers, etc. It is common for individual pole top attachment structures to be combined with other compatible attachments to provide poles with a multitude of unique functions and applications. For example, AutoDesigner considers over 400 possible combinations of pole-top structures as discussed in Chapter 4 and while such a number represents a significant portion of the possible combinations of pole-top structures it is by no means an exhaustive list [5].

Figure 2.4 illustrates a sample of some of the most common pole-top structure attachments and combinations of structure attachments that are used by the DFO's designers when designing DOP.

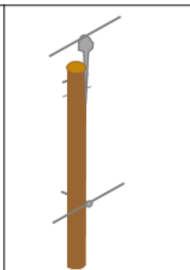
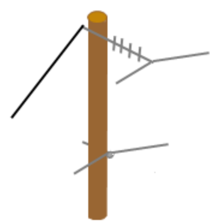
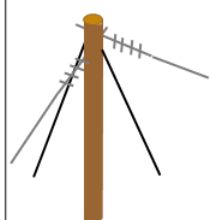
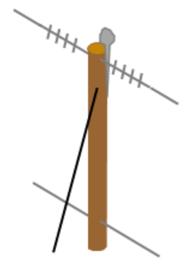
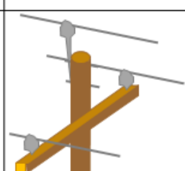
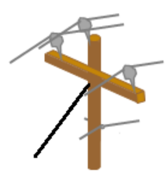
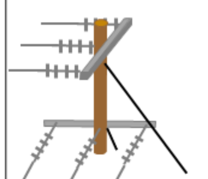
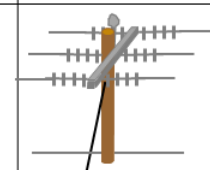
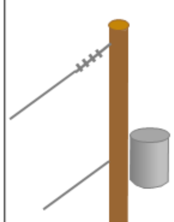
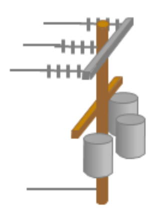
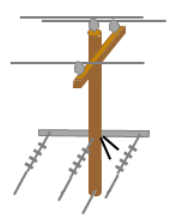
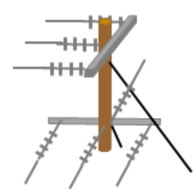
Simple Single Phase Structure Attachments				
Description	R112 (Single Phase Inline Tangent Structure)	R109,G40A (Single Phase Deflection Structure with Downhaul Guy)	R130,2xG25AF (Single Phase Corner Structure with Two Downhaul Guys)	R152,G25A (Single Phase Dead-End Carry-On Structure with Downhaul Guys)
Simple Three Phase Structure Attachments				
Description	N12 (Three Phase Inline Tangent Stucture)	N11,N0B,G40A (Three Phase Deflection Structure with Neutral Wire and Downhaul Guy)	N32,2xG40A (Three Phase Corner Structure with Two Downhaul Guys)	N52,N0A,G40A (Three Phase Dead-End Carry-On Structure with Downhaul Guy)
Structure Attachment Combinations				
Description	R140,R180,E12 (Single Phase Dead-End Structure with Single Phase Transformer and Equipment Ground)	N42,N82,R0,E12 (Three Phase Dead-End Structure with Three Phase Transformer and Equipment Ground)	N12,N55,N0A,R0,G50A (Three Phase Inline Tangent with Three Phase Tap-Off Structure with neutral wires and Downhaul Guy)	N32,R253B,2xG40A (Three Phase Corner Structure with Two Downhaul Guys and a Single Phase Tap-Off on Back of Lower Cross-Arm)

Figure 2.4: Sample of Common Pole Top Structure Attachments Used by the DFO. [5]

Note that each individual structure attachment label referenced in the description cells of Figure 2.4 is referred to as a compatible unit (e.g. N12 or R252). A combination of compatible units (e.g. N32,R253B,2xG40A) is referred to in the thesis as a structure pattern and occurs when a pole has more than one structure attachment.

Pole Loading

One of the most critical considerations in designing DOP is ensuring that the pole structures are adequately sized and classed to be able to withstand the worst-case loading conditions applied by conductor tension, wind-loading as well as conductor and attachment weights. Note that recent changes to the utility code requirements in Canada requires all distribution structures to be analyzed for the ability to withstand maximal force loads using non-linear analysis including a buckling check [4]. The most common means to achieve the code requirement is to use the method of FEA which considers the deformation of the pole structure due to the applied force loads. A stable structure is capable of undergoing slight deformation during FEA while eventually converging to a new equilibrium state that can support all force-loading. Note that numerous commercial software packages are capable of performing FEA on utility pole structures including PLS-POLE which is utilized in the generation of the PoleCheck2.0 lookup tables discussed in Chapter 5 [7]. Note that Figure 2.5 illustrates an example of a loaded wood pole structure with a single downhaul guy modelled in PLS-POLE before and after it undergoes deformation using FEA. Note that the right-hand panel of Figure 2.5 illustrates the results of the FEA for eight different directions of wind-loading. The structure depicted in the figure only remains acceptably stable for two of the eight possible wind directions and therefore does not satisfy the FEA check.

Pole loading is the result of three classes of physical force loads that poles experience.

The first and most significant force load on a pole is the longitudinal loading which

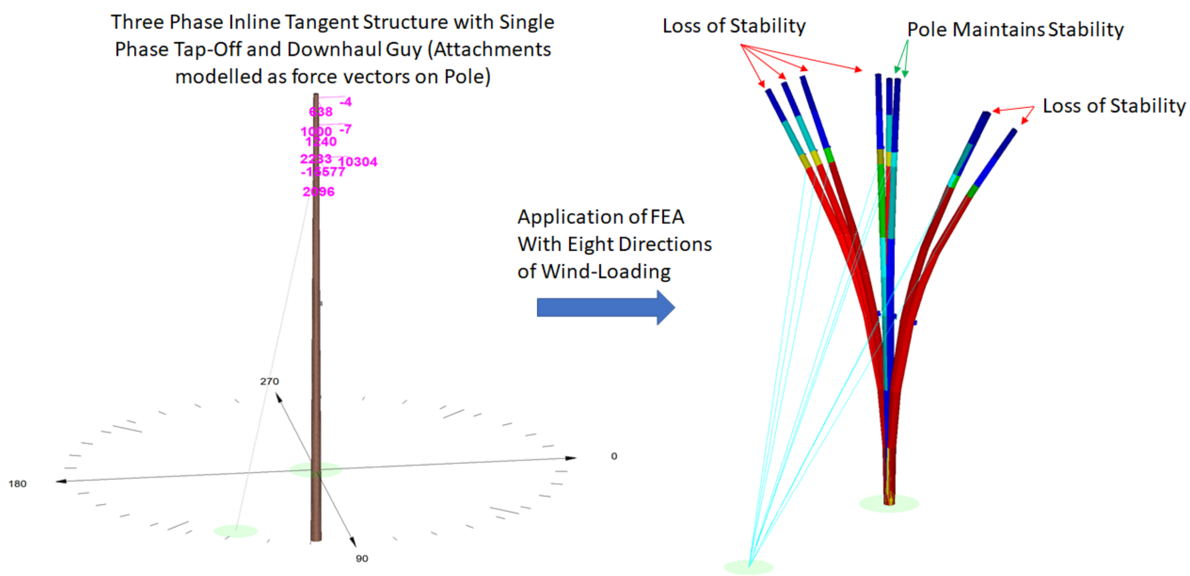


Figure 2.5: Pole Structure Before and After FEA Application in PLS-POLE.

represents the tensile force exerted by tensioned electrical conductor. For example, fully tensioned three phase conductors may exert a tensile force of up to 55kN on a pole attachment point. That being said, for poles with inline tangent structure attachments the vast majority of the longitudinal loading will be cancelled by the incoming and outgoing tangential spans which are usually approximately oriented on opposite sides of the pole. For conductor tap-off and dead-end structures, however, the longitudinal loading experiences minimal cancellation from other conductor spans and so the resulting force is generally too great for a pole structure to withstand by itself. For this reason, a full tension tap-off or dead-end structure attachment usually requires a down-hall guy to be installed on the side of the pole opposite the tap-off or dead-end structure attachment for structural stability. Note that slack spans are special low-tension spans where the unbalanced longitudinal load can be supported by a pole that does not have a downhaul guy provided that the pole has been deep-set. Slack spans are generally used when downhaul guys are not practical due to space constraints and are discussed further in the next subsection. Note that longitudinal load must be calculated under worst-case seasonal conditions which, in Alberta, usually occurs during intensely cold winter conditions where the conductor experiences thermal contraction as well as the buildup of frost or ice on the conductor surface [5] [4].

The transverse loading, which is due to wind loading effects on conductor and pole structures comprise another force load that must be considered when assessing pole stability. Each pole structure must be able to support the total transverse loading on the surface of the pole, the surface of any pole-mounted equipment and downhaul guy wires as well as the surface area of half the span lengths of all incoming and outgoing conductors that are attached to the pole. Note that under normal conditions, 6.5mm of frost or ice buildup is considered as added conductor surface area which is referred to as medium loading. Furthermore, in certain regions of Alberta an ice-buildup phenomenon may occur on bare conductor wire which can result in up to an 18 mm ice coating, which is referred to as heavy loading. The force applied by wind loading is much more severe in heavy loading areas when compared to medium due to the increased conductor surface area. Note that in the PoleCheck2.0 constraint module, discussed in Chapter 4, wind is considered from eight possible directions [5] [4].

The third category of force loads on poles is the vertical force exerted by the weight of conductor and equipment that are attached to the pole top. As with wind loading effects, the pole must be able to support half of the span length of conductor weight for all incoming and outgoing spans that are attached to the pole. Furthermore, the weight created by heavy loading conditions must be represented with an increased conductor weight due the ice loading. Cross-arms, insulators, pins and equipment weight must also be applied to the pole. Note that while vertical forces applied to a rigid upright pole may not immediately appear to be the most severe contributor to the loss of pole stability, it must be considered that when a pole undergoes deformation due to conductor tension and wind loading conditions, the vertical forces on a deformed pole can plausibly start to have a more significant impact [4].

When all three of the sources of force loads on the pole are considered together, the structure attachment point on a pole can be represented with a single, resolved force vector. Figure 2.6 illustrates an example of how a complex combination of structure attachments can be resolved down to three force vectors. Note that in figure 2.6, the N12 inline tangent structure attachment that comprises attachment 1 has a slight deflection (less than four degrees) and so the longitudinal forces of the incoming and outgoing span segments do not completely cancel.

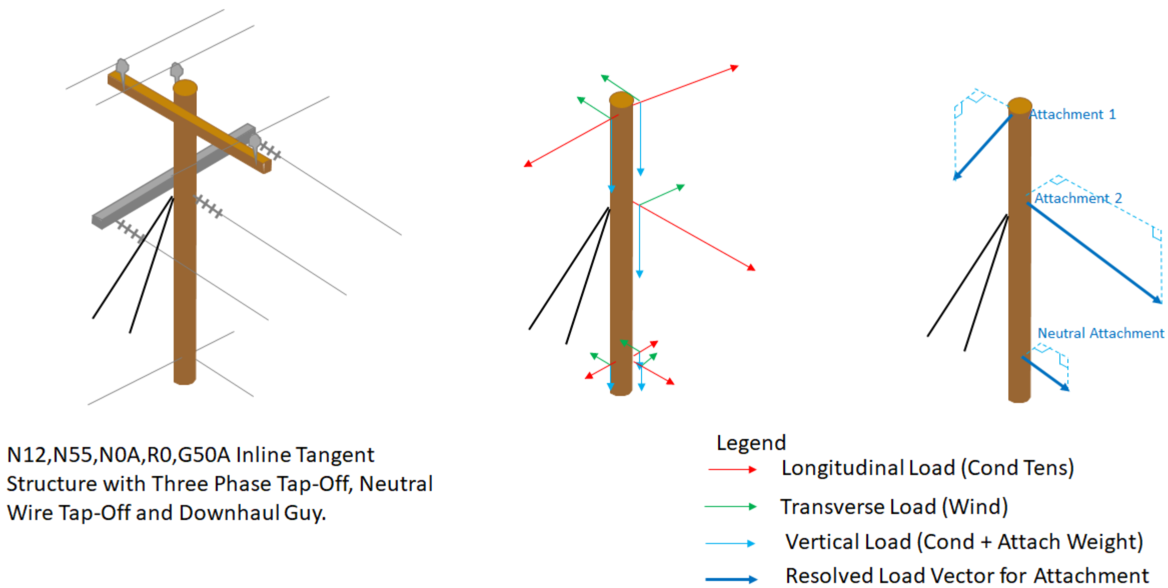


Figure 2.6: Resolving Transverse Longitudinal and Vertical Loads to Individual Attachment Force Vectors. [5]

Utility code in Canada requires the application of loading factors to the various classes of forces applied to a pole. Table 2.2 summarizes the loading factors required for longitudinal, transverse and vertical forces under both grade 1 and grade 2 constructions. All force vectors must be multiplied with the applicable loading factor prior to the FEA check. Grade 1 construction requires a greater degree of safety in loading factors compared to grade 2 and it is used for designing DOP that crosses over special crossings such as railways. Grade 2 construction is used by the DFO for most normal construction conditions [4][5].

Condition	Grade 1 Load Factor	Grade 2 Load Factor
Longitudinal Load on Attachments without Break in Conductor Tension	1.2	1.0
Longitudinal Load on Attachments with Break in Conductor Tension	1.9	1.3
Transverse Load	1.9	1.3
Vertical Load	2.0	1.5

Table 2.2: Table of Loading Factors for pole loads. Adapted from the Canadian Standards Association Overhead Powerline Utility Standard which is adopted as code in Alberta. [4] [6]

AutoDesigner Cond No.	Conductor Type and Name	Cond. In Use or Recently Used by DFO	Diameter	Ruling Span Heavy Loading (m)	Ruling Span Medium Loading (m)	Max Conductor Tension, Med Loading Ruling Span (kN)	Modelled Conductor Tension Slack Spans (kN)	Max Sag Med Loading, 100m span length (m)
1	#8 HiCON	No	-	-	110.0	-	1.0	1.0
2	# BANTAM	No	-	-	110.0	-	1.0	2.17
3	#6 ACSR	No	0.0049	-	110.0	3.3	1.0	2.78
4	#4 ACSR	Yes	0.0062	90.0	110.0	4.8	1.0	2.56
5	#2 ACSR	No	0.0080	90.0	110.0	5.0	1.0	2.35
6	1/0 ACSR	Yes	0.0101	90.0	110.0	6.7	1.0	2.75
7	2/0 ACSR	No	0.0113	90.0	110.0	7.5	2.0	2.29
8	266 MCM ACSR	Yes	0.0163	70.0	110.0	13.9	2.0	2.71
9	477 MCM ACSR	Yes	0.0218	70.0	85.0	13.9	2.0	3.13

Table 2.3: Table of commonly encountered conductor types for high voltage application in the DFO's service area [5].

2.2.3 Review of Distribution Powerline Spans

Powerline Conductor

Powerline conductor is bare, metallic stranded wire that is strung between structures and is the means by which electrical energy is conducted along DOP. The DFO uses ACSR powerline conductor where the outer strands of the conductor are made of aluminum for the purpose of electrical conduction while the core strands are composed of steel and are primarily intended for reinforcing the strength of the conductor and allowing longer conductor spans. Table 2.3 summarizes the types of high voltage powerline conductor that is commonly encountered in DOP designs [5].

Note that a significant subset of the conductors listed in Table 2.3 are no longer used by the DFO but may still need to be considered when interacting with existing DOP in AutoDesigner which occurs frequently in rebuild designs. AutoDesigner is capable of modelling the conductor sag profiles of all the conductor types shown in Table 2.3, however, when modelling pole loads it will conservatively approximate the conductor type with the closest available in-use conductor type shown on the table. In other words, the PoleCheck2.0 constraint module is only capable of considering the in-use conductor types shown in Table 2.3 while the ClearanceCalc and FloaterCheck constraint modules can consider the full spectrum of conductor types listed.

Conductor Tension

Conductor tension measures the near-horizontal force (in Newton's) that a tensioned powerline conductor exerts on the structure attachments that are supporting the conductor. Conductor tension varies based on the size of the conductor, conductor temperature, and heavy or medium loading conditions. Larger conductor sizes require a greater conductor tension in order to maintain an acceptable sag profile. Higher conductor temperatures, which can be due to factors such as ambient temperature or conductor current causing heating of the metal, result in lower conductor tension due to thermal expansion of the conductor. Similarly, the presence of frost or ice loading creates additional conductor tension at the structure attachments due to the additional upward force needed to balance the increased weight profile of the conductor[5] [24].

Note that tight span conductor is field tensioned by the DFO's powerline technicians using a tensiometer to match a standard print that provides pre-defined conductor tensions based on conductor size, heavy or medium loading conditions and conductor temperature.

Conductor Sag

Conductor sag, or maximum sag, is the height in meters between the lowest conductor elevation along a span and the attachment height of the lowest supporting powerline structure. Conductor sag varies based on conductor size, ambient temperature, span length, and the presence of ice or frost loading. Increased conductor temperature results in greater conductor sag due to thermal expansion of the conductor metal. Increasing span length also results in greater conductor sag since conductor tension is held constant for a particular type of conductor across the various span lengths as per DFO standards as well as the fact that inline tangent structure attachments (which are the prevailing structure attachments found on poles) cannot support a change in conductor tension. Furthermore, the presence of ice or frost loading introduces additional conductor sag due to the additional weight profile of the conductor [5] [8].

It is important to note that conductor sag also varies based on attachment elevation of the two supporting powerline structures as a result of the location of the maximum sag point shifting along the span. When the attachment elevation of the two supporting powerline structures is equal, the location along the span where the maximum sag is observed is at the mid-point between the two structures and the conductor sag reaches its maximum value. That said, it is far more common to encounter the situation where the attachment elevation of one of the adjacent supporting powerline structures is greater than the other. The difference in elevation may be due to factors such as: ground elevation differences, differences in the height of the poles used for the structure, different structure attachment heights or different set depths of the poles. When the conductor attachment elevation on an adjacent structure is different, the point of maximum sag of a powerline conductor is off-centre and is biased towards the structure with the lower attachment elevation. It can also be observed that when the attachment elevations of a span are uneven the conductor sag with respect to the lower attachment elevation is reduced. Figure 2.7 illustrates examples of a span with adjacent structures that have equal attachment elevation versus a span that has adjacent structures with different attachment elevations [5] [8].

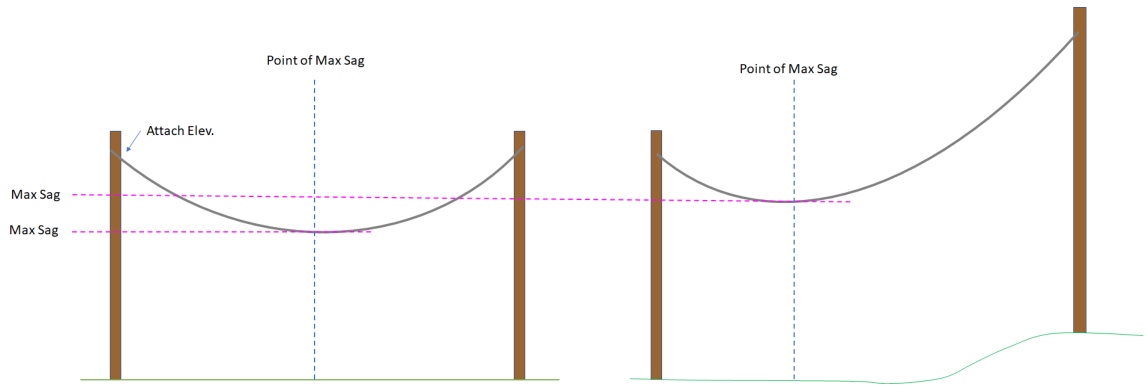


Figure 2.7: Conductor Sag for Even and Uneven Attachment Elevations.

Slack Spans

Slack spans are short, low-tension conductor spans that can be attached to a pole without the need for a downhaul guy wire or tangential span to provide force cancellation provided that the slack span's supporting structures are deep-set at least 1.0m. DFO standards require slack spans to have a span length not exceeding 35 meters for conductor sizes equal to or less than the diameter of 1/0 ACSR and not exceeding 20 meters for conductor sizes greater than 1/0 ACSR [5].

Slack span conductor is hand-tensioned by field crews without the use of a tensiometer and so the tension values provided in Table 2.3 for slack spans should be treated as approximate, conservative values. The tension values for slack span conductor in Table 2.3 account for an inherent contraction of the conductor in cold weather conditions assuming that the slack span is hand-strung in warmer weather [5] [24] [25].

Finally, slack spans have much greater conductor sag relative to their span length compared to tight spans due to the lower conductor tension of the hand-tensioned conductor. The DFO has a convention when calculating clearances to approximate the conductor sag of a slack span as being 1.5m lower than the lowest adjacent conductor

Type of Crossing with Abbreviation	Minimum Clearance for Neutral Conductor (m)	Minimum Clearance for High Voltage Conductor (m)	Snow Cover Required
Roads or Industrial Site Premises (RD, RDCL, or RDSH)	6.7	7.0	No
Agricultural (AG)	6.2	6.5	No
Highways (HW)	8.6	8.6	No
High Pressure Pipeline (P/L)	5.0	5.3	Yes
Pedestrian (PED)	4.5	4.8	Yes
Railway (RR)	8.0	8.3	No
Residential Driveway (DR)	5.0	5.3	No

Table 2.4: Typical powerline crossing categories and required conductor clearance as per DFO standards [5] [8].

attachment elevation for conductor sizes less than 1/0 ACSR and 2.5m for conductor sizes greater than 1/0 ACSR [8].

Conductor Clearance

Possibly the most critical design parameter that is determined from the conductor sag of a span is the clearance of the span over crossings that are traversable by the public. There are a number of different crossing types outlined in code over which energized DOP spans must maintain a minimum clearance [6]. Table 2.4 outlines some of the common crossing types as well as the required clearances that must be maintained as per DFO standards which meet or exceed the requirements laid out in code [8] [5] [6].

Note that the pedestrian and agricultural clearance categories listed in Table 2.4 are unique in that they may not be confined to a crossing corridor with clear physical boundaries. In fact, the pedestrian clearance applies to all land that is accessible to non-qualified utility personnel while agricultural clearances apply to all cultivated land that is not segregated from the powerline right-of-way via a fence. As a result, calculating pedestrian and agricultural clearances is generally accomplished as per formula 2.1 where the clearance is by default calculated at the point of maximum sag

[8]. Note that an example of an agricultural crossing is shown in Figure 2.8.

$$C = L - M - G \qquad (2.1)$$

$$C = Pedestrian\, or\, Agricultural\, Clearance$$

$$L = Lowest\, Adjacent\, Attachment\, Elevation$$

$$M = Maximum\, Sag$$

$$G = Ground\, Elevation\, under\, Point\, of\, Maximum\, Sag$$

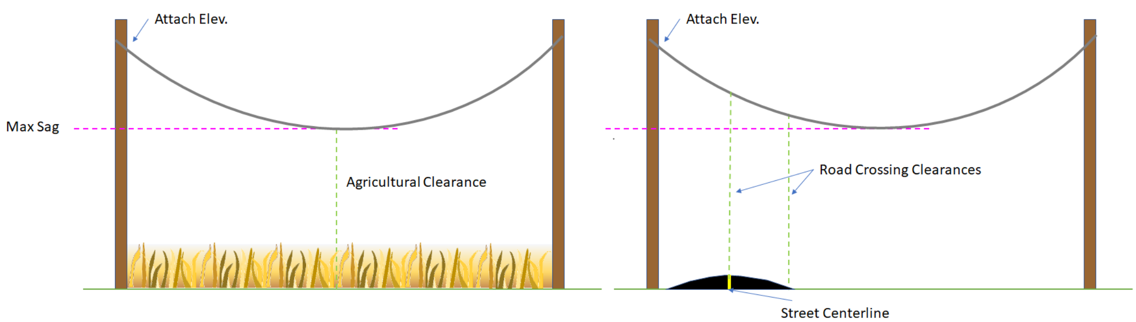


Figure 2.8: Examples of Conductor Clearance over Agricultural Area and Road Crossing.

The remaining clearances listed in Table 2.4 usually have defined boundaries or corridors that only conflict with a portion of a powerline span. It is normal practice to calculate powerline clearance of crossings such as roadway crossings at the two road shoulder locations where the conductor sag is likely to be at the greatest across the crossing surface as well as at the street centerline where the ground elevation may be the highest. That said, using the conductor clearance at the point of maximum sag for these calculations is often unnecessarily conservative. For example, a powerline span may be 100m in length where the point of maximum sag is somewhere near the midpoint of the span. That said, a road crossing may have its road shoulders located 10 and 15m away from the one of the poles which would position the entire crossing under conductor that is substantially higher in elevation than the point of maximum sag. An empirically tested means by which to calculate conductor clearance over corridor-type crossings when the point of maximum sag is the only available conductor sag data can be achieved by using polynomial interpolation as shown in Equation 2.2 [24]. Note that an example of a road crossing is shown in Figure 2.8 where it can be seen that the crossing corridor is well away from the point of maximum sag for the conductor span.

$$C = L - M * [1 - 4 * [\frac{|D_a - D_c|}{2 * D_a}]^2], \qquad (2.2)$$

$$C = Road,\ Rail,\ or\ Pipeline\,Crossing\,Clearance$$

$$L = Lowest\,Adjacent\,Attachment\,Elevation$$

$$M = Maximum\,Sag$$

$$D_a = distance\,between\,maximum\,sag\,and\,pole\,with\,lowest\,attach\,elevation$$

$$D_c = distance\,between\,crossing\,location\,and\,pole\,with\,lowest\,attach\,elevation$$

Note that utility codes in Canada require considering the effects of snow buildup under conductor clearance [4]. As a result, crossings such as pedestrian and high-pressure pipeline right of ways where snowmobiles or pedestrian traffic may foreseeably be travelling on the top of the snow surface must account for snow depth by subtracting typical maximum snow-depths for a given region from the calculated clearance values [5] [8].

Conductor Uplift

In addition to conductor clearance, assessing conductor uplift on structures is a code requirement and can be determined using conductor sag information [4].

Conductor uplift is a measure of the net upward force exerted on a structure attachment of a pole by the tensions of an incoming and outgoing span that resolve into a single upward pulling force vector on the structure. Uplift occurs when there are at least three consecutive utility poles installed in a straight or minimally deflected alignment and where conductor spans are interconnecting each of the poles. The presence of conductor uplift on a given pole can be most easily understood by envisioning a hypothetical conductor being strung directly between the previous and subsequent pole with no attachment to the pole under investigation. If the resulting conductor sag of the hypothetical conductor at the location of the pole under investigation results in a conductor elevation that is greater than the actual structure attachment elevation of the pole under investigation, then an uplift condition exists on the pole in the real scenario where the three poles are interconnected with conductor. Note that the uplift calculations must be performed under minimum sag conditions (as opposed to maximum conductor sag conditions used for calculating conductor clearance) which normally occur during cold conductor temperatures without the presence of frost or ice loading [4] [5]. Note that the conductor uplift scenario is illustrated in figure 2.9.

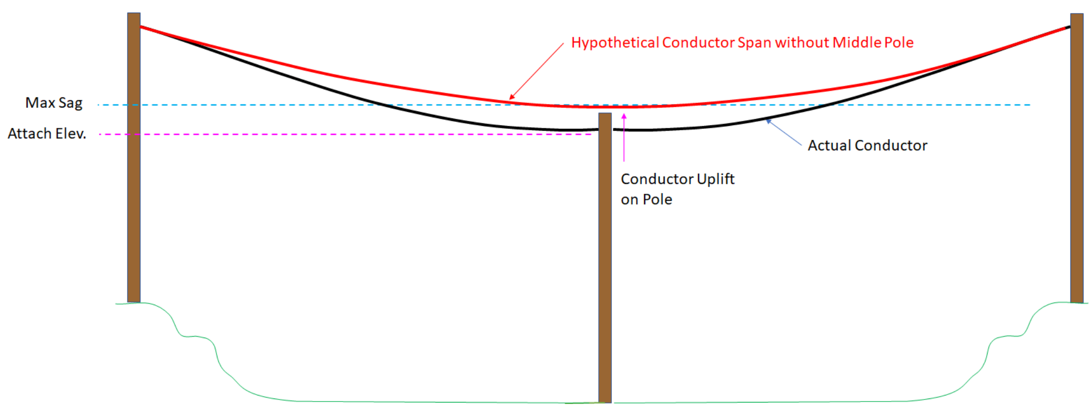


Figure 2.9: Example of Conductor Uplift on Three Pole Circuit.

Conductor uplift concerns are common along powerline spans where soil elevation changes greater than 1.5m occur between poles that are set at normal span lengths apart. Uplift concerns can become especially severe when a pole is set into ground that is at a lower elevation than both of its neighboring poles resulting in a potential upward force contribution from both spans on the pole. The potential for uplift to occur at a pole in a DOP design also increases when conductor spans lengths are shortened.

The issue of conductor uplift is of greatest concern with poles that have pin-style attachments such as the insulators that are used on the inline tangent structures shown in Figure 2.4. With pin-style insulators, any upward vertical force on the attachment may cause the attachment to become unsecured from the pole or cross-arm. The uplift condition is much less of a concern on structures that have termination attachments such as those on the dead-end carry-on structure as these attachments are capable of withstanding considerable uplift. In extreme cases, however, it is possible for uplift to be severe enough such that the upward force exerted on the pole exceeds force from the weight of the pole, itself, which can subsequently result in a pole being physically pulled out of the ground [5].

As per code requirements, the uplift condition must be assessed on poles and addressed so as to not create failures in structures or structure attachments [4]. The most common solutions for an uplift condition encountered on the typical DOP Design that is being automated by AutoDesigner is to either decrease the heights of the neighboring poles, increase the height of the pole experiencing uplift, utilize a slack-span if the span lengths are short enough, apply a deep-set to one of the neighboring poles or to utilize a dead-end carry on structure instead of a inline tangent structure on the pole experiencing uplift.

In summary, when looking generally at the conductor clearance and conductor uplift avoidance requirements on a design, it can be seen that the two conditions are often diametrically opposed where increasing pole height can alleviate a low conductor clearance but can simultaneously introduce a conductor uplift condition. As a result, it is often necessary to evaluate both of these constraints each time a pole height is modified on a design.

2.2.4 Introduction to Distribution Overhead Powerline Grounding

It is necessary to understand the practices relating to the grounding of DOP in order to understand the full optimization functionality of AutoDesigner. Specifically, this subsection introduces the neutral wire and ground rod in the context of earth return and multi-grounded neutral grounding used by the DFO for grounding DOP.

Overhead Neutral Wire

DOP typically carries either one or three energized phase conductors near the top of the pole structure for the purpose of conducting electrical energy from the source to the downstream load transformers. In certain circumstances, however, a second or fourth wire can be observed on the DOP which is usually located about two meters below the lowest phase conductors in rural applications or over three meters in urban applications. This additional conductor is referred to as a neutral conductor and serves as a possible return path for unbalanced electrical current that is returning from the load transformers and going back to the electrical source (usually the source is a transmission substation). According to DFO standards, the overhead neutral wire must always be the same size of conductor as the conducting phase wires. Note that Figure 2.10 illustrates an example of a three-phase inline tangent structure that is carrying a neutral 2.0 meters below the cross-arm [5].

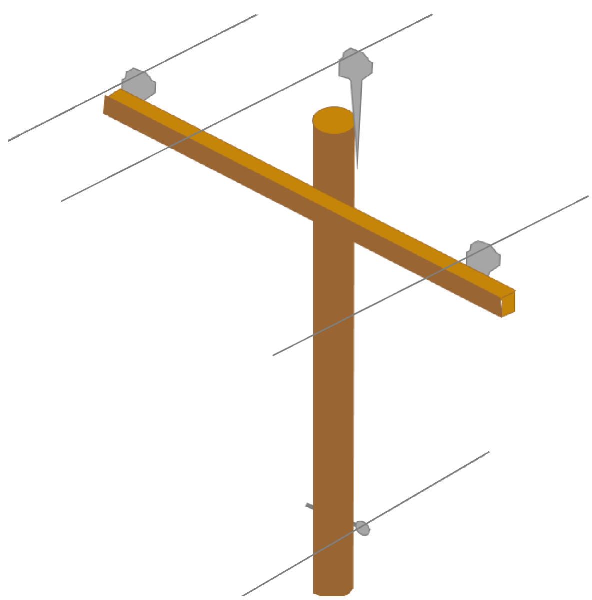


Figure 2.10: Three Phase Inline Tangent Structure with Overhead Neutral Wire.

Ground Rod

Ground rods are installed at a variety of DOP structures and are used to bring the electrical potential of pole equipment, pole attachments or the neutral wire to the ground's potential. The DFO's ground rods are composed of at least two bare metallic 1.8m long rods coupled together and pounded into the ground usually in very close proximity to the pole structure that it is associated with. Ground rods are then connected to a run of stranded copper conductor which typically runs up the powerline structure to a neutral wire, or to pole top equipment such as a transformer or riser. Alternatively, in some cases, the stranded copper wire may be terminated in open air near the top of the pole for the purposes of providing a safety ground for powerline technicians during future construction or maintenance activities. When multiple ground rods are installed in close proximity to each other, it is necessary for the ground rods to be kept a minimum distance apart from each other in the ground in order for the rods to provide optimal grounding. The optimal distance between ground rods is roughly equal to the height of the ground rods, which corresponds to about 4 meters [5].

Earth Return Grounding

The first of two practices for grounding DOP utilized by the DFO is earth return grounding [5]. Earth return grounding is typically only used in rural areas and it utilizes a grounding system where a continuous overhead neutral wire is not present. Instead, the entirety of unbalanced return current from load transformers served by the DOP returns to the source substation through the earth. The advantage of earth return grounding is primarily economic in nature as the lack of a neutral wire allows for shorter poles as ground clearances can be measured directly to the phase conductors.

Earth return grounding requires the installation of a minimum of two ground rods to ground each piece of electrical equipment such as overhead transformers or risers.

The two-ground rod requirement is typically satisfied in one of three ways without violating the 4m ground rod separation rule:

1. Provide a single ground rod at the equipment pole, run a neutral conductor one span away to the nearest utility pole structure, terminate the neutral wire at the nearby pole and install a second ground rod,

2. If pole contains a riser structure, make use of the concentric neutral of underground cable to provide a path to a second ground point at the other end of the underground cable segment,

3. Install two ground rods at a single pole structure.

Note that the third option to install two ground rods at a single structure is regarded as a last resort by the DFO due to the need to perform 4.0m of hand-trenching in order to maintain a 4.0m separation between ground rods. As a result, when installing equipment (other than riser poles) in earth return areas, it is most common for a neutral to be run a single span away to an adjacent pole. It is usually only when ground clearances impede the use of a neutral that the two-ground option is considered at a pole [5].

Note that Figure 2.11 illustrates an example of a single-phase DOP with two pole-mount transformers and earth return grounding.

Overhead Multi-Grounded Neutral

The second grounding practice for DOP that is employed by the DFO is to construct a Multi-Grounded Neutral (MGN) system. Unlike earth return grounding where the overhead neutral wire can only be found near equipment structures for short span segments, the MGN system makes use of an extensive network of overhead neutral wire that is grounded in many locations. An MGN overhead neutral wire must have at least five ground rods in different locations connected to it. Practically speaking, an

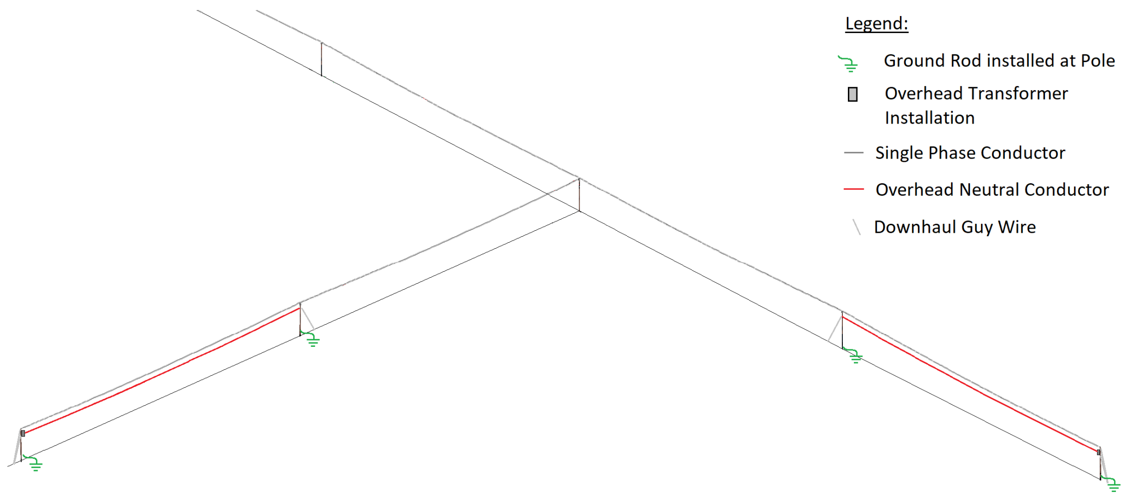


Figure 2.11: Sample of a Single-Phase Distribution Overhead Powerline with Earth Return Grounding
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MGN system may have hundreds if not thousands of interconnected grounds spanning urban areas or large rural networks. The main benefit of an MGN system over an earth return system is the significantly improved grounding capabilities made possible by having many grounding electrodes interconnected by conductor [5].

The DFO requires that any overhead MGN system have at least one ground rod installed every 400 to 500 meters. This separation roughly corresponds to a single ground rod being installed every four spans. Due to this requirement, in an MGN system, it is common to find ground rods installed at pole structures that only contain inline tangent structures and are a long distance away from any equipment structures [5].

Note that Figure 2.12 illustrates an example of single-phase DOP with two pole-mount transformers with an interconnected overhead neutral wire in an MGN system.

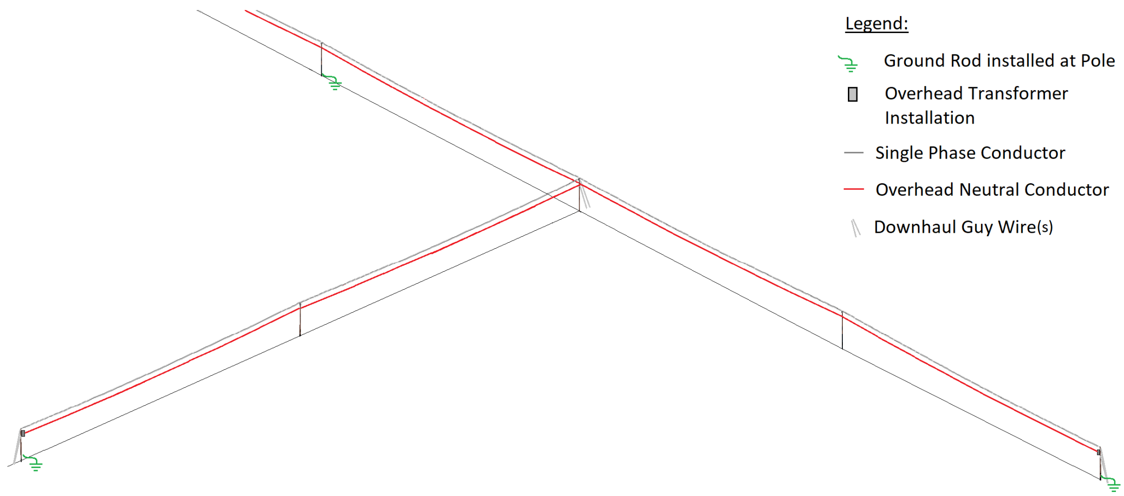

Figure 2.12: Sample of a Single-Phase Distribution Overhead Powerline with a Multi-Grounded Neutral System

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Chapter 3

Methodology of AutoDesigner

This chapter provides an in-depth analysis of the various working modules that comprise AutoDesigner. The intent of this chapter is to provide the reader with a high-level understanding of AutoDesigner's functionality. Note that discussion that specifically pertains to the PoleCheck2.0 constraint module is reserved for Chapter 4 due to the unique level of complexity in the module's implementation. That said, the analysis of the rest of AutoDesigner's functionality is discussed in this Chapter and discussion is divided based on the five sub-modules illustrated in Figure 1.1.

Note that AutoDesigner is implemented using Python version 3.6.4 within the Jupyter Notebook development environment using a personal laptop computer that is running a Windows 10 operating system.

3.1 Interpretation of Input Data from CSV File and from User Input

The first step in AutoDesigner's optimization process is to interpret the survey CSV file that is supplied by the user along with several data fields that the user must populate as input into AutoDesigner's user interface. Figure 3.1 illustrates the design interface which is implemented using Python's tkinter library.

The survey CSV file is a standard deliverable from the DFO's survey department and is primarily used for the purpose of GIS mapping. That being said, a properly

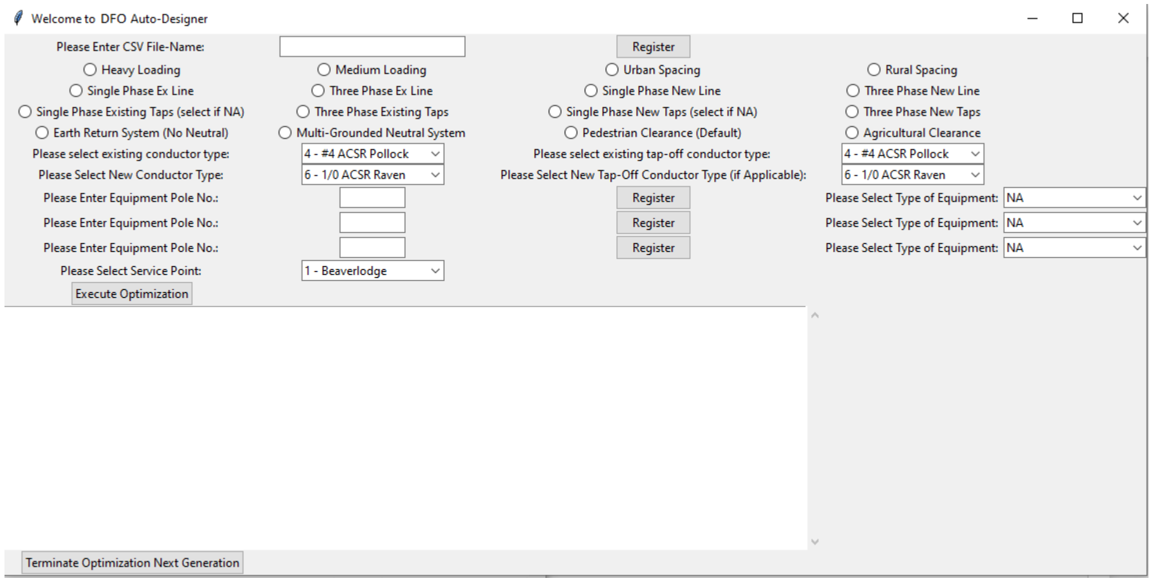
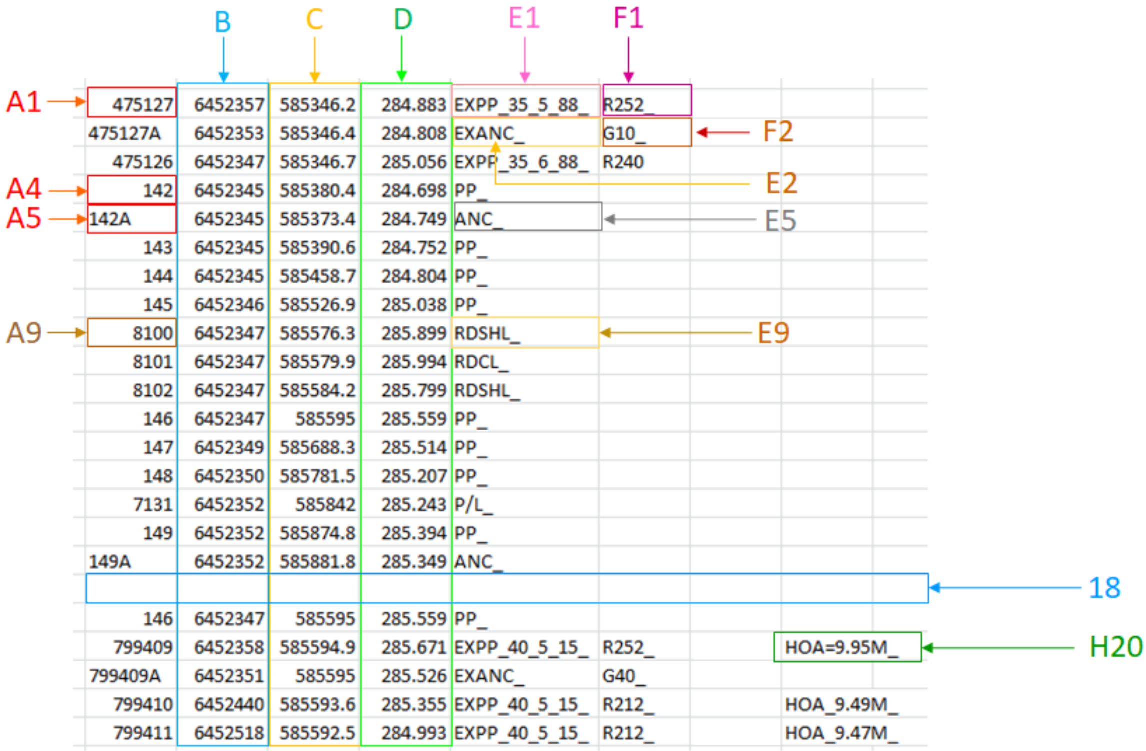


Figure 3.1: AutoDesigner Graphical User Interface.

populated survey CSV file conveniently happens to contain most of the necessary design data that is required by AutoDesigner for design optimization. Put simply, a survey CSV file is a list of survey data points where each row of the file represents a single location on the surface of the earth and contains the geographical coordinates of the location, the ground elevation, as well as additional identification information provided by surveyor. Figure 3.2 illustrates a short survey CSV file for a small DOP rebuild segment that is used throughout the chapter to illustrate the operation of the various components of AutoDesigner. Figure 3.3 illustrates the resulting design that is ultimately generated by AutoDesigner for which the CSV file is provided as initial input. Note that some of the content shown in Figure 3.3 such as the presence of slack spans or whether existing poles are to be upgraded or replaced cannot be determined before optimization. The purpose of presenting Figure 3.3 at such an early stage in the chapter is to illustrate to the reader a complete design in order to convey how the CSV file specifies the placement of new and existing poles, placement of anchors, as well as the conductor connections between each pole.

Figure 3.2 provides annotation for the distinct data-fields supplied in CSV file. The left-most column (referred herein as column A) provides identification labelling



475127	6452357	585346.2	284.883	EXPP_35_5_88_	R252_	
475127A	6452353	585346.4	284.808	EXANC_	G10_	
475126	6452347	585346.7	285.056	EXPP_35_6_88_	R240	
142	6452345	585380.4	284.698	PP_		
142A	6452345	585373.4	284.749	ANC_		
143	6452345	585390.6	284.752	PP_		
144	6452345	585458.7	284.804	PP_		
145	6452346	585526.9	285.038	PP_		
8100	6452347	585576.3	285.899	RDSHL_		
8101	6452347	585579.9	285.994	RDCL_		
8102	6452347	585584.2	285.799	RDSHL_		
146	6452347	585595	285.559	PP_		
147	6452349	585688.3	285.514	PP_		
148	6452350	585781.5	285.207	PP_		
7131	6452352	585842	285.243	P/L_		
149	6452352	585874.8	285.394	PP_		
149A	6452352	585881.8	285.349	ANC_		
146	6452347	585595	285.559	PP_		
799409	6452358	585594.9	285.671	EXPP_40_5_15_	R252_	HOA=9.95M_
799409A	6452351	585595	285.526	EXANC_	G40_	
799410	6452440	585593.6	285.355	EXPP_40_5_15_	R212_	HOA_9.49M_
799411	6452518	585592.5	284.993	EXPP_40_5_15_	R212_	HOA_9.47M_

Figure 3.2: Short Segment of a Survey CSV File for a DOP Design Rebuild.

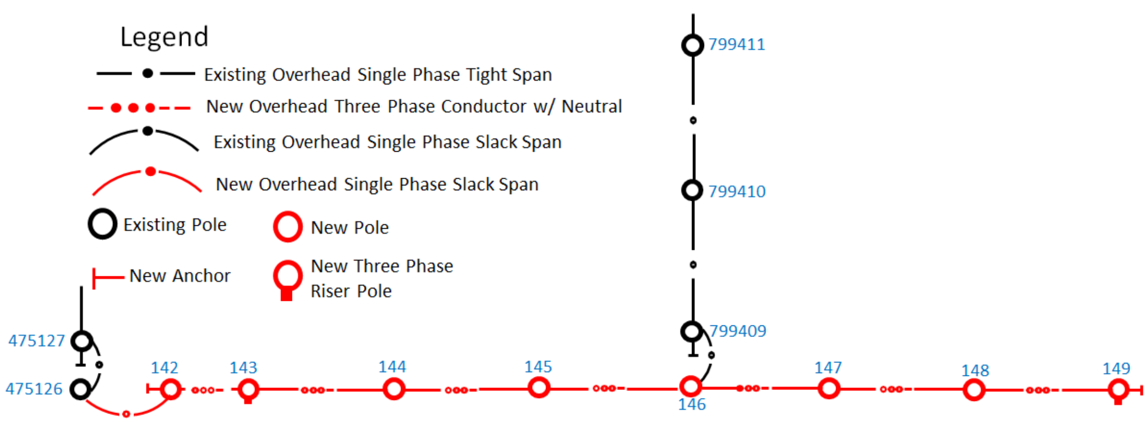


Figure 3.3: Illustration of Resulting Design from CSV File Segment.

for each survey location where each populated row represents a single location. Each survey location in a CSV file corresponds to one of the following location points on a DOP design:

1. Location of an existing pole,

2. Location of a new pole,

3. Location of an existing or proposed anchor,

4. A marker to represent a point of interest on a powerline crossing.

3.1.1 Identification Labels of Survey CSV File Data Points

AutoDesigner interprets which of the above categories each survey location in the CSV file belongs to by evaluating the identification string in column A. An identification string that can be interpreted as an integer with a value greater than 10,000 is recognized by AutoDesigner as representing an existing pole. Note that cell A1 in Figure 3.2 is an example of an existing pole and its six-digit numerical designation comprises the DFO's asset number that identifies the pole [5]. All asset numbers used by the DFO should contain at least six digits and so using 10,000 as the minimum criteria to classify a CSV row as being an existing pole is a sufficiently low threshold to avoid the misclassification of existing poles.

AutoDesigner classifies new pole locations on the basis of their CSV file survey locations having an identification string with a numerical value that is less than 500. The six-digit asset number of new poles is generally not assigned by the DFO until after commissioning of the DOP installation. As a result, it is normal convention for the first new pole on a DOP design to start with an identifier of 1, the second new pole to have an identifier of 2, etc... While it is possible for a DOP project to have more than 500 poles and thereby exceed the identification cut-off for new poles in AutoDesigner, such a project would represent approximately 50 km of new line which is uncommon. Furthermore, such a large project would need to be broken up into many smaller projects before being optimized by AutoDesigner as the software is only designed to handle up to 50 pole projects and so the re-numbering of new poles would need to occur once the new pole identifiers start to exceed 500.

Survey location identifiers that have numerical-valued strings between values of 500 and 10,000 are interpreted by AutoDesigner as being powerline crossing identifiers. These survey locations do not represent the locations of any DOP assets but, rather, signal a point of interest within a powerline crossing. The location usually represents a point along the crossing profile that the surveyors foresee to be the worst case in terms of crossing clearance and is either due to a particularly high ground elevation at the location or a point along the crossing where the powerline sag is expected to be most significant. As a number of different crossings categories exist (as discussed in Chapter 2), further analysis is required to properly classify the crossing beyond just its identification number.

Survey location identifiers can also be non-numerical data strings which specify down-haul guy wire anchor locations and are denoted with "A" or "B" characters at the end of the string. Anchor locations must be associated with a nearby pole structure and normal convention is for the anchor location identifier to contain the numerical identifier of its associated pole structure prior to the "A" or "B" identifier. Note that it is also preferred convention for each row of the CSV file that specifies an anchor location to come immediately after the parent pole structure on the CSV list, however, AutoDesigner solely relies on the former practice of identifying the parent pole with the numerical substring contained within its data identification field. Note that each pole structure may have up to two anchors locations associated with it where the first anchor location is identified with the "A" suffix and the second is identified with the "B" identifier.

3.1.2 CSV Survey Data Point Location Information

Each row of the CSV file that specifies a survey location contains location information that is determined in the field by surveyors. As shown in Figure 3.2, Columns B and C of the CSV file specifies the UTM Zone 11 or Zone 12 coordinates of the survey location. Columns B and C specify the northing and easting coordinates of each survey location in meters as per UTM standards [9]. Column D of the survey CSV file represents the ground elevation at the survey location in meters with respect to sea level.

3.1.3 Existing Pole Characteristics and Attachment Fields

Columns E, F and H of the survey CSV file, as shown in Figure 3.2, are additional information fields that vary based on the category of the survey location represented by the CSV row. This subsection specifically deals with the contents of columns E, F and H when the survey location is referring to an existing pole. When the survey CSV location is specifying an existing pole, columns E typically contains information on the pole's class, height and year of installation as shown in cell E1 in Figure 3.2. Column F typically contains information on the pole's structure attachments as shown in cell F1 of Figure 3.2. Column H contains field measured information on the existing pole's structure attachment heights in meters which may be different then the design specified heights of new structures due to existing structures being built to old standards, the settlement or heaving of the ground around the pole causing different set-depths than originally designed, or field installation errors. In the case of three phase structure attachments, column H typically provides measured height of the cross-arms on the pole (denoted by HOA or HOX) while for single phase structure attachments survey provides the measured height of the conductor attachment on the pole (usually denoted by HOC).

Existing Pole-Top Structure Information

When the row of a CSV file is referring to an existing pole structure, cell E of the CSV row contains a string that provides information regarding the structure attachments at the top of the pole. AutoDesigner seeks to accurately interpret the data string and convert it into a series of physical parameters to represent the pole top structure. Physical parameters include factors such as attachment heights of conductor with respect to the top of the pole, the presence of pole-top equipment, the continuity of conductor tension, etc. In order to obtain the necessary physical parameters, AutoDesigner must first associate the existing pole structure with a valid structure pattern that is contained within the structure parameter list. Note that the structure parameter list is discussed in greater detail in the next subsection and contains detailed physical parameters for over 400 different structure patterns. Note that when a structure pattern containing multiple compatible units are present on an existing pole, proper convention for the string contained in cell E is for each structure attachment compatible unit to be separated with an underscore character. For example, in the case of cell F1 in Figure 3.2, a single phase dead-end carry-on attachment is present at the top of the pole (R252). On the other hand, a more complicated structure pattern may take the following form in the Eth cell: "N52_R0_G40A_G40A_". AutoDesigner extracts each individual structure compatible unit from the text string and attempts to identify the most suitable structure pattern from the structure parameter list by using a point-based scoring system. Points are awarded as shown in the below list where the weighting of the point system is determined empirically in order to reward, but not absolutely require, compatible units to appear in the same order on the CSV file as they appear in the structure parameter list:

1. After extracting individual compatible units from cell E of CSV row, scan through all possible structure patterns in structure parameter list. For each structure pattern:

(a) Begin by awarding a score of 0.0,

(b) If a compatible unit identified in the CSV file string correlates with the first compatible unit in the structure pattern from the structure parameter list, award a score of 0.5 to the structure pattern,

(c) If the first compatible unit in the structure parameter list structure pattern also happens to be the first compatible unit that appears in the CSV file string, then award an additional 0.15 to the score to the structure pattern,

(d) If a compatible unit identified in the CSV file string matches with the second compatible unit in the structure pattern from the structure parameter list, award a score of 0.2 to the structure pattern,

(e) If the second compatible unit on the structure parameter list structure pattern also happens to be the second compatible unit that appears in the CSV file string, then add an additional 0.15 award to the score to the structure pattern,

(f) Repeat for third and fourth compatible units in the structure pattern and award subsequently reduced reward levels,

(g) Apply a 0.001 penalty factor for structure patterns that contain additional compatible that are not contained in the CSV file string,

2. After generating a reward value for each structure pattern in the structure parameter list, select the structure pattern with the highest reward total.

Note that cell E of the survey CSV file should always be populated for rows that reference existing pole structures. If a cell is found to be empty for an existing pole structure, AutoDesigner will attempt a best guess at the type of structure pattern that may be present on the pole based on the input data provided in the user interface window shown in Figure 3.2. That being said, AutoDesigner's accuracy may be severely impaired without having accurate structure attachment information for existing poles and this functionality should not be relied on for DOP designs that require authentication. It is, therefore, strongly recommended that the designer ensures that all existing pole CSV rows have valid structure attachment data and that the designer populates any missing data before running AutoDesigner on the CSV file.

Height of Attachment and Height of Conductor Data

Cell H20 in Figure 3.2 illustrates a sample string which contains a height of attachment value of 9.95m. Note that the HOA string may contain more than one height value which typically occurs on poles with combination structure patterns such as an inline tangent pole with a tap-off structure. Typically, the largest HOA value corresponds to the attachment height of the top attachment and the lower value corresponds to the height of the second attachment, etc. In some cases, the surveyor may neglect to include all attachment height values present on poles that have multiple attachments which leaves AutoDesigner with the need to perform a best-guess analysis to determine which height value corresponds to which attachment as well as to accurately extrapolate the missing value. AutoDesigner follows the rule-set laid out below when mapping HOA or HOC values to attachment heights on pole structures:

1. Apply design attachment heights to pole structure attachments by extracting values from structure parameter list for a structure pattern that most closely resembles the list of structure attachments supplied in column E of the CSV file,

2. If the CSV file row has no HOA or HOC data available, then terminate the process. Otherwise,

    - If at least one HOA or HOC value is available, apply it to the top attachment point (if three phases, treat as HOA) or the top conductor height (if single phase treat as HOC). All other attachment and conductor heights are to be shifted by the difference between the supplied HOA or HOC value and the attachment height initially assumed from design standards.

- If precisely two HOA or HOC values are available,
  - Check to see if existing pole-top structure pattern includes an overhead neutral wire. If so, then assume that second HOC value refers to neutral attachment height. Apply second HOC to neutral and shift any pole tap-offs by the difference that exists between the higher design attachment height and the supplied HOC value of the top attachment.
  - If pole does not contain a neutral wire, then apply second HOC value to any tap-offs that may exist
- If precisely three HOA or HOC values are available,
  - Always assign the smallest HOA or HOC value to the overhead neutral wire if it exists and the largest HOC value to the top attachment or conductor.
  - If no overhead neutral wire is present on pole, assign the smallest value to the tap-off conductor heights and do not utilize the middle HOA or HOC value

Note that it can be seen in Figure 3.2 for other existing pole rows that column H is not always populated. While AutoDesigner is capable of handling the lack of HOC or HOA data and will refer to the structure parameter list, which is discussed in depth in the next section, to obtain and use the designed structure attachment heights, these design heights must be treated as approximate information. It is not recommended that the design engineer authenticate designs from AutoDesigner whose CSV files contain missing HOC or HOA data without additional design review. Without HOA or HOC data, AutoDesigner is not able to accurately check conductor clearance and uplift considerations which are discussed later in the chapter.

3.1.4 Existing Guy Wire Types

Note that compatible unit references for existing guy wire types may be contained either cell E of the anchor CSV data row or cell E of the parent structure's CSV row. AutoDesigner looks in both locations for guy wire information. An example of an anchor CSV row that contains a description of the existing guy wire compatible unit is shown in cell E5 in Figure 3.2. AutoDesigner looks in cell E of the anchor CSV data row to see if the "EXANC" or "ANC" string is present when the parent structure is determined to be an existing pole. The "EXANC" string labelling a guy wire that is associated with an existing pole indicates that both the pole and the guy wire is existing, while an "ANC" identifier indicates that the pole is existing, but the guy wire is being installed as part of the new DOP design. Note that anchors that are associated with any new poles are assumed to be new anchors even if the anchor location is being re-used from a previously salvaged pole. In the case of encountering the "EXANC" string in the anchor's Eth cell, AutoDesigner assigns the type of guy wire compatible unit that is specified in the CSV file. If no existing guy wire compatible unit is supplied or if the compatible unit is not recognizable, AutoDesigner performs a best guess of the anchor type based on the number of phases and whether or not an overhead neutral wire is present. Note that all new guy wire types are determined during evaluation of the PoleCheck constraint module that is discussed later in the Chapter.

3.1.5 CSV Crossing Type Identification

In the case of CSV rows that identify powerline crossing locations, column E identifies the type of crossing as shown in cell E9 of Figure 3.2. The type of crossing is denoted with an abbreviation. Table 2.4 contains, in the first column of the table, the abbreviations that correspond to the various crossing types that AutoDesigner is capable of recognizing.

3.1.6 CSV File Identification Tap-Off Structures

CSV files denote tap-off structures with a blank row as shown in row 18 of Figure 3.2 followed by a reprint of the CSV row representing the pole structure that is being tapped off of. A tap-off is, by definition, a powerline structure that has both incoming and outgoing mainline spans but with at least one additional new circuit that also originates at the pole. Normally, tap-offs are attached lower down the pole than the incoming and outgoing powerline and are often oriented nearly perpendicular to the incoming and outgoing line. A representation of a tap-off pole can be seen with pole 146 illustrated in Figure 3.3. For a pictorial representation of a tap-off structure, refer to the second structure from the bottom right in Figure 2.4.

3.1.7 User-Interface Input Data Fields

Despite providing much of the required information that is needed to optimize a DOP design, some additional information is required by AutoDesigner that is not present within the CSV file. The additional information is accepted through AutoDesigner's user interface which is illustrated in Figure 3.2. Table A.1 in Appendix A lists the complete set of user input fields that are present in the user interface as well as the acceptable ranges of input values that AutoDesigner accepts from the user for each field.

3.2 Construction of Linked List Data Structure and Finalization of Non-Optimizable Design Characteristics

Once the Survey CSV data file and initial input from the user is successfully gathered and interpreted by AutoDesigner, a significant portion of the design is capable of being finalized using rule-based analysis prior to initiating the optimization process. The physical orientation between the poles, the span lengths, and the complete set of details of the existing powerline structures as well as the presence of crossings under spans list must all be determined and modelled within AutoDesigner prior to setting up the chromosome that is used by the genetic algorithm. Essentially, AutoDesigner ensures that by the time the genetic algorithm is initiated, the overall design is fully presentable with only the optimizable design characteristics left as unknowns. In this pre-optimization stage, two important lookup tables are utilized which include the structure parameter list and the neutral structure parameter list. Both lists are discussed in the section.

3.2.1 Linked List Data Structure

After reading in data from the survey CSV file, it is essential that AutoDesigner stores information pertaining to the various poles and spans that comprise a DOP design in an efficient manner that can allow for rapid data access during the optimization process. Furthermore, it is desirable for any data structure used to store DOP design parameters to be able to compliment the physical reality of the DOP in order to allow for easy debugging and identification of errors.

As discussed in Chapter 2 and illustrated in Figure 3.3, DOP is composed of sequential poles that are connected by spans of conductor. Most pole structures have a single incoming span and a single outgoing span; however, some poles may have one or even two additional outgoing tap-off spans. Each pole and span possess numerous design parameters, some of which can be determined without the use of optimization while certain characteristics can only be determined as part of an optimization procedure. Using a linked list that is composed of alternating Pole and Span objects allows for a concise means to store all of the design parameters associated with a DOP design. The linked list data structure compliments the physical layout of the DOP while also providing a means to directly access any tap-off circuits without the need for a searching algorithm. The linked list is traversed by accessing Pole objects and then shifting the reference to the stored Span reference to move to an adjacent span. The Span object then contains a reference to another Pole object which can be accessed through a reference, and so on. The linked list data structure used in AutoDesigner is doubly-linked which allows for both forward and reverse traversal of the DOP design data. Each Pole object must be able to contain references for up to four span objects while each span object need only contain references for two pole objects. Accessing mainline pole and span objects as well as exploring the pole and span objects contained in any tap-off circuits which, themselves, may have additional tap-off circuits is accomplished using a recursive traversal routine with back-tracking capabilities that operates in a similar manner to an elementary maze exploration algorithm [10].

Figure 3.4 illustrates an example of the linked list structure that is constructed for a portion of the DOP design shown in Figure 3.3. Note that Tables A.2 and A.3 in Appendix A tabulates a complete list of attributes and methods contained in the Pole class including brief descriptions. Similarly, Tables A.4 and A.5 contain a complete list of attributes and methods contained in the Span class.

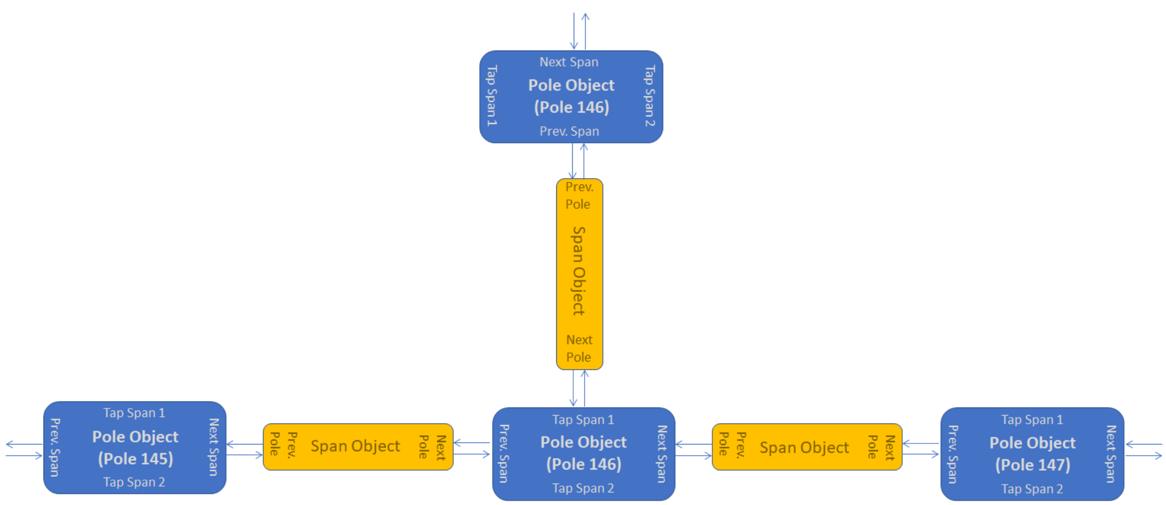


Figure 3.4: Illustration of Linked List Data Structure with Pole and Span Objects.

3.2.2 Classifying Existing Slack Spans

Upon inspecting the survey CSV file sample illustrated in Figure 3.2, it is evident that there is no standardized means to indicate whether existing short spans have tensions that are slack or tight. Note that the distinction between slack spans and tight spans are discussed in Chapter 2. While AutoDesigner could be altered to include additional input fields for the user to specify which existing spans are slack or tight, it is felt that this information can be determined with an acceptable degree of accuracy using rule-based analysis. The decision as to whether or not to classify an existing short span as being slack or tight can be made in most cases by looking for the presence of an anchor, or lack thereof, on the previous or subsequent poles that are supporting the span. Note that it is assumed that anchor information on the survey CSV file is complete and accurate. In the case of a slack span that is a part of a continuous mainline, an anchor should exist that is oriented to support the tight spans that come before and/or after the slack span. A particular exception to this rule occurs when there are two consecutive existing slack spans in a series in which case the nearest anchor may be several poles away. Additionally, if a slack-span is a tap-off span, then the lack of an anchor on the tap-off pole is often a reliable means to verify that it is a slack-span. That said, it may occur in rare cases that an existing pole has two existing tap-off spans that are potential slack spans that are oriented on opposite sides of the pole. In this case, it may be impossible to determine with complete certainty if the short span tapping off the pole is a slack or non-slack. In this case, a best-guess is applied to the slack or tight classification of the span and the user is given the ability to modify the span classification in the preliminary staking list which is discussed later in the section. Note that there is no need to classify new short spans as slack or tight in the pre-optimization stage since this design parameter is determined by the genetic algorithm during optimization and is discussed later in the chapter.

3.2.3 Classifying Spans as New or Existing

Whether a span is new or existing is also not directly indicated in the survey CSV file. While the classification may seem intuitive in the majority of cases, significant complexity exists in determining the new or existing classification of a span that is attached to both new and existing pole structures. This especially challenging on re-build projects where new powerline is tied into numerous existing feeders as shown in Figure 2.3. For example, in what case should existing tap-off conductor be re-strung back to the new tap-off pole and in what cases should the tap-off span be completely replaced with new conductor? The following list outlines the rule-based analysis used to determine the classification of a given span as new or existing:

If, both the previous pole and the next pole are existing poles,

  Then, classify the current span as existing.

If, both the previous pole and the next pole are new poles,

  If, poles and spans both immediately before and after the current new span and poles are existing (indicates an island of two new poles in an otherwise existing alignment),

  Then, classify the span between the two poles as existing,

  Else, classify the span between the two poles as new.

If, the previous pole is existing and the next pole is new,

  If, the previous pole is not a tap-off pole and has a pole-top structure that does not break the tension of the current span (e.g. an inline tangent structure),

    If, the previous span before the previous pole is also an existing pole,

    Then, classify the span as existing.

    Else, classify the span as new (indicates a new span that is extending an existing mainline).

  Else, classify the span as new.

If, the previous pole is new and the next pole is an existing pole and the current span is a tap-off,

If, the next span after the next pole is also an existing pole,

If, the structure attachment on the next pole indicates that the incoming main-span does not currently exist (indicates a rebuild tap-off span that needs to be reconnected to the mainline using a new span of conductor),

Then, classify the span as new.

Else, classify the span as existing. (indicates a rebuild tap-off span that is reconnected to the mainline using the existing conductor span),

If, the previous pole is new and the next pole is an existing pole and the current span is not a tap-off,

If, the pole one span before the previous pole is an existing pole,

Then, classify the span as existing (previous pole must be a new pole installed along an existing mainline, e.g. tap-off pole),

If, next pole has a pole-top structure that does not break the tension of the current span (e.g. an inline tangent structure),

Then, classify the span as new,

Else, classify the span as existing,

3.2.4 The Structure Parameter List

The structure parameter list is a lookup table that contains the complete list of pole top structure combinations, also known as structure patterns, that AutoDesigner is capable of considering. The list serves as a repository of the DFO's DOP standards library for use by AutoDesigner. For each structure pattern, the list provides complete structural dimensions and constraints that need to be adhered to in order to properly comply with DFO standard practices and to model the pole's physical construction. Table A.6 in the appendix lists the complete set of data-fields that the structure parameter list contains for each structure pattern along with descriptions of each field. The structure parameter list contains over 400 individual rows where each row represents an acceptable combination of compatible units that may be installed on a pole. It is important to note that while the structure parameter list is used prior to optimization in the determination of existing pole structure patterns, it is also heavily utilized during the optimization process as discussed later in the chapter. It can be seen that many of the values contained in Table A.6 are very similar in description and function to Pole Attributes discussed in Table A.2 as the structure parameter list serves as the main repository of information for populating each pole's structural information and constraints.

The first column of the structure parameter list is labelled strPattern and lists the base set of compatible units that are present on the pole for each row. Each individual compatible unit within the strPattern cell is separated by a comma character in the structure pattern data string. In some cases, additional compatible units are required to be added to the string in the strPattern cell later in the design process such as the case with poles that contain equipment grounds, when neutral structures are present on the pole or when downhaul guy wires are present on the pole. In the case of equipment grounds, the precise number of ground rods installed at each pole for new construction is an indirectly optimizable parameter that AutoDesigner determines during optimization. As a result, it does not make sense to specify the grounding-related compatible units explicitly on the structure parameter list (neutral continuity is discussed further in section 3.5). Instead, the structure parameter list contains a column that is labelled numGndPoints which specifies the number of interconnected ground rods that are required to be electrically connected to any pole structure that utilizes the structure pattern being specified. In the case of neutral attachments installed on the pole, the DFO's unique identification practices between its three phase and single-phase standards library requires a patchwork approach towards specifying neutral structure attachments. In the case of a single-phase structure where the neutral wire maintains the same continuity as that of the pole top compatible unit, the neutral structure information is completely contained within the single-phase compatible unit structure for the corresponding top phase attachments. That said, if the pole top structure overhanging the neutral wire is a three-phase structure or if it is a single-phase structure with incoming and outgoing phase conductor spans but where the neutral only exists for one of the two spans, then neutral compatible units must be specified separate from the pole top compatible units. For structures where separate neutral compatible units are required, the string "neut" is appended to the end of the strPattern text string within the structure parameter list. The "neut" label removes the need for the structure parameter list to cover all possible combinations of neutral attachments on a given structure pattern. Furthermore, the selection of neutral attachments represents a very simple optimization activity and opportunity for cost savings exists if neutral structures can be determined as a separate sub process that occurs during optimization. Examples of when separate neutral attachments are required are depicted in Table 3.1. Finally, downhaul guy wires are determined separate from the structure parameter list either in the survey CSV file for existing construction or as an optimizable parameter within the poleCheck2.0 constraint module for new construction and does not require specification on the structure parameter list.

StrParamList StrPattern Cell Contents	Final Structure Pattern After Optimization	Description
R112	R112	Single phase inline tangent structure with an incoming and outgoing overhead neutral wire.

R212,Neut	R212,R0,G40AF	Single phase inline tangent structure with a neutral that terminates at the pole structure and requires a downhaul guy wire to anchor the neutral termination.
N12,Neut	N12,N0C	Three phase inline tangent structure with a neutral inline tangent structure (note that the requirement for an N0C versus an R0 for a new pole structure in AutoDesigner can only be determined by looking for the presence of a neutral attachment on the adjacent poles).

Table 3.1: Samples of Structure Patterns that Contain Overhead Neutral Wire Attachments.

Note that the details of the available neutral attachment structures are contained in the neutral structure parameter list which is discussed in the next subsection.

3.2.5 The Neutral Structure Parameter List

The neutral structure parameter list serves a very similar function to that of the structure parameter list, however, it strictly pertains to neutral attachment components where the neutral attachment is not already being specified by a single-phase compatible unit on the pole. The neutral structure parameter list is comparatively small with respect to the structure parameter list and only contains 26 rows and 30 columns. The columns of the neutral structure parameter list are specified in Table A.7 in the appendix. Each row of the neutral structure parameter list represents a possible combination of acceptable neutral attachment structures that may be present on a pole. Figure 3.5 lists a sample of potential neutral structure patterns contained on the neutral structure parameter list.

Note that when separate neutral structure patterns are required from that of the pole-top conductor, AutoDesigner selects a valid neutral structure pattern from the neutral structure parameter list using a cost minimization function that is separate

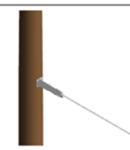
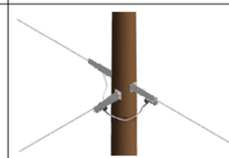
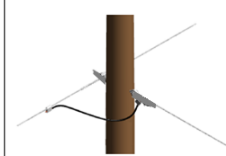
StrPattern Sample from Neutral Structure Parameter List	Description	Illustration
R0	Neutral dead-end structure which may be installed on the incoming or outgoing main-line, the first tap-span or the second tap-span.	
R0,R0,R0	Three-way neutral dead-end structure. Neutral terminations will be present on all but one of the incoming or outgoing main-line or the first or second tap-span.	
N0C,R0	Alternate three-way neutral structure containing an inline tangent neutral structure (N0C) and a neutral termination structure (R0). Normally, the inline tangent neutral structure is installed for incoming and outgoing main-line neutral line while the R0 is installed for the neutral of a tap-off structure.	

Figure 3.5: Samples of Neutral Structure Patterns Contained in the Neutral Structure Parameter List. [5]

from the main optimization algorithm. The cost minimization operates by identifying the subset of available neutral structure patterns that satisfy the requirements of the neutral attachments required at the pole. Next, the strCost, constHours and punishmentFactor cells of each of the candidates are converted into a total neutral structure pattern cost in dollars, where the candidate with the lowest overall cost is selected as the neutral structure.

3.2.6 The Preliminary Staking List

The preliminary staking list is the first output generated by AutoDesigner and is the only output that is made available to the user prior to the optimization process. The intention of the preliminary staking list is to provide the user with the ability to view, before optimization, the portion of the DOP design that is finalized using rule-based analysis. In addition, the preliminary staking list also enables the user to have access to a selection of advanced optimization features within AutoDesigner that are not available from the user interface window. Figure 3.6 illustrates a portion of the preliminary staking list that is generated for the segment of DOP shown in

Figure 3.3.

ELEV (m)	STR. NO.	ASSET ID	DEFLN	SPAN (m)	HEIGHT/Cl	TYPE
4 x 1/0 ACSR Raven OVERHEAD - MEDIUM						
285.39	475119	475119	L 084°31'		0/0	Ex. Pole: 35/6,R240
				29.61		*Potential Slack-Span
285.0	150		L 002°28'		*/*	,*
				32.66		*Potential Slack-Span
284.83	151		L 000°02'		*/*	,*
				106.50		
284.53	152		R 000°01'		*/*	,*
				106.49		
284.33	153		L 000°00'		*/*	,*
				106.49		
284.20	154		L 000°00'		*/*	,*
				106.49		As-Built P/L ___ m at ___ °C 70 m from STR#154
283.77	155		R 000°00'		*/*	,*
				106.70		
284.25	156		L 000°00'		*/*	,*
				99.00		As-Built RD ___ m at ___ °C 7 m from STR#156 As-Built RD ___ m at ___ °C 9 m from STR#156 As-Built RD ___ m at ___ °C 12 m from STR#156
284.14	157		R 000°00'		*/*	,*
				99.01		
284.18	158		L 000°00'		*/*	,*
				99.00		
283.93	159		R 000°00'		*/*	,*
				98.99		
283.76	160		R 000°00'		*/*	,*
				99.00		
283.60	161		L 000°00'		*/*	,*
				99.01		
283.58	162		R 000°00'		*/*	,*
2 x #4 ACSR Pollock OVERHEAD - MEDIUM						
284.25	156		L 106°07'		0/0	Material Already Called For
				9.89		Slack-Span
284.25	475109	475109	R 016°09'		0/0	Ex. Pole: 35/6,R212, R0,E12,G10

Figure 3.6: Illustration of a Portion of a Preliminary Staking List.

Note that the preliminary staking list uses a format and layout that is very similar to the design staking lists that are used by the DFO. The staking list is one of the primary design documents that the DFO issues to its construction crews for DOP new extensions and rebuilds. The beginning of each conductor segment in the staking list is annotated with a title row that indicates the number of conductors that each structure carries, the size of each conductor, the ACSR conductor name as well as the loading condition of the line for the segment. Title rows printed in red indicate that the DOP segment is a new proposed installation, while a black row indicates that the conductor segment already exists. A new title row is printed every time one of the design parameters listed in the title box changes. Every second row starting with the row that is immediately below the title row contains a numerical value listed in the Str. No. column and corresponds to a pole structure where red represents new and black represents existing poles. The pole structure row also lists details that are extracted or calculated from the survey CSV file such as ground elevation, span deflection angle and direction, the height and class of existing poles, as well as any existing pole-top compatible units. Each pole structure row is partitioned by a span row that lists the length of the span that is strung between the adjacent poles, whether the span is a slack span or a potential slack span in the case of new construction (the word "potential" indicates that the parameter has not yet been optimized), as well as the location of any surveyed crossing locations that are present underneath the span. Similar to the survey CSV file, tap-off span segments contain a reprinted row indicating the tap-off pole structure that the tap-off segment originates at.

In addition to the columns shown in Figure 3.6, additional columns are present to the right of the table that list the states of many of the relevant attributes for the Pole and Span objects that are not listed in the main body of the staking list. A small sample of the columns that are listed to the right of the table illustrated in Figure 3.6 are shown in Figure 3.7. For a complete list of Pole and Span object attributes, please refer to Tables A.2 and A.4 in Appendix A.

strPatternEx/isTightSpan	strPatternNew/isExistingSpan	neutStrPatternEx/numPhases	neutStrPatternNew/hasNeutral	topToCond1/condType	topToCond2/heavyLoading
R240	*			0.1	
*	0	3	1	6	0
	*		*	*	*
*	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
1	0	3	1	6	0
	*		*	*	*
0	1	1	1	4	0
R212,Neut		R0		0.23210000000000092	

Figure 3.7: Illustration of a Portion of the Additional Spreadsheet Columns Located to the Right of the Preliminary Staking List.

It can be seen that figures 3.6 and 3.7 also contains a large number of purple ’*’ characters in various cells of the staking list. The ’*’ character represents a design attribute that is not currently known but is to be determined during the optimization process. In the case of advanced users, asterisk values in the columns located to the right of the main staking list body may be replaced with the constraint operators listed in Table 3.2.

Constraint Operator	Operator Description
_in_	Used to constrain text string design parameters. Operator imposes a requirement on the optimization process to only consider design parameters that result in text strings that contain the character sequence that comes immediately after the operator.
_ex_	Used to constrain text string design parameters. Operator imposes a requirement on the optimization process to only consider design parameters that result in text strings that do not contain the character sequence that comes immediately after the operator.
_em_	Used to constrain text string design parameters. Operator imposes a requirement on the optimization process to only consider design parameters that result in empty text strings.
_==_	Used to constrain numerical design parameters. Operator imposes a requirement on the optimization process to only consider design parameters that result in values that are equal to the numerical value that comes immediately after the operator.
_⟨=_	Used to constrain numerical design parameters. Operator imposes a requirement on the optimization process to only consider design parameters that result in values that are greater than or equal to the numerical value that comes immediately after the operator.
_⟩_	Used to constrain numerical design parameters. Operator imposes a requirement on the optimization process to only consider design parameters that result in values that are less than the numerical value that comes immediately after the operator.

Table 3.2: Table of Constraint Operators for Use in the Preliminary Staking List.

By replacing the asterisks in the columns located to the right of the main staking list body, the design parameter that the cell is representing will be constrained during the optimization process to follow the behavior of the constraint operator. Note that each constraint operator (except for_em_) requires one or more characters to be entered immediately after the operator. In the case of the numerical constraint operators described in Table 3.2, the characters that come immediately after the operators must represent either an integer or a floating-point number. An example of a constraint operation to require that the optimization scheme selects a 45-foot pole at a particular structure would involve typing "_==_45" into the appropriate cell of the poleHeight column to the right of the main staking list body. Similarly, if the user wished to constrain a particular pole location to use the N12 three phase inline tangent structure, the user would enter "_in_N12" into the correct pole row of the strPatternNew/isExistingSpan column.

Note that after producing the preliminary staking list, AutoDesigner reads the updated data and stores any of the constraint operations inputted by the user as text strings in the Pole and Span attributes of the linked list.

3.3 Optimization using Genetic Algorithm with State Space Reduction of Design Parameters and Memory

After generating and re-interpreting the preliminary staking list, AutoDesigner prepares the DOP design for the implementation of the genetic algorithm. The efficient operation of the genetic algorithm is crucial in achieving the third objective of the thesis statement which requires AutoDesigner to maintain a reasonably short optimization time for large projects. In order to optimize DOP designs in an expedient manner, AutoDesigner makes use of both a method that reduces the state space of design parameters prior to optimization as well as a sparse memory look-up table that is used during optimization for storing the past outputs of constraint modules that are needed for evaluating the fitness function. AutoDesigner adapts a DOP design to conform to the genetic algorithm by creating a chromosome and then mapping each optimizable design parameter in the DOP to an individual gene within the genetic algorithm chromosome. Each gene within the chromosome is then manipulated by the genetic algorithm which then alters the state of the individual design parameters within the DOP linked list that are mapped to the chromosome allowing for a gradual convergence towards a decent local minimum using evolutionary principles.

3.3.1 State Space Reduction of Design Parameters

Before the genetic algorithm can be applied it is necessary to reduce the state-space of the unknown design parameters down to a size that is manageable in order to allow for an improved optimization time. For example, Table 3.3 lists the unknown design parameters that are common to each pole and span in a DOP design that must be optimized by the genetic algorithm. the second column of Table 3.3 lists the number of potential selections of design parameters within each Pole and Span object that may be adopted during optimization without any filtering of non-applicable states.

Pole Object		
Design Parameter Description	Number of Combinations Prior to Filtering	Number of Combinations After Filtering
Pole Height	5	5
Pole Class	5	5
Pole Deep-Set	4	4
Structure Pattern	400	8
Total	40,000	800
Span Object		

Design Parameter Description	Number of Combinations Prior to Filtering	Number of Combinations After Filtering
Slack Span/Tight Span	2	1
Total	2	

Table 3.3: Table of Possible States of Design Parameters for a New Pole and Span Object Before and After Elimination of Non-Compliant Candidates. Post Filtering Column Assumes a New Three Phase 40 ft. Pole Installed in an Alignment with No Deflections or Tap-Offs and a Span Length that is Greater than 35m.

For example, on a project that calls for 50 new poles and 50 new spans, it is obvious that the initial state space of design variables shown in the second column of Table 3.3 is immensely large and would prove to be well beyond optimization capabilities of a personal desktop computer, especially within the 1 hour timeframe target set out in the third objective of the thesis statement. As a result, in order to substantially reduce the state space and improve the computation time, all design parameter selections that can be established as being uniformly non-valid regardless of the design decisions that are made for other components are removed from the state space prior to beginning the optimization process. As can be seen from the third column of Table 3.3, for a new three phase 40 ft. pole that is installed in an alignment with no deflections or tap-offs, the number of potential combinations for the pole's design parameters can be reduced by a factor of 50. Furthermore, any span that has a length greater than 35m can be established to always be a tight span regardless of the design decisions made during optimization, thereby reducing the state space of the span by half. The reduction of the state space of design parameters at individual pole and spans provides for a multiplicative reduction in overall complexity of the DOP project which immeasurably improves the performance of the genetic algorithm for larger DOP designs.

It can be seen in the third column of Table 3.3 that the reduction in design parameter state space is in large part achieved by reducing the number of potential structure patterns that the Pole object may assume during optimization. The list of available structure patterns that a pole may utilize is obtained from the structure parameter list which is discussed in the previous section. The structure parameter list contains over 400 different structure patterns and each structure pattern contains a number of constraints such as: minimum and maximum deflection angles for the mainline spans, the presence of tap-off spans, compatible conductor types for each spans, required number of phases for each span, heavy loading withstand capabilities, the presence of equipment on the pole, the presence of overhead neutral attachments for each span, etc. AutoDesigner creates a checklist of unchangeable physical constraints intrinsic to a particular pole location for each optimizable pole in the DOP design that can be compared directly against the fields in the structure parameter list. Then, AutoDesigner applies the checklist to the total list of structure patterns that are present on the structure parameter list and retains only those structure patterns that pass all of the requirements on the checklist. Using this method, the vast majority of available structure patterns can be established as being non-applicable to the pole location and can be struck from the list of states that the genetic algorithm must search during optimization.

3.3.2 Formulation of the Genetic Algorithm Chromosome

In order for the genetic algorithm to be able to perform the optimization of a DOP design, the complete set of undetermined DOP design parameters must be mapped to a chromosome. Each gene within the genetic algorithm chromosome is composed of an integer value that ranges from 0 to 99. Each gene maps to a particular design parameter in the DOP design that requires optimization. Figure 3.8 illustrates a small segment of the mapping from the DOP design illustrated in Figure 3.3. Note that structure 150 requires a transition from an incoming mainline with a single phase span to an outgoing mainline span with three phases, the span length between structures 150 and 151 is short enough such that span 150-151 may be a slack-span or a tight-span depending on the optimization process and, finally, structure 151 is a structure-type that commonly specifies an inline tangent three phase structure but may also utilize a dead-end carry structure which is normally only utilized if an uplift condition exists at the pole.

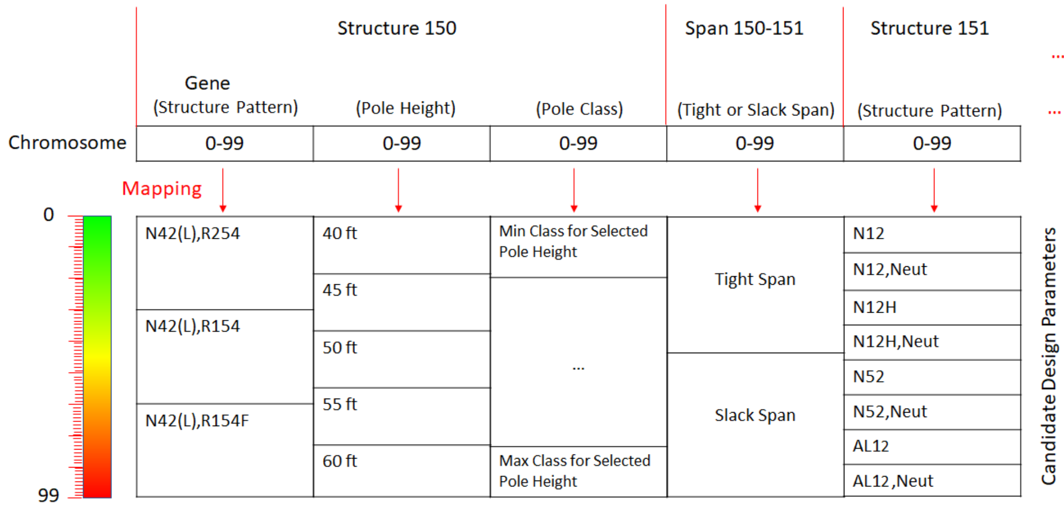


Figure 3.8: Illustration of Mapping Between Genetic Algorithm Chromosome and Design Parameters.

Note that what is not shown in Figure 3.3 is an example of an existing pole structure. Unlike with new pole structures where the structure pattern gene strictly maps to a list of new compatible structure patterns, with existing poles, the structure pattern gene maps to a list that contains three subsets that are denoted by the first three characters of the text string containing a "_1_', '_2_', or '_3_' value. Each subset is described below:

_1_ Do not salvage any pole components and only specify structure patterns that are valid tap-offs or new mainline extensions of the existing structure pattern that is currently installed. Ignore the subsequent three genes that specify a new pole height, pole class and set depth since the pole is not being altered in this scenario, _2_ Salvage the existing pole's structure attachments but do not salvage the pole, itself. In this case, the set of structure patterns that the gene may map to is identical to the case where a completely new pole is called for, however, the values of the subsequent three genes are ignored as the pole will remain unaltered.

_3_ Salvage the entire pole structure and all attachments and replace with a completely new pole. In this case, treat the existing pole structure as a completely new pole and consider pole height, pole class and set depth gene values.

3.3.3 Genetic Algorithm Implementation

The genetic algorithm is implemented in Python using the DEAP library and by adapting a sample implementation of the One Max genetic algorithm that is available on the DEAP tutorial page [11]. Note that the One Max implementation is inverted into a One Min configuration for use by AutoDesigner and the fitness function minimized during optimization is depicted in Equation 3.1.

$$F = DOP\,Design\,Total\,Material\,Cost\,+$$
$$(DOP\,Design\,Total\,Labour\,Hours) * (DFO\,Burdened\,Labour\,Hourly\,Rate) +$$
$$(Total\,No.\,of\,Constraint\,Violations) * (\$1,000,000) \qquad (3.1)$$

The parameters of the genetic algorithm implementation are listed in Table 3.4. Note that the population size, the cross-over rate and the mutation rate are determined as part of the hyper-parameter search discussed in Chapter 5. Note that an individual, as referred to in Table 3.1, refers to a chromosome that is encoded with a vector of integer values which can be mapped back to a complete DOP design as illustrated in Figure 3.8. When the chromosome is considered in conjunction with the preliminary DOP design, an individual refers to a specific and complete DOP design that may or may not contain constraint violations. Furthermore, a population of individuals represents the complete set of chromosomes that are created for a single generation of the genetic algorithm optimization.

Genetic Algorithm Parameter	Description	Value
Tournament Size	When determining pairs of mating parents for the creation of the next generation of individuals, randomly select the specified number of individuals from the current population and select the individual that is evaluated to have the lowest overall fitness function cost as the first parent. Repeat this process for the second parent.	3
Probability of Crossover	The probability that a pair of selected parents will perform crossover or mating.	To be determined by the hyper-parameter search in Chapter 5.
Probability of Mutation for the Individual	The probability that a given individual undergoes mutation of its chromosome at the beginning of a new generation. Note that the type of mutation selected for use by AutoDesigner is the indice shuffle mutation method where the values of individual genes within the chromosome are swapped, subject to the probability of mutation parameter value.	To be determined by the hyper-parameter search in Chapter 5.
Max Generations	The max possible number of generations that that the genetic algorithm can undergo before terminating.	2000
Probability of Mutation for the gene	The probability that two genes within an individual's chromosome will be swapped as part of the mutation operation occurring on a given individual.	0.05
Max Generations with No Cost Reduction	The maximum number of consecutive generations where the best performing individual does not achieve a reduction in cost before the genetic algorithm terminates provided that the best performing individual achieves an fitness function value that is less than the target cost criteria.	20
Target Cost	The minimum fitness function value of the best performing individual in a generation that is required in order for the genetic algorithm to consider the max generations with no cost reduction criteria in terminating the genetic algorithm.	1,000,000
Population Size	The number of individuals that comprise a generation of the genetic algorithm.	To be determined by the hyper-parameter search in Chapter 5.

Table 3.4: Table of Parameter Descriptions and Values Used in the Genetic Algorithm Optimization.

3.3.4 Updating of Linked List Data Structure with Attributes Specified by the Genetic Algorithm

As discussed in the previous subsections, the vector of integer values that compose a genetic algorithm chromosome maps to form a complete set of attributes that are needed to finalize a DOP design. In other words, each of the fields denoted on the preliminary staking list with an '*' character can be fully populated once the contents of an individual's chromosome are mapped into corresponding design attributes during optimization using the method illustrated in Figure 3.8. The data encoded into a genetic algorithm individual completes the preliminary DOP design, however, the chromosome vector data by itself is not meaningful. Therefore, to evaluate the fitness function of an individual which is mainly composed of the project cost of a complete DOP design, each attribute from the individual must be loaded into the linked list data structure so that a complete design can be realized.

Note that despite the number of individuals that are generated by the genetic algorithm optimization process being very large, AutoDesigner maintains only a single linked list data structure. As a result, the fitness of each individual of the genetic algorithm is evaluated sequentially. First a backup of each Pole and Span object within the linked list data structure is created immediately after the preliminary staking list values are loaded back in to the DOP linked list. The state of the linked list after adopting any user constraints entered into the preliminary staking list represents the most complete preliminary DOP design that can be realized without the use of optimization. Once a backup is created, the original Pole and Span objects are then populated with the contents of the mapping of a particular individual's chromosome. Next, the evaluation of the fitness function of the individual is calculated by traversing the Pole and Span objects of the linked list at which point the constraint modules are computed and any punishment factors are added to the total cost. Finally, after the fitness function is determined, the state data within the backups of each Pole and Span object are copied back into the data structures which restore the state of the linked list to the way it was immediately prior to optimization. Restoring the back-up values allows for the next individual's fitness function to be calculated without having to undo changes that may have been made to data values contained in the linked that are not represented with an asterisk (e.g. as occurs when replacing an existing pole with a new pole).

3.3.5 Implementation of a Sparse Memory Look-Up Table for PoleCheck and ClearanceCalc Constraint Module Output

As is discussed in the previous subsection, the evaluation of the fitness function for the genetic algorithm requires the output from each of the five constraint modules in order to determine the presence of and the weights of any penalty factors that need to be applied to the total DOP project cost. Specifications of the five constraint modules are discussed in detail in the next section and Chapter where the constraint modules include: PoleCheck, ClearanceCalc, FloaterCheck, neutral continuity and grounding module as well as a slack span and pole deep-set module. The PoleCheck constraint module must be calculated at every pole structure that is impacted by the new construction of the DOP, while the ClearanceCalc constraint module must be similarly computed at every span. Now, it must be understood that the fitness function needs to be calculated for each individual where an individual may contain up to 50 new pole structures and spans. Furthermore, each generation of the genetic algorithm may contain thousands of individuals and there may be hundreds of generations in total. As a result, it can be easily seen that any computationally intensive operations that occur in calculating the fitness function is highly penalizing on the computation time of the genetic algorithm. Unfortunately, unlike the latter constraint modules which are computationally simple, the PoleCheck constraint module requires computationally intensive searching algorithms while the ClearanceCalc constraint module requires a significant number of mathematical calculations in order to arrive at an output.

In order to remedy the complexity introduced by the PoleCheck and ClearanceCalc constraint modules, 3-dimensional sparse lookup tables are implemented for both modules that store the output of past results to prevent duplication of calculations. The decision to use a sparse lookup table is based on the need to eliminate any computationally intensive searching algorithms and instead allow for direct addressing of past outputs. It is important to note that the size of the lookup tables is considerable and substantially increase the memory usage of AutoDesigner, however, the additional memory usage is determined to be acceptable in order to achieve the vast performance increase made possible by utilizing the sparse lookup tables.

The first dimension of the lookup tables is used to address the correct pole or span and can be indexed by simply counting the number of Pole or Span objects in the linked list starting at the beginning. Indexing the second dimension of the lookup tables is more complex as the second dimension must contain, as rows, all possible variations of poles or spans that may be encountered by the PoleCheck or ClearanceCalc constraint modules, respectively. The maximum number of rows contained in the second dimension of the PoleCheck and ClearanceCalc lookup tables are calculated in equations 3.2 and 3.3 while the means for direct addressing of rows is depicted in equations 3.4 and 3.5.

$$\boldsymbol{M_{Rows,PC}} = M_{Struct,PC}(N_{st}(n) + \frac{1}{n_{ph}} + \frac{1}{n_{ph}n_{ds}} + \frac{1}{n_{ph}n_{ds}n_{slack}} + \frac{1}{n_{ph}n_{ds}n_{slack}^2} + \frac{1}{n_{ph}n_{ds}n_{slack}^3} + \frac{1}{n_{ph}n_{ds}n_{slack}^4}) \qquad (3.2)$$

$$\boldsymbol{M_{Rows,CC}} = M_{Struct,CC}(N_{st}(n) * N_{st}(n+1) + \frac{1}{n_{ph}} + \frac{1}{n_{ph}^2} + \frac{1}{n_{ph}^2 n_{ds}} + \frac{1}{n_{ph}^2 n_{ds}^2} + \frac{1}{n_{ph}^2 n_{ds}^2 n_{slack}}) \qquad (3.3)$$

$$\boldsymbol{G_{Row,PC(n)}} = M_{Struct,PC}(S_{ga_index}(n) + (\frac{H(n) - H_{min}}{5}) * \frac{1}{n_{ph}} + (\frac{D_s(n)}{0.5}) * \frac{1}{n_{ph}n_{ds}} + T_{inc\_main} * \frac{1}{n_{ph}n_{ds}n_{slack}} + T_{out\_main} * \frac{1}{n_{ph}n_{ds}n_{slack}^2} + T_{tap1} * \frac{1}{n_{ph}n_{ds}n_{slack}^3} + T_{tap2} * \frac{1}{n_{ph}n_{ds}n_{slack}^4}) \qquad (3.4)$$

$$\boldsymbol{G_{Row,CC}(n, n+1)} = M_{Struct,CC}(S_{ga_index}(n) * N_{st}(n+1) + S_{ga_index}(n+1) +$$

$$(\frac{H(n) - H_{min}}{5}) * \frac{1}{n_{ph}} + (\frac{H(n+1) - H_{min}}{5}) * \frac{1}{n_{ph}^2} +$$

$$(\frac{D_s(n)}{0.5}) * \frac{1}{n_{ph}^2 n_{ds}} + (\frac{D_s(n+1)}{0.5}) * \frac{1}{n_{ph}^2 n_{ds}^2} + T_{curr} * \frac{1}{n_{ph}^2 n_{ds}^2 n_{slack}}) \qquad (3.5)$$

$$\boldsymbol{n_{ph}} \; = \; No.\,of\,pole\,heights\,recognized\,by\,PoleCheck \; = \; 6$$

$$\boldsymbol{n_{ds}} \; = \; No.\,of\,valid\,pole\,set\,depths \; = \; 4\,(ds \; = \; 0,\; 0.5,\; 1.0,\; 1.5)$$

$$\boldsymbol{n_{slack}} \; = \; Tight/slack\,span\,tension\,combinations \; = \; 2\,(tight\,span\,or\,slack\,span)$$

$$\boldsymbol{M_{Rows,PC}(n)} \; = \; Number\,of\,rows\,contained\,in\,the\,second\,dimension\,of$$

$$the\,3D\,PoleCheck\,lookup\,table$$

$$\boldsymbol{M_{Rows,CC}(n, n+1)} \; = \; Number\,of\,rows\,contained\,in\,the\,second\,dimension\,of\,the$$

$$3D\,ClearanceCalc\,lookup\,table$$

$$\boldsymbol{G_{Row,PC(n)}} \; = \; The\,row\,number\,that\,contains\,the\,identical\,past\,PoleCheck$$

$$results\,for\,pole\,n.$$

$$\boldsymbol{G_{Row,CC(n,n+1)}} \; = \; The\,row\,number\,that\,contains\,the\,identical\,past\,ClearanceCalc$$

$$results\,for\,the\,span\,between\,pole\,n\,and\,n+1$$

$$\boldsymbol{T_{inc,main}(n)} = Tight\,or\,slack\,status\,of\,incoming\,main - line\,of\,pole\,n$$

$$(tight \; = \; 1,\; slack \; = \; 0)$$

$$\boldsymbol{T_{out,main}(n)} = Tight\,or\,slack\,status\,of\,incoming\,main - line\,of\,pole\,n$$

$$(tight \; = \; 1,\; slack \; = \; 0)$$

$$\boldsymbol{T_{tap1}(n)} = Tight\,or\,slack\,status\,of\,incoming\,main - line\,of\,pole\,n$$

$$(tight \; = \; 1,\; slack \; = \; 0)$$

$$\boldsymbol{T_{tap2}(n)} = Tight\,or\,slack\,status\,of\,incoming\,main - line\,of\,pole\,n$$

$$(tight \; = \; 1,\; slack \; = \; 0)$$

$$\boldsymbol{M_{Struct,PC}} = Number\,of\,rows\,required\,to\,store\,all\,possible\,pole$$
$$height,\,pole\,deep-set\,and\,tight/slack$$
$$combinations\,at\,a\,particular\,pole\,structure\,for\,a\,given$$
$$structure\,pattern\,attachment\,=\,384$$
$$\boldsymbol{N_{st}(n)} = Number\,of\,structure\,pattern\,combinations\,that\,could\,be\,selected$$
$$by\,the\,genetic\,algorithm\,at\,pole\,n$$
$$\boldsymbol{S_{ga_index}(n)} = The\,structure\,pattern\,indice,\;number\,that\,is\,currently\,selected\,by$$
$$the\,genetic\,algorithm\,at\,pole\,n$$
$$\boldsymbol{M_{Struct,CC}} = Number\,of\,rows\,required\,to\,store\,all\,possible\,pole\,height,$$
$$pole\,deep-set\,and\,tight/slack\,combinations$$
$$at\,a\,particular\,pole\,structure\,for\,a\,given\,structure\,pattern\,attachment\,at$$
$$pole\,n\,and\,pole\,n+1\,=\,1152$$
$$\boldsymbol{H(n)} = Pole\,height\,in\,feet\,(5\,foot\,increments).$$
$$\boldsymbol{H_{min}} = Min\,pole\,height\,in\,feet(35\,ft.).$$
$$\boldsymbol{D_s} = Pole\,deep-set\,depth\,in\,0.5m\,increments.$$

The third dimension of the lookup tables contain either empty fields or the complete set of returned values from the PoleCheck or ClearanceCalc constraint modules when it was run in the past for the specific pole or span configuration that is currently under investigation. Note that read and write operations to and from the lookup tables are addressed in the same manner as shown by Equations 3.4 and 3.5. Note that additional explanation regarding the specific outputs returned from the PoleCheck and ClearanceCalc constraint modules are discussed in the next subsection and chapter.

3.3.6 Termination of the Genetic Algorithm and Finalization of DOP Design

The genetic algorithm optimization process terminates either after 2,000 generations have lapsed or if the fitness function of the best performing individual in a generation remains unchanged for 20 consecutive generations while falling below $1,000,000 (i.e. no constraint violations are present in the design). When the stopping criteria are reached, the individual with the lowest fitness function cost is retrieved and, for a second time, is mapped to the linked list data structure. For the second mapping, instead of reverting back to the preliminary DOP design after the fitness function is determined, the linked list is left with all design parameters fully populated and the resulting DOP design is considered final. At this time, the final calculation summaries and reports are generated for the DOP design which is discussed in detail in the next two sections.

3.4 Implementation of Constraint Modules with the Exclusion of PoleCheck2.0

Five constraint modules are utilized in AutoDesigner to force the genetic algorithm optimization process to comply with specific design requirements that cannot be determined prior to the optimization process. The ClearanceCalc constraint module is adapted from a tool that is used by the DFO and which calculates the minimum worst-case conductor clearance over crossings as per utility code [4]. The FloaterCheck constraint module, which is also designed by the DFO and is related to the ClearanceCalc tool, evaluates the conductor uplift condition on pin-type insulators that occur under minimum conductor sag scenarios. The pole deep-set constraint module enforces the requirement for poles with unsupported slack spans to be deep-set at least 1.0 meter. The neutral continuity and grounding constraint module enforces the requirement for overhead neutral wire to be terminated with appropriate pole-top attachments and ground rods as well as ensure that the required number and spacing of ground rods is maintained in a multi-grounded neutral system.

Note that discussion on the major component of the fifth constraint module, PoleCheck2.0, is reserved for Chapter 4 due to the complexity of the implementation as well as PoleCheck2.0's application as a standalone design tool for use by the DFO. PoleCheck2.0 is designed to completely replace the use of PoleCheck1.0 by AutoDesigner. PoleCheck1.0 is a series of pole-loading lookup tables created by the DFO for the purposes of analyzing loading on individual pole structures. Initially, in the devilment of AutoDesigner, PoleCheck1.0 was used as the primary means of calculating force loading on pole structures during optimization. Unfortunately, due to some code compliance and stability challenges that occur when using PoleChec1.0, the tool is deemed determined to be inadequate for use in AutoDesigner if the tool is deployed for widespread use by the DFO. Unfortunately, at the time of writing the thesis, it is not possible for PoleCheck2.0 to completely replace the use of PoleCheck1.0 in the evaluation of AutoDesigner and so a high-level discussion on PoleCheck1.0 is provided in this section with an analysis of the particular code compliance issues that arise when using the tool.

Note that all of the constraint modules provide an output in the form of a cost penalty factor which is to be added to the fitness function of an individual during the genetic algorithm optimization process. A penalty factor cost of 0.0 corresponds to a DOP design segment that satisfies the requirements of the constraint modules while a penalty value equal to $1,000,000 or greater indicates that the design segment fails to comply with the requirements imposed by the constraint module. Constraint modules are evaluated after all optimizable design components are added to the linked list data structure from the genetic algorithm individual during fitness function evaluation. Constraint module evaluation occurs while the linked list data structure is being traversed to add up the construction material cost, labour cost and constraint violation penalties of each pole and span object in the DOP design for evaluation of the fitness function.

3.4.1 ClearanceCalc Constraint Module

The most critical constraint module after PoleCheck is the ClearanceCalc constraint module. ClearanceCalc is responsible for computing the maximum conductor sag of a span and assessing whether the worst-case span clearance meets the requirements outlined by DFO standards and in utility codes. The implementation of ClearanceCalc that is used by AutoDesigner is adapted directly from an Excel-based tool that is actively in use by the DFO for calculating conductor clearances of individual spans over crossing locations [8]. Note that the Excel-based algorithm is reproduced with permission from the DFO as a Python Class for use by AutoDesigner in order to eliminate the lag associated with interfacing directly with a Microsoft Excel worksheet. That being said, the ClearanceCalc algorithm used by AutoDesigner is unaltered from the one that is in-use by the DFO and so an in-depth analysis of the algorithm s beyond the scope of the thesis. Instead, the subsection focuses on the means by which AutoDesigner utilizes the ClearanceCalc constraint module, the necessary inputs and outputs provided to and obtained from the module and the output report that is generated by the module. That said, for more information on the technical concepts behind conductor clearance calculations, please refer to Chapter 2 of the thesis.

AutoDesigner utilizes the ClearanceCalc module upon encountering a Span object during linked list traversal that is either a new span or is an existing span that is related to some portion of new construction. For example, an existing span that is attached to a pole that is being upgraded or replaced must be assessed for conductor clearance since the new pole may potentially reduce conductor clearances. On the other hand, an existing span that is not connected to any pole structures that are being modified on the project can be safely considered to not have a reduced clearance due to the project scope and so ClearanceCalc performs no calculations on the span. Note that an existing span that may be evaluated by ClearanceCalc for one individual of the genetic algorithm may not necessarily be evaluated for all individuals. The reason for this is due to the situation where an existing pole may be upgraded or replaced as part of a design decision made by the state of the structure pattern gene for existing pole structures. When an existing pole structure is upgraded the immediate effect is that the adjacent spans must now be evaluated for clearances.

The inputs to the ClearanceCalc constraint module with descriptions are listed in Table A.8 of the Appendix. It can be seen that in order to compute the clearance of a span, information relating to both the span as well as the two supporting pole structures are required.

The ClearanceCalc constraint module returns two outputs. The first output is an integer that contains a sum of all of the constraint violations identified under the span where each violation is represented by an integer value of 1 (note that this value is multiplied with a value $1,000,000 after being returned to the fitness function evaluation function and forms the punishment factor for the ClearanceCalc constraint module). The second output from ClearanceCalc is an output string that provides a row of text for each crossing under the span being investigated that contains the crossing type abbreviation, the clearance calculated by ClearanceCalc and the required clearance for the crossing type. Note that in the event that the clearance is inadequate the output string contains text indicating that a violation is present at the beginning of the string. The output string is eventually added to a calculation summary report which, for the best performing individual at the end of the optimization process, gets printed to a text file for the user to review. The calculation summary report is discussed in greater detail in the next section.

Note that the ClearanceCalc class contains a method called writeToClearanceCalc which is used to write the results of the ClearanceCalc constraint module to an Excel workbook that is in the same format as the ClearanceCalc tool that is used by the DFO. The method makes use of the Python 'openpyxl' library to populate values to a hidden row in a template ClearanceCalc Excel Worksheet which the Excel template then maps to the appropriate data fields on the worksheet by using formulas. The worksheet contains the unmodified algorithm from the DFO's ClearanceCalc tool and serves as an additional independent validation of the results that are produced by AutoDesigner. Furthermore, the worksheet uses a familiar format and is intended to serve as a useful design validation aid for the DFO's designer and authenticating engineer. Note that AutoDesigner only calls the writeToClearanceCalc method once the best performing individual is determined after the genetic algorithm optimization has terminated. Figure 3.9 illustrates a sample of the Excel output report format after the template is populated with the ClearanceCalc input values from AutoDesigner.

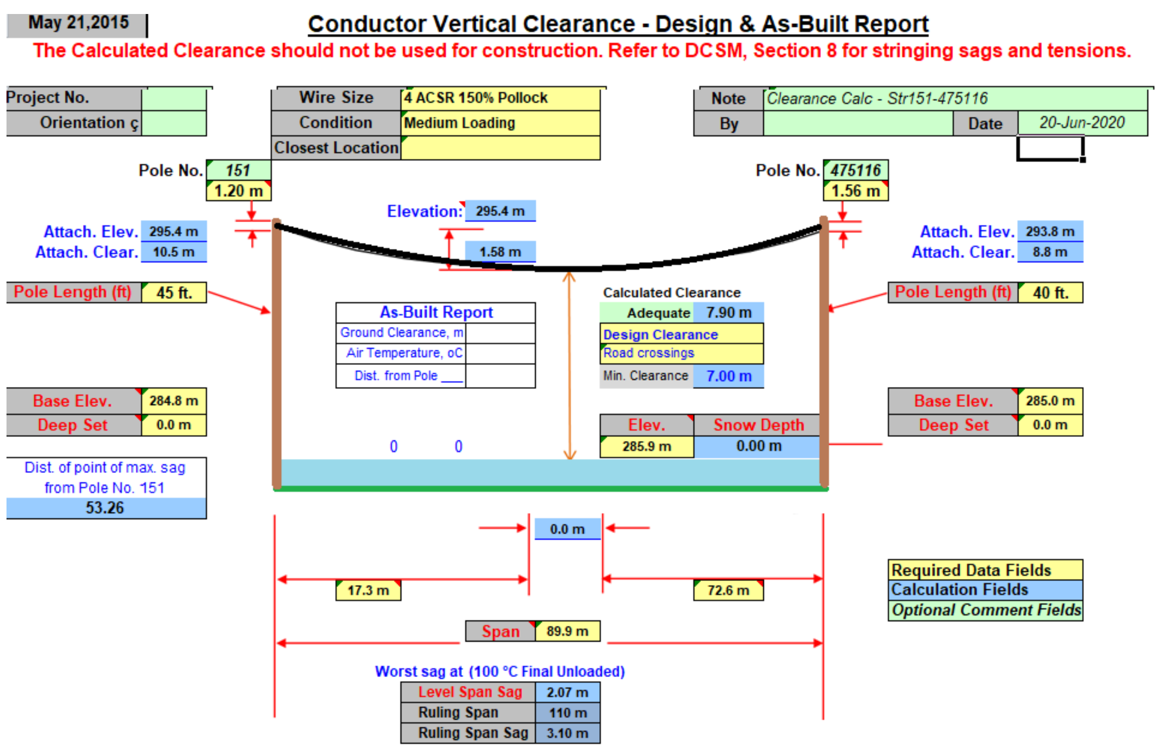


Figure 3.9: Sample of Output Report Generated from ClearanceCalc Constraint Module in a similar format as used by the DFO. [8]

3.4.2 FloaterCheck Constraint Module

The FloaterCheck constraint module performs a check for the conductor uplift condition on poles which is of most significant concern for poles that have pin-style insulator attachments. The implementation of the FloaterCheck constraint module is very similar to ClearanceCalc in that the DFO maintains an Excel-based tool referred to as FloaterCheck that contains a complete algorithm to calculate conductor uplift [8]. Again, AutoDesigner reproduces the algorithm in Python with the permission of the DFO in order to achieve maximum computational performance during optimization. It is important to note that the FloaterCheck Python implementation is a part of the same class as the ClearanceCalc constraint module within AutoDesigner which mirrors the DFO's implementation of ClearanceCalc and FloaterCheck which also share a common Excel Workbook. This subsection focuses on the utilization of the FloaterCheck constraint module by AutoDesigner, the input and output data provided to and from the module, discussion of the special considerations made by AutoDesigner's implementation of FloaterCheck for severe conductor uplift that can result in a pole floating condition, and the output reports generated by the module. As with conductor clearance, please refer to Chapter 2 for a technical analysis into the conductor uplift condition.

AutoDesigner requires the FloaterCheck constraint module to be used whenever it encounters a Pole object that has a pole previous to it as well as a pole after it in an alignment that has a deflection that is less than 45°. Traditionally, conductor uplift is a concern when a pin-type insulator is used to support the conductor that can pop out when any upward force is applied. That said, the PoleCheck constraint module also considers the possibility of the pole being physically pulled out of the ground due to uplift which may occur in rare cases when the uplift is severe and when the attachments are used that are not susceptible to conductor uplift. As a result, any centre pole that is a part of a series of three consecutive poles interconnected with conductor and aligned with a relatively small deflection is analyzed by FloaterCheck.

The inputs required for the PoleCheck constraint module with descriptions are listed in Table A.9 of the Appendix. It can be seen that the PoleCheck constraint module requires data on the pole under investigation as well as its two neighboring poles along with information on the two spans that interconnect the series of poles.

The PoleCheck constraint module provides three outputs. The first output is the punishment factor associated with an unacceptable uplift condition that is present on the pole or structure. A punishment factor value of 0.0 indicates that no violations are present, while a value over 1.0 indicates that an unacceptable uplift condition is present. Note that the punishment factor for the FloaterCheck constraint module is graded based on the severity of the violation. In other words, a FloaterCheck constraint violation will produce a punishment factor of at least 1.0, however, more severe violations may be given decimal values that approach 2.0 or even higher. When the punishment factor is multiplied by $1,000,000 and added to the fitness function of the individual, the effect of the graded punishment factor serves to reward the genetic algorithm optimization method for changes to the design that reduce the severity of the conductor uplift violation, even if it is not completely eliminated. The graded punishment factor serves to help provide a more guided slope along the cost optimization surface for the genetic algorithm to traverse which can help to lead it to a minimum more quickly. Note that the ClearanceCalc constraint module does not utilize graded punishment factors and rather represents any violation with a 1.0 punishment factor. That said, as opposed to FloaterCheck, the ClearanceCalc constraint module can accumulate multiple violations per span and so the effect of graduated punishment factor can be approximated with multiple clearance violations, albeit in a more discretized manner.

The second output from the PoleCheck constraint module is a text string that summarizes the results from the FloaterCheck calculation. The text string indicates if any violations are present and then proceeds to list, as a summation equation, the degree of uplift that is contributed from each of the two spans that are attached to the pole under investigation. The FloaterCheck algorithm uses a non-physical measurement referred to as weight span which is calculated for each of the two spans and that measure the degree of uplift as a proportion of the span length in meters where a negative value indicates an upward force contribution from the span. The text string prints the summation of the individual weight span contributions from the two spans along with the sum of weight spans where if the sum is a negative value, a floater condition may exist. In the event of the summed weight spans being negative, FloaterCheck assesses the type of pole top attachment. If the applicable pole top attachment is not susceptible to conductor uplift, the overall pole weight is then assessed. If the pole weight is determined to be more than twice the maximum possible uplift force from the conductors, then no violation is present, and the text string indicates that the uplift condition is acceptable. In the event that the uplift force is greater than 50% of the pole weight, FloaterCheck issues a constraint violation but also indicates that side-guys may be considered to rectify the violation. Note that in the case that the pole has an attachment that is susceptible to conductor uplift, the provision for the use of side-guys is not made. Note that the third output from FloaterCheck simply indicates a 1 value if side-guys should be considered to rectify an uplift condition where the value is 0 for all other scenarios.

In the event that a conductor uplift condition is present on the pole under investigation but FloaterCheck is recommending that side-guys be considered, AutoDesigner evaluates whether 3.0m long inline side-guys installed on either side of the pole is feasible. In particular, AutoDesigner looks to see if any crossings are present within 13.0m of the pole on either side and that there isn't already an anchor being used at the pole for another purpose. If crossings exist or one or more of the anchor fields for the Pole object is already populated, then the constraint violation issued by FloaterCheck is upheld and the punishment factor is added to the fitness function of the individual being evaluated. If side-guys are allowed and both anchor fields are available, then the G17BFF side-guys are added to the pole object and the punishment factor is struck.

Note that the FloaterCheck constraint module also has a method called writeToFloaterCheck which functions in a very similar manner to writetoClearance-

Calc and produces an output report that is in the same format as the FloaterCheck Excel tool that is used by the DFO. AutoDesigner utilizes the 'openpyxl' library to populate an empty, pre-formatted template with values located in a hidden row. Figure 3.10 illustrates a sample of the Excel output report format after the template is populated with the FloaterCheck input values from AutoDesigner. Finally, it is important to note that unlike the ClearanceCalc constraint module, the FloaterCheck module does not make use of a sparse look-up table memory function. The reason for not implementing memory functionality for FloaterCheck is partially due to the larger number of input variables for FloaterCheck whose calculations span three pole structures instead of the two that are considered by ClearanceCalc as well as the fact that FloaterCheck's algorithm is much less computationally-intensive compared to ClearanceCalc.

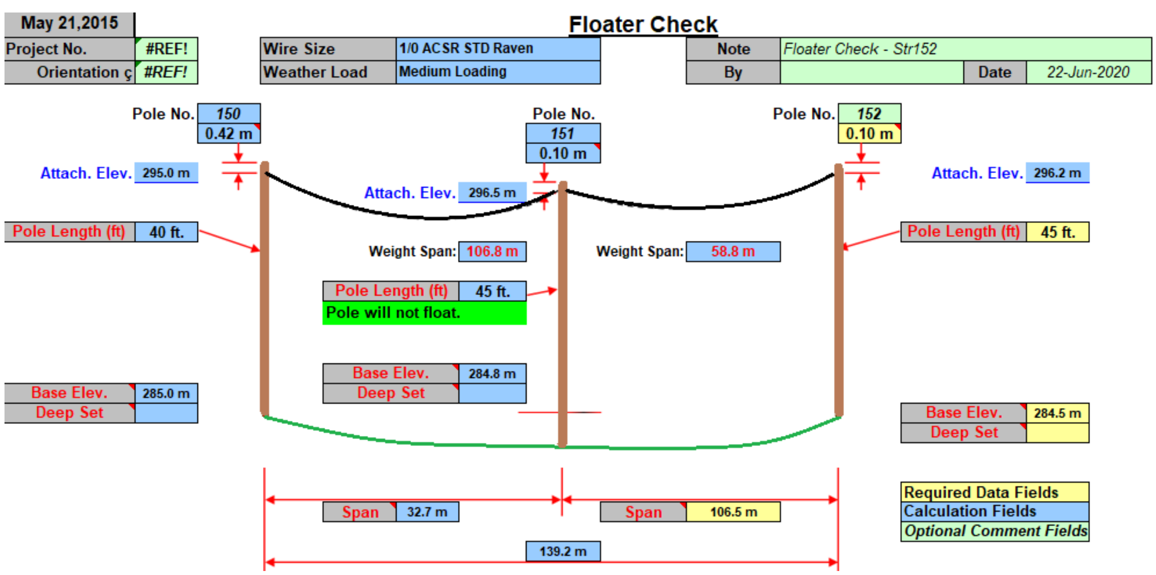


Figure 3.10: Sample of Output Report Generated from the FloaterCheck Constraint Module in a similar format as used by the DFO. [8]

3.4.3 Slack Span and Pole Deep-Set Validation Constraint Module

The slack span and deep-set constraint module seek to ensure that poles that contain slack-spans that are not supported by an anchor or another span are deep-set at least

1.0m as per DFO standards. The constraint module evaluates the compliance of all poles in a DOP design that support at least one slack-span and the evaluation is performed immediately after the PoleCheck constraint module evaluation is performed on the pole. Similar to both FloaterCheck and PoleCheck, the slack-span and deep-set constraint module is only called to evaluate the compliance of new poles or existing poles that have some new construction associated with it. Because of the relatively small number of slack-spans that tend to exist on a typical DOP project, the number of times that the slack span and deep-set constraint module is called is significantly less than the PoleCheck, ClearanceCalc or FloaterCheck constraint modules making it less of a bottleneck on the overall optimization time.

Note that the slack span and deep-set constraint module is a patchwork module that functions very differently on the basis of whether the PoleCheck analysis is performed using PoleCheck2.0, PoleCheck1.0 or if pole case identification errors are present in the PoleCheck2.0 analysis output. In the case where the PoleCheck2.0 constraint module is successfully used to evaluate the pole structure; the slack span and deep-set constraint module merely validates that the selected deep-set value for the current pole structure is equal to or greater than the deep-set specified in the PoleCheck2.0 case for the specified structure pattern. As discussed in Chapter 4, each PoleCheck2.0 case is custom-designed to specify an adequate deep-set value that is sufficient to support the pole-top structure pattern. As a result, it is unnecessary for the slack span and deep-set constraint module to manually calculate pole-top force loadings and independently determine whether a pole deep-set is necessary when PoleCheck2.0 is providing a pole loading assessment.

That being said, in cases when PoleCheck2.0 is unable to perform a valid pole-loading assessment or if the legacy PoleCheck1.0 implementation is used for the pole-loading calculations, the slack span and deep-set constraint module must perform a complete assessment of the pole structure to determine whether a deep-set is required. The cases where PoleCheck2.0 is unable to arrive at a valid output is discussed in detail in Chapter 4 and such a scenario is always accompanied by a constraint violation that is thrown by PoleCheck2.0. While the need to evaluate the deep-set status of a pole that has already been given a constraint violation may seem trivial, special care is taken in the development of AutoDesigner to arrive at accurate fitness function values for all individuals comprising the genetic algorithm, even those that contain constraint violations. Accurately representing the cost optimization hypersurface even when a design is non-compliant is likely to provide the most meaningful learning reinforcement for the genetic algorithm allowing it to more quickly converge to a strong minimum project cost.

In the case when the detailed assessment of a pole's slack span and deep-set design parameters are required, the slack span and deep-set constraint module performs the following analysis:

If, the pole being analyzed contains an inline tangent structure and one of the spans of the tangent structure is a slack span but not the other,

Then, cite a constraint violation but **do not** exit module,

If, the pole structure being analyzed already has a deep-set of at least 1.0m,

Then, exit the constraint module with no additional violations cited,

For each slack span attached to the pole structure:

If, the tension vector of the slack span is being mostly cancelled by the tension of other slack-spans (i.e. each anchoring slack span has not more than 1,000N of residual tension in the direction perpendicular to the slack being analyzed and have enough projected tension to cancel 90% of the tension of the slack span being analyzed),

Then, exit constraint module without citing additional violations,

Else if, the unbalanced slack span on the pole is oriented approximately opposite to one or more tight-spans (i.e. each anchoring tight-span has not more than 1,000N of residual tension that is not anchoring the slack span being analyzed),

Then, exit constraint module without citing additional violations,

Else if, the unbalanced slack spans on the pole are oriented approximately opposite to an anchor (i.e. the anchor has not less than 3.0m of projected length that is anchoring the slack span being analyzed).

Then, exit constraint module without citing additional violations.

Note that the decision to not exit the constraint module immediately after establishing that one of the two spans associated with an inline tangent structure is a slack-span is made due to the fact that a missing pole deep-set (which is analyzed later in the module) is a separate design error that should be additionally punished. Also, note that the reference to projected tension and anchor length in the above list refers to the dot product projection of a tension or anchor vector onto a unit vector that is oriented on the opposite side of the pole of the slack span being analyzed. Similarly, the residual refers to the amount of the tension that is perpendicular to the projected component. Note that the tensions and percentages used in the above table are determined empirically through trial and error to compliment DFO design practices of when poles should be deep-set and not deep-set. The 3.0m anchor length referred to in the above list comes from DFO recommended standards for anchoring slack spans. Note that Figure 3.11 shows three sample cases of poles that have new slack spans and provides an evaluation of whether or not a 1.0m deep-set is required on the pole.

The slack span and deep-set constraint module accepts as input lists that detail the characteristics of all slack spans, tight spans and anchors that are attached to the pole. The output from the constraint module includes the number of constraint violations and an output string that provides an explanation of the constraint violation (an empty string is returned if no constraint violations are present).

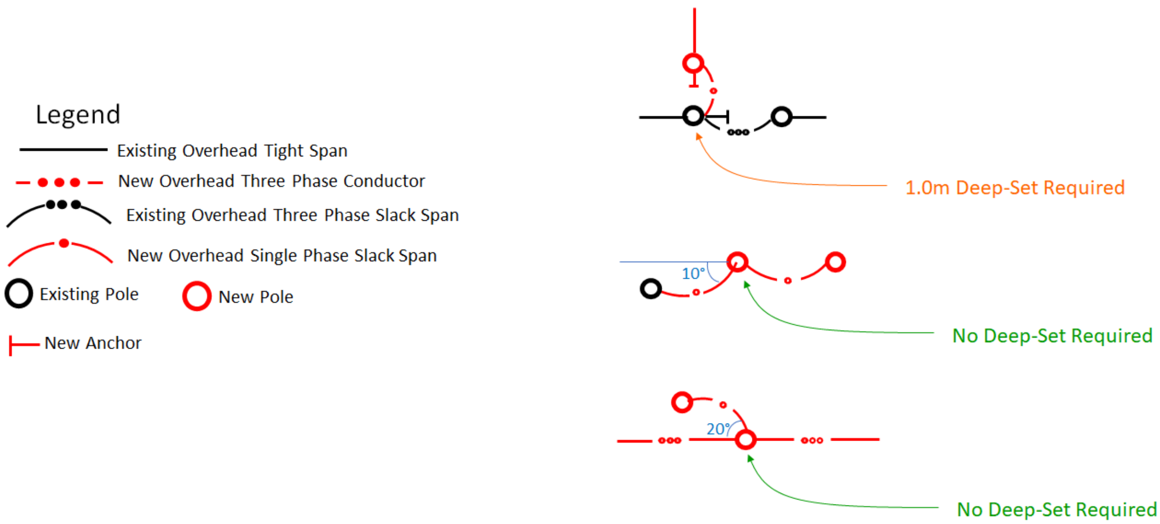


Figure 3.11: Examples of Poles with Slack-Spans and Requirement for 1.0m Deep-Set.

3.4.4 Grounding and Neutral Continuity Constraint Module

The grounding and neutral continuity constraint module ensures that the appropriate pole top neutral attachments are present on a pole and that a ground rod is also present on the pole if required for equipment grounding or to maintain the required 400-500m grounding intervals in an overhead multi-grounded neutral system. Please refer to Chapter 2 for additional discussion on the technical considerations associated with DOP grounding. Evaluation of the grounding and neutral continuity constraint module is performed immediately after the slack span and deep-set constraint module and is evaluated on individual pole structures that are either new or have some new construction associated with it.

The first purpose of the constraint module is to ensure that spans that contain an overhead neutral wire are attached to poles that have the appropriate neutral attachment fields populated in the Pole structure. As discussed in the previous section, the structure parameter list frequently specifies the presence of neutral attachments on a pole structure using a generic ”Neut” label within the structure pattern that must eventually be replaced with valid neutral attachment structures using the neutral structure parameter list. The ”Neut” label may be referring to a neutral attachment that is present underneath as few as one of the span attachments on the pole or as many as three. Because the genetic algorithm optimization does not have the ability to directly specify a neutral on a span object, it must therefore control the presence of a neutral by toggling between structure patterns that have a provision for a neutral attachment versus those that do not. AutoDesigner then reasons out which spans must have neutral attachments on the basis of which of the adjacent poles also have neutral attachments. It often arises during the early stages of the optimization process that AutoDesigner chooses for a single pole to have a neutral attachment but where all of the adjacent poles have no provisions for neutrals, which is not a valid design decision. In this example, one of the spans attached to the pole is selected as having a neutral during population of the linked list Span object data values. That said, the next pole subsequent to the span in question will have no neutral attachment which is where the grounding and neutral continuity constraint module throws a constraint violation. The objective is to promote the selection of structure patterns that result in a realizable neutral configuration, regardless of whether the presence of a neutral at a particular location is nonsensical (the costly nature of such a decision serves as its own punishment factor for the genetic algorithm optimization).

The second purpose of the constraint module is to ensure that the pole being analyzed contains a ground rod, if one is required. Note that this section of the constraint module primarily specifies a correct value for the number of ground rods that are required at the pole being analyzed rather than solely being focused on issuing constraint violations. The following list contains the criteria covered that the constraint module considers when determining the required number of ground rods along with the number of ground rods that are specified by the constraint module in each of the conditions.

If, an incoming mainline neutral wire is present on the pole,

If, no neutral wire extends past the pole location,

Then, call for a ground rod at the pole if one is not already specified by the structure pattern (all neutral segments must be terminated with a ground rod),

If, neutral wire extends past the pole location,

Then, call for a ground rod at the pole if it has been approximately 400 meters since the neutral wire was last grounded.

If, no incoming mainline neutral wire is present on the pole,

If, none of the outgoing spans contain a neutral attachment,

If, the selected structure pattern at the pole requires contains transformer equipment (which requires two interconnected ground rod locations) and less than two ground rods are present at the pole,

Then, cite a constraint violation for an insufficient number of ground rods being present at the pole,

If, precisely one of the outgoing spans contain a neutral attachment,

Then, call for a ground rod at the pole if one is not already specified by the structure pattern (all neutral segments must begin with a ground rod),

If, more than one of the outgoing spans contains a neutral attachment,

Then, do not place a ground rod but update the distance to the closest ground rod to half that of the maximum allowable distance (about 200 meters),

Note that inputs for the grounding and neutral continuity constraint module include flags that indicate the presence of neutral wires on all spans attached to the poles, the number of ground rods called for at the pole, whether the structure pattern requires a ground rod to be installed at a remote pole and connected via a neutral and whether the previous span is a tap-off from another mainline. The outputs from the constraint module includes the final number of ground rods specified for the pole, the number of constraint violations as well as an output string that provides details on any constraint violations that are cited (and empty string is returned if not violations are present).

3.4.5 PoleCheck1.0 Legacy Constraint Module

While PoleCheck2.0 is discussed in detail in Chapter 4, this subsection provides a high-level overview of the basic functionality and limitations of PoleCheck2.0's predecessor constraint module, PoleCheck1.0. The ultimate intention in the development of AutoDesigner is for PoleCheck2.0 to completely replace the use of PoleCheck1.0 for pole-loading calculations. Unfortunately, due to time constraints, it is not possible to generate the complete set of PoleCheck2.0 lookup tables that are needed in order to eliminate the use of PoleCheck1.0 by the time of the thesis completion. As a result, it is necessary for both PoleCheck1.0 and PoleCheck2.0 to remain as active modules in AutoDesigner for the hyper-parameter search and evaluation activities contained in Chapters 4 and 5 of the thesis. PoleCheck2.0 is used to perform pole loading calculations for poles that utilize structure patterns that are available in PoleCheck2.0 while PoleCheck1.0 is used to perform structure loading calculations for the remaining structure patterns. As additional PoleCheck2.0 tables gradually become available for use, the use of PoleCheck1.0 will gradually decline and will ultimately be phased out completely.

PoleCheck1.0 uses a very similar implementation to that of PoleCheck2.0 in that both modules are composed of a series of extensive look-up tables that cover a selection of structure patterns that may be installed on a pole. PoleCheck1.0 contains approximately 40 lookup tables where each table represents a single structure pattern that is commonly installed on poles. Note that Table A.10 contains a list of the complete set of pole-top structure patterns that PoleCheck1.0 contains where each entry in the table represents a single lookup table. Within a given lookup table, the individual rows provide a pole utilization value that is calculated in PLS-Pole for the structure pattern in question given a set of parameters that provide the complete set of information is required in order to physically model the pole structure. For example, the contents contained in the individual's cells of each table row of a PoleCheck1.0 table are listed in Table 3.5 along with the range of potential values in the context of an N32 three-phase corner pole structure.

PoleCheck1.0 Table Parameter	Range of Values for N32 Structure
Loading	Heavy, Medium
Ruling Span	No value, assume standard span lengths
Deflection	90°
Anchor Structure	G50
Anchor Lead Length 1	5.5, 7.5, 9.5, 11.5
Anchor Lead Length 2	5.5, 7.5, 9.5, 11.5
Conductor	6, 8, 9 (See Table 2.3 for numerical mapping to conductor type)
Pole Height	35, 40, 45, 50, 55, 60
Pole Type	LP,WR (Lodge Pole Pine, Western Red Cedar)
Pole Class	1, 2, 3, 4, 5
Pole Utilization	floating-point value in percent or NA text string

Table 3.5: Table of PoleCheck1.0 parameters for determining pole utilization for a specific structure pattern.

When extracting a pole utilization value from a lookup table, the PoleCheck1.0 constraint module must search for a value that most closely represents the design parameters of the pole structure that is under investigation. To aid in a sequential search, the columns of the pole check lookup table that are listed at the beginning of each row of Table 3.6 are sorted in ascending alphanumeric order with the Pole Class column being sorted first (right-most column before Pole Utilization) with subsequent sorts being applied to each column going back to the Loading column. The constraint module then performs a sequential search starting at the Loading column where it moves ahead one column and retaining the last row number of the previous column's search each time an acceptable value is found. The search stops once it reaches the Conductor column where all pole heights, pole types and pole classes that fall under the correct conductor type are considered as potential candidates to be returned back to AutoDesigner. PoleCheck1.0 returns the pole utilization from the group of candidates that is closest to but just under 100%. The decision to return the candidate whose value is just under 100% represents a rudimentary cost optimization technique since such a structure will likely be cheaper than pole structures that have pole utilizations that fall well below 100%. Note that in addition to returning the pole utilization, PoleCheck1.0 also returns the selected pole class, pole height, pole composition, anchor types, anchor lengths, anchor orientations, the number of constraint violations and a text string summarizing the pole loading calculation assumptions and results.

Note that the pole utilization is a value that is produced as output from PLS-Pole's non-linear analysis and represents the state of the most stressed member in the pole structure after loads are applied [7]. A utilization value greater than 100% represents a failure of one or more members comprising the pole structure while values less than 100% represent configurations in which the pole is able to withstand the applied forces and the resulting deformation does not yield a structure failure. The string value 'NA' is printed in the pole utilization row usually when the utilization far exceeds 100% and indicates that PLS-Pole is unable to arrive at a pole utilization value. As a result, only pole utilizations that contain a floating-point value that is less than 100% are considered to comply with the requirements of PoleCheck1.0. Values over 100% or NA values are returned to AutoDesigner as a constraint violation by the module where degree of punishment factor starts at 1.00 for a utilization that is just over 100% and increases linearly with higher pole utilizations similar to the

FloaterCheck constraint module discussed in a previous subsection.

Unfortunately, as can be seen by reviewing the contents of Table A.10 in the Appendix, the number of PoleCheck1.0 structure patterns are very limited and only represent a small fraction of the possible pole-top structure patterns that may be installed on poles. This limitation represents a major drawback in the use of PoleCheck1.0 by AutoDesigner. It is a requirement of non-linear analysis that all force-loads be applied to poles prior to the application of finite elements analysis [4], as a result, when a structure pattern is used in a DOP design that is not covered under one of the roughly 40 PoleCheck1.0 lookup tables, there is no accurate means to adjust the results to account for the separate force loadings without performing a new non-linear analysis calculation. Since PoleCheck1.0 is only capable of retrieving pole utilization values from a lookup table and cannot independently perform a FEA computation, there is no licit way for PoleCheck1.0 to compute the force loading for structure patterns that it does not have a lookup table prepared for.

In order to address the scenarios where PoleCheck1.0 does not have a valid lookup table for the structure, the constraint module is provided with the ability to add up force utilizations that are extracted from different lookup tables in a manner that is similar to superposition where the total sum must remain under 100%. It is important to emphasize that while this approach is not valid under non-linear analysis and is only done as a last resort in order for certain pole loading computations to be realizable using PoleCheck1.0, in many cases adding the pole utilizations results in a significantly conservative design and in many cases may specify a pole that far exceeds the requirements specified by PoleCheck2.0. Nevertheless, any pole loadings produced by AutoDesigner that require the superposition sum of lookup tables must be independently reviewed and validated by the authenticating engineer prior to the issuing of final drawings.

The PoleCheck1.0 constraint module performs analysis on pole structures using the data string contained in the poleCheckPattern attribute of the Pole object. Data strings that begin with a '_' character trigger the use of PoleCheck1.0 for the pole analysis and the subsequent string content indicates the means by which the pole utilization is calculated. The data string must contain at least one PoleCheck1.0 structure pattern which uses the same name and format as the look-up table names shown in Figure A.10. PoleCheck1.0 structure patterns that immediately come after the '_1_' tag in the string are associated with the incoming mainline span in the pole loading calculations, structure patterns that come after '_2_' are associated with the outgoing mainline span, while '_3_' and '_4_' specifies structure patterns that are associated with the first and second tap-off spans, if they exist. When different structure patterns are immediately listed after different span tags, this means that the superposition of pole utilizations is required to determine the pole loading. In the case where a structure pattern contains a 'Neut' tag in the data string, a PoleCheck1.0 lookup table is referenced immediately after the span identification tag that assumes a continuous neutral wire. In addition, a second related look-up table is referenced immediately after the first and is separated by a '/' where the only difference is that the second table does not contain any neutral attachments. The second lookup table is required when a continuous neutral wire is not present across the structure pattern requiring the phase wire attachments to be evaluated separate from the neutral attachments, using the superposition technique. Table 3.6 illustrates examples that show how pole utilizations are set up and evaluated based on the data string that is present in the structure parameter list.

Structure Parameter List Structure Pattern	poleCheckPattern Attribute	Description of how PoleCheck1.0 Calculates Pole Utilization
R109F	_1_2_R109F	Only a single PoleCheck1.0 lookup table is required. Model incoming and outgoing mainline spans with the R109F look-up table.
N42,N55	_1_N42_2_N55	Superposition of two pole utilizations is required.
N12,N55,R253B	_1_2_3_N55_4_R240	Superposition of two pole utilizations are required. The incoming and outgoing mainline as well as the three-phase tap-off span are represented with the N55 PoleCheck1.0 lookup table. The second single phase tap-off span is represented with the R240 structure whose utilization must be added to the N55 utilization.

N12,R154,R254,Neut	_1_2_N12,N0/N12_-3_R154_4_R254	Superposition of up to four pole utilizations are required. The incoming and outgoing mainline spans are represented with the N12,N0 or N12 PoleCheck1.0 lookup table depending on the presence of a continuous overhead neutral. The R154 and R254 tap-off structures are computed using the R154 and R254 pole check look up tables, respectively. Pole utilization is calculated by adding pole utilizations from N12 or N12,N0 structure, R154 and R254 structures together (if N12 structure is used without the N0, then add the pole utilization from an additional R240 structure to approximate the neutral wire termination that must be present on the pole).

Table 3.6: Table of PoleCheck1.0 Parameters for Determining Pole Utilization for a Specific Structure Pattern. Note that all Scenarios Listed in the Table Assume that all Spans Attached to Poles are Tight Spans.

Note that because the PoleCheck1.0 lookup tables consider all spans to be tight-spans, modelling the effects of slack-spans in the pole loading calculations presents considerable difficulty. Slack spans, as discussed in Chapter 2, are short, low-tension spans whose effect on pole loading is normally much less than that of a tight-span but that which should still be considered. The effects from slack spans on pole loading in PoleCheck1.0 cannot be performed using the superposition of pole utilizations because no base slack-span look-up table case exists in PoleCheck1.0's library. As a result, the only option that remains to account for the impact of slack-spans on poles using PoleCheck1.0 would be to apply an adjustment factor to the pole utilization percentage. Without the ability to investigate pole-loading cases that have been conducted for slack-spans, such an adjustment factor lacks a technical basis. Furthermore, it is generally the case through empirical observation, that slack-spans have a fairly minimal impact on pole class selection. As a result, PoleCheck1.0 opts to completely neglect the impact of slack-spans on the pole loading calculation, again with the caveat that the authenticating engineer must review such structures prior to issuing the final design to construction.

PoleCheck1.0 has additional difficulty when modelling the pole loading of structures that contain equipment such as pole-top transformers or riser structures. Pole-top equipment has both a weight as well as a surface area that can add to the vertical force and the transverse loads under wind-loading conditions near the top of the pole. The difficulty of modelling these effects in PoleCheck1.0 is due to the fact that none of the lookup tables have considered the effects of equipment weight and surface area when determining pole utilizations. Again, no options exist to account for the effect of equipment in PoleCheck1.0 except to apply a completely arbitrary adjustment factor to the pole utilization. Also, as with slack-spans equipment weight usually does not significantly impact pole class selection unless the equipment is particularly large. For this reason, PoleCheck1.0 does not model any equipment structures on poles and, instead, relies on the designer and authenticating engineer to apply engineering judgment to structures that contain equipment in order to account for its effect.

While the PoleCheck1.0 constraint module has significant gaps in the conditions that it can consider for pole loading cases, its lookup tables are derived from a tool that is being actively used by the DFO for the design of DOP and numerous other DFO's across Canada are currently using tools with similar limitations [personal correspondence with CSA C22.3 No. 7 Working Group voting member]. Tools such as PoleCheck1.0 are designed with the intention that professional judgment is needed to fill the gaps in the tool's capabilities. The use of superposition of pole utilizations, the lack of consideration of slack-span and equipment loading on pole structures are all attempts by the PoleCheck1.0 constraint module to approximate the judgment process that a designer must progress through when determining if a particular pole utilization from the module is accurate.

Finally, it is important to note that another major drawback in the use of PoleCheck1.0 are the significant number of missing pole utilization data points that occur within the lookup tables, themselves. Unlike PoleCheck2.0, the PoleCheck1.0 lookup tables are generated by hand through extensive manual analysis performed by the DFO's standards group. As a result, the potential exists for human error or for certain cases to be left out that are considered unlikely candidates in real-world scenarios. Unfortunately, in the course of the genetic algorithm optimization process performed by AutoDesigner, many unlikely candidate individuals are routinely evaluated before the optimization can converge on a desired output. As a result, the use of PoleCheck1.0 presents stability issues for AutoDesigner where certain structure patterns produce constraint violations due to missing cases which then forces AutoDesigner to make use of non-optimal structure patterns just to avoid the constraint violations produced by the missing structures. This decision can appear to be the result of an optimization error made by AutoDesigner when in fact it is due to missing information on the PoleCheck1.0 tables.

As can be seen above, PoleCheck1.0 presents many limitations and challenges and is simply not an adequate pole-loading tool for use by automated DOP design software that is being deployed to novice users. For this reason, the original scope of the thesis is expanded to include the development and testing of PoleCheck2.0 which effectively mitigates almost all of the limitations presented by PoleCheck1.0. Discussion on PoleCheck2.0 is provided in Chapter 4.

3.5 Output of Final Design Documents from AutoDesigner

After the top performing individual is determined and the genetic algorithm terminates its optimization process, a series of final design documents are generated and added to the same file location as the survey CSV file. The generated design documents are in a format that is recognizable by the DFO's designers and is intended to fit seamlessly with existing design practices utilized by the DFO. The final design documents that are generated by AutoDesigner for the final DOP design are as follows:

1. Final design staking list,

2. DFO material management system CSV loading file,

3. Battery of ClearanceCalc output summary reports,

4. Battery of FloaterCheck output summary reports,

5. Battery of PoleCheck2.0 output summary reports,

6. Text file summary of all constraint module outputs,

3.5.1 Final Staking List

The final staking list comprises the primary output from AutoDesigner and contains all of the final design data that is generated by AutoDesigner for the best performing individual from the genetic algorithm optimization. Note that the final staking list is generated in much the same manner as the preliminary staking list, which is discussed in Subsection 3.2.6 and even the same methods are used within the Pole and Span classes for the preliminary staking list are used to generate the final staking list. The main difference between the final and preliminary staking lists is the state of the optimizable design parameters which are denoted with '*' characters on the preliminary staking list. In the case of the final staking list, all fields on the staking list are fully populated and colour-coded to represent new, existing and salvaged structures. Figure 3.12 illustrates the final staking list for the design that is first introduced in Figure 3.3. Note that for illustrative purposes, the preliminary staking list from Figure 3.6 is reprinted alongside the final staking list to show the user the specific changes that are made between the two documents.

As can be seen in Figure 3.12, most of the changes that occur between the preliminary and final staking lists relate to the filling in of all '*' fields with final design parameter values. That being said, it can be seen that existing pole 475119 near the top of the list is being converted from an existing pole in the preliminary staking list to a pole that is being salvaged and replaced with a new structure in the final staking list. As a result, the colour-coding and structures associated with pole 475119 have changed despite the fact that, at the time of generating the preliminary staking list, the structure did not appear to be optimizable. Furthermore, it can also be seen that

Preliminary Staking List:

ELEV (m)	STR. NO.	ASSET ID	DEFLN	SPAN (m)	HEIGHT/CI	TYPE
4 x 1/0 ACSR Raven OVERHEAD - MEDIUM						
285.39	475119	475119	L 084°31'		0/0	Ex. Pole: 35/6,R240
				29.61		*Potential Slack-Span
285.0	150		L 002°28'		*/*	,*
				32.66		*Potential Slack-Span
284.83	151		L 000°02'		*/*	,*
				106.50		
284.53	152		R 000°01'		*/*	,*
				106.49		
284.33	153		L 000°00'		*/*	,*
				106.49		
284.20	154		L 000°00'		*/*	,*
				106.49		As-Built P/L ___ m at ___ °C 70 m from STR#154
283.77	155		R 000°00'		*/*	,*
				106.70		
284.25	156		L 000°00'		*/*	,*
				99.00		As-Built RD ___ m at ___ °C 7 m from STR#156 As-Built RD ___ m at ___ °C 9 m from STR#156 As-Built RD ___ m at ___ °C 12 m from STR#156
284.14	157		R 000°00'		*/*	,*
				99.01		
284.18	158		L 000°00'		*/*	,*
				99.00		
283.93	159		R 000°00'		*/*	,*
				98.99		
283.76	160		R 000°00'		*/*	,*
				99.00		
283.60	161		L 000°00'		*/*	,*
				99.01		
283.58	162		R 000°00'		*/*	,*
2 x #4 ACSR Pollock OVERHEAD - MEDIUM						
284.25	156		L 106°07'		0/0	Material Already Called For
				9.89		Slack-Span
284.25	475109	475109	R 016°09'		0/0	Ex. Pole: 35/6,R212, R0,E12,G10

Final Staking List:

ELEV (m)	STR. NO.	ASSET ID	DEFLN	SPAN (m)	HEIGHT/CI	TYPE
3 x 1/0 ACSR Raven OVERHEAD - MEDIUM						
285.39	475119		L 084°31'		40/5	Salv. Ex Pole: 35/6,R240 Install New: N42(L),R254,Deep-Set: 1.0m
				29.61		Slack-Span
285.0	150		L 002°28'		40/4	N52,R0,E12,G60FFF(7m West)
4 x 1/0 ACSR Raven OVERHEAD - MEDIUM						
285.0	150		L 002°28'		40/4	N52,R0,E12,G60FFF(7m West)
				32.66		
284.83	151		L 000°02'		45/5	N12,R254,N0C,G40BF(7m North)
				106.50		
284.53	152		R 000°01'		45/5	N12,N0C
				106.49		
284.33	153		L 000°00'		45/5	N12,N0C
				106.49		
284.20	154		L 000°00'		45/5	N12,N0C,E12
				106.49		As-Built P/L ___ m at ___ °C 70 m from STR#154
283.77	155		R 000°00'		45/5	N12,N0C
				106.70		
284.25	156		L 000°00'		45/5	N12,R254,R254,N0C
				99.00		As-Built RD ___ m at ___ °C 7 m from STR#156 As-Built RD ___ m at ___ °C 9 m from STR#156 As-Built RD ___ m at ___ °C 12 m from STR#156
284.14	157		R 000°00'		40/5	N12,N0C
				99.01		
284.18	158		L 000°00'		45/5	N12,N0C,E12
				99.00		
283.93	159		R 000°00'		40/5	N12,N0C
				98.99		
283.76	160		R 000°00'		45/5	N12,N0C
				99.00		
283.60	161		L 000°00'		45/5	N12,N0C
				99.01		
283.58	162		R 000°00'		45/4	N42,R0,E12,G60FFF(10m East)
1 x #4 ACSR Pollock OVERHEAD - MEDIUM						
284.25	156		L 106°07'		0/0	Material Already Called For
				9.89		Slack-Span
284.25	475109	475109	R 016°09'		0/0	Ex. Pole: 35/6,R212,R0,G10(5m South)

Figure 3.12: Sample of Final Staking List Alongside Preliminary Staking List.

span fields that are denoted with "*Potential Slack Span" tags on the preliminary staking list may or may not end up being classified as actual slack spans in the final staking list. For example, on the final staking list, the potential slack span between pole 475119 and pole 150 is classified as a slack-span on the final staking list while the potential slack span between pole 150 and 151 ends up being classified as a tight span on the final staking list.

Finally, the final staking list also prints the additional columns to the right of main staking list body as shown in Figure 3.7 for the preliminary staking list. As is the case with the preliminary staking list, these columns provide the user with much of the detailed design information contained within the Pole and Span objects of the final optimized linked list data structure representing the DOP. That being said, the final staking list is considered final and no provision exists for entering user constraint values as may be done on the preliminary staking list.

3.5.2 DFO Material Management CSV Loading File

In addition to the final staking list, a material management loading file is generated in a format that can be directly uploaded into the DFO's material management software. Unlike the final staking list, the material management CSV loading file does not contain information on spans, pole deep-sets, anchor directions and lengths or crossing locations under spans. Instead, the file only contains information relating to material structures such as pole structures, pole top attachments, guy wires, and ground rods. The distinction between new, existing and salvaged structures is made by means of text colouring individual structures or attachments based on the red, black and green convention used throughout the thesis. Figure 3.13 illustrates a sample of the material management CSV loading file that is produced for the design shown in Figure 3.3.

475121	35/5	R140	R180	E12	G10			
475120	35/6	R252	R0	E12	EXANC			
475119	35/6	R240	40/5	N42	R254			
150	40/4	N52	R0	E12	G60	ANC-F	ANC-F	ANC-F
151	45/5	N12	R254	N0C	G40B	ANC-F		
152	40/5	N12	N0C					
153	40/5	N12	N0C					
154	40/5	N12	N0C	E12				
155	40/5	N12	N0C					
156	40/5	N12	R254	R254	N0C			
157	40/5	N12	N0C					
158	40/5	N12	N0C	E12				
159	40/5	N12	N0C					
160	40/5	N12	N0C					
161	40/5	N12	N0C					
162	40/5	N42	R0	E12	G60	ANC-F	ANC-F	ANC-F
475109	35/6	R212	R0	E12	G10			
475110	40/5	R140	R180	E12	G10			
205526	45/5	R180	R140	E12	G10	R240	E3	
475116	40/5	R212	R0	E12	G10			
475117	35/6	R112						

Figure 3.13: Sample of DFO Material Management CSV Loading File Output.

3.5.3 PoleCheck2.0, ClearanceCalc and FloaterCheck Output Reports and Summary Text File

As discussed in the previous section, the ClearanceCalc and FloaterCheck constraint modules both generate a final output Excel report for each span or pole that is evaluated by the constraint modules in the final DOP design after the genetic algorithm optimization is complete. Similarly, as discussed in Chapter 4, the PoleCheck2.0 constraint module also generates a final Excel-based output report during the evaluation of the final DOP design that summarizes the assumptions and force vectors that contribute to the pole loading condition. The complete battery of output reports is added to a folder titled 'calculations' which is located in the same directory as the survey CSV loading file after AutoDesigner terminates execution of the genetic algorithm. While the output reports serve as a detailed justification of the relevant design calculations performed by the constraint modules, AutoDesigner also provides a more succinct summary text file that does not require the user to open numerous Excel sheets. Figure 3.14 illustrates a sample of the output from the summary text file for a portion of the DOP design shown in Figure 3.3.

```
Pole Check, Clearance Calc and Floater Check Outputs:
Clearance Calc: 475120 - 475119 Clearances Meet Required Height: PED -> 6.1571903682676865 >
4.8
poleCheck str 475119: : No Pole Check Rows Found -> Pole Utilization:0.0%
Clearance Calc: 475119 - 150 Clearances Meet Required Height: PED -> 6.933292631522818 > 4.8
poleCheck str 150: N42,R0: (Medium, 110m Ruling Span, 0° Deflection, G60: 7m,  1/0 ACSR
Raven, 40ft pole,  Western Red Cedar,  Class: 4 Pole, 61.72% Utilization) -> Pole
Utilization:61.72%
Clearance Calc: 150 - 151 Clearances Meet Required Height: PED -> 7.42624825652282 > 4.5
Floater Check: 151 No Floater Issues -> 106.84279014334784 + 83.81353641966824 =
190.65632656301608m
poleCheck str 151: N12,N0 + R254: (Medium, 110m Ruling Span, 0° Deflection, 0m,  1/0 ACSR
Raven, 45ft pole,  Western Red Cedar,  Class: 5 Pole, 47.71% Utilization) +
(Medium, 110m Ruling Span, 0° Deflection, G40: 7m,  #4 ACSR Pollock, 45ft pole,  Western Red
Cedar,  Class: 5 Pole, 14.51% Utilization) -> Pole Utilization:62.22%
Clearance Calc: 151 - 152 Clearances Meet Required Height: PED -> 5.7387627965484285 > 4.5
Floater Check: 152 No Floater Issues -> 22.690874775371967 + 56.8162785584199 =
79.50715333379188m
Pole Check: Pole 152(_m_N12,Neut(SL)_11--): Deep-Set: 0.0, (Loading: medium, Grade Inc: 2,
Grade Out: 2, Incoming Span: Tight, 1/0 ACSR Raven, 112.2m span length, Outgoing Span:
Tight, 1/0 ACSR Raven, 112.2m span length, Deflection Main: 180.0°, 40ft Western Red Cedar
pole,  Class: 5, 86.14% Utilization)
```

Figure 3.14: Sample of Calculation Output Summary Report.

References

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[5] Distribution Facility Operator with Service Area in Alberta, Canada, *Distribution construction standards manual*, English, version Last Updated April 15, 2020, Distribution Facility Operator, 978 pp., April 2020.

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[9] Government of Canada, *The utm grid - civilian utm grid reference*. [Online]. Available: https://www.nrcan.gc.ca/earth-sciences/geography/topographic-information/maps/utm-grid-map-projections/utm-grid-civilian-utm-grid-reference/9785.

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Chapter 4

Methodology of PoleCheck2.0

Chapter 4 discusses the implementation of PoleCheck2.0 as a constraint module for use by AutoDesigner. PoleCheck2.0 is essentially a large repository of lookup tables that contain FEA pole utilization results produced by PLS Pole for different combinations of pole structure patterns, loadings, deflections, span tensions, conductor types, pole heights, pole classes and pole compositions [7]. This chapter discusses the two modules that comprise the generation script for the PoleCheck2.0 data tables along with briefly discussing the implementation of PoleCheck2.0 in AutoDesigner.

4.1 Pole Case Generation Module

The first module of the PoleCheck2.0 generation script is a PLS Pole case generator. The module is written using Python and takes, as input, a manually populated spreadsheet referred to as the PoleCheck2.0 structure list. At the time of the thesis evaluation, the PoleCheck2.0 structure list contains nearly 2,000 rows where each row represents the full set of physical parameters that are required to generate a complete PoleChek2.0 lookup table using PLS-Pole. The PoleCheck structure list is derived from the structure parameter list that is discussed in the previous chapter. Each row from the structure parameter list is expanded by manual data entry into as few as two or as many as several dozen PoleCheck2.0 structure list rows where each row considers a unique combination of possible tight or slack span configurations on the pole and the potential neutral attachment locations in the event that the "Neut" tag is present in the structure pattern. The pole case generator module outputs an intermediate spreadsheet, referred to as the PLS Pole FEA case list, where each row of the spreadsheet contains the complete set of data required by PLS Pole to perform FEA on a single pole configuration. Where a structure parameter list row may be multiplied into dozens of PoleCheck2.0 structure list rows, the PLS Pole FEA case list is expanded by the pole case generator to contain up to several thousand times more rows than that of the PoleCheck2.0 structure list. The first three stages of the flowchart depicted in Figure 4.1 illustrates the multiplicative relationship between a single structure pattern on the structure parameter list, the number of rows on the PoleCheck2.0 structure list and the number of rows present on the PLS Pole FEA case list.

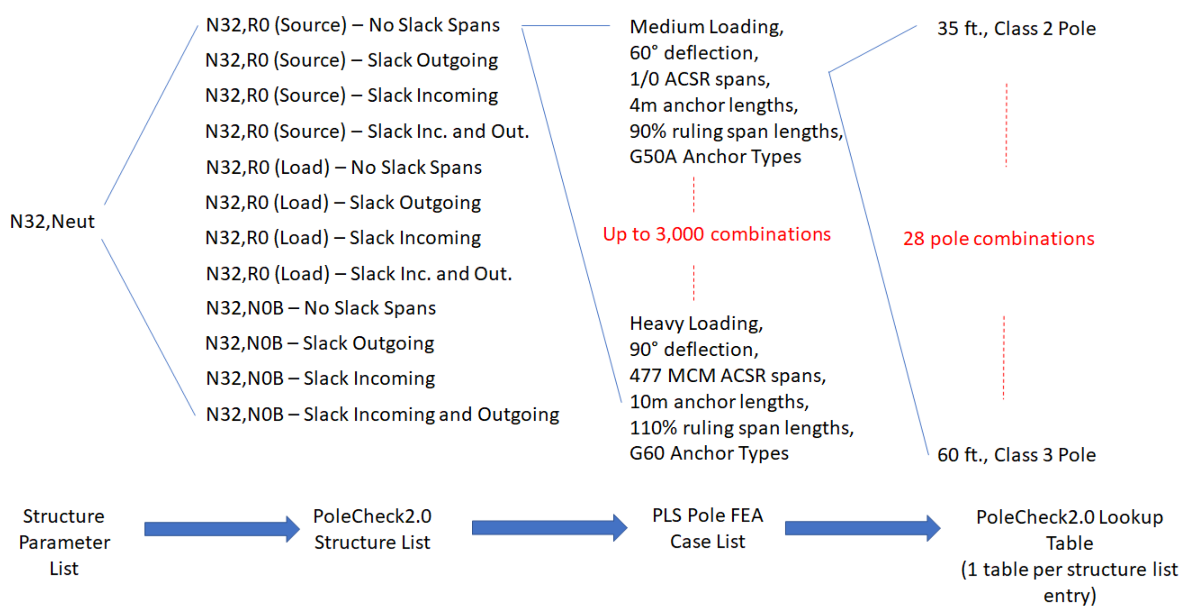


Figure 4.1: Tree Expansion of PoleCheck2.0 Lookup Tables from Structure Parameter List Entry.

The PoleCheck2.0 structure list specifies the physical parameters that are necessary to model a pole structure in PLS Pole as well as the complete range of variability for each manipulated variable that is to be considered in the final PoleCheck2.0 lookup table. Physical parameters that are included as fields on the PoleCheck2.0 structure list and which are needed to model a pole structure in PLS include measurements such as:

- attachment heights of cross-arms or conductors,
- pole set depth,
- weights of attachments and pole-mounted equipment,
- deflections of conductor spans,
- types of conductors,
- types of anchors,
- lengths of anchors.

For a complete list of parameters that are specified on the PoleCheck2.0 structure list as well as descriptions, please refer to Table A.11 in Appendix A.

It is not enough for the PoleCheck2.0 structure list to merely specify the physical attachments and geometry on a pole structure given that a single row of the PoleCheck2.0 structure list is ultimately expanded to form a complete PoleCheck2.0 lookup table. A lookup table requires a set of manipulated variables that can be varied by the user for which results are readily available. The PoleCheck2.0 structure list must, therefore, be capable of specifying physical parameters that need to be varied as well as the range of values that each ranged parameter may assume. Table A.11 in Appendix A flags the parameters on the PoleCheck2.0 structure list that may assume ranged values. Specifying ranged values on the PoleCheck2.0 structure list is accomplished by either populating both a minimum and a maximum parameter field that explicitly exists on the structure list for the purposes of creating a range of values or by listing multiple values in a single cell and using commas to delineate each value that is to exist within the range. Figure 4.2 lists each of the PoleCheck2.0 structure list parameters that may contain ranged values and, using the N32 corner deflection structure pattern as an example, demonstrates how the ranged functionality of PoleCheck2.0 structure list may be utilized.

PoleCheck2.0 Structure List Parameter(s) with Range Functionality	Sample Range for N32,Neut Structure	Corresponding Manipulated Variable on PoleCheck2.0 Lookup Table	Description
Loading	heavy,medium	Loading	Heavy and medium loading conditions are to be considered for all structure combinations on list.
GradeInc	1,2	GradeInc	Grade 1 and grade 2 construction is to be considered for incoming span.
GradeOut	1,2	GradeOut	Grade 1 and grade 2 construction is to be considered for the outgoing span.
CondTypesAttach1	6,8,9	CondTypeIncMain	1/0 ACSR, 266 MCM ACSR and 477 MCM ACSR are to be considered on the incoming span for all structure combinations.
CondTypesAttach2	6,8,9	CondTypeOutMain	1/0 ACSR, 266 MCM ACSR and 477 MCM ACSR are to be considered on the outgoing span for all structure combinations.
minDeflAttach2; maxDeflAttach2	0,0,0; 30,30,30	DeflectionMain	The deflection of the outgoing mainline with respect to the incoming mainline must assume deflections of 0°, 10°, 20° and 30° for 1/0 ACSR, 266 MCM ACSR and 477 MCM ACSR for all combinations of the other manipulated variables.
typeAncOne	G50A,G40A	AncType	Both the G40A and G50A anchor types for anchoring the incoming mainline are to be considered for all combinations of the other manipulated variables.
lenMinAncOne, lenMaxAncOne	4,4; 10,10	anc1Length	Incoming mainline anchor length must assume lengths of 4.0m, 6.0m, 8.0m and 10.0m for all combinations of the other manipulated variables.
typeAncTwo	G50A,G40A	AncType	Both the G40A and G50A anchor types for anchoring the outgoing mainline are to be considered for all combinations of the other manipulated variables.
lenMinAncTwo, lenMaxAncTwo	4,4; 10,10	anc2Length	Ougoing mainline anchor length must assume lengths of 4.0m, 6.0m, 8.0m and 10.0m for all combinations of the other manipulated variables.

Table 4.1: Table of PoleCheck2.0 Structure List Parameters that Contain Ranged Values for the N32 Structure Pattern.

The PoleCheck2.0 structure list is formatted in a manner that allows for up to four separate span attachment points to be modelled on a pole, up to two anchor attachments as well as a dedicated neutral attachment point that may have up to four vertically-spaced neutral attachments which is to be resolved to a single point load on the pole. Each span attachment on the pole may have an incoming and outgoing span defined on the PoleCheck2.0 structure list that is resolved to a single point load on the pole. The incoming span of attachment 1 is, by default, considered to have a conductor orientation of 0° in the PoleCheck2.0 case generator which corresponds to the positive Y direction, in cartesian coordinates in PLS-Pole . The orientation of the subsequent attachments is defined in reference to the incoming span of attachment 1. Note that the second, third and fourth span attachments may alternatively contain pole-mounted equipment in place of a conductor span, in which case the surface area and weight of the equipment must be specified on the PoleCheck2.0 structure list.

Note that the four conductor attachment points on the pole do not need to be defined on the PoleCheck2.0 structure list as being the incoming mainline span, the outgoing mainline span, etc. Instead, the PoleCheck2.0 case generator reasons out through rule-based analysis what each attachment on the pole represents, physically. The below list provides a summary of the rule-based analysis for the first two phase attachments specified on the PoleCheck2.0 structure list:

If, current attachment being investigated is attachment 1,

> **If,** attachment 1 has an incoming span specified on the structure list,
>
> **Then,** denote the attachment 1 incoming span as being the incoming mainline span,

If, attachment 1 has an outgoing span specified on the structure list,

Then, denote the attachment 1 outgoing span as being the outgoing mainline span.

If, Current attachment being investigated in attachment 2,

If, attachment is defined as being synchronized with attachment 1,

Then, treat attachment 2 as being a part of the inline tangent structure specified by attachment 1 with attachment 2's incoming and outgoing conductors considered as being a component of the incoming and outgoing mainline spans. (e.g. N12 pole-top structure).

Else if, attachment 2 is not synchronized with attachment 1, attachment 2's incoming spans are not specified, and attachment 1 has both incoming and outgoing mainline spans,

If, attachment is defined as being synchronized with attachment 1,

Then, treat attachment 2 as representing tap-off 1.

Else if, attachment 1 does not contain an outgoing span while attachment 2 does not contain an incoming span,

Then, treat attachment 2's outgoing span as representing the outgoing mainline span (e.g. N32 pole-top structure).

Note that once each of the attachments defined in the PoleCheck2.0 structure list is mapped to a corresponding conductor span, equipment structure or neutral attachment, the task of converting the attachment points into force vectors is undertaken. As discussed in Chapter 2, the force vectors that are applied to a pole attachment are composed of transverse, longitudinal and vertical components. Note that each attachment point is modelled in PLS-Pole as a concentrated load with an attachment elevation that is equal to that of the top mounting bolt of the attachment of the actual constructed structure. Each concentrated load is composed of a longitudinal, transverse and vertical force component that acts on the pole model as shown in Figures 2.5 and 2.6.

4.1.1 Longitudinal Pole Loading Calculation

PoleCheck2.0 calculates the longitudinal force for each attachment point on the pole that supports conductor spans. Note that equipment structure attachments only contribute a transverse and vertical force component to the pole loading and do not have a longitudinal force component. As discussed in Chapter 2, the longitudinal force is the result of conductor tension pulling on the pole structure. In the case of inline tangent structures, most or all of the longitudinal forces from a span may be cancelled at the attachment point by another opposing span that is pulling in the opposite direction.

The longitudinal force of each span component (incoming and outgoing) of a pole attachment is calculated using equation 4.1 [4]. The two components are then added together, vectorially.

$$F_{L,s} = LF_s * A_{v,a} * \phi_s * T_{c,s} \qquad (4.1)$$

where,

$$\boldsymbol{F_{L,s}} = Longitudinal\, force\, for\, a\, span\, of\, single\, phase\, or\, three\, phase\, conductor$$

$$(pulling\, outward\, from\, pole\, in\, the\, direction\, of\, the\, conductor\, span).$$

$$\boldsymbol{LF_s} = Loading\, factor\, for\, the\, span\, as\, per\, Canadian\, Electrical\, Code\, C22.3\, No.1,$$

$$see\, Table\, 2.2$$

$$\boldsymbol{A_{v,a}} = Attachment\, to\, conductor\, vertical\, ratio\, for\, attachment.$$

$$Common\, values\, include\, 1.05\, or\, 1.02.\; Accounts\, for$$

$$the\, increased\, force\, exerted\, by\, conductor\, on\, pole\, due\, to$$

$$wire\, attachment\, heights\, that\, are\, higher\, than\, the\, bolt\, attachment\, point.$$

$$\boldsymbol{\phi_s} = Number\, of\, phases\, for\, conductor\, span\, under\, investigation.$$

$$\boldsymbol{T_{c,s}} = Conductor\, tension,\; as\, per\, Table\, 2.3\, for\, the\, conductor\, span\, under$$

investigation

Note that the attachment to conductor vertical ratio is extracted from the PoleCheck2.0 structure list as a static value and does not change on the basis of the pole height being investigated by PoleCheck2.0. While, technically the ratio should decrease with increasing pole structure heights, the attachment to conductor vertical ratio is created with the conservative assumption that all pole heights are 35 ft which represents the minimum pole height considered by PoleCheck2.0.

4.1.2 Vertical Pole Loading Calculation

Vertical loading applied to attachment points are the result of the weight exerted by equipment, attachment fixtures such as cross-arms or insulators, or the conductor that is being supported by the attachment fixtures. Note that for conductor spans, the weight contribution from only half of the span length is considered as being supported by a given pole structure [4]. Furthermore, the weight of ice loading must be accounted for when assessing conductor weight. In the case of medium loading weather conditions, conductor weight must include 6.5mm of ice loading, while in heavy loading conditions the conductor weight must include 18.0mm of ice loading [4].

Equation 4.2 outlines the method that that the PLS case generator uses to calculate vertical forces at each attachment point.

$$F_{V,a} = 0.5 * L_{inc} * W_{inc} * \phi_{inc} * g * LF_{inc} +$$
$$0.5 * L_{out} * W_{c,out} * \phi * g * LF_{out} \qquad (4.2)$$

where,

$$\boldsymbol{F_{V,a}} = Vertical\,force\,for\,a\,single\,attachment\,point\,(pulling\,downwards).$$

$$\boldsymbol{L_{inc}} = Incoming\,span\,length\,in\,metres.$$

$$\boldsymbol{W_{inc}} = Unit\,conductor\,weight\,in\,kg/m,\;for\,incoming\,conductor$$

$$span\,for\,heavy\,or\,medium\,loading.$$

$$\boldsymbol{\phi_{inc}} = Number\,of\,phases,\;incoming.$$

$$\boldsymbol{g} = Standard\,acceleration\,due\,to\,gravity,\;m/s^2.$$

$$\boldsymbol{L_{out}} = Outgoing\,span\,length\,in\,metres.$$

$$\boldsymbol{W_{out}} = Unit\,conductor\,weight\,in\,kg/m,\;for$$

$$outgoing\,conductor\,span\,for\,heavy\,or\,medium\,loading.$$

$$\boldsymbol{\phi_{out}} = Number\,of\,phases,\;outgoing\,span.$$

4.1.3 Transverse Pole Loading Calculation

As discussed in Chapter 2, transverse loading results from the effect of wind forces that are exerted on a conductor span, equipment installation or structure attachment fixtures. Transverse loading is directly proportional to the surface area of the conductor, equipment or attachments.

The PoleCheck2.0 case generator calculates wind loading forces for eight possible directions in 45° increments. As per the requirements specified in the CSA C22.3 No.1 electrical code, wind loading must be applied to a conductor with a specified amount of ice loading or frost loading, which represents the worst-case wind-loading condition. In the case of medium loading, 6.5mm of ice loading is assumed to be present on the conductor while under heavy loading conditions 18.0mm of ice-loading is present [4]. Note that the PoleCheck2.0 case generator models the ice-loaded surface area as a flat-faced surface of dimensions that are equal to the diameter of the conductor plus twice the ice-loading thickness. As with the vertical loading calculation, each pole is required to withstand the wind-loading for half of the span length for each span that is supported by the pole.

Note that the transverse loading vector is be applied strictly in the horizontal and orthogonal incident angle with respect to the conductor span. As a result, the wind loading vector and the transverse loading vector are not identical. Figure 4.2 illustrates the resolved force vectors on a number of conductor spans attached to a pole.

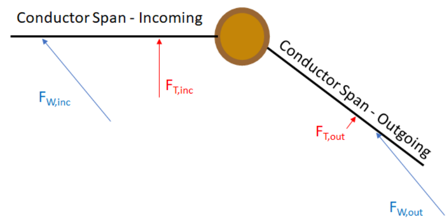


Figure 4.2: Illustration of Resolved Wind Loading Vectors on Conductor Spans.

Note that equations 4.3 and 4.4 depict the calculation for the wind force loading vector prior to being resolved into the transverse loading vector that is orthogonal and incident to the conductor span.

$$F_{W,s} = P * 0.5 * D_{c,tot,s} * \phi_s * g * LF_s * A_{v,a} \qquad (4.3)$$

$$D_{tot,s} = D_{c,s} + 2 * T_{Ice} \qquad (4.4)$$

where,

$$\boldsymbol{F_{W,s}} = Wind\,loading\,force\,on\,pole\,for\,a\,given\,span\,in\,kN.$$

$$\boldsymbol{P} = Wind\,pressure\,in\,N/m^2.$$

$$\boldsymbol{\phi_s} = Number\,of\,phases\,for\,conductor\,span\,under\,investigation.$$

$$\boldsymbol{LF_s} = Loading\,factor\,for\,span\,as\,per\,Canadian\,Electrical\,Code\,C22.3\,No.1,\;see$$

$$Table\,2.2$$

$$\boldsymbol{A_{v,a}} = Attachment\,to\,conductor\,vertical\,ratio\,for\,attachment.$$

$$Common\,values\,include\,1.05\,or\,1.02.\;Accounts\,for\,the\,force\,increase$$

$$due\,to\,conductor\,being\,installed\,vertically\,above\,the\,attachment\,bolt.$$

$$D_{tot,s} = Total\,diameter\,of\,conductor\,and\,ice\,loading\,in\,meters\,for\,span$$

$$D_{c,s} = Conductor\,diameter\,in\,meters\,for\,span$$

$$T_{Ice} = Ice\,thickness\,in\,meters.$$

Finally, once the wind-loading force vector is computed, the transverse loading vector is determined using equation 4.5 [26].

$$\vec{F_{T,s}} = \vec{F_{W,s}} - \left[\frac{\vec{F_{W,s}} \cdot \vec{C_s}}{\vec{C_s} \cdot \vec{C_s}} \right] * \vec{C_s} \qquad (4.5)$$

where,

$$\vec{F_{T,s}} = Transverse\,loading\,force\,on\,pole\,for\,a\,given\,span\,in\,kN.$$

$$\vec{C_s} = Unit\,vector\,representing\,conductor\,orientation\,with\,respect\,to\,pole\,for\,span.$$

It is important to note that since the wind loading is calculated from eight possible directions, each wind loading calculation performed by the PoleCheck2.0 case generator results in a list of eight values.

4.1.4 Generation of PLS Pole FEA Case List

Once the pole loading is calculated for each attachment on a pole structure, the PLS Pole FEA case list is generated. Each row of the PLS Pole FEA case list comprises a single case that must be evaluated using the Optimal Pole Selection module within PLS Pole which is discussed in detail in the next section [7]. As a result, each row of the PLS Pole FEA case list must contain the complete set of information that is required by PLS Pole. PLS Pole performs FEA on a pole structure using a pole model file (.pol) as well as a loading file (.lca). The pole model file contains details on the physical dimensioning of attachment points, pole set depths and anchor lengths while the loading file contains the complete candidate set of force vectors that are to act on each attachment point of the pole structure [7].

Each force vector recognized by the loading file is composed of the vectoral sum of the longitudinal, vertical and transverse force components as discussed in the previous subsection and which are then further transformed into cartesian coordinates for use by PLS. Note that, as discussed in the previous subsection, the transverse force component of each attachment force vector contains eight different unique values which is the result of wind loading being considered from eight possible directions. As a result, for each attachment force load value, the loading file must contain eight different force loadings to represent the various wind directions. Table A.12 in the Appendix lists the complete set of data fields contained in each row of the PLS Pole FEA case list as well as distinguishing between whether each data value corresponds to a value that is added to the pole model file or the loading file.

A data field within the PLS Pole FEA case list that is of particular interest is the justification string. The justification string contains text specifying detailed equations that derive the longitudinal, vertical and transverse loading forces for each attachment on the pole structure. The justification string is utilized in the PoleCheck2.0 output report and is intended to provide the designer with a complete explanation of all calculations that occur prior to the application of FEA to the pole structure.

4.2 PLS Pole User Interface Automation and PoleCheck2.0 Table Generation

Once the PLS Pole FEA case list is generated, each row of the list is then used to perform a battery of FEA runs using PLS-Pole for all of the combinations of pole heights and classes that are listed in Table 2.1. The content of each individual PLS Pole FEA case list row is loaded into a templated PLS pole model file and a templated loading file which are both required by PLS Pole in order to perform FEA [7]. PLS Pole allows for the pole model file and loading files to be saved in an ASCII format which means that the files can be easily searched and populated within Python by loading the files as text strings. The pole model template file is created by taking a basic pole structure in PLS pole with five attachments and up to two anchors and where each attachment point supports a simple strain insulator that is capable of having a concentrated load applied to it via the loading file. Each concentrated load corresponds to one of the pole attachment loads calculated in the previous section. Note that the strain insulators do not serve a purpose on the pole besides providing a location to apply a pole attachment load. Geometric information such as the height and orientation of each strain insulator is removed from the template pole model file and replaced with identification labels that match the naming convention used in the first 40 columns of the PLS Pole FEA case list. Similarly, the loading file has had its numerical values representing the concentrated load force vectors in Newtons replaced with labels that match the columns of the PLS Pole FEA case list located after the 40th column (please refer to Table A.12 in the Appendix for a list of all column names from the PLS Pole FEA case list). By treating the two template files as data strings in Python, the various identification tags are easily located and populated with values from the corresponding parameter from the PLS Pole FEA case list using Python's 'replace' command. Please refer to the left-hand-side of Figure 2.5 in Chapter 2 for a sample of a fully populated pole model that is loaded into PLS Pole where there is a single G40 guy wire as well as three strain insulators carrying non-zero concentrated loads. In actuality, the pole shown in Figure 2.5 is approximating a structure that is similar to the N12,N55 structure shown in the bottom row of Figure 2.4.

Note that a significant number of templated pole model files are created due to the combination of possible guy wires as well as the potential presence of a pole deep-set for each structure pattern being investigated. Despite all conductor and equipment-based pole attachments being stripped away in the pole model and represented as concentrated loads in PLS Pole, the guy wires and poles are considered as a single structure that must undergo FEA and experience deformation as a result of the applied load [4]. The anchor types that may be placed on a pole includes the G40, G25, G50 and G60 anchors, while pole deep-sets of 0.0 and 1.0m are considered. As up to two anchors may be present at a given pole structure, a total number of 27 different templated pole model files are created for use by the automation script and where the specified file for a given PLS Pole case is determined based on the text string stored in the PoleBaseFile column of the PLS Pole FEA case list row (the parameter value contains the file name of the templated pole model file).

4.2.1 PLS Pole User Interface Automation Script

The module needed within PLS-Pole to perform FEA is referred to as the Optimum Pole Selector and is only accessible through PLS-Pole's user interface window with no provision for command line interface access [7]. As a result, it is necessary to develop an automation script in Python that is able to interact with PLS through automated keyboard strokes as well as automatic mouse clicks and movements. The pyAutoGUI library is used to enable the Python script to control mouse and keyboard operation during the generation of the PoleCheck2.0 tables. The user interface automation script performs the following actions:

1. Opens a populated pole model file from within PLS-Pole (note that the loading is already referenced internally within the templated pole model file and so it is automatically loaded into PLS along with the pole model file),

2. Initiate the Optimum Pole Selector from within PLS-Pole by opening the 'Model' drop-down menu and selecting 'Optimum Pole Selection' using hotkeys,

3. Control mouse movement within the Optimum Pole Selector interface to click and drag and select the available poles contained in the structure library and initiate the FEA,

4. Control mouse movements in the output report window of the Optimum Pole Selector to select the entire results text string and copy the contents to the clipboard,

5. Close the Optimum Pole Selector output report window as well as the pole model file window and await population of the next pole model and loading files by the PoleCheck2.0 generation script,

Illustrations of the Optimum Pole Selector interface window as well as the populated output report window, corresponding to steps 3 and 5 in the above list, are illustrated in Figures 4.3 and 4.4.

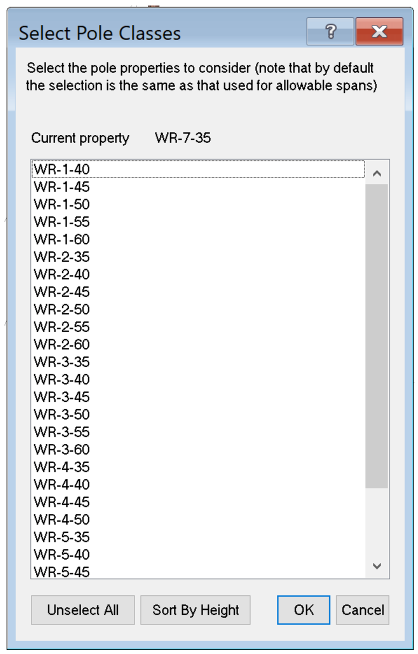


Figure 4.3: Illustration of the Optimum Pole Selector Interface Window.

As can be seen in Figure 4.4, pole heights and classes that result in a utilization that is less than 100% are considered by PLS Pole to be compliant structures configurations, while utilizations greater than 100% are found to be in violation. Furthermore, the pole selections that result in non-compatible geometries despite not having a pole utilization value defined.

Note that the automation script contains significant error-handling procedures beyond the basic capabilities listed above and three such capabilities are provided as examples. First, if none of the selected poles produce a pole utilization that is less than 100% then PLS-Pole produces an error message which the automation script is capable of handling by existing via a hotkey selection. Secondly, the automation script is designed to deal with variable speed of output report generation by repeat-

```
PLS-POLE Version 16.20x64    12:43:40 AM Sunday, July 26, 2020
ATCO Electric Distribution - Canada

Optimum Pole Selection Report:

Costs are determined by looking up the stock number for a pole property in the parts list.
A cost of 0.00 will be printed if the pole property does not have a stock number.
In multi-pole structures the cost and weight printed are per pole.

Trying "WR-1-40" cost $0.00 weight of 7130.0 (N) usage is 51.34% for pole "P1"   Current Best  ??
Trying "WR-1-45" cost $0.00 weight of 8596.0 (N) usage is 77.39% for pole "P1"
Trying "WR-1-50" cost $0.00 weight of 10061.8 (N) usage is 417.63% for pole "P1"   NG
Trying "WR-1-55" cost $0.00 weight of 11651.5 (N) usage is 374.77% for pole "P1"   NG
Trying "WR-1-60" cost $0.00 weight of 13370.1 (N) usage is 327.62% for pole "P1"   NG
Trying "WR-2-35" cost $0.00 weight of 5105.6 (N) usage is 56.70% for pole "P1"   Current Best  ??
Trying "WR-2-40" cost $0.00 weight of 6297.9 (N) usage is 78.88% for pole "P1"
Trying "WR-2-45" cost $0.00 weight of 7501.4 (N) usage is 479.06% for pole "P1"   NG
Trying "WR-2-50" cost $0.00 weight of 8817.4 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-2-55" cost $0.00 weight of 10250.7 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-2-60" cost $0.00 weight of 11627.2 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-3-35" cost $0.00 weight of 4446.3 (N) usage is 87.96% for pole "P1"   Current Best  ??
Trying "WR-3-40" cost $0.00 weight of 5413.4 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-3-45" cost $0.00 weight of 6481.5 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-3-50" cost $0.00 weight of 7655.4 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-3-55" cost $0.00 weight of 8789.6 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-3-60" cost $0.00 weight of 10006.0 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-4-35" cost $0.00 weight of 3749.7 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-4-40" cost $0.00 weight of 4595.8 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-4-45" cost $0.00 weight of 5536.2 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-4-50" cost $0.00 weight of 6451.6 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-5-35" cost $0.00 weight of 3188.4 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-5-40" cost $0.00 weight of 3933.6 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-5-45" cost $0.00 weight of 4767.4 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-6-35" cost $0.00 weight of 2743.7 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-6-40" cost $0.00 weight of 3323.5 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-6-45" cost $0.00 weight of 3962.7 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG
Trying "WR-7-35" cost $0.00 weight of 2267.8 (N) Problem performing analysis: the property probably isn't compatible with the pole's top geometry  NG

The best property is "WR-3-35" for which the pole weighs 4446.3 (N) and costs $0.00.
Your pole has been set to use this property.
```

Figure 4.4: A Sample of the Optimum Pole Selector Output Report.

edly copying to the clipboard the last characters of the output report and looking for a text string that matches the 'property.' string seen at the end of the report illustrated in Figure 4.4. Only once a fully generated output report is available does the user interface script copy the output report for final parsing of result data and then proceeds to close the report output window. Finally, since a given PoleCheck2.0 lookup table can include thousands of rows of entries in the PLS Pole FEA case list, many consecutive runs of the Optimum Pole Selector are typically required to produce a PoleCheck2.0 lookup table. After a significant number of runs (normally more than 600), PLS-Pole starts to experience lag and the generation time of the output reports starts to increase significantly. To handle the lag effect, the automation script is provided with the added capability to close PLS-Pole completely and restart the program after the lag exceeds a pre-determined amount of time. Restarting of PLS Pole is performed using hotkey commands to open the Windows 10 'Run' command bar and then relaunch PLS-Pole by entering the complete file path to the pole model file. Reliably restarting PLS requires significant pre-determined delays added to the automation script to allow for successful startup of the software. Furthermore, the automation script is given the ability to close numerous pop-up windows that are displayed during the PLS-Pole startup procedure to allow the script to eventually return to the main procedure listed above. Note that after several days of continuous operation, it is typically required for the workstation to be manually restarted as unforeseen errors such as the inability to open new pole model files or commands not being read due to operating system lag begin to manifest.

4.2.2 PoleCheck2.0 Table Generation

After each Optimum Pole Selector output report is copied to the clipboard by the automation script, the pole utilization data is extracted and added to a table that eventually forms a complete PoleCheck2.0 lookup table. The pole utilization data is stored in column 30 of the PoleCheck2.0 lookup table while the previous columns contain the values of the various manipulated variables that the PoleCheck2.0 user has the ability to specify. Note that 10 additional columns are located to the right of the pole utilization column in each PoleCheck2.0 lookup table and are reserved for the justification string that is discussed in the previous section. The justification string is copied from the PLS Pole FEA case list and is divided into 10 substrings which is done to minimize the file size of the numpy array which is used to print the PoleCheck2.0 CSV file. The justification string is added intermittently to the PoleCheck2.0 lookup table at the beginning of each new segment of rows that pertain to a unique Optimum Pole Selector run, which means that the justification string is printed to the PoleCheck2.0 lookup table every 28 rows. Please refer to Table A.13 in the Appendix for a complete list of all columns contained in the PoleCheck2.0 lookup table with descriptions provided.

Once a complete PoleCheck2.0 lookup table is assembled within Python, the columns are sorted into ascending alphanumeric order starting at column 29 and proceeding backwards to the first column. Note that columns 4 to 12 are excluded from the sorting procedure as they remain unchanged across a complete PoleCheck2.0 lookup table. The sorting procedure allows for a sequential searching algorithm to be implemented in AutoDesigner as discussed in the next section. A sequential search of the PoleCheck2.0 lookup tables is intended to allow for the shortest possible evaluation time of the PoleCheck constraint module during AutoDesigner's genetic algorithm optimization. Note that in addition to sorting, the automation script also inserts a row at the top of columns 1 through 26 of the PoleCheck2.0 lookup table that lists the row number indices of all value changes that occur in the column below. The indice list allows for an even faster searching time where AutoDesigner is not required to iteratively evaluate individual values in a PoleCheck2.0 table to find a match but can rather jump to the next indice as soon as the searching algorithm determines that a particular value is non-compatible. Finally, the PoleCheck2.0 lookup table is saved in a CSV format using a filename that is based on the 'Standard' column of the PLS Pole FEA case list as described in Table A.12 of the Appendix. Note that the trigger for the automation script to print a PoleCheck2.0 lookup table to file occurs whenever the value of the 'Standard' column in the PLS Pole FEA case list changes.

4.3 Implementation of PoleCheck2.0 in AutoDesigner's PoleCheck Constraint Module

The PoleCheck constraint module in AutoDesigner utilizes the PoleCheck2.0 lookup tables in a similar manner to that of PoleCheck1.0, however, there are some improvements that allow for an increased speed of computation. Unlike with PoleCheck1.0, the PoleCheck constraint module does not load all of the PoleCheck2.0 data tables into memory during program initiation and instead only loads the PoleCheck2.0 lookup tables that are required for a specific project as they are needed to evaluate pole loading. The data size of the PoleCheck2.0 data tables exceeds PoleCheck1.0 by more than three orders or magnitude where the total size of all PoleCheck2.0 lookup tables are likely to exceed 20 GB once tables are produced to cover all structure patterns listed in the structure parameter list. That said, the genetic algorithm optimization is likely to consider only a small fraction of the total lookup tables for a given project and so it is not necessary to load all of the tables into memory. For example, a project is classified as either medium or heavy loading in the user interface which can immediately eliminate up to half of the possible PoleCheck2.0 lookup tables as candidates for use by the genetic algorithm optimization for a given design. Once a PoleCheck2.0 lookup table is loaded into memory it is stored in a sparsely populated three-dimensional list data structure within Python where the indices of the first dimension correspond to the structure pattern row number on the structure parameter list while the remaining two dimensions contain the contents of the lookup table. The use of a sparse data structure allows for direct addressing of PoleCheck2.0 data tables which avoids the need for an iterative searching algorithm when retrieving lookup tables that have already been loaded into memory.

Another important feature utilized by the PoleCheck constraint module when searching Polecheck2.0 lookup tables is the ability to reverse the polarity of any tap-off spans that are modelled in AutoDesigner with respect to the mainline deflection. Reversing tap-off span polarity is an important feature because the PoleCheck2.0 lookup tables only study deflections of the outgoing mainline span in a single direction. For example, for an N12 inline tangent structure carrying 1/0 ACSR conductor, the PoleCheck2.0 tables consider deflections ranging from 0° up to 4° only in the rightward direction. That being said, in reality, the 0° up to 4° deflection may be oriented in either the left or right directions. For a normal N12 tangent structure modelled in PoleCheck2.0, the distinction between a left or rightward deflection is not relevant as wind loading is studied from eight possible directions and so equivalent results are obtained by symmetry. That being said, if a tap-off span is also present on the pole structure, the deflection direction of the outgoing mainline span becomes significant especially since PoleCheck2.0 considers the tap-off orientation on both sides of the pole. If the mainline span deflects in the leftward direction, it is important to reverse the orientation of the tap-off span on the pole structure in order for the correct PoleCheck2.0 tap-off deflection scenario to be assessed.

The PoleCheck constraint module also implements a mapping algorithm that establishes a relationship between anchor lengths and orientations specified on the survey CSV file and the anchor lengths and orientations specified in the PoleCheck2.0 lookup table. Each PoleCheck2.0 case specifies anchor lengths and orientations in the data dump at the end of the justification string. PoleCheck2.0 indicates anchor orientations by specifying which spans on the pole a given guy wire is anchoring. For example, if a single guy wire is indicated as anchoring an incoming and outgoing mainline span and there is a deflection of 30° in the leftward direction on the outgoing mainline span, then AutoDesigner interprets the anchor orientation as being 105° with respect to the incoming mainline span. In reality, the orientation of the anchor on the survey CSV file is unlikely to be measured exactly at 105° and so provided that the surveyed anchor orientation and the PoleCheck2.0 anchor orientation falls within 10° of each other, AutoDesigner projects the surveyed anchor length vectorially onto the PoleCheck2.0 anchor length and uses the slightly shortened length as the surveyed anchor length when searching for a minimum permissible anchor length in PoleCheck2.0.

Similar to PoleCheck1.0's implementation in AutoDesigner, AutoDesigner also is capable of placing inline anchors that are not specified on the survey CSV file provided that no crossings are present within 10.0m of the inline anchor location. As a result, in many cases the PoleCheck constraint module will not throw a constraint violation if an inline anchor is missing from the survey CSV file. On the other hand, in the event that an out-of-span anchor is missing from the survey CSV file, AutoDesigner will throw a constraint violation as the CSV file provides no visibility of potential conflicts that lie out-of-span.

The PoleCheck constraint module performs a sequential search of the required PoleCheck2.0 lookup table starting at the first column and moving rightward while utilizing the table indices at the top of the lookup table (Please refer to Table A.13 in the Appendix for a complete list of all columns contained in a PoleCheck2.0 lookup table). Once the correct value is identified for a particular PoleCheck2.0 parameter (e.g. heavy loading) the starting indice and the ending indice for the range of rows in the PoleCheck2.0 lookup table that contain this value is stored and the remaining search occurs between these two ranges. This process is repeated for each column of the PoleCheck2.0 lookup table up to and including the anchor length columns. Once the range of acceptable candidate pole structures is fully narrowed down, what often remains is a list of pole heights, classes, compositions and anchor types that have common values for all preceding columns in the PoleCheck2.0 lookup table. Unlike PoleCheck1.0 which selects the pole structure from the list whose utilization falls just under 100%, PoleCheck2.0 evaluates the material cost and labour of the pole and anchor type for all candidate structures and then selects the cheapest overall structure whose utilization falls below 100%. This method of selecting the optimal pole candidate is an improvement over the method used for PoleCheck1.0 since a proper cost optimization is now possible which compliments the larger cost optimization objective used in the genetic algorithm optimization. In cases when no pole candidates are found, a constraint violation is thrown. Note that when no candidates are found, the situation is often due to a missing anchor or a slack-span and tight-span combination on an inline tangent structure that does not allow for a tension change.

After a successful PoleCheck2.0 candidate is identified, a text string is created summarizing the various columns of the pole structure for inclusion in the calculation output summary report text file. Note that an example of the data string produced by PoleCheck2.0 can be seen in Pole 152 in Figure 3.14.

In additional to producing a calculation output text string, during the generation of the final output reports after the genetic algorithm optimization is complete, the PoleCheck constraint module also produces a custom Excel-based output report for all pole structures whose loading makes use of a PoleCheck2.0 lookup table. The PoleCheck constraint module utilizes the same 'openpyxl' library in Python as is used by the ClearanceCalc and FloaterCheck constraint modules. A single column in the PoleCheck2.0 report Excel sheet is populated with outputs from the PoleCheck constraint module which are subsequently mapped to the various fields of the output report. The PoleCheck2.0 output report formats and displays the complete justification text string along with outputs from the various columns from the PoleCheck2.0 lookup table. Figure 4.5 illustrates a sample of the PoleCheck2.0 output report.

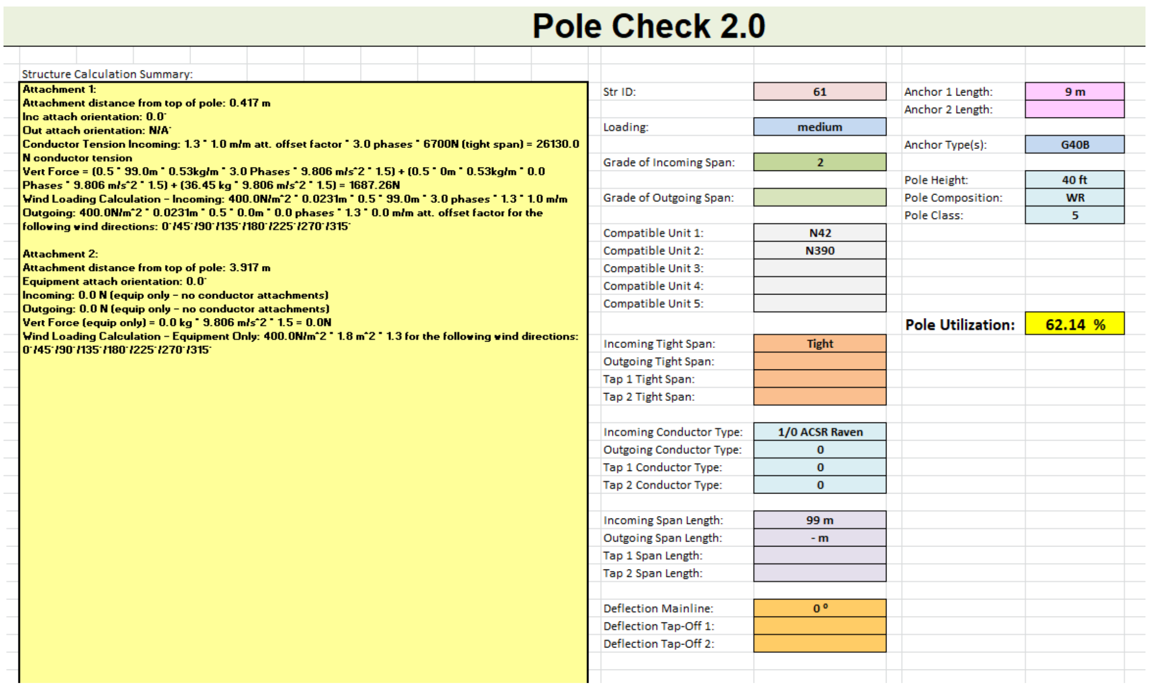


Figure 4.5: Sample of Output Report Generated by PoleCheck2.0 Constraint Module.

References

[4] CSA Group, *C22.3-no.1-15 oh system*, English, version June 2015, CSA Group, 190 pp., June 2015.

[7] Power Line Systems, *Pls pole version 14.40 user's manual*.

[26] Dan Margalit and Joseph Rabinoff, *Interactive linear algebra - 6.3 orthogonal projection*. [Online]. Available: https://textbooks.math.gatech.edu/ila/projections.html.

Chapter 5

Hyperparameter Optimization

As discussed in Chapter 3, the population size, crossover rate and mutation rate genetic algorithm hyperparameters are determined by means of a hyperparameter search. The hyperparameter search involves a rigorous trial of a large number of potential combinations of the three hyperparameters under investigation across multiple DOP designs. Three sample survey CSV files are utilized in the hyperparameter search where AutoDesigner is used to optimize a DOP design for each file. The first of the three CSV files represents a short, three phase DOP with 9 new poles where the design is terminated on either end with three phase riser structures. The second CSV file represents a second smaller three phase design that contains 16 poles and which taps off of existing overhead mainline and terminates at a three-phase riser structure. The third CSV file represents a larger three phase design that contains 35 poles. Note that due to computational complexity, the full set of hyperparameters are evaluated only on the first two designs, where the larger design is only evaluated for the population size hyperparameter.

Note that the range of the hyperparameters for the hyperparameter search are, in part, derived from Patil and Pawar [3] as well as from empirical experience in testing AutoDesigner. Patil and Pawar established that mutation rates between 0.001 and 0.05 generally result in the best performance for a genetic algorithm. Furthermore, the paper references optimal crossover rates as commonly falling between 0.6 and

0.95 throughout the review. For this reason, the hyperparameter search confines its investigation of crossover and mutation rates to fall between 0.6 to 0.9 and 0.0005 to 0.04, respectively [3]. To maintain the number of search cases at a computationally feasible level, approximately ten samples of each value are explored within the two ranges provided above for crossover and mutation rates. For the population size, empirical experience from prior testing of AutoDesigner leads to the observation that larger population sizes (in the thousands) yields the best optimized project costs. As a result, the population size range is deliberately left large with 10 potential ranges explored with values ranging from 20 to 5,120 with samples increasing geometrically between the two boundaries. Note that in the third design, due to the complex nature of the 35-pole design, hyperparameter values up to 15,360 are explored.

The best performing hyperparameters are determined on the basis of which configuration provides the lowest overall project cost. In the event of a tie, the total optimization time is considered as a secondary factor in determining the best performing set of hyperparameters. It must be understood that due to the random elements within the genetic algorithm optimization process, the same configuration may not always produce the same set of results and so common high performing hyperparameter combinations between the investigated designs are considered when determining the winner. Furthermore, unlike crossover rate and mutation rate, the population size is treated as a variable parameter that depends heavily on complexity of the design. Larger values for population size may be selected as the winning candidate if there is evidence that the larger population size more stably converges on a lower cost minimum even if smaller populations candidates can achieve the same cost but with lower reliability.

5.1 Hyperparameter Test Case 1: Nine Pole Distribution Overhead Powerline Project

Figure 5.1 illustrates the DOP design being investigated while Table 5.1 lists the top ten best-performing hyperparameter combinations where the best performing combination is listed in bold. Please refer to Table B.1 in the Appendix for the survey CSV file and user input selection and Table B.2 in the Appendix for the complete data output from the hyperparameter search.

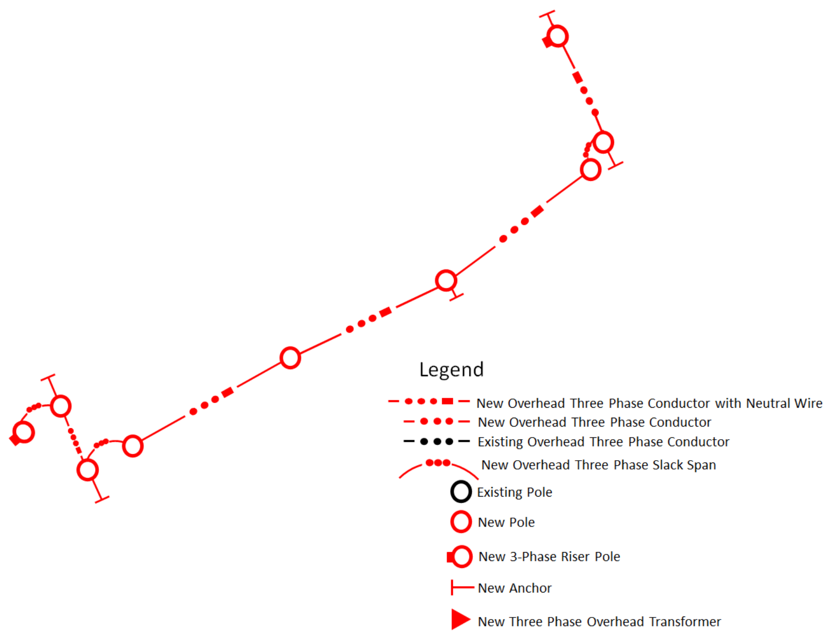


Figure 5.1: Design Drawing Illustrating Test Case 1.

No.	Population	Crossover Rate	Mutation Rate	Min. Cost ($)	Compuation Time (minutes)
368	**320**	**0.8**	**0.03**	**25450.69**	**0.6**
369	320	0.8	0.035	25450.69	0.61
345	320	0.7	0.015	25450.69	0.63
396	320	0.95	0.02	25450.69	0.67
380	320	0.85	0.04	25450.69	0.69
397	320	0.95	0.025	25450.69	0.7
375	320	0.85	0.015	25450.69	0.72
455	160	0.85	0.015	25472.94	0.26
331	320	0.65	0.0005	25495.2	0.48

Table 5.1: Table of Top Ten Best Performing Hyperparameter Combinations for Test Case 1.

Note that population size appears to be the most important hyperparameter in achieving the minimum project cost. Surprisingly, the highest population sizes do not achieve the lowest cost minimum, while a population size of 320 appears to be optimal. Crossover and mutation rate do not appear to show a significant correlation to performance where values spanning the range of investigated values can be found in the top 10 performing candidates for these two hyperparameters.

5.2 Hyperparameter Test Case 2: Seventeen Pole Distribution Overhead Powerline Project

Figure 5.2 illustrates the DOP design being investigated while Table 5.2 lists the top 14 best-performing hyperparameter combinations where the best performing combination is listed in bold. Please refer to Table B.3 in the Appendix for the survey CSV file and user input selection and Table B.4 in the Appendix for the complete data output from the hyperparameter search.

No.	Population	Crossover Rate	Mutation Rate	Min. Cost ($)	Compuation Time (minutes)
368	320	0.8	0.03	25450.69	0.6
459	160	0.85	0.035	33243.99	0.73
464	160	0.9	0.01	33243.99	0.79
369	320	0.8	0.035	33243.99	1.05
396	320	0.95	0.02	33243.99	1.26
359	320	0.75	0.035	33243.99	1.32
378	320	0.85	0.03	33243.99	1.32
338	320	0.65	0.03	33243.99	1.33
375	320	0.85	0.015	33243.99	1.33
386	320	0.9	0.02	33243.99	1.33
327	320	0.6	0.025	33243.99	1.34
387	320	0.9	0.025	33243.99	1.48
347	320	0.7	0.025	33243.99	1.52
283	**640**	**0.8**	**0.005**	**33243.99**	**1.63**

Table 5.2: Table of Top Fourteen Best Performing Hyperparameter Combinations for Test Case 2.

Note that despite the top 12 performing cases using a population size of either 160 or 320, the case with a population size of 640 is selected as the best overall performing hyperparameter combination. The reason for selecting the larger population size is that only a small fraction of the scenarios involving the population sizes of 160 or 320 are able to achieve the lowest attained overall project cost in the search while the nearly half of the cases involving a 640-population size are able to achieve the minimum obtained cost. The larger population size does come at the expense of a greater computation time, however, given how short the overall time to optimize a design that is less than 20 poles, there is little expense in allowing for a longer computation time in this scenario. There is again not much clarity gained from the hyperparameter search regarding the importance of the crossover rate and the mutation rate as values from across the studied range all appear at the top of the list. On the other hand, population size appears to have a very significant impact where population sizes below 640 have significant difficulty achieving the minimum project cost while all sizes larger than 640 do not. It may even be advisable to proceed with a population size of 1280 as this population size has an even greater proportion of candidates that achieved that minimum project cost than that of 640.

5.3 Hyperparameter Test Case 3: Thirty-Two Pole Distribution Overhead Powerline Project

Figure 5.3 illustrates the DOP design being investigated. Note that due to the computational complexity associated with optimizing a 32-pole design, only the population size is studied for the third test case. The mutation rate and the crossover rate are both held constant at 0.25 and 0.75 based on the approximately mean values of the studied ranges. Figure 5.3 illustrates the DOP design being investigated while Table

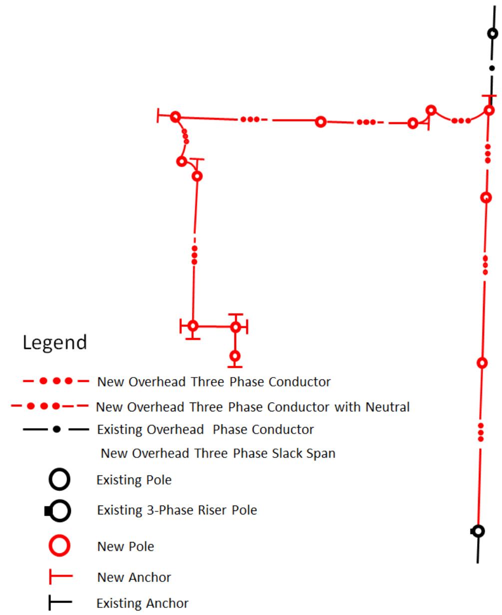


Figure 5.2: Design Drawing Illustrating Test Case 2.

5.3 lists the complete results of the hyperparameter search where the best performing population size value is listed in bold. Please refer to Table B.5 in the Appendix for the survey CSV file and user input selection associated with the test case.

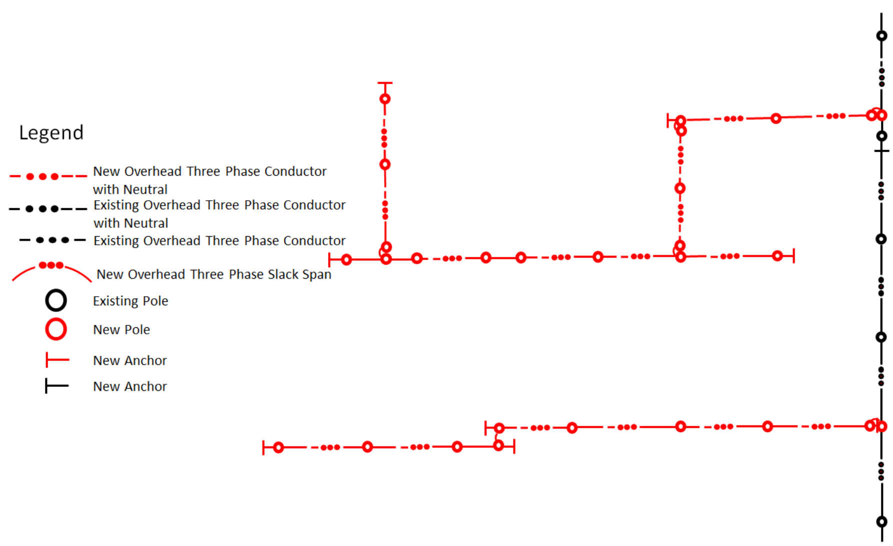


Figure 5.3: Design Drawing Illustrating Test Case 3.

No.	Population Size	Crossover Rate	Mutation Rate	Min. Cost	Computation Time
1	15360	0.75	0.025	$59021.78	138.02 min

2	**10240**	**0.75**	**0.025**	**$59021.78**	**96.76 min**
3	5120	0.75	0.025	$59106.9	58.36 min
4	2560	0.75	0.025	$59066.3	27.7 min
5	1280	0.75	0.025	$59888.85	17.71 min
6	640	0.75	0.025	$59581.29	10.72 min
7	320	0.75	0.025	$60104.75	7.56 min
8	160	0.75	0.025	$63639.32	3.35 min
9	80	0.75	0.025	$62971.4	1.78 min
10	40	0.75	0.025	$2195598.88	0.81 min
11	20	0.75	0.025	$3875651.8	0.12 min
12	10	0.75	0.025	$4941468.89	0.16 min

Table 5.3: Table of Top Ten Best Performing Hyperparameter Combinations for Test Case 3.

As with the second test case, large population sizes once again are shown to play a significant role in reducing optimized material and construction labour costs. The benefit of lower cost must be weighed against the massive cost in computation time, however, as increasing population size approaches a one-to-one relationship with the time required to arrive at an optimized design.

References

[3] Patil V.P. and Pawar D.D., "The optimal crossover or mutation rates in genetic algorithm: A review," *International Journal of Applied Engineering and Technology, 38*, 2015.

Chapter 6

Results, Evaluation and Conclusion

The chapter provides tables and figures that pertain to the final evaluation of the performance of both PoleCheck2.0 and AutoDesigner. The chapter also provides final discussions evaluating the performance of PoleCheck2.0 and AutoDesigner and goes on to provide an overall conclusion for the thesis. The chapter concludes by providing thoughts for future work.

6.1 PoleCheck2.0 Results for Evaluation

Given the complexity of PoleCheck2.0 as well as its potential application as a standalone tool, a specific portion of the results chapter is dedicated to providing an evaluation of PoleCheck2.0 that is separate from AutoDesigner.

Evaluating the performance of PoleCheck2.0 is accomplished by comparing the pole utilization percentages provided by the PoleCheck2.0 lookup tables against the pole utilizations generated by the original PoleCheck1.0 lookup tables for equivalent powerline structures and configurations. Unfortunately, a direct comparison is difficult to achieve since span lengths, deflections, anchor types and lengths are required to be precisely identical between the two cases to allow for a fair comparison to be made. To provide an accurate means of comparison, existing PoleCheck1.0 cases are modified and re-run for this chapter to specifically conform to the physical parameters of the specific PoleCheck2.0 cases being investigated. The approach requires updating the custom PoleCheck1.0 model in PLS-CADD for each individual case and then applying FEA using the exact same procedure as is carried out to generate the original lookup table for PoleCheck1.0. Approximately 50 cases are provided in Table C.1 in the Appendix where the percent difference between the PoleCheck2.0 and PoleCheck1.0 pole utilizations are provided across six different structure patterns. Table 6.1 summarizes the average, maximum and minimum percent differences, and correlation coefficients for each of the six structure patterns listed in Table C.1.

Structure Pattern	PoleCheck2.0 Max % Difference below PoleCheck1.0 Pole Util.	PoleCheck2.0 Max % Difference above PoleCheck1.0 Pole Util.	PoleCheck2.0 average % Difference with Respect to PoleCheck1.0 (Positive Values Indicate That PoleCheck2.0 Utilization is Higher than PoleCheck1.0)	Correlation Coefficient
N32	1.96%	55.30%	11.69%	0.988
N42	NA	46.0%	20.01%	0.972
N11	NA	43.4%	30.8%	0.954
N12,N55	10.5%	90.7%	17.3%	0.890
N12	NA	0.464%	0.369%	1.00
N11H	5.34%	657%	169.46%	0.679

Table 6.1: Table Summarizing PoleCheck2.0 Evaluation Case Pole Utilization Against PoleCheck1.0 Equivalent Case Pole Utilization.

6.2 PoleCheck2.0 Evaluation of Results

The pole utilizations produced by PoleCheck2.0 for the cases listed in Table C.1 correlate acceptably well with the values generated using the methodology of PoleCheck1.0. Divergent cases between the two pole loading tools are present, however, they can be reasonably well-justified. The correlation coefficient remains around 0.9 or higher for all of the structure patterns listed in Table 5.1 with the exception of the N11H structure which has a small sample size and a single test case is observed where PoleCheck2.0 has a much higher utilization than the value obtained from PoleCheck1.0. PoleCheck2.0 performs acceptably well for the purposes of the thesis, however, additional test cases should be performed before engineering authentication of

PoleCheck2.0 occurs.

In the majority of cases where divergence in results between PoleCheck1.0 and PoleCheck2.0 is observed, PoleCheck2.0 is producing the more conservative pole utilizations, however, in some cases PoleCheck1.0 is more conservative and these particular cases require special attention. It can be noted that the structure patterns where PoleCheck2.0's utilizations are falling most significantly under the utilizations produced by PoleCheck1.0 belong to the N32 and N12,N55 structure patterns. It is important to note that these two structure patterns contain 90°, or near 90°, deflections. It is the case that PoleCheck1.0, which relies on the use of PLS-CADD to generate the force loading file that is applied to its pole structure, assumes that all conductor spans on the pole are experiencing maximal wind-loading simultaneously [22]. PoleCheck2.0, on the other hand, considers wind from eight possible directions and considers only the orthogonal incident component of the total wind loading on a particular conductor span. As a result, while these two methods should arrive at very similar transverse force loading values for inline tangent structures that have minimal conductor deflections, for structures with 90° deflections it is expected that the PoleCheck1.0 methodology may be more conservative. The results confirm the expected trend as numerous cases in the N32 and N12,N55 structure patterns contains slightly higher PoleCheck1.0 utilizations compared to PoleCheck2.0. It is important to note that both wind-loading calculation methodologies are permitted in the utility code and so deviation between the two sets of results are not necessarily problematic [4].

More generally, deviations between PoleCheck1.0 and PoleCheck2.0 pole utilizations can also be understood to be the result of differences in how the tools model the pole structure. In PoleCheck1.0, the cross-arms, insulators, guy wires and cross-arm braces are all considered as being a part of the pole model and all components undergo deformation during FEA. PoleCheck2.0, on the other hand, only considers the pole and guy wires in the FEA deformation analysis where the cross-arm, insulators and conductor attachments are resolved down to a single concentrated load located at the top attachment bolt location on the pole. As numerous bolt locations are generally present for a given conductor attachment, assuming that the full load is exerted at the top bolt location is a conservative assumption due to it creating a greater moment with respect to the bottom of the pole structure or the nearest guy wire attachment point. The resolving of force loads to the top bolt location may contribute towards making PoleCheck2.0 more conservative than PoleCheck1.0. Conversely, by considering the deformation of cross-arms and braces during FEA, PoleCheck1.0 may experience a higher pole utilization than PoleCheck2.0 in some cases if the most strained components during FEA are found to be a cross-arm or brace. PoleCheck2.0 does not have visibility of the utilization of components such as cross-arms and so the failure of these components is outside of the scope of PoleCheck2.0. While such a limitation may appear to be problematic for PoleCheck2.0, it must be considered that the only means to resolve a non-compliant pole structure in PoleCheck2.0 is to specify a different pole height, class, composition or guy wire type, and so neither PoleCheck1.0 nor PoleCheck2.0 may be the correct tool to consider the failure of components such as cross-arms. It is, therefore, necessary that the DFO's standards group evaluates pole attachment equipment on a more general basis to ensure that all load-bearing components that are attached to a pole structure are suitable for the maximum force-loading conditions that may be encountered.

Finally, it is also important to note that pole utilizations do not increase linearly and, in some circumstances, the differences between a 500% and a 90% pole utilization may be the result of a very small increase in pole loading. As a result, it may not be accurate to assume that large differences in pole utilizations between the two tools for some outlying cases are the result of errors in either of the tools.

Overall, it is felt that while PoleCheck1.0 and PoleCheck2.0 do not correlate perfectly, that the implementation for PoleChek2.0 is valid, that it complies with code requirements, and that it is suitable for use as a constraint module within AutoDesigner for the purposes of the thesis.

6.3 AutoDesigner Results for Evaluation

The Evaluation of AutoDesigner is performed by carrying out design optimization on three previously untested DOP projects. Note that all three projects under evaluation have also been designed by a human designer without any foreknowledge of the design that is proposed by AutoDesigner. The first design is a short DOP extension which contains approximately 10 optimizable pole structures, the second design has approximately 15 optimizable pole structures and the third design is a large design with 39 optimizable pole structures. The final staking list generated by AutoDesigner for each design is then compared against the human-created staking list with any design differences noted. Note that, in the figures provided, the formatting for both staking lists are altered to allow for maximum comparability between the two outputs. Accessory components such as pole-top fuse structures or cattle guards to protect downhaul guy wires in agricultural areas are omitted from the human-created designs to allow for a more exact comparison with the AutoDesigner output since AutoDesigner does not specify components that are unrelated to the design optimization process. Also note that the green rectangles in the staking list comparison figures denote design decisions that, after review, are determined to be superior to the alternative design's approach, orange rectangles denote potentially questionable design decisions and red rectangles denote a design decision that omits one or more required rules. Furthermore, for each of the three cases, the total material and construction cost of the optimized design is reported in terms of percent difference between the optimized design and the human-created design where a negative value indicates that AutoDesigner produces the overall cheaper design.

For the first design, an additional table is generated that reports the computation time of the first eleven generations of the genetic algorithm with the constraint module memory feature turned on versus being turned off. Finally, in the case of the third

Figure 6.1: Design Drawing Illustrating Evaluation Case 1.

evaluation scenario, an additional table is provided that reports the total computation time measured on a high-performance desktop computer for the purposes of evaluating the third thesis objective.

6.3.1 Evaluation Case 1: 10 Pole DOP Design

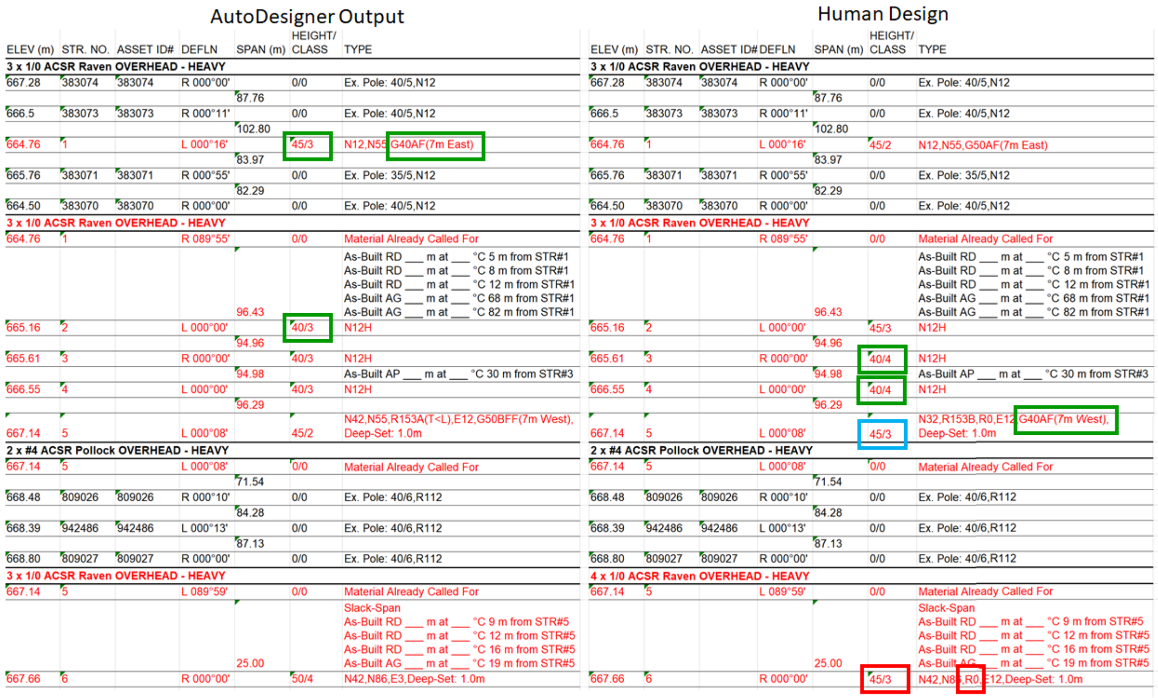
Figure 6.1 illustrates the design layout of the evaluation case while Figure 6.2 illustrates the staking lists for both the optimized and human-created designs. Note that the survey CSV file and user input data supplied to AutoDesigner is provided in Table C.2 of the Appendix. Table 6.2 indicates the percent difference in the sum of final material and labour costs between the human-created design and the output from AutoDesigner. Table 6.3 provides details on the computation times of the first eleven genetic algorithm generations with constraint module memory turned on versus being turned off.

AutoDesigner Material and Construction Cost Percent Difference with Respect to Human-Created Design	+4.23%

Table 6.2: Table Summarizing Percent Difference Between AutoDesigner and Human-Created Design Final Project and Material Costs for Evaluation Case 1.

Generation	Computation Time with Memory Turned Off	Computation Time with Memory Turned On	% of PoleCheck Cases Utilized from Memory	% of ClearanceCalc Cases Utilized from Memory%
0	17s	7s	0.717	0.288
1	11s	0s	0.990	0.793
2	12s	0s	0.992	0.783
3	12s	0s	0.998	0.832
4	13s	0s	0.997	0.863
5	13s	0s	0.999	0.872
6	14s	0s	0.997	0.895
7	15s	0s	0.999	0.911
8	14s	0s	0.998	0.939
9	13s	0s	0.998	.0952
10	14s	0s	1.0	0.965
Total	**13 min.**	**1 min.**		

Table 6.3: Computation Time Comparison with Constraint Module Memory Turned On versus Constraint Module Memory Turned Off for First Eleven Generations of Evaluation Case 1.



AutoDesigner Output

ELEV (m)	STR. NO.	ASSET ID#	DEFLN	SPAN (m)	HEIGHT/ CLASS	TYPE
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
667.28	383074	383074	R 000°00'		0/0	Ex. Pole: 40/5,N12
				87.76		
666.5	383073	383073	R 000°11'		0/0	Ex. Pole: 40/5,N12
				102.80		
664.76	1		L 000°16'		45/3	N12,N55 G40AF(7m East)
				83.97		
665.76	383071	383071	R 000°55'		0/0	Ex. Pole: 35/5,N12
				82.29		
664.50	383070	383070	R 000°00'		0/0	Ex. Pole: 40/5,N12
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
664.76	1		R 089°55'		0/0	Material Already Called For
				96.43		As-Built RD ___ m at ___ °C 5 m from STR#1 As-Built RD ___ m at ___ °C 8 m from STR#1 As-Built RD ___ m at ___ °C 12 m from STR#1 As-Built AG ___ m at ___ °C 68 m from STR#1 As-Built AG ___ m at ___ °C 82 m from STR#1
665.16	2		L 000°00'		40/3	N12H
				94.96		
665.61	3		R 000°00'		40/3	N12H
				94.98		As-Built AP ___ m at ___ °C 30 m from STR#3
666.55	4		L 000°00'		40/3	N12H
				96.29		
667.14	5		L 000°08'		45/2	N42,N55,R153A(T<L),E12,G50BFF(7m West), Deep-Set: 1.0m
2 x #4 ACSR Pollock OVERHEAD - HEAVY						
667.14	5		L 000°08'		0/0	Material Already Called For
				71.54		
668.48	809026	809026	R 000°10'		0/0	Ex. Pole: 40/6,R112
				84.28		
668.39	942486	942486	L 000°13'		0/0	Ex. Pole: 40/6,R112
				87.13		
668.80	809027	809027	R 000°00'		0/0	Ex. Pole: 40/6,R112
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
667.14	5		L 089°59'		0/0	Material Already Called For
				25.00		Slack-Span As-Built RD ___ m at ___ °C 9 m from STR#5 As-Built RD ___ m at ___ °C 12 m from STR#5 As-Built RD ___ m at ___ °C 16 m from STR#5 As-Built AG ___ m at ___ °C 19 m from STR#5
667.66	6		R 000°00'		50/4	N42,N86,E3,Deep-Set: 1.0m

Human Design

ELEV (m)	STR. NO.	ASSET ID#	DEFLN	SPAN (m)	HEIGHT/ CLASS	TYPE
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
667.28	383074	383074	R 000°00'		0/0	Ex. Pole: 40/5,N12
				87.76		
666.5	383073	383073	R 000°11'		0/0	Ex. Pole: 40/5,N12
				102.80		
664.76	1		L 000°16'		45/2	N12,N55,G50AF(7m East)
				83.97		
665.76	383071	383071	R 000°55'		0/0	Ex. Pole: 35/5,N12
				82.29		
664.50	383070	383070	R 000°00'		0/0	Ex. Pole: 40/5,N12
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
664.76	1		R 089°55'		0/0	Material Already Called For
				96.43		As-Built RD ___ m at ___ °C 5 m from STR#1 As-Built RD ___ m at ___ °C 8 m from STR#1 As-Built RD ___ m at ___ °C 12 m from STR#1 As-Built AG ___ m at ___ °C 68 m from STR#1 As-Built AG ___ m at ___ °C 82 m from STR#1
665.16	2		L 000°00'		45/3	N12H
				94.96		
665.61	3		R 000°00'		40/4	N12H
				94.98		As-Built AP ___ m at ___ °C 30 m from STR#3
666.55	4		L 000°00'		40/4	N12H
				96.29		
667.14	5		L 000°08'		45/3	N32,R153B,R0,E12 G40AF(7m West), Deep-Set: 1.0m
2 x #4 ACSR Pollock OVERHEAD - HEAVY						
667.14	5		L 000°08'		0/0	Material Already Called For
				71.54		
668.48	809026	809026	R 000°10'		0/0	Ex. Pole: 40/6,R112
				84.28		
668.39	942486	942486	L 000°13'		0/0	Ex. Pole: 40/6,R112
				87.13		
668.80	809027	809027	R 000°00'		0/0	Ex. Pole: 40/6,R112
4 x 1/0 ACSR Raven OVERHEAD - HEAVY						
667.14	5		L 089°59'		0/0	Material Already Called For
				25.00		Slack-Span As-Built RD ___ m at ___ °C 9 m from STR#5 As-Built RD ___ m at ___ °C 12 m from STR#5 As-Built RD ___ m at ___ °C 16 m from STR#5 As-Built AG ___ m at ___ °C 19 m from STR#5
667.66	6		R 000°00'		45/3	N42,N8[illegible],R0,E12,Deep-Set: 1.0m

Figure 6.2: Staking List Output Comparison Between AutoDesigner and Human-Created Design for Evaluation Case 1.

6.3.2 Evaluation Case 2: 15 Pole DOP Design

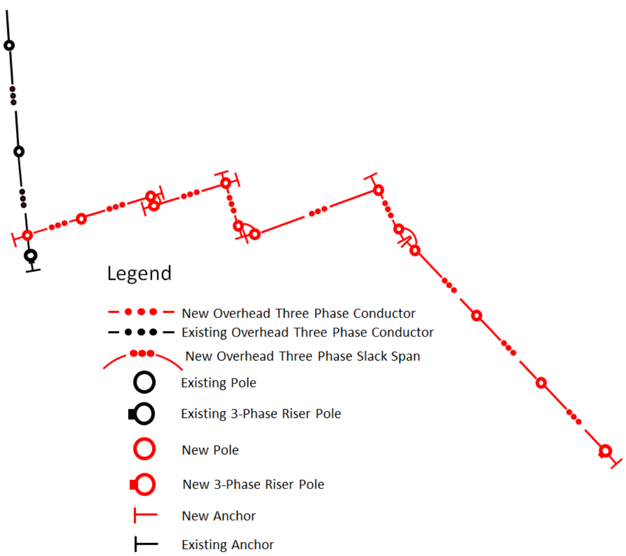


Figure 6.3: Design Drawing Illustrating Evaluation Case 2.

Figure 6.3 illustrates the design layout of the second evaluation case while Figure 6.4 illustrates the staking lists for both the optimized and human-created designs. Table 6.4 indicates the percent difference in the sum of final material and labour costs between the human-created design and the output from AutoDesigner.

AutoDesigner Material and Construction Cost Percent Difference with Respect to Human-Created Design	-4.37%

Table 6.4: Table Summarizing Percent Difference Between AutoDesigner and Human-Created Design Final Project and Material Costs for Evaluation Case 2.

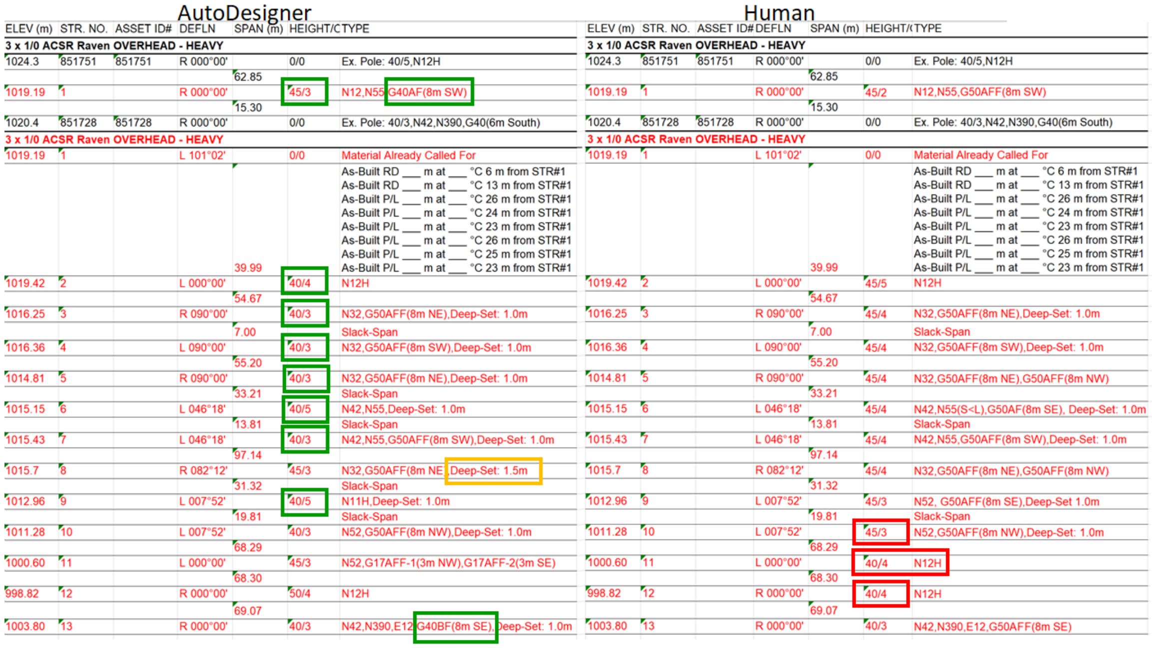


Figure 6.4: Staking List Output Comparison Between AutoDesigner and Human Design for Evaluation Case 2.

6.3.3 Evaluation Case 3: 39 Pole DOP Design

Figure 6.5 illustrates the design layout of the final evaluation case while Figures 6.6 and 6.7 illustrates the staking lists for both the optimized and human-created designs. Table 6.5 indicates the percent difference in the sum of final material and labour costs between the human-created design and the output from AutoDesigner while Table 6.6 lists the total computation time in minutes required to complete the optimization process.

AutoDesigner Material and Construction Cost Percent Difference with Respect to Human-Created Design	0.208%

Table 6.5: Table Summarizing Percent Difference Between AutoDesigner and Human-Created Design Final Project and Material Costs for Evaluation Case 3.

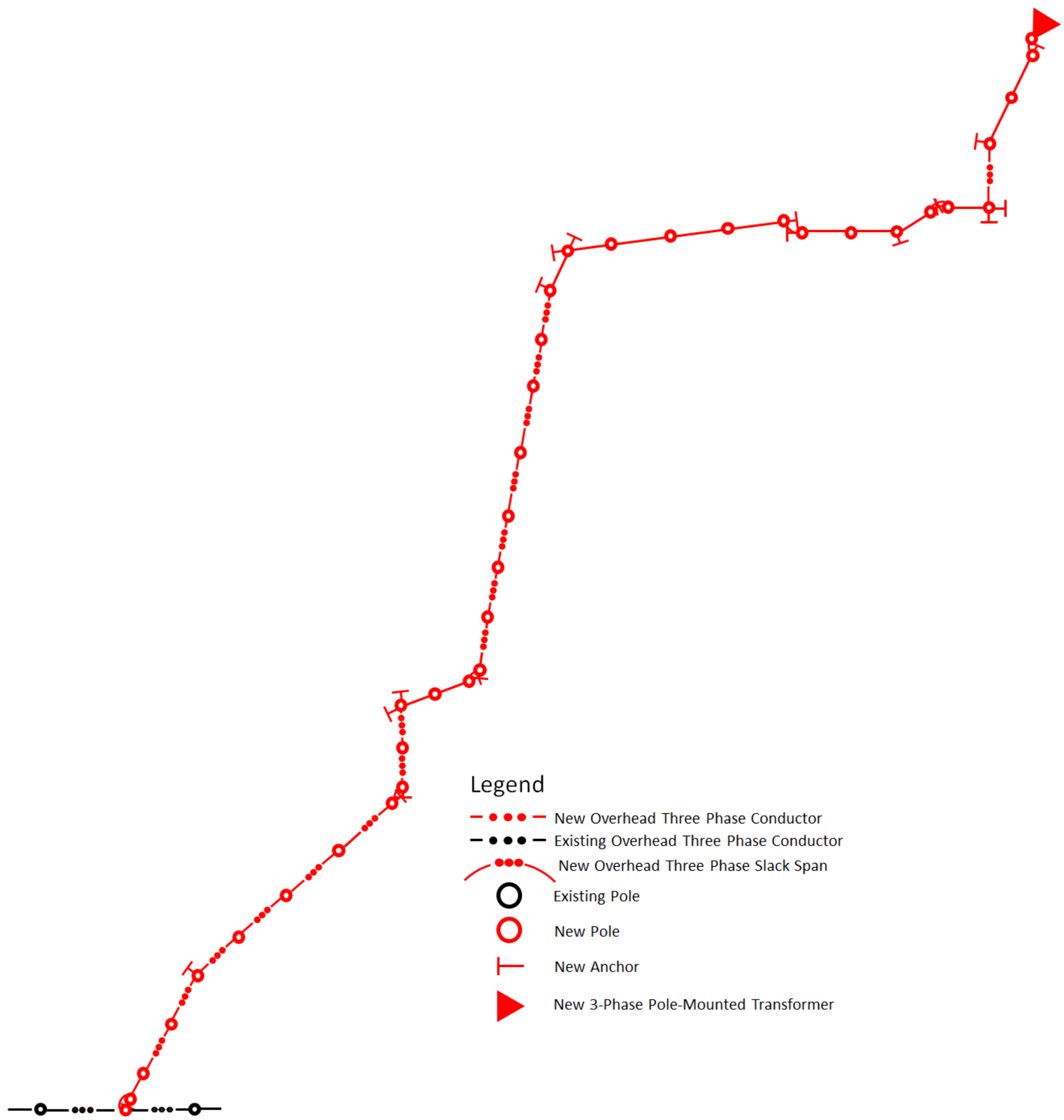


Figure 6.5: Design Drawing Illustrating Evaluation Case 3.

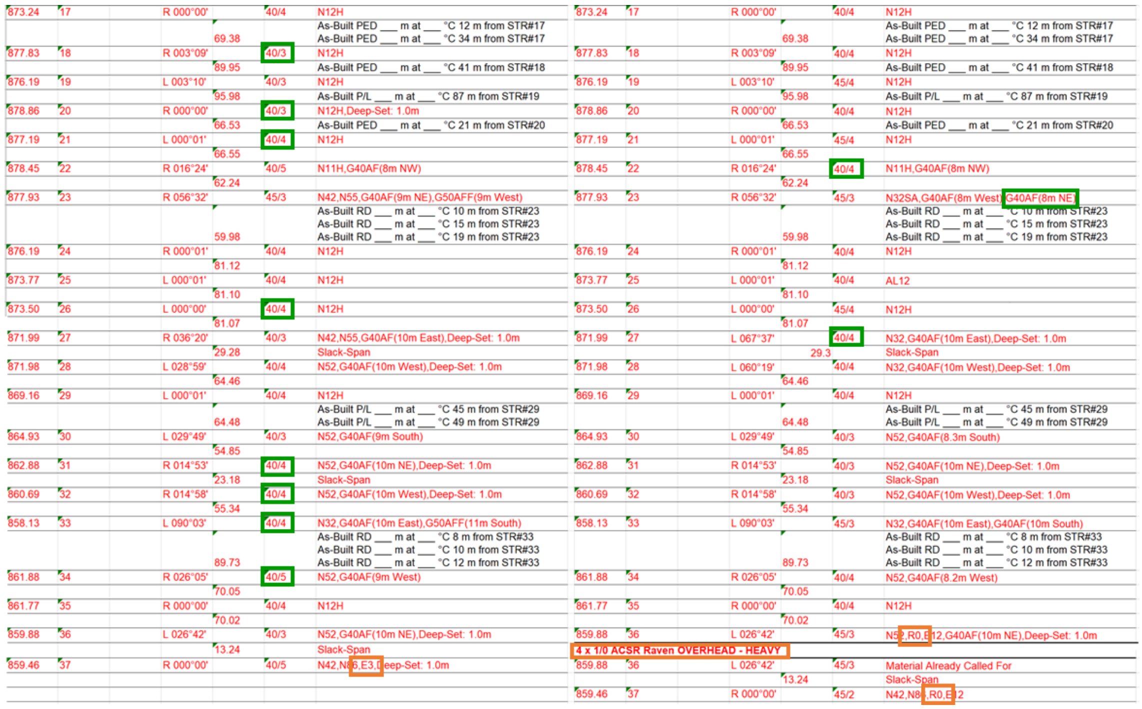
AutoDesigner

ELEV (m)	STR. NO.	ASSET ID#	DEFLN	SPAN (m)	HEIGHT/C	TYPE
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
896.38	324928	324928	R 000°00'		0/0	Ex. Pole: 40/4,N12
				78.42		
899.62	324929	324929	L 000°06'		0/0	Ex. Pole: 35/3,N12
				97.72		As-Built P/L ___ m at ___ °C 39 m from STR#324929 As-Built P/L ___ m at ___ °C 46 m from STR#324929
899.72	324930	324930	R 000°01'		0/0	Salv. Ex: N12 Ex. Pole: 45/2, Install New: N52
				16.11		
900.45	1		R 000°01'		45/2	N12,N55,Deep-Set: 1.0m
				97.20		As-Built RD ___ m at ___ °C 5 m from STR#1 As-Built RD ___ m at ___ °C 8 m from STR#1 As-Built RD ___ m at ___ °C 12 m from STR#1
905.85	324931	324931	L 000°43'		0/0	Ex. Pole: 40/4,N12
				57.38		
911.31	324932	324932	R 000°00'		0/0	Ex. Pole: 35/3,N12
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
900.45	1		L 061°32'		0/0	Material Already Called For
				14.98		Slack-Span
900.28	2		R 000°02'		40/4	N52,G40AF(10m SW),Deep-Set: 1.0m
				40.15		As-Built PED ___ m at ___ °C 29 m from STR#2
902.38	3		R 000°01'		40/4	N12H,Deep-Set: 1.0m
				80.79		As-Built P/L ___ m at ___ °C 18 m from STR#3
899.64	4		R 000°00'		40/4	N12H
				80.79		
901.5	5		R 020°27'		40/5	AL11(HL),G40AF(9m NW)
				71.40		
900.25	6		R 000°00'		40/4	N12H
				92.46		As-Built RD ___ m at ___ °C 3 m from STR#6 As-Built RD ___ m at ___ °C 25 m from STR#6
894.26	7		L 000°00'		45/4	N12H
				92.46		As-Built P/L ___ m at ___ °C 52 m from STR#7 As-Built P/L ___ m at ___ °C 77 m from STR#7
892.97	8		R 000°00'		45/3	N52
				103.60		As-Built PED ___ m at ___ °C 44 m from STR#8
893.42	9		L 028°48'		45/3	N52,G40AF(10m NE),Deep-Set: 1.0m
				21.89		Slack-Span
892.62	10		L 020°09'		40/4	N52,G40AF(10m South),Deep-Set: 1.0m
				53.46		
888.60	11		L 000°00'		40/4	N12H
				55.10		As-Built P/L ___ m at ___ °C 41 m from STR#11
886.48	12		R 069°01'		40/4	N32,G40AF(10m North),G50AFF(8m SW)
				49.69		
883.40	13		L 000°01'		40/4	N12H
				54.45		
881.62	14		L 028°49'		40/3	N52,G40AF(10m NE),Deep-Set: 1.0m
				16.93		Slack-Span
878.45	15		L 030°31'		40/4	N42,N55,G40AF(9m South),Deep-Set: 1.0m
				69.31		
864.71	16		R 000°00'		50/4	N52,G17AFF-1(3m South),G17AFF-2(3m North)
				69.30		
873.24	17		R 000°00'		40/4	N12H

Human

ELEV (m)	STR. NO.	ASSET ID#	DEFLN	SPAN (m)	HEIGHT/C	TYPE
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
896.38	324928	324928	R 000°00'		0/0	Ex. Pole: 40/4,N12
				78.42		
899.62	324929	324929	L 000°06'		0/0	Ex. Pole: 35/3,N12
				97.72		As-Built P/L ___ m at ___ °C 39 m from STR#324929 As-Built P/L ___ m at ___ °C 46 m from STR#324929
899.72	324930	324930	R 000°01'		0/0	Ex. Pole: 45/2,N12Y, Install New: N12
				16.11		
900.45	1		R 000°01'		45/3	N12,N55,Deep-Set: 1.0m
				97.20		As-Built RD ___ m at ___ °C 5 m from STR#1 As-Built RD ___ m at ___ °C 8 m from STR#1 As-Built RD ___ m at ___ °C 12 m from STR#1
905.85	324931	324931	L 000°43'		0/0	Ex. Pole: 40/4,N12
				57.38		
911.31	324932	324932	R 000°00'		0/0	Ex. Pole: 35/3,N12
3 x 1/0 ACSR Raven OVERHEAD - HEAVY						
900.45	1		L 061°32'		0/0	Material Already Called For
				14.98		Slack-Span
900.28	2		R 000°02'		45/3	N52,G40AF(10m SW)
				40.15		As-Built PED ___ m at ___ °C 29 m from STR#2
902.38	3		R 000°01'		40/4	N12H
				80.79		As-Built P/L ___ m at ___ °C 18 m from STR#3
899.64	4		R 000°00'		45/4	N12H
				80.79		
901.5	5		R 020°27'		40/4	N11H,G40AF(9m NW)
				71.40		
900.25	6		R 000°00'		45/4	N12H
				92.46		As-Built RD ___ m at ___ °C 3 m from STR#6 As-Built RD ___ m at ___ °C 25 m from STR#6
894.26	7		L 000°00'		45/4	AL12
				92.46		As-Built P/L ___ m at ___ °C 52 m from STR#7 As-Built P/L ___ m at ___ °C 77 m from STR#7
892.97	8		R 000°00'		45/3	N12H
				103.60		As-Built PED ___ m at ___ °C 44 m from STR#8
893.42	9		L 028°48'		45/3	N52,G40AF(10m NE),Deep-Set: 1.0m
				21.89		Slack-Span
892.62	10		L 020°09'		40/3	N52,G40AF(10m South),Deep-Set: 1.0m
				53.46		
888.60	11		L 000°00'		40/4	N12H
				55.10		As-Built P/L ___ m at ___ °C 41 m from STR#11
886.48	12		R 069°01'		40/4	N32,G40AF(10m N),G40AF(7.5m SW)
				49.69		
883.40	13		L 000°01'		40/4	N12H
				54.45		
881.62	14		L 028°49'		40/3	N52,G40AF(10m E),Deep-Set: 1.0m
				16.93		Slack-Span
878.45	15		L 030°31'		45/3	N52,G40AF(9m South),Deep-Set: 1.0m
				69.31		
864.71	16		R 000°00'		45/3	N52,G40AF(8m S),G40AF(10.0m N)
				69.30		
873.24	17		R 000°00'		40/4	N12H

Figure 6.6: Staking List Output Comparison Between AutoDesigner and Human Design for Evaluation Case 3, Part 1 of 2.



873.24	17	R 000°00'		40/4	N12H
					As-Built PED ___ m at ___ °C 12 m from STR#17
			69.38		As-Built PED ___ m at ___ °C 34 m from STR#17
877.83	18	R 003°09'		40/3	N12H
			89.95		As-Built PED ___ m at ___ °C 41 m from STR#18
876.19	19	L 003°10'		40/3	N12H
			95.98		As-Built P/L ___ m at ___ °C 87 m from STR#19
878.86	20	R 000°00'		40/3	N12H,Deep-Set: 1.0m
			66.53		As-Built PED ___ m at ___ °C 21 m from STR#20
877.19	21	L 000°01'		40/4	N12H
			66.55		
878.45	22	R 016°24'		40/5	N11H,G40AF(8m NW)
			62.24		
877.93	23	R 056°32'		45/3	N42,N55,G40AF(9m NE),G50AFF(9m West)
					As-Built RD ___ m at ___ °C 10 m from STR#23
					As-Built RD ___ m at ___ °C 15 m from STR#23
			59.98		As-Built RD ___ m at ___ °C 19 m from STR#23
876.19	24	R 000°01'		40/4	N12H
			81.12		
873.77	25	L 000°01'		40/4	N12H
			81.10		
873.50	26	L 000°00'		40/4	N12H
			81.07		
871.99	27	R 036°20'		40/3	N42,N55,G40AF(10m East),Deep-Set: 1.0m
			29.28		Slack-Span
871.98	28	L 028°59'		40/4	N52,G40AF(10m West),Deep-Set: 1.0m
			64.46		
869.16	29	L 000°01'		40/4	N12H
					As-Built P/L ___ m at ___ °C 45 m from STR#29
			64.48		As-Built P/L ___ m at ___ °C 49 m from STR#29
864.93	30	L 029°49'		40/3	N52,G40AF(9m South)
			54.85		
862.88	31	R 014°53'		40/4	N52,G40AF(10m NE),Deep-Set: 1.0m
			23.18		Slack-Span
860.69	32	R 014°58'		40/4	N52,G40AF(10m West),Deep-Set: 1.0m
			55.34		
858.13	33	L 090°03'		40/4	N32,G40AF(10m East),G50AFF(11m South)
					As-Built RD ___ m at ___ °C 8 m from STR#33
					As-Built RD ___ m at ___ °C 10 m from STR#33
			89.73		As-Built RD ___ m at ___ °C 12 m from STR#33
861.88	34	R 026°05'		40/5	N52,G40AF(9m West)
			70.05		
861.77	35	R 000°00'		40/4	N12H
			70.02		
859.88	36	L 026°42'		40/3	N52,G40AF(10m NE),Deep-Set: 1.0m
			13.24		Slack-Span
859.46	37	R 000°00'		40/5	N42,N86,E3,Deep-Set: 1.0m

873.24	17	R 000°00'		40/4	N12H
					As-Built PED ___ m at ___ °C 12 m from STR#17
			69.38		As-Built PED ___ m at ___ °C 34 m from STR#17
877.83	18	R 003°09'		40/4	N12H
			89.95		As-Built PED ___ m at ___ °C 41 m from STR#18
876.19	19	L 003°10'		45/4	N12H
			95.98		As-Built P/L ___ m at ___ °C 87 m from STR#19
878.86	20	R 000°00'		40/4	N12H
			66.53		As-Built PED ___ m at ___ °C 21 m from STR#20
877.19	21	L 000°01'		45/4	N12H
			66.55		
878.45	22	R 016°24'		40/4	N11H,G40AF(8m NW)
			62.24		
877.93	23	R 056°32'		45/3	N32SA,G40AF(8m West),G40AF(8m NE)
					As-Built RD ___ m at ___ °C 10 m from STR#23
					As-Built RD ___ m at ___ °C 15 m from STR#23
			59.98		As-Built RD ___ m at ___ °C 19 m from STR#23
876.19	24	R 000°01'		40/4	N12H
			81.12		
873.77	25	L 000°01'		40/4	AL12
			81.10		
873.50	26	L 000°00'		45/4	N12H
			81.07		
871.99	27	L 067°37'		40/4	N32,G40AF(10m East),Deep-Set: 1.0m
			29.3		Slack-Span
871.98	28	L 060°19'		40/4	N32,G40AF(10m West),Deep-Set: 1.0m
			64.46		
869.16	29	L 000°01'		40/4	N12H
					As-Built P/L ___ m at ___ °C 45 m from STR#29
			64.48		As-Built P/L ___ m at ___ °C 49 m from STR#29
864.93	30	L 029°49'		40/3	N52,G40AF(8.3m South)
			54.85		
862.88	31	R 014°53'		40/3	N52,G40AF(10m NE),Deep-Set: 1.0m
			23.18		Slack-Span
860.69	32	R 014°58'		40/3	N52,G40AF(10m West),Deep-Set: 1.0m
			55.34		
858.13	33	L 090°03'		45/3	N32,G40AF(10m East),G40AF(10m South)
					As-Built RD ___ m at ___ °C 8 m from STR#33
					As-Built RD ___ m at ___ °C 10 m from STR#33
			89.73		As-Built RD ___ m at ___ °C 12 m from STR#33
861.88	34	R 026°05'		40/4	N52,G40AF(8.2m West)
			70.05		
861.77	35	R 000°00'		40/4	N12H
			70.02		
859.88	36	L 026°42'		45/3	N52,R0,E12,G40AF(10m NE),Deep-Set: 1.0m
4 x 1/0 ACSR Raven OVERHEAD - HEAVY					
859.88	36	L 026°42'		45/3	Material Already Called For
			13.24		Slack-Span
859.46	37	R 000°00'		45/2	N42,N86,R0,E12

Figure 6.7: Staking List Output Comparison Between AutoDesigner and Human Design for Evaluation Case 3, Part 2 of 2.

Total AutoDesigner Computation Time to Perform Optimization	170 min.

Table 6.6: Table Summarizing Total Computation Time for AutoDesigner to Complete the Optimization of the Third Evaluation Case.

6.4 AutoDesigner Evaluation of Results

6.4.1 Analysis of Results for Evaluation Case 1

AutoDesigner's performance in optimizing the 10 pole DOP design reveals how the use of AutoDesigner can assist designers in avoiding significant design errors that can impact safety as well costs on a DOP design. While the percent difference listed in Table 6.2 indicates that the human-created design yields a lower overall material and construction cost, the human-created design accomplishes the lower cost at the expense of making a significant design omission. The design omission is denoted with red boxes on the right-hand-side of Figure 6.2 and results in a clearance violation between pole structures 5 and 6. Specifically, the use of an overhead neutral wire between poles 5 and 6 is problematic since the neutral attachment on pole 6 is lowered to approximately 4.0m below the top of the pole due to the presence of an overhead pole-mount transformer. The conductor span between poles 5 and 6 crosses over a road which, for an overhead neutral requires 6.7m of clearance, as per DFO standards. The use of 45-foot poles by the human designer results in a neutral clearance that is significantly under 6.0m. It appears that the human design fails to consider the presence of the vertically-spaced neutral wire when calculating the conductor clearance between poles 5 and 6. If such a design were to go to construction, significant costs are likely to be incurred in correcting the human-created design during construction activities. The design suggested by AutoDesigner, on the other hand, while using more expensive and taller poles and utilizing the more labour intensive transformer grounding option that does not require an overhead neutral wire, results in a higher material and labour cost but the design is fully compliant with DFO standards and does not contain any discernable design omissions.

It is also curious that the human designer decides to use 40 ft. class 4 poles at poles 2 and 3 since this pole class technically has a pole utilization that is slightly over 100% in both PoleCheck1.0 and PoleCheck2.0. AutoDesigner is technically correct to be using the class 3 poles in this instance, however, it appears that the human designer is assuming that the pole composition for poles 2 and 3 is lodgepole pine and not western red cedar, as AutoDesigner is assuming. AutoDesigner always assumes the western red cedar pole composition as there is currently no standardized way to specify pole to specify pole composition on DFO bill of material documents. Because the western red cedar composition is less conservative than the lodgepole pine composition under pole loading analysis, it is used as the default pole composition for all PoleCheck2.0 pole loading calculations [5]. That being said, it is possible that the human designer could take special precautions to ensure that a lodgepole pine pole is used in the construction of poles 2 and 3 and so the decision to specify class 4 poles is not considered to be a design omission.

The only easily observable limitations in the AutoDesigner design pertains to Pole 5 and the selection of a class 2 pole as well as the use of the N42,N55 structure combination. The use of a class 2 pole at pole 5 by AutoDesigner is more conservative than the class 3 pole suggested by the human designer and is likely the result of AutoDesigner utilizing the original PoleCheck1.0 lookup tables due to a PoleCheck2.0 lookup table not being available at the time of evaluation. As discussed in Chapter 4, PoleCheck1.0 is implemented for complicated structure patterns by summing the pole utilizations of numerous simpler pole structures that are contained within the combination of structure attachments. While such a method to calculate pole utilization needs to be treated with caution, it is often the case that this method suggests a more conservative design than what would be suggested by PoleCheck2.0 or a design that is modelled using software such as PLS-CADD. That said, it is important to note that the human-designer also does not have access to PoleCheck2.0 for this pole structure and so it is unclear precisely how the human-created design determined that a 45 ft. class 3 pole is adequate at pole 5. Empirical experience may have factored into the human designer's decision to use a class 3 pole. Note that this limitation on the part of AutoDesigner is likely to be remedied once the PoleCheck2.0 tables are fully generated. Furthermore, the use of the N42,N55 structure combination by AutoDesigner at pole 5, while not incorrect, is a more complex suggestion than the more naturally-suited N32 structure suggested by the human designer. The reason for AutoDesigner utilizing the N42,N55 is that the structure parameter list does not currently contain an N32,R153A structure pattern where the lower three phase circuit of the N32 structure is considered to be the tap-off (normally the R153A single phase attachment is considered to be the tap-off). This problem can be easily remedied by making a small change to the survey CSV file in defining which circuit is the tap-off and which is the outgoing mainline. In either case, the use of the N42,N55 structure is not incorrect and will result in essentially the same hardware being installed on the pole.

Finally, Table 6.3 lists the computation time for the first eleven generations of the genetic algorithm optimization when constraint module memory is turned on versus being turned off. It is very clear that the use of constraint module memory provides for a massive decrease in computation time and that it is an essential component of the AutoDesigner software. Without the use of constraint module memory, it is unlikely that 40 or even 30 poles designs would be computationally feasible for AutoDesigner to optimize.

In summary, it is felt that AutoDesigner performs quite well in the first evaluation case, specifically in how the software avoids making a severe design omission that is made in the human-created design. While the overall project cost suggested by AutoDesigner is slightly higher than the human design, the cost of correcting design errors must be considered since correcting a clearance violation during construction such as the one in the human-created design is likely to far exceed the slightly higher material and labour costs suggested by AutoDesigner.

6.4.2 Analysis of Results for Evaluation Case 2

The 15-pole DOP design scenario results in a clearly superior performance by AutoDesigner when compared to the human-created design. In the second evaluation case, AutoDesigner both avoids design omissions that the human-created design contains and also produces a design that has an overall lower material and construction labour cost.

The core design decisions that enables AutoDesigner to achieve a lower project cost compared to the human design in case 2 relates primarily to the pole class selection at pole 1 and the pole height selections for poles 2 through 9. AutoDesigner makes use of the PoleCheck2.0 data tables for pole structure 1 which calls for a 45 ft. class 3 pole structure. The human-created design utilizes PoleCheck1.0 for the pole class calculation which calls for a 45 ft. class 2 pole. The reason for the difference in pole class determination is due to PoleCheck1.0 assuming a longer ruling span length as well as assuming that there is a deflection on the mainline inline tangent structure. Both assumptions are not required in PoleCheck2.0 due to the presence of additional cases that cover both a deflected and non-deflected inline tangent structure. In other words, PoleCheck2.0 is able to be less conservative in its pole-class analysis due to the more plentiful number of cases that are available in its lookup tables. Furthermore, the decision to use 45 ft. poles uniformly between structures 2 to 9 by the human designer is likely the result of fatigue associated with individually computing span clearances by hand especially when no crossings other than pedestrian traffic is present under the line. AutoDesigner, on the other hand, performs clearance calculations for each individual span and optimizes for lowest cost option while still meeting the required pedestrian clearances.

As with the first evaluation case, the human-created design again falls subject to making significant omissions in its design. Specifically, poles 10, 11 and 12 fail to account for the steep drop off in elevation that occurs between poles 10 and 11. An 11-meter drop in elevation over a single span creates a considerable conductor uplift effect on the lower pole and the human-created design appears to completely miss accounting for the uplift condition. If the human-created design is built as specified, it could result in a significant conductor uplift that could cause the pin-type insulators on the inline tangent structure to pop out of the cross-arm on the pole. AutoDesigner, on the other hand, correctly recognizes the drop in elevation and calls for a dead-end carry-on structure that does not have pin-style insulators and further fortifies pole 11 by calling for inline side-guys which help to anchor the pole to the ground and avoid the possibility that the pole, itself, could be pulled out of the ground due to extreme uplift forces.

In summary, it is felt that for the second evaluation case, AutoDesigner outperforms the human-created design both in terms of making accurate design decisions as well as minimizing overall construction and material expenses.

6.4.3 Analysis of Results for Evaluation Case 3

In the third and final case, neither AutoDesigner's design output nor the human-created design clearly outperforms the other. For the third case, the human-created design is quite rigorous in selecting optimal design decisions for most of the new pole structures contained in the DOP design. While AutoDesigner is able to make selections for a number of pole structures that are more cost effective than those chosen in the human-created design, a number of cases also occur where AutoDesigner makes a less optimal decision than the human-created design. Table 6.5 indicates that the human-created design very marginally outperforms the AutoDesigner design in terms of final material and construction cost, however, this must be weighed against several financially costly decisions that AutoDesigner makes that may improve the overall quality of the design.

The first example of a superior design decision made by AutoDesigner is in the application of a 1.0m deep-set at pole structure 3 in Figure 6.6. As discussed in Chapter 2, pole deep-sets are normally applied to support dead-end or tap-off poles that contain unanchored slack-spans. That being said, in the case of the design decision at pole 3, AutoDesigner is applying a deep-set to an inline tangent structure in order to avoid creating an uplift condition at pole 4 due to a significant drop in elevation between the two pole structures. Normal design practice is to make use of a a taller pole at pole 4 to eliminate the uplift condition, however, the use of a deep-set at pole 3 represents a cheaper alternative design. As a result of the lowered conductor attachment height at pole 3, AutoDesigner is able to utilize a cheaper 40 ft. pole structure at pole 4 instead of utilizing the 45 ft. pole selected by the human designer. While the use of a deep-set to avoid a floater condition is not a completely novel practice, it is uncommon to see when specifying 40 and 45 ft. poles as it requires significant calculation effort and designers do not generally regard the use of 45 ft. poles as representing a significant enough of a cost increase over a 40 ft. pole to justify the effort. That said, because of AutoDesigner's rigorous utilization of FloaterCheck calculations, the optimization of pole deep-sets to cheaply mitigate conductor uplift conditions is a natural means of optimizing a design for the software. While the practice is not unheard of, the application of a deep-set at pole 3 represents a unique application of a technique that is made advantageous through the use of AutoDesigner.

A second example of where AutoDesigner makes a potentially more correct design decision than that of the human-created design is at pole 16 in Figure 6.6. In this second example, AutoDesigner selects a 50 ft. pole while the human-created design uses a 45 ft. pole. Pole 16 is likely installed at the bottom of an embankment where the elevation of the previous adjacent pole is 14m higher than the elevation at pole 16. The use of a dead-end carry-on structure and inline side-guys in both designs alleviates concerns of a conductor uplift condition, however, minimum conductor clearance between the conductor span and the embankment is potentially problematic. Unfortunately, survey does not provide a location measuring ground elevation for the span between poles 15 and 16 and so AutoDesigner assumes a linear slope between the two poles and calculates the minimum conductor clearance that occurs as a result. AutoDesigner determines that a 50 ft. pole is necessary to maintain pedestrian clearances along the hypothetical embankment profile. The human-created design appears to not have used the same methodology to arrive at the pole height selection. Neither approach appears to be completely correct and, ideally, survey should provide additional data to confirm the embankment clearance. In either case, AutoDesigner suggests a more conservative design clearance in the face of missing information, albeit, the decision to use a 50 ft. pole also comes at a significant cost increase.

An example of where the human-created design suggests a more cost optimal design decision compared to AutoDesigner can be observed at pole 15. At pole 15, the human-created design selects a single cross-arm dead-end carry-on structure as opposed to the two cross-arm corner structure selected by AutoDesigner. The reason for

AutoDesigner selecting the more expensive structure is that the conductor deflection exceeds the 30° maximum deflection that is allowed by the dead-end carry-on structure by approximately 1°. Currently, AutoDesigner allows for conductor deflections that exceed the stated maximum specified on the structure parameter list by up to 0.5° before the structure pattern is barred from consideration by the genetic algorithm optimization. Conversely, the human designer is able to determine that such a deflection violation is insignificant and proceeds with using the dead-end carry-on structure. In the future, AutoDesigner may be provided with a percentage-based allowance factor that provides for more leniency for maximum deflection limits specified on the structure parameter list.

Another difference in design decisions made by AutoDesigner and the human designer that is worth noting occurs at poles 36 and 37. AutoDesigner utilizes the E3 grounding at the pole-mount transformer pole 37 which involves installing two ground rods at one pole location, while the human-created design utilizes an overhead neutral which is run back and terminated at pole 36 with a single ground rod being installed at each pole. AutoDesigner's decision to utilize the E3 grounding allows for shorter poles to be used at poles 36 and 37 as well as a smaller class of pole to be used at pole 37. That being said, E3 grounding is a very labour intensive grounding method and the human designer likely avoids the use of the E3 structure for this reason. AutoDesigner also recognizes the labour expense associated with the E3 grounding as five construction labour hours of punishment factor are applied to the N42,N86 structure pattern in the structure parameter list which is treated as a direct adder to the structure cost within AutoDesigner. That being said, in spite of the punishment factor, AutoDesigner still finds that the decision to use the E3 grounding is worth the cost in order to be able to use less expensive pole structures. The truly correct design decision in this situation is a matter of perspective and the approaches suggested by both of the designs can be said to have merit.

As a final note, it can be seen that the total computation time required for AutoDesigner to optimize the third evaluation case is just short of three hours. Such a time requirement does exceed the third objective of the thesis which aims for a 40-pole design to be optimized within two hours. That being said, it is important to note that the third objective of the thesis is intended to be regarded as an approximate target and despite requiring additional time, it is felt that AutoDesigner's overall time usage does not fall massively out of line with the target. While reducing population size can easily decrease computation time below the 2-hour limit, as shown in Chapter 5, such a practice is also likely to increase the final optimized cost. It is important to note that a 40 pole DOP design such as the one depicted in the third evaluation case likely takes a human designer several days of design time to complete manually and so allowing an additional hour of computation time for AutoDesigner to generate the best quality design that it is capable of producing is considered to be a worthwhile sacrifice.

In summary, for the third evaluation case, both the AutoDesigner design and the human-created design are well-optimized for cost and neither design falls subject to any obvious design omissions. AutoDesigner demonstrates a capacity to make several non-conventional and impressive design decisions while also making some less optimal design decisions due to its rigid thresholds in interpreting design rules that human designers are not subject to or because of the lack of PoleCheck2.0 tables. It is likely that with the natural progression of AutoDesigner's development, AutoDesigner can generate a design that has a total material and construction cost that is significantly below the threshold of the human-created design. AutoDesigner's computation time is a bit longer than originally targeted, however, its ability to produce a near complete DOP design with limited human input provides immense value in the design of a project that is considered by the DFO to represent a large DOP design.

6.5 Overall Conclusion

In the three investigated cases, AutoDesigner fulfills the first two objectives of the thesis by producing designs that are fully compliant with code requirements and DFO standard practices while also demonstrating the ability to make optimization decisions that result in a lower overall construction and material cost. In the first two evaluation cases, AutoDesigner avoids making significant design omissions that are made in the human-created designs that could have meaningful impact the overall quality of the DOP, if constructed. Furthermore, in all three cases, AutoDesigner demonstrates the capability to identify cost savings that the human-created designs are unable to realize. In the third evaluation case, by deep-setting an inline tangent pole structure, AutoDesigner is able to avoid the need to install a taller pole at an adjacent location to avoid an upift condition. In the second evaluation case, AutoDesigner is able to precisely distinguish between the need for 40 ft. and 45 ft. poles for a section of line that contains borderline clearance violations while the human-created design opts for the simpler but more costly uniform use of 45 ft. pole structure. Furthermore, in both the second and third evaluation cases, AutoDesigner is capable of making a judgment call between running an overhead neutral wire one span back from the transformer pole versus installing two ground rods at the transformer pole with no neutral wire. In both cases, AutoDesigner selects the no-neutral wire option in order to realize significant savings in pole heights while also maintaining a safe conductor clearance where the human-created design opts to use the overhead neutral wire resulting in an either a design omission or more costly, taller poles. Nevertheless, it is also important to note that significant debugging is still required when using AutoDesigner and so despite its successful performance on the three evaluated designs, its output still requires rigorous review by the DFO's designers as well as engineer authentication prior to being issued for construction.

The third objective of the thesis, requiring AutoDesigner to optimize a 40 pole

DOP design within approximately two hours of computation time, proves to be a more challenging objective to achieve. Despite the massive reduction in computation time availed by the use of the constraint module memory, AutoDesigner requires nearly 3 hours of computation time in order to fully optimize the 40-pole structure evaluation case. While the time required for computation of the third evaluation case can be easily reduced by decreasing the population size, as shown in Chapter 5, doing so will likely have a detrimental effect on the overall optimized material and construction costs. It is felt that achieving a maximally cost-optimized design is of significant importance and that it should not be sacrificed in order to improve computation time. Furthermore, the time required to optimize the 40 pole design is not unreasonably long and is considered to satisfy the general intent of the third objective. That being said, significant future work can be undertaken to improve the overall computation time and is discussed in the subsequent section.

In conclusion, in spite of some difficulty in precisely achieving the third thesis objective, it is felt that AutoDesigner meets and exceeds the expectations of the first two objectives while still satisfying the intent of the third objective. AutoDesigner represents a successful proof of concept in the automated design of DOP and provides real-world benefits that may be of significant, tangible value to the DFO and its designers.

6.6 Future Work

Despite successfully implementing AutoDesigner across a variety of projects, significant future work is required in order to develop a software platform that is acceptable for widespread use by the DFO's design staff.

Most immediately, PoleCheck2.0 lookup tables must be generated for the remainder of the DFO's standards library. At the time of completing the evaluation section of the thesis, only a portion of the DFO's three phase structure attachment library is modelled in PoleCheck2.0, requiring the use of PoleCheck1.0 for numerous three phase structures as well as the entire single-phase library. As mentioned in Chapter 3, when using PoleCheck1.0, AutoDesigner is required to make certain assumptions that may be problematic under the Canadian Electrical Code which requires that a non-linear analysis calculation be performed on all pole-loading calculations [4]. As a result, pole class recommendations made by AutoDesigner using PoleCheck1.0 must be treated with caution and independently verified by the DFO's designers.

To address the performance speed limitation of AutoDesigner, additional work is planned to enable AutoDesigner to make use of multicore processing within the Windows 10 operating system during the during the genetic algorithm optimization stage. Initial attempts at implementing multithreading in Python by using internal libraries did not result in success. That said, a possible implementation that may be more successful may include running additional instances of AutoDesigner in the background during program execution which focus solely on evaluating the objective functions of a sub-population within a generation of individuals. Running multiple instances of AutoDesigner relies on the operating system to automatically partition the instances across the available CPU cores on the desktop workstation.

In the event that AutoDesigner is adopted for use as design software by the DFO, additional work is planned to improve AutoDesigner's user interface, specifically in regard to the use of the preliminary staking list to specify advanced design requirements. Currently, access to advanced user input features in AutoDesigner requires the user to enter constraint operators in a preliminary staking list document that is generated by AutoDesigner prior to entering the genetic algorithm optimization process. Instead, in the future, a more user-friendly interface is planned that places pole structures on a map canvas prior to executing the optimization process. The map interface can allow for improved user accessibility and greater visibility of design parameters prior to entering the optimization process.

Finally, as part of a longer-term view of AutoDesigner's lifecycle, a dedicated FEA engine may be implemented to ensure that AutoDesigner's pole loading analysis continues to comply with future electrical code requirements [4]. Eventually, as electric utility codes continue to impose more rigorous requirements on DOP installations, the use of lookup tables may no longer remain a feasible means to calculate pole loading. For example, if requirements to account for soil holding strength or to analyze weather loading conditions beyond just medium or heavy loading conditions begin to be imposed on pole loading analysis under code, the number of combinations required in the PoleCheck lookup tables are likely to become too extensive to be contained within a lookup table format. In such a case, AutoDesigner can be outfitted with its own FEA engine where custom pole geometries are analyzed and undergo FEA during the optimization process. While an increased computation time may become a factor with real-time FEA analysis during genetic algorithm optimization, the constraint module memory capabilities that AutoDesigner is currently outfitted with can allow for a rapid retrieval of previously computed results in much the same manner that the outputs from PoleCheck lookup tables for previously computed individuals are stored for fast retrieval.

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Appendix A: Data Tables Pertaining to Methodology Discussions

Table A.1: Input data fields and allowable user entries in AutoDesigner user interface.

Field Description	Input	Input	Input	Input	Input	Input	Input	Input	Input
CSV File Name	User-Defined								
Loading	Heavy	Medium							
Neutral Spacing	Urban	Rural							
Num Phases of Existing Mainline	Single	Three							
Num Phases of New Mainline	Single	Three							
Num Phases of Existing Tap-Offs	Single	Three							
Num Phases of New Tap-Offs	Single	Three							
Type of Grounding	Earth Return	MGN							
Prevailing Clearance Type	Pedestrian	Agricultural							
Conductor Type Existing Mainline	#8 HiCON	BANTAM	#6 ACSR	#4 ACSR	#2 ACSR	1/0 ACSR	2/0 ACSR	266 MCM ACSR	477 MCM ACSR
Conductor Type Existing Tap-Off	#8 HiCON	BANTAM	#6 ACSR	#4 ACSR	#2 ACSR	1/0 ACSR	2/0 ACSR	266 MCM ACSR	477 MCM ACSR
Conductor Type New Mainline	#4 ACSR	1/0 ACSR	266 MCM ACSR	477 MCM ACSR					
Conductor Type New Tap-Off	#4 ACSR	1/0 ACSR	266 MCM ACSR	477 MCM ACSR					
Pole-Top Equipment 1 Pole No.	Integer in Range 1-500	Leave Blank							
Pole-Top Equipment 1 Pole Type	R180	R182	N82	N82A	N86	N86A	R390	R390A	N390
	N390ALeave Blank								
Pole-Top Equipment 2 Pole No.	Integer in Range 1-500	Leave Blank							
Pole-Top Equipment 2 Pole Type	R180	R182	N82	N82A	N86	N86A	R390	R390A	N390

	N390A	Leave Blank							
Pole-Top Equipment 3 Pole No.	Integer in Range 1-500	Leave Blank							
Pole-Top Equipment 3 Pole Type	R180	R182	N82	N82A	N86	N86A	R390	R390A	N390
	N390A	Leave Blank							
Nearest Service Point	Designated DFO Service Points								

Table A.2: Table of Pole Class Attributes with Descriptions and Ranges of Potential Values.

Attribute Name	Description of Attribute
isExisting	Value set to 0 if pole is new, 1 if pole is existing.
optimizableExPole	Value set to 1 if pole is existing and at end or beginning of CSV file where prev/next pole is unknown, 0 otherwise.
utmNorthing	Floating point value for UTM Northing that is extracted from survey CSV File.
utmEasting	Floating point value for UTM Easting that is extracted from survey CSF File.
baseElevation	Floating point value for elevation above sea level in meters extracted from survey CSV File.
poleHeight	Optimizable parameter: pole height value in feet or left as '*' if value not yet optimized.
poleClass	Optimizable parameter: pole class rating in the range of 1 to 7 or left as '*' if value not yet optimized.
poleComposition	Optimizable parameter: pole composition abbreviated with values such as WR (Western Red Cedar) or LP (Lodge-Pole Pine) or '*' if not yet optimized.
deepSet	Optimizable parameter: value set to 0.0,0.5,1.0 or 1.5 or '*' if not yet optimized.
mainSpanIncOrientation	Floating point value in degrees, contains orientation with respect to due north of the incoming main-span line. Field is left blank if there is no incoming span.
mainSpanOutOrientation	Floating point value in degrees, contains orientation with respect to due north of the outgoing main-span line. Field is left blank if there is no outgoing span.
tapOneOrientation	Floating point value in degrees, contains orientation with respect to due north of the first tap-off span. Field is left bank if there are no tap-offs.
tapTwoOrientation	Floating point value in degrees, contains orientation with respect to due north of the second tap-off span. Field is left blank if there is no second tap-off.
ancOneType	Optimzable Parameter: string for anchor type of first anchor on pole. May have values such as: "G40A", "G25B", "G60","EXANC" or may be left blank if no anchor or '*" if not yet optimized.
ancOneLength	Floating point value in meters. Indicates anchor length of first anchor, may be left blank if no anchor present on pole or presence of anchor is not yet optimized.
ancOneOrientation	Floating point value in degrees. Indicates guy wire orientation with respect to due north, may be left blank if no anchor is present on pole or presence of anchor is not yet optimized.
ancTwoType	Optimzable Parameter: string for anchor type of second anchor on pole. May have values such as: "G40A", "G25B", "G60","EXANC" or may be left blank if no second anchor or '*" if not yet optimized.
ancTwoLength	Floating point value in meters. Indicates anchor length of second anchor, may be left blank if no second anchor present on pole or presence of anchor is not yet optimized.
ancTwoOrientation	Floating point value in degrees. Indicates guy wire orientation with respect to due north, may be left blank if no second anchor is present on pole or presence of anchor is not yet optimized.
numExGndRods	Value set to either 0, 1 or 2. Integer value that represents the total number of existing ground rods present at existing pole. Set to 0 if pole is not existing.
numNewGndRods	Optimizable parameter. Represents the total number of new ground rods installed at pole. May be 0, 1, 2 or set to '*' if not yet optimized.
breakTensionMain	Value extracted from structure parameter list. Determined by the type of compatible unit on pole. Set to 0 if pole top structure is an inline tangent or deflection, set to 1 if pole is a dead-end or dead-end carry-on, set to 2 if uncommon structure where conductor has unbroken tension between a mainline and a tap-off (only for non-typical tap-off structures). Value may be set to '*' if pole top structure is not yet optimized.
mainlineFloaterCheckNotRequired	Value extracted from structure parameter list. Determined by the type of compatible unit on pole. Set to 0 if pole top structure supporting the incoming and outgoing mainline conductors is susceptible to uplift condition, set to 1 if pole top structure is not susceptible to conductor uplift and set to 2 if the pole top structure is susceptible to uplift but not between the incoming and outgoing mainline conductor spans. Value may be set to '*' if not yet optimized.

strPatternEx	Contains a string representing the compatible units on an existing pole that are currently present. Field is left blank if pole is new. Components may be removed from string or string may be removed entirely is existing pole is upgraded or replaced in the course of the design optimization process.
strPatternNew	Optimizable parameter. Contains a string representing the new pole-top structures that are to be installed on a pole. Value may be blank for an existing pole that is not directly associated with a design or '*' if the pole is related to the new design but not yet optimized. Blanked out strPatternNew fields may become populated with optimizable existing poles if the pole is upgraded or changed out during optimization.
neutStrPatternEx	Contains a string representing the existing neutral conductor compatible units on an existing pole, if a neutral is present. Field is left blank if no neutral is present on pole, otherwise field follows a similar rule-set as the strPatternEx field.
neutStrPatternNew	Contains a string representing the new neutral conductor compatible units installed on a pole, if a neutral is present. After optimization is complete, field is left blank if no neutral is present on pole. Field is marked with an '*' prior to optimization regardless of whether or not user has specified a neutral MGN system due to the possibility of earth-return neutral for pole top equipment which may extend one or more spans away from equipment poles.
salvAttachPole	Indicates whether existing pole has attachments removed or if pole is replaced. Value is initialized to zero and left unchanged until after optimization. If pole is existing, value gets set to 1 if pole top equipment has been replaced with existing structures removed and value is set to 2 if entire pole is removed and replaced with a new pole.
topToCond1	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the conductor of the incoming single phase main line or the centre phase of a three phase incoming mainline. Value is left blank if no incoming mainline is possible and may be set to '*' prior to optimization if pole is existing but is being fed by a new line.
topToCond2	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the second highest phase conductor of a three phase line. Value is left blank if line is defined by user as single phase or if no incoming mainline is possible. Value may be set to '*' prior to optimization if pole is existing but being fed by a new line.
topToCond3	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the lowest phase conductor of a three phase line. Value is left blank if line is defined by user as single phase or if no incoming mainline is possible. Value may be set to '*' prior to optimization if pole is existing but being fed by a new line.
topToCond4	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the conductor of the outgoing single phase main line or the centre phase of a three phase outgoing mainline. Value is left blank if no outgoing mainline is possible. Value may be set to '*' prior to optimization if pole is existing but is feeding a new line segment that is an extension of the mainline.
topToCond5	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the second highest phase conductor of a three phase line. Value is left blank if line is defined by users as single phase or if no outgoing mainline is possible .Value may be set to '*' prior to optimization if pole is existing but feeding a new line.
topToCond6	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the lowest phase conductor of a three phase line. Value is left blank if line is defined by users as single phase or if no outgoing mainline is possible. Value may be set to '*' prior to optimization if pole is existing but feeding a new line.
topToTap1	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the single phase conductor of the first tap-off circuit or the center phase of a three phase tap-off circuit. Value is left blank if no tap-off circuits are possible on pole. Value may be set to '*' prior to optimization on an existing pole that may be tapped off of for a new line extension.
topToTap2	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the second phase of a three phase tap-off circuit. Value is left blank if no tap-off circuits are possible on pole. Value may be set to '*' prior to optimization on an existing pole that may be tapped off of for a new line extension.
topToTap3	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the second phase of a three phase tap-off circuit. Value is left blank if no tap-off circuits are possible on pole. Value may be set to '*' prior to optimization on an existing pole that may be tapped off of for a new line extension.
topToN1	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the incoming mainline neutral conductor. Value is set to '*' pre-optimization unless no incoming mainline span is present. Post-optimization, the value is either left blank or contains the distance from top of pole for the incoming mainline neutral conductor.
topToN2	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the outgoing mainline neutral conductor. Value is set to '*' pre-optimization unless no outgoing mainline span is present. Post-optimization, the value is either left blank or contains the distance from top of pole for the outgoing mainline neutral conductor.

topToNT	Value extracted from structure parameter list. Floating point value that measures the distance from the top of the pole to the attachment elevation of the tap-spans neutral conductor. If two tap-offs are present, both tap-offs are constrained to have the same neutral attachment value. Value is set to '*' prior to optimization if a tap-off span is present on pole. Post-optimization, the value is either left blank or contains the distance from the top of pole for the tap-span neutral conductor.
topToAttach1	Value extracted from structure parameter list. Floating point value that measures the distance from the top of pole to the highest attachment bolt on a pole structure. Value is set to '*' pre-optimization for new pole structures.
SWGRNeeded	Value extracted from structure parameter list. Value that represents the need for a second ground rod on a separate pole for certain equipment structures. Value is set to 0 if a second ground rod at a remote pole is not required and set to 1 if it is required.
strPatternIfAddTap	Value extracted from structure parameter list. String that contains the potential set of compatible units for pole-top structure combinations if current pole-top structure is tapped off of. Field is left blank if current pole-top structure cannot be tapped off of.
strPatternIfExtendMainline	Value extracted from structure parameter list. String that contains the potential set of compatible units for pole-top structure combinations if current pole-top structure is extended to have an outgoing mainline. Field is left blank if current pole-top structure already has an outgoing mainline.
strPatternGAIndex	Integer value that contains the index of the pole-top structure compatible unit selected by the genetic algorithm from the list of candidate structures for the pole. Value is used in the memory lookup tables for fast recall of past optimized results. Value is initiated as 0 and changed to an integer in the range of potential pole top structures during optimization.
equipStr	String that contains that specific equipment structure compatible unit that is selected by user in the AutoDesigner user interface for new poles or interpreted in the compatible unit's field of the survey CSV file for existing pole structures. Value is left blank if no equipment structures are present on pole.
horizOffsetFactor	Value extracted from structure parameter list. Floating point value measuring in meters the distance from the centre of the cross-arm attachment for the mainline conductor with respect to the centre of the pole. Value is initially set to '*' and given a floating point value after optimization when a pole-top structure is selected. Most pole structures will set this value to 0.0
poleCheckPattern	Value extracted from structure parameter list. Unique address associating structure pattern with a specific poleCheck1.0 or poleCheck2.0 computation table. Strings beginning with a '_' character reference a structure pattern to a poleCheck1.0 table or set of tables while strings beginning with '$' reference the structure pattern to a poleCheck2.0 table.
exPoleDesignVsActualAttach	Floating point value that is populated for existing poles. Contains the vertical difference in meters between the attachment height of the top attachment mounting bolt and the field measured value obtained from the survey CSV file.
contNeutMainline	Value extracted from structure parameter list. Integer with value 0, 1 or 2. A value of 0 indicates either that no neutral is present on mainline or that the mainline incoming and outgoing spans are single phase and that only one of the incoming or outgoing spans have a neutral conductor present. A value of 2 is assigned with the incoming and outgoing mainline is a three phase structure and a neutral is indicated in the pole's structure as being present but it is unclear from the structure parameter alone whether the neutral is continuous or if it is only present on the incoming or outgoing mainline spans.
num1PhTapNeuts	Value extracted from structure parameter list. Value is set to 0, 1 or 2 after pole is assigned a structure pattern and indicates the number of single phase tap-off spans present on pole that include a neutral conductor.
neutStrPatternExCost	Value extracted from the neutral structure parameter list. Floating point value that represents the material cost of an existing neutral structure on a pole as if it had been installed using current standards and rates. Value is used to determine the incremental material cost of upgrading a neutral structure with a new extension of a mainline or a tap-off.
neutStrPatternExConstHours	Value extracted from the neutral structure parameter list. Value is used in the same manner as neutStrPatternExCost however represents the construction labour cost.
exStrCost	Value extracted from structure parameter list. Floating point value that represents the material cost of an existing structure on a pole as if it had been installed using current standards and rates. Value is used to determine the incremental material cost of upgrading pole-top structure with a new extension of a mainline or a tap-off.
exStrConstHours	Value extracted from the structure parameter list. Value is used in the same manner as exStrCost however represents the construction labour cost.
strCost	Floating point value that represents the total material cost of new construction on a pole. Costs may include the cost of the pole, pole-top attachments, neutral attachments, downhaul guy wires and anchors and pole-top equipment.
constHours	Floating point value that represents the total construction labour associated with new construction work on a pole. Costs may include labour associated with installing a pole, adding pole-top attachments, performing a deep-set of a pole, and installing anchors and downhaul guy wires.
strID	String value assigned from the survey CSV file to denote a particular pole location. Value will contain a six digit number if it represents an existing pole location or a number from 1 to 500 if it represents a new pole location.
nextSpan	Reference to the span object representing the previous span in the linked list. Value is set to None if no previous span is present at pole.
tapSpan1	Reference to the span object representing the first tap-off span object in the linked list that is associated with the current pole. Value is set to None if no tap spans are present at pole.

tapSpan2	Reference to the span object representing the second tap-off span object in the linked list that is associated with the current pole. Value is set to None if less than two tap spans are present at pole.
prevSpan	Reference to the span object representing the next mainline span in the linked list. Value is set to None if no next span of the mainline is present at pole.
poleBackup	Reference to a pole object containing the pre-optimization state of the current pole structure. poleBackup is used to restore the current pole structure to its pre-optimization state during optimization between evaluations of individuals in the genetic algorithm.

Table A.3: Table of Pole Class Methods with Descriptions of Operation.

Attribute Name	Description of Method Operation
__init__	Initializes a new Pole object with basic parameters that are directly available from the survey CSV file and which are common to both existing and new pole structures such as UTM coordinates, elevation, and presence of anchors.
addExistingInfo	Called when Pole object represents an existing pole structure. All remaining details for existing pole that are not added during initialization are added.
calcPoleDeflection	calculates and returns the deflection angle in degrees for the main span or the tap-off span(s) with respect to the incoming main span.
convertAngleToDegMinutes	Converts the supplied pole deflection angle to a value that conforms to the notation used in the staking list which represents deflection in terms of left or right directions followed by the degrees in minutes and seconds. Returns a string in the form "L 002°28'"
getDeflType	Method to determine the type of conductor to use when determining from the structure parameter list the allowable range of deflection for a for a pole top structure. Method selects the largest conductor size of incoming and outgoing main span conductor types.
detNeutralAttachStrs	Method to determine a cost-optimal set of neutral attachment structures based on the pole deflections, the presence of tap-offs and the pole-top attachments. Method returns a string containing the neutral structure pattern along material and labour cost of neutral structure or returns an empty string and 0 cost values if no neutral is present on pole.
verifyAncTypes	Method that populates existing anchors prior to design optimization that are not clearly specified on survey CSV file using best-guess analysis. If anchor is determined to be anchoring a new circuit, anchor type is set to '*'.
removeStruct	Method that removes one neutral structure from the supplied structure pattern string. Removes either "R0" or "Neut" from the supplied string. Returns the supplied string unchanged if no neutral structures can be found.
detNewNeutAttachAndCost	Method that calls detNeutralAttachStrs and adds the returned labour costs to the total structure costs. Sets neutStrPatternNew to the returned string if the string is not empty.
detExNeutAttachAndCost	Method to determine the existing neutral structure attachments on pole. Method calls detNeutralAttachStrs and subtracts from the returned string the neutral attachments that are associated with any new spans that might be attached to the existing pole. Method populates neutStrPatternEx, neutStrPatternExCost and neutStrPatternExConstHours in pole object.
getDirFromOrient	Method that takes an input an orientation with respect to north in degrees and returns a directional string for use in the staking list. Values returned include 'N','NE','E','SE','S','SW','W' or 'NW'.
genStakingListRow	Method to generate the structure row of either the preliminary or final staking lists.
updatePole	Method to update pole object with any changes that are specified by the user on the preliminary staking list.
calcAncOrSpanPolar	Method that takes as input the UTM coordinates of anchor or an adjacent pole that is associated with the pole object and returns an anchor length in meters along with an orientation or a span length in meters along with an orientation.
goToFirstPole	Method that traverses backwards along linked list until reaching pole that has no previous span object which correlates to the first pole in the linked list.
searchListForPoleNumber	Method that traverses the linked list recursively searching for a pole object with a strID matching the supplied input string. Method returns pole object when found or returns None if cannot find a match.
goToPoleNumber	Method recursively searches linked list until finding pole object with ID equal to that of strID. If cannot find a match, the method returns None.
goToClosestPrevTapOffSpan	Method traverses back from current pole object to find and return the most recent span object that is a tap-off of another mainline. If method cannot find such a span, the method returns the first span object in linked list.
goToNextSpan	Method moves linked list to the next span object in the list. If there is no further span available at pole object, then method traverses backwards along linked list until finding a pole object that has a tap-off span and returns the next tap-off span.
addNextSpan	Method is used during construction of linked list and accepts input data regarding the location of a pole structure that is adjacent to the structure represented by the current Pole object. Method creates a new Span object and links the Pole objects nextSpan, tapSpan1 or tapSpan2 fields to reference the new Span object depending on user input.
addTapInfoToExPole	Method for adding tap-off information to an existing pole where the tap-off details were not originally added to the pole based on the supplied compatible units in the survey CSV file. This situation occurs when an existing pole is being tapped off of but the survey field crews only make mention of the pole-top structures that are currently present on the pole.

extendExDeadend	Method is very similar to addTapInfoToExPole except that it is for existing poles where new line is extending the mainline circuit rather than tapping off. Outgoing or incoming mainline attachment information is added to the pole structure that was not present in the survey CSV pole-top structure information.
getMaxTopToCond	Method returns the lowest attachment elevation present on pole.
initBackup	Method accepts the complete list of attributes supplied as input (obtained from a master Pole object) and assigns to current Pole object. Current Pole object is intended to be used as backup for the master Pole object.
createBackup	Method calls initBackup for the purposes of creating a backup Pole object for the current (master) Pole object.
restoreBackup	Method performs shallow copy of backup Pole object and transfers value into current (Master) pole object. Shallow copy includes copying references to adjacent span objects but the copy method does not dive into the span objects.
removeDuplicateStrs	Method assists with the generation of the loading file for the DFO's material management system. Method accepts two lists of structure patterns and removes duplicate compatible units that exist on both lists. Duplicate structures may be removed from both lists or only one of the lists depending on the state of a user-specified flag.
generateStrList	Method assists with the generation of the loading file for the DFO's material management system. Method appends extracts compatible units from a supplied string and appends to a supplied list of compatible units.
colourCodeStrs	Method assists with the generation of the loading file for the DFO's material management system. Method looks at two supplied lists of compatible unit strings where one list contains the final set of structures on the pole and the other the initial set and determines which structures are being removed. Colour coding denotes structures being removed with a green colour that is by prefaced in the string with a ”¡g¿”, existing compatible units are denoted with black (”¡b¿”) and new compatible units with red (”¡r¿”).
convertToDMACompatUnits	Method assists with the generation of the loading file for the DFO's material management system. Method takes compatible units specified in strPatternEx and strPatternNew Pole attributes and converts them into a form that is recognizable by the DFO's material management system.
genDMARow	Method assists with the generation of the loading file for the DFO's material management system. Method parses the strPatternEx and strPatternNew attributes and returns a list of colour-coded compatible units that are represented in a form that is recognizable by the material management software. Colour coding denotes structures being removed with a green colour that is by prefaced in the string with a ”¡g¿”, existing compatible units are denoted with black (”¡b¿”) and new compatible units with red (”¡r¿”).
convertFromStrListToString	Method assists with the generation of the loading file for the DFO's material management system. Method accepts a list of compatible units and returns it as a string with each compatible unit separated with commas.
updatePoleWithOptimization	Method updates the pole with the optimization selection from the genetic algorithm individual for the current pole object. All fields containing '*' characters are populated with applicable values. Neutral discontinuities are eliminated or are flagged for constraint violations by the neutral and ground rod constraint module.

Table A.4: Table of Span Class Attributes with Descriptions and Ranges of Potential Values.

Attribute Name	Description of Attribute
isTapOff	Attribute is an integer value which indicates whether Span object is the first span in a tap-off circuit. Value is set to 1 if the Span object is the first span in a tap-off circuit, otherwise value is set to 0.
isExistingSpan	Attribute is an integer value which indicates whether the span is new or existing. Value is set to 1 if the span is existing, otherwise set to 1.
isTightSpan	Attribute is an integer value which indicates whether Span tension is tight or is a slack span. Value is set to set 1 if tight, 0 if slack.
numPhases	Attribute is an integer value that indicates the number of phase conductors present in span. Value is set to 1 if span is single phase, 3 if span is three phase.
MGN	Attirbute is an integer value that indicates whether an overhead neutral wire is present in span. Value is set to 1 if an overhead neutral wire is present, 3 if no neutral wire is present.
condType	Attribute is an integer value that indicates the conductor type of the span conductor. Values correspond to the conductor numbering outlined in Table 2.3.
heavyLoading	Attribute is an integer value that indicates the requirement to account for heavy ice loading conditions in conductor sag and pole loading calculations. Values corresponding to 1 represent heavy loading while a value of 0 represents medium loading.
grade	Attribute is an integer value that indicates the requirement to consider increased loading factors in pole loading calculations as defined by the Canadian Electrical Code, Part 3 Overhead standard [4] and depicted in Table 2.2. A value of 1 indicates that grade 1 loading factors are to be used while a value of 2 indicates that grade 2 loading factors may be used.
urbanSpacing	Attribute is an integer value that indicates the requirement for additional neutral to phase separation for construction in urban areas. A value of 1 indicates that urban spacing must be applied to neutral spacing while a value of 0 indicates that normal 2.0m neutral separation values may be used.

spanLength	Attribue is a floating point value that represents the length of the current span measured as a direct line between the UTM coordinates of the two adjoining pole structures.
crossingTypes	Attribute is a list of strings that contains the abbreviations of all crossing types that occur along the span as per the abbreviations depicted in Table 2.4. Note that the list must contain a minimum of one crossing abbreviation (PED or AG) due to the need for a general crossing classification for the span that is measured at the point of greatest sag.
crossingLocs	Attribue is a list of floating point values that contains the distance in meters of each crossing abbreviation contained in crossingTypes from the location of the previous pole. Note that crossingLocs may be shorter than crossingTypes by one element due to the need for crossingTypes to contain a general crossing that is measured at point of greatest conductor sag if a crossing point is not present in the survey CSV file.
crossingElevs	Attribue is a list of floating point values that contains the elevation above sea level in meters of each crossing survey data point indicated in crossingTypes by abbreviations. Note that crossingElevs may be shorter than crossingTypes by one element due to the need for crossingTypes to contain a general crossing that is measured at point of greatest conductor sag where the elevation at the point of greatest sag is interpolated if a crossing point is not present in the survey CSV file.
spanCost	Attribute is a value, in dollars, that represents the total material cost associated with the span conductor. For new spans, the value is assigned '*'.
nextPole	Attribute is a reference to the next pole object in the linked list. This value must never be left as None after construction of the linked list.
prevPole	Attribue is a reference to the previous pole object in the linked list. This value must never be left as None after construction of the linked list.
spanBackup	Attribute is a reference to a span object containing the pre-optimization state of the current span. spanBackup is used to restore the current span object to its pre-optimization state during optimization between evaluations of individuals in the genetic algorithm.

Table A.5: Table of Pole Class Methods with Descriptions of Operation.

Attribute Name	Description of Method Operation
__init__	Initializes a new Span object with basic parameters that are directly available from user input or which can be determined through rule-based analysis.
detExSlackNonTap	Method that applies rule-based analysis to determine if a newly instantiated span object is a slack-span or a tight-span. Note that method is applied only when spans are not tap-off spans.
detExSlackTap	Method that applies rule-based analysis to determine if a newly instantiated span object is a slack-span or a tight-span. Note that method is applied only to spans that are tap-offs.
spanOrientNextPole	Method that returns the floating point orientation of the span's attachment point at the next pole in degrees with respect to due north.
spanOrientNextPoleFullyInit	Method that returns the floating point orientation of the span's attachment point at the next pole in degrees with respect to due north without the next pole being fully initialized. The method accepts as input the UTM coordinates of the next pole.
calcCrossingLoc	Method that takes as input the UTM coordinates of a crossing location from the survey CSV file and projects the crossing onto the span alignment. The method returns the distance of the projected crossing location along with span with respect to the previous pole in meters.
goToFirstPole	Method that calls and returns the previous Pole objects goToFirstPole method.
addNextPole	Method that creates a new Pole object for the nextPole. Method returns the instantiated pole object.
calcSpanLength	Method calculates the floating point distance in meters between two sets of UTM coordinates representing the new pole and previous pole location and returns the value.
getPrevPole	Method returns the previous pole object in the linked list.
goToPoleNumber	Method that accepts an integer structure ID, calls the goToPoleNumber method in the previous pole object and returns the output.
detIfSpanIsTap1or2	Method assesses whether the current span is a first tap-off, a second tap-off or not a tap-off span. Returns 0 if not a tap-off, returns 1 if span is the first tap-off on a pole and 2 if it is the second.
genStakingListRow	Method to generate the span row of either the preliminary or final staking lists.
updateSpan	Method to update Span object with any changes that are specified by the user on the preliminary staking list.
goToNextPole	Method that returns the object reference of the next pole.
setNumPhases	Method that sets the numPhases attribute to the supplied input integer.
setMGN	Method that sets the MGN attribute to the supplied input integer.
convertToExSpan	Converts an existing span to a new span as well as setting MGN, numPhases and condType to the input-specified values.
initBackup	Method accepts the complete list of attributes supplied as input (obtained from a master Span object) and assigns to current Span object. Current Span object is intended to be used as backup for the master Pole object.
createBackup	Method calls initBackup for the purposes of creating a backup Span object for the current (master) Span object.

restoreBackup	Method retrieves values stored in span backup and copies them back into the fields original span object.
updateSpanWithOptimization	updates span object with characteristics chosen by GA. Primarily, this involves classifying span as a slack or tight-span, however, indirectly the span will also be classified as a MGN or non-MGN span based on whether the previous pole has attachments for neutral wire (these attachments would have been determined by the optimization of the pole object, span object will compliment the selection). Span cost is updated at this stage as well.

Table A.6: Table of Structure Parameter List Data Fields with Descriptions.

Data Field Name	Description
strPattern	Contains a data string where each row represents a different potential set of pole top structure combinations. Each compatible unit is separated by a comma and additional compatible units may be added to the pole structure such as neutral attachments, grounding structures and downhaul guy wire structures.
topToCond1	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the incoming main-line span or the middle conductor of the incoming main-line span in the case of a three phase line. Value is left blank if structure pattern does not have any incoming main-line conductor.
topToCond2	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the second phase of a three phase incoming main-line span. Note that the value is left blank if the structure pattern specifies a single phase main-line or if there is no incoming main-line conductor on structure.
topToCond3	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the third phase of a three phase line incoming main-line span. Note that the value is left blank if the structure pattern specifies a single phase main-line or if there is no incoming main-line conductor on structure.
topToCond4	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the incoming main-line span or the middle conductor of the outgoing main-line span in the case of a three phase line. Value is left blank if structure pattern does not have any outgoing main-line conductor.
topToCond5	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the second phase of a three phase incoming main-line span. Note that the value is left blank if the structure pattern specifies a single phase main-line or if there is no incoming main-line conductor on structure.
topToCond6	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the third phase of a three phase line outgoing main-line span. Note that the value is left blank if the structure pattern specifies a single phase main-line or if there is no outgoing main-line conductor on structure.
topToTap1	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of any single phase tap-off conductors or the middle phase of any three phase tap-off conductors. Note that the value is left blank if the structure pattern does not specify any tap-off conductors.
topToTap2	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the second phase of any three phase tap-off conductors. Note that the value is left blank if the structure pattern does not specify any tap-off conductors or if the tap-off structures are only single phase.
topToTap3	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the third phase of any three phase tap-off conductors. Note that the value is left blank if the structure pattern does not specify any tap-off conductors or if the tap-off structures are only single phase.
topToN1Rural	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the incoming main-line neutral conductor assuming that the DOP is being installed in rural areas. Note that the value is left blank if the structure pattern does not specify a neutral conductor on the incoming main-line span.
topToN2Rural	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the outgoing main-line neutral conductor assuming that the DOP is being installed in rural areas. Note that the value is left blank if the structure pattern does not specify a neutral conductor on the outgoing main-line span.
topToN1Urban	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the incoming main-line neutral conductor assuming that the DOP is being installed in an urban area. Urban spacing provides additional neutral separation to allow for future equipment installation on pole without reducing design clearances over roadways, etc. Note that the value is left blank if the structure pattern does not specify a neutral conductor on the incoming main-line span.
topToN2Urban	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the outgoing main-line neutral conductor assuming that the DOP is being installed in an urban area. Urban spacing provides additional neutral separation to allow for future equipment installation on pole without reducing design clearances over roadways, etc. Note that the value is left blank if the structure pattern does not specify a neutral conductor on the outgoing main-line span.

topToNTap	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of the tap-span neutral conductors. Note that the value is left blank if the structure pattern does not specify a neutral conductor on the tap-spans.
topToAttach1	Contains a floating point value that represents the vertical separation in meters between the top of the pole structure and the elevation of top mounting bolt specified by the structure pattern. Value serves as a reference measurement for HoX data specified on the survey CSV file. This value should never be left blank.
topToS1Rural	Note that this is a future data-field that is not currently being utilized by AutoDesigner. Contains a floating point value that represents the vertical separation in meters between the top of the pole and the secondary conductor on the incoming main-span assuming that the DOP is located in a rural area.
topToS2Rural	Note that this is a future data-field that is not currently being utilized by AutoDesigner. Contains a floating point value that represents the vertical separation in meters between the top of the pole and the secondary conductor on the outgoing main-span assuming that the DOP is located in a rural area.
topToS1Urban	Note that this is a future data-field that is not currently being utilized by AutoDesigner. Contains a floating point value that represents the vertical separation in meters between the top of the pole and the secondary conductor on the incoming main-span assuming that the DOP is located in an urban area.
topToS2Urban	Note that this is a future data-field that is not currently being utilized by AutoDesigner. Contains a floating point value that represents the vertical separation in meters between the top of the pole and the secondary conductor on the outgoing main-span assuming that the DOP is located in an urban area.
topToSTap	Note that this is a future data-field that is not currently being utilized by AutoDesigner. Contains a floating point value that represents the vertical separation in meters between the top of the pole and the secondary tap-span conductors.
brkTensionMainline	Contains an integer value that is set to 0 if the incoming and outgoing main-line has no break in tension across the pole structure (e.g. an inline tangent structure). The integer value is set to 1 if there is an interruption in tension between the incoming and outgoing mainline conductor (e.g. dead-end carry-on structure) or if one of the incoming or outgoing mainline conductors are not present (e.g. dead-end structure). Integer value is set to 2 if there is a continuous, uninterrupted tension between attachments other than the incoming and outgoing mainline conductor. Note that this value should never be blank.
mainlineFloaterCheckNotRequired	Contains an integer value that is largely a mirror of the brkTensionMainline field discussed above. Note that this value may diverge from the brkTensionMainline if there is an inline tangent structure that is not susceptible to the conductor uplift condition (e.g. armless construction may have insulators that cannot be damaged from uplift). Currently, brkTensionMainline and mainlineFloaterCheckNotRequired are identical columns. Note that this value should never be blank.
numGndPoints	Integer value that represents the number of ground rods that need to be electrically interconnected with the structurePattern in question. Note that ground rods do not necessarily need to be installed at the same location but may be interconnected via an overhead neutral wire with other nearby pole structures that contain ground rods. Note that this parameter is validated during optimization via the neutral continuity and ground rod constraint module. Note that this value should never be blank.
SWGRNeeded	Integer value that may be set to 0 or 1 and where 1 indicates that an additional ground rod at a remote pole needs to be interconnected with current pole structure via an overhead neutral wire. Note that this value is currently only set to 1 for overhead transformer structures.
minDefl8HiCON-1	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is #8 HiCON. Note that because DFO standards do not currently specify deflections for #8 HiCON, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDeflBantam-2	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is BANTAM. Note that because DFO standards do not currently specify deflections for BANTAM, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl6ACSR-3	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 6 ACSR. Note that because DFO standards do not currently specify deflections for #6 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl4ACSR-4	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is #4 ACSR. Field may be left blank if pole structure is not compatible with #4 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.

minDefl2ACSR-5	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 2 ACSR. Note that because DFO standards do not currently specify deflections for #2 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl1/0ACSR-6	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 1/0 ACSR. Field may be left blank if pole structure is not compatible with 1/0 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2/0ACSR-7	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 2/0 ACSR. Note that because DFO standards do not currently specify deflections for 2/0 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl266MCM-8	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline conductor must have in order for the structure pattern to be validly utilized assuming that the mainline spans is 266 MCM ACSR. Field may be left blank if pole structure is not compatible with 266 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl477MCM-9	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline conductor must have in order for the structure pattern to be validly utilized assuming that the mainline spans is 477 MCM ACSR. Field may be left blank if pole structure is not compatible with 477 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl8HiCON-1	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is #8 HiCON. Note that because DFO standards do not currently specify deflections for #8 HiCON, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDeflBantam-2	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is BANTAM. Note that because DFO standards do not currently specify deflections for BANTAM, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl6ACSR-3	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 6 ACSR. Note that because DFO standards do not currently specify deflections for #6 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl4ACSR-4	Contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is #4 ACSR. Field may be left blank if pole structure is not compatible with #4 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2ACSR-5	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 2 ACSR. Note that because DFO standards do not currently specify deflections for #2 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl1/0ACSR-6	Contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 1/0 ACSR. Field may be left blank if pole structure is not compatible with 1/0 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2/0ACSR-7	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 2/0 ACSR. Note that because DFO standards do not currently specify deflections for 2/0 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.

minDefl266MCM-8	Contains a floating point value that specifies the maximum allowable deflection that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 266 MCM ACSR. Field may be left blank if pole structure is not compatible with 266 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl477MCM-9	Contains a floating point value that specifies the maximum allowable deflection that the incoming and outgoing mainline spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 477 MCM ACSR. Field may be left blank if pole structure is not compatible with 477 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minTapDefl	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that tap-off spans can have with respect to the incoming mainline. Field may be left blank if not tap-off structures are specified by the structure pattern.
maxTapDefl	Contains a floating point value that specifies the maximum allowable deflection angle in degrees that tap-off spans can have with respect to the incoming mainline. Field may be left blank if not tap-off structures are specified by the structure pattern.
tapOrientedOppositeAPhaseOrTap	Contains an integer value that is populated when a structure pattern specifies two tap-off spans. A value set to 0 indicates that the two tap-off spans do not share a common attachment structure such as a cross-arm and are, therefore, not constrained to have a deflection that does not exceed the allowable deflection of the cross-arm structure. A value that is set to 1 indicates that the two tap-off spans do share a common structure and that the deflection of the each tap-off span must be constrained by the deflection of the other. Field is left blank for structure patterns that do not contain two tap-off spans.
numPhasesMain	Primarily contains an integer value that indicates the number of phases present on the main-line. Note that value is set to the string value of "3/1" in cases when the incoming mainline span and the outgoing mainline span transitions between a three phase circuit and a single phase circuit. Field should not be left empty.
num1PhTaps	Contains an integer value that lists the number of single phase tap-off circuits specified by the structure pattern. Value should not be left empty.
num3PhTaps	Contains an integer value that lists the number of three phase tap-off circuits specified by the structure pattern. Value should not be left empty.
num1PhTapNeuts	Contains an integer value that lists the number of tap-off circuits that contain overhead neutral wires. Value should not be left empty.
strPatternIfAddTap	Contains a string that provides a list of other structure patterns contained on the structure parameter list that the current structure pattern can be expanded into if an existing pole structure is modified to contain a new tap-off span. Each structure pattern in the list is seperated by a "/" character. Field may be left blank if structure cannot accommodate any additional tap-off spans or if tap-off spans are not compatible with structure pattern (e.g. dead-end structures).
strPatternIfExtendMainline	Contains a string that provides a list of other structure patterns contained on the structure parameter list that the current structure pattern can be expanded into if an existing pole structure lacks an incoming or outgoing mainline attachment and can be expanded to accommodate a new extension of the mainline. Each structure pattern in the list is separated by a "/" character. Field is left blank if structure already contains incoming and outgoing mainline spans.
equipStr	Contains a string that lists the equipment structure compatible unit by itself. Note that equipment structure is normally contained within the structure pattern string as a single compatible unit (e.g. R180 or N390), however, this field provides the value by itself without the need to interpret or extract the equipment structure from the structure pattern string. Field is left blank if no equipment structure is specified by structure pattern.
equipCost	May contain a floating point value that lists the material cost in dollars of the equipment structure, by itself. Field is used by AutoDesigner when existing pole structures are upgraded to include new mainline extension or tap-off circuits where the existing pole already contains an equipment structure (allowing for the cost of the equipment structure to be extracted from the upgrade cost of the pole). Field is set to 0 if no equipment is specified in structure pattern. Value should never be blank.
equipHours	May contain a floating point value that lists the construction labour hours associated with the installation of the equipment structure, by itself. Field is used by AutoDesigner when existing pole structures are upgraded to include new mainline extension or tap-off circuits where the existing pole already contains an equipment structure. Field is set to 0 if no equipment is specified in structure pattern. Value should never be blank.
contNeutMainline	Value contains an integer that is set to 1 when an overhead neutral wire is for certain present both on the incoming and outgoing mainline spans. Value is set to 2 when the presence of a neutral on both the incoming and outgoing mainline spans is uncertain but where a neutral must be present on one of the two spans (such as the case with three phase structure patterns where the "Neut" label is present). Value is set to 0 when a neutral is for certain not present on both the incoming and outgoing mainline spans. Note that the field should never be left blank.
heavyLoading	Value contains an integer that is set to 1 when the structure pattern is capable of withstanding both heavy and medium ice loading weather conditions. Value is set to 0 if the structure pattern is only suitable for medium loading weather conditions. Field should never be left blank.

horizOffsetFactor	Contains a floating point value that indicates the maximum differential in meters of the separation between the two outer conductors of a three phase span from the pole structure. Note that normally, the outer conductors of three phase spans are equal distance from the pole structure except in the case of under-strung attachment arms (N13) where one of the outer phases are approximately a half meter further away from the pole than the other outer conductor. In the case of a non-zero value, the offset in meters must be accounted for in the total structure deflection. Value is set to 0 if no asymmetry is present between the outer conductors or if the field is non-applicable (e.g. single phase mainline). Field should never be left blank.
poleCheckPattern	Contains a text string that references the structure pattern to the applicable PoleCheck look-up table or table(s). In the case of structures that utilize the PoleCheck1.0 lookup tables, the text string begins with a ”_” character and where ”_1_”,”_2_”,”_3_” and ”_4_” tags are used to prefix the applicable poleCheck1.0 tables and associate each table with one of the incoming mainline, outgoing mainline, first or second tap-off spans. In the case of PoleCheck2.0. the text string begins with a ”$” character and where the structure pattern string is repeated directly after the initial character with no further characters provided. Note that PoleCheck1.0 references may refer to multiple lookup tables while a PoleCheck2.0 reference only refers to a single lookup table.
strCost	Contains a floating point value that specifies the total material cost in dollars of all structures specified by the structure pattern. Note that neutral structures denoted by the ”Neut” tag are not included in material costs nor are down-haul guy wires or ground rods. Field must not be left blank.
constHours	Contains a floating point value that specifies the total construction labour in hours that are required to install all structures specified by the structure pattern. Note that neutral structures denoted by the ”Neut” tag are not included in labour hours nor are down-haul guy wires or ground rods. Field must not be left blank.
punishmentFactor	Contains a floating point value that specifies additional construction labour cost in hours to be added to the constHours field by AutoDesigner. Note that field is kept separate from AutoDesigner since the labour hours included are designed to represent hidden costs associated with certain structures that are not fully represented by the construction labour hours provided by the DFO. Note that this is done in order to provide the most accurate cost optimization results while not obscuring the accuracy of the labour hours obtained from the DFO's material management system.

Table A.7: Table of Neutral Structure Parameter List Data Fields with Descriptions.

Data Field Name	Description
neutStrPattern	Contains a data string where each row represents a different potential set of neutral attachment structure combinations. Each individual neutral compatible unit is separated by a comma character or in the case where multiples of the same structure is present within the string it may be shorted by the use of the ”2x”, ”3x” or ”4x” prefix followed by just a single reference to the repeating structure.
prevSpanNeutAttNeeded	Contains an integer value where 1 indicates that the structure pattern contains a neutral attachment for the incoming mainline span that is separate from the mainline compatible unit and 0 indicates that no separate neutral attachment is provided. Value should not be blank.
nextSpanNeutAttNeeded	Contains an integer value where 1 indicates that the structure pattern contains a neutral attachment for the outgoing mainline span that is separate from the mainline compatible unit and 0 indicates that no separate neutral attachment is provided. Value should not be blank.
tapSpanOneNeutAttNeeded	Contains an integer value where 1 indicates that the structure pattern contains a neutral attachment for the first tap-off span that is separate from the mainline compatible unit and 0 indicates that no separate neutral attachment is provided. Value should not be blank.
tapSpanTwoNeutAttNeeded	Contains an integer value where 1 indicates that the structure pattern contains a neutral attachment for the second tap-off span that is separate from the mainline compatible unit and 0 indicates that no separate neutral attachment is provided. Value should not be blank.
brkTensionMainlineNeut	Contains an integer value where 1 indicates that the neutral is continuous with unbroken tension along the incoming to outgoing mainline neutral spans. Integer value is set to 2 if there is a continuous, uninterrupted tension between attachments other than the incoming and outgoing mainline neutral conductor. Integer is set to 0 if none of the neutral attachments share continuous tension. Note that this value should never be blank.
minDefl8HiCON-1	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is #8 HiCON. Note that because DFO standards do not currently specify deflections for #8 HiCON, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.

minDeflBantam-2	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is BANTAM. Note that because DFO standards do not currently specify deflections for BANTAM, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl6ACSR-3	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 6 ACSR. Note that because DFO standards do not currently specify deflections for #6 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl4ACSR-4	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline neutral conductor is #4 ACSR. Field may be left blank if pole structure is not compatible with #4 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2ACSR-5	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 2 ACSR. Note that because DFO standards do not currently specify deflections for #2 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl1/0ACSR-6	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline neutral conductor is 1/0 ACSR. Field may be left blank if pole structure is not compatible with 1/0 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2/0ACSR-7	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 2/0 ACSR. Note that because DFO standards do not currently specify deflections for 2/0 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl266MCM-8	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral conductor must have in order for the structure pattern to be validly utilized assuming that the mainline neutral spans is 266 MCM ACSR. Field may be left blank if pole structure is not compatible with 266 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl477MCM-9	Contains a floating point value that specifies the minimum allowable deflection angle in degrees that the incoming and outgoing mainline neutral conductor must have in order for the structure pattern to be validly utilized assuming that the mainline neutral spans is 477 MCM ACSR. Field may be left blank if pole structure is not compatible with 477 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl8HiCON-1	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is #8 HiCON. Note that because DFO standards do not currently specify deflections for #8 HiCON, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.

minDeflBantam-2	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is BANTAM. Note that because DFO standards do not currently specify deflections for BANTAM, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl6ACSR-3	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 6 ACSR. Note that because DFO standards do not currently specify deflections for #6 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl4ACSR-4	Contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline neutral conductor is #4 ACSR. Field may be left blank if pole structure is not compatible with #4 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2ACSR-5	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is # 2 ACSR. Note that because DFO standards do not currently specify deflections for #2 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl1/0ACSR-6	Contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline neutral conductor is 1/0 ACSR. Field may be left blank if pole structure is not compatible with 1/0 ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl2/0ACSR-7	Note that this is an unused data field that is not currently being utilized by AutoDesigner. When used, the field contains a floating point value that specifies the maximum allowable deflection angle in degrees that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline conductor is 2/0 ACSR. Note that because DFO standards do not currently specify deflections for 2/0 ACSR, the column is not currently being utilized. Note that the numerical index located after the dash character corresponds with the conductor numbering provided in Table 2.3.
minDefl266MCM-8	Contains a floating point value that specifies the maximum allowable deflection that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline neutral conductor is 266 MCM ACSR. Field may be left blank if pole structure is not compatible with 266 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
minDefl477MCM-9	Contains a floating point value that specifies the maximum allowable deflection that the incoming and outgoing mainline neutral spans must have in order for the structure pattern to be validly utilized assuming that the mainline neutral conductor is 477 MCM ACSR. Field may be left blank if pole structure is not compatible with 477 MCM ACSR or if one of the incoming or outgoing main-line conductors are not present on structure.
maxTapDefl	Contains a floating point value that specifies the maximum allowable deflection in degrees of a tap-off span with respect to the incoming mainline span orientation. Field may be left blank if not tap-off spans are allowed for in the neutral structure pattern.
tapOrientedOppositeAPhaseOrTapNeut	Contains an integer value where 1 indicates that a neutral tap-span shares a common structure with another neutral tap-off or mainline span. A value of 0 indicates that neutral tap-offs do not share any common structures with other neutral spans. Field may be blank if no tap-offs are specified by neutral structure parameter.
strCost	Contains a floating point value that specifies the total material cost in dollars of all structures specified by the neutral structure pattern. Field must not be left blank.
constHours	Contains a floating point value that specifies the total construction labour in hours that are required to install all structures specified by the neutral structure pattern. Field must not be left blank.

punishmentFactor	Contains a floating point value that specifies additional construction labour cost in hours to be added to the constHours field by AutoDesigner. Note that field is kept separate from AutoDesigner since the labour hours included are designed to represent hidden costs associated with certain structures that are not fully represented by the construction labour hours provided by the DFO. Note that this is done in order to provide the most accurate cost optimization results while not obscuring the accuracy of the labour hours obtained from the DFO's material management system.

Table A.8: Table of Input Values for the ClearanceCalc Constraint Module

poleAHeight	The height in feet of the first supporting pole for the span whose clearance is under investigation.
poleANormalSetDepth	The normal set-depth in meters for the first supporting pole of the span. Note that his value extracted from the DFO's standards and varies based on a pole's height and is listed in the third column of Table 2.1.
poleATopToCondMax	The distance in meters measured from the top of the pole to the lowest conductor attachment point of the span in question on the first supporting pole. If the span in question contains an overhead neutral wire then this attachment height is used to calculate the distance value.
poleABaseElev	The elevation above sea level in meters at the base of the first supporting pole.
poleADeepSet	The depth measured in increments of 0.0m, 0.5m, 1.0m or 1.5m for which the first supporting pole is set deeper than its normal set depth.
poleBHeight	The height in feet of the second supporting pole for the span whose clearance is under investigation.
poleBNormalSetDepth	The normal set-depth in meters for the second supporting pole of the span.
poleBTopToCondMax	The distance in meters measured from the top of the pole to the lowest conductor attachment point of the span in question on the second supporting pole.
poleBBaseElev	The elevation above sea level in meters at the base of the second supporting pole.
poleBDeepSet	The depth measured in increments of 0.0m, 0.5m, 1.0m or 1.5m for which the second supporting pole is set deeper than its normal set depth.
condType	An integer value representing the conductor type of the span being analyzed. Note that the integer value correlates to conductor numbering scheme listed in the first column of Table 2.3.
spanLength	The length of the span under investigation in meters.
isTightSpan	A 1 or 0 valued integer indicating whether the span under investigation is a tight or slack span. A value of 1 corresponds to a tight-span while a value of 0 corresponds to a slack-span.
heavyLoading	A 1 or 0 valued integer indicating whether the span under investigation is located in a region that has the potential for heavy-ice loading weather conditions. A value of 1 corresponds to a requirement for heavy loading design while a value of 0 corresponds to medium loading.
crossingTypes	A list of strings where each string contains an abbreviation for an applicable crossing location underneath the span being investigated. Note that abbreviations correspond to the abbreviations in the first column of Table 2.4. Note that the length of the crossingTypes list may be one element longer than the crossingLocs and crossingElevs lists indicating that the last crossing abbreviation is a general crossing classification for the entire span (such as pedestrian or agricultural) that is to be measured at the point of greatest conductor sag.
crossingLocs	A list of floating point values in meters that contains the distance from the first supporting pole to each of the surveyed crossing locations underneath the span under investigation.
crossingElevs	A list of floating point values in meters that contains the elevation above sea level of each of the surveyed crossing locations underneath the span under investigation.
strIDA	A string that contains the structure number for the first supporting pole structure.
strIDB	A string that contains the structure number for the second supporting pole structure.

neutPresent	A 1 or 0 valued integer that indicates whether an overhead neutral wire is present and is not flat-spaced with another phase wire on the span being investigated. If the value is set to 1, then a neutral is present and the neutral is vertically spaced lower on the pole then the nearest phase wire which indicates that the conductor clearance requirements can be reduced to the neutral conductor heights listed in the second column of Table 2.4. If the value is set to 0, then a neutral is not present or it is flat-spaced with the phase conductor which requires the larger clearance values listed in the third column of Table 2.4 to be utilized.

Table A.9: Table of Input Values for the FloaterCheck Constraint Module

poleAHeight	The height in feet of the pole that is previous to the pole being analyzed.
poleANormalSetDepth	The normal set-depth in meters for the pole that is previous to the pole being analyzed. Note that his value extracted from the DFO's standards and varies based on a pole's height and is listed in the third column of Table 2.1.
poleATopToCond	The distance in meters measured from the top of the pole to the conductor attachment point of the interconnecting span for the pole that is previous to the pole being investigated. Note that if the span contains three phases then the phase with the greatest drop in attachment elevation between the pole being investigated and the previous and next pole is used for the attachment height values.
poleABaseElev	The elevation above sea level in meters at the base of the pole that is previous to the pole under investigation.
poleADeepSet	The depth measured in increments of 0.0m, 0.5m, 1.0m or 1.5m for the pole that is previous to the pole under investigation.
poleBHeight	The height in feet of the pole that is being analyzed.
poleBNormalSetDepth	The normal set-depth in meters for the pole that is being analyzed.
poleBTopToCond	The distance in meters measured from the top of the pole to the conductor attachment point of the interconnecting span for the pole that is being investigated. Note that if the span contains three phases then the phase with the greatest drop in attachment elevation between the pole being investigated and the previous and next pole is used for the attachment height values.
poleBBaseElev	The elevation above sea level in meters at the base of the pole that is under investigation.
poleBDeepSet	The depth measured in increments of 0.0m, 0.5m, 1.0m or 1.5m for the pole that is under investigation.
poleBMainlineFloaterCheckNotRequired	Integer value that if equal to 0, indicates that the pole under investigation contains an insulator type that is susceptible to conductor uplift. In the case of the PoleCheck constraint module, this condition requires that absolutely no uplift exists on the pole under investigation. If the integer value is greater than 0 then conductor uplift is not a concern for the insulator attachments on the pole under investigation and so conductor uplift can be permitted such that it does not pose a risk to causing the pole, itself to float.
poleBMass	Floating point value representing the pole mass in kg of the pole that is under investigation. Value is used when assessing whether a floater condition is sufficient to cause the pole structure itself to be pulled out of the ground due to uplift. In such a case, the PoleCheck constraint module prescribes the use of side-guys to further anchor the pole structure.
poleCHeight	The height in feet of the pole that is next after the pole being analyzed.
poleCNormalSetDepth	The normal set-depth in meters for the pole that is next after the pole being analyzed.
poleCTopToCond	The distance in meters measured from the top of the pole to the conductor attachment point of the interconnecting span for the pole that is next after the pole being investigated. Note that if the span contains three phases then the phase with the greatest drop in attachment elevation between the pole being investigated and the previous and next pole is used for the attachment height values.
poleCBaseElev	The elevation above sea level in meters at the base of the pole that is next after the pole that is under investigation.
poleCDeepSet	The depth measured in increments of 0.0m, 0.5m, 1.0m or 1.5m for the pole that is next after the pole under investigation.
condType	An integer value representing the maximum conductor type out of span that is previous the pole under investigation and the span that is following the pole under investigation. Note that the integer value correlates to conductor numbering scheme listed in the first column of Table 2.3.
condTension	The maximum design tension of the conductor indicated by the condType field. Value is used for calculating maximum uplift force on pole in case where the use of side-guys are being assessed to prevent the pole from being pulled out of the ground.

spanLength1	Floating point value representing the span length in meters of the span that is previous to the pole that is under investigation.
spanLength2	Floating point value representing the span length in meters of the span that is next after the pole that is under investigation.
heavyLoading	A 1 or 0 valued integer indicating whether the spans prior to and subsequent to the pole under investigation are located in a region that has the potential for heavy-ice loading weather conditions. A value of 1 corresponds to a requirement for heavy loading design while a value of 0 corresponds to medium loading.
strIDA	A string that contains the structure number for the pole structure that is prior to the pole under investigation.
strIDB	A string that contains the structure number for the pole structure that is under investigation.
strIDC	A string that contains the structure number for the pole structure next after the pole that is under investigation.

Table A.10: PoleCheck1.0 Structure Pattern Lookup Tables

Structure Pattern Lookup Table	Description of Structure Pattern.
AL11	Armless angle three phase tangent structure.
AL11,N0	Armless angle three phase tangent structure with continuous overhead neutral wire.
N11	Three phase tangent deflection structure for medium-loading applications only.
N11,N0	Three phase tangent deflection structure for medium-loading applications only with continuous overhead neutral wire.
N11H	Three phase tangent deflection structure for heavy-loading applications.
N11H,N0	Three phase tangent deflection structure for heavy-loading applications with continuous overhead neutral wire.
N12	Three phase inline tangent structure for medium-loading applications only.
N12,N0	Three phase inline tangent structure for medium-loading applications only with continuous overhead neutral wire.
N12H	Three phase inline tangent structure for heavy-loading applications.
N32	Three phase corner structure.
N32,N0	Three phase corner structure with continuous overhead neutral wire.
N32(SL)	Three phase corner structure where the outgoing mainline attachment is at a higher elevation on the pole structure than the incoming mainline attachment (special application).
N32,2xR0(SL)	Three phase corner structure where the outgoing mainline attachment is at a higher elevation on the pole structure than the incoming mainline attachment (special application). Structure includes a continue overhead neutral wire.
N32,2xR0	Three phase corner structure with overhead neutral wire on the incoming and outgoing mainline spans but which has a dead-end carry-on attachment at the pole structure.
N42	Three phase dead-end structure.
N42,R0	Three phase dead-end structure with an overhead neutral wire terminating at the structure.
N52	Three phase dead-end carry-on structure.
N55,R0	Three phase tap-off structure with an N12 three phase inline tangent structure mainline and overhead neutral wires on all spans.
R109	Single phase tangent deflection structure with a vertically spaced overhead neutral wire (for deflections up to 30 degrees).
R109F	Single phase tangent deflection structure with a flat-spaced overhead neutral wire. (flat-spaced refers to an application where a cross-arm supports the neutral and phase wire at the same elevation as opposed to having the neutral vertically spaced at least 2.0m lower than the phase wire on the pole. Flat spacing is done in scenarios when additional neutral-to-ground clearance is required).
R209	Single phase tangent deflection structure.
R110	Single phase tangent angle structure (for deflections between 30 and 60 degrees) with continuous overhead neutral wire.
R210	Single phase tangent angle structure.
R112	Single phase inline tangent structure with continuous, vertically-spaced overhead neutral wire.
R112F	Single phase inline tangent structure with continuous, flat-spaced overhead neutral wire.
R212	Single phase inline tangent structure.

R130	Single phase corner structure with overhead neutral dead-end carry-on structure.
R230	Single phase corner structure.
R130(SL)	Single phase corner structure where the outgoing mainline attachment is at a higher elevation on the pole structure than the incoming mainline attachment (special application). A vertically spaced overhead neutral wire is installed in a dead-end carry-on configuration on the structure.
R230(SL)	Single phase corner structure where the outgoing mainline attachment is at a higher elevation on the pole structure than the incoming mainline attachment (special application).
R140	Single phase dead-end structure with an overhead, vertically-spaced overhead neutral wire terminating at the structure.
R240	Single phase dead-end structure.
R140F	Single phase dead-end structure with a flat-spaced overhead neutral wire terminating at the structure.
R152	Single phase dead-end carry-on structure with a vertically spaced overhead neutral wire on the incoming and outgoing spans that is installed with a dead-end carry-on attachment.
R252	Single phase dead-end carry-on structure.
R152F	Single phase dead-end carry-on structure with a flat-spaced overhead neutral wire that is installed at the same elevation and using the same configuration as the phase wire on a cross-arm.
R154	Single phase tap-off structure from an R112 inline tangent structure where all spans have an overhead neutral wire.
R254	Single phase tap-off structure from an R212 inline tangent structure.

Table A.11: Parameters Contained in the PoleCheck2.0 Structure List

PoleCheck2.0 Structure List Parameter Name	Parameter May be Specified on Structure List as a Ranged Value	Description of Parameter
strPattern		Name of structure pattern from structure paremeter list. In the event that the structure pattern contains a "Neut" label, the strPattern field may be appended with a (S), (L), (SL),(SLT1),(SLT2), etc... to indicate specifically which attachments contain a neutral attachment (source, load, tap-off 1 or tap-off 2).
incSlackTight		Integer flag or left as '-' if no incoming mainline. A 1 value indicates a tight incoming mainline span, 0 indicates a slack-span on the incoming mainline.
outSlackTight		Integer flag or left as '-' if no outgoing mainline. A 1 value indicates a tight incoming mainline span, 0 indicates a slack-span on the incoming mainline.
tap1SlackTight		Integer flag or left as '-' if no tap-span 1. A 1 value indicates a tight tap-span 1, 0 indicates a slack-span on tap-span 1.
tap2SlackTight		Integer flag or left as '-' if no tap-span 2. A 1 value indicates a tight tap-span 1, 0 indicates a slack-span on tap-span 2.
compatUnit1		String value containing the first compatible in from the structure pattern. "Neut" structure pattern is populated with the most common neutral structure. Note that parameter is not used by AutoDesigner and is intended for easy selection of compatible units if PoleCheck2.0 is used by DFO as a standalone tool.

compatUnit2		String value containing the second compatible in from the structure pattern. ”Neut” structure pattern is populated with the most common neutral structure. Note that parameter is not used by AutoDesigner and is intended for easy selection of compatible units if PoleCheck2.0 is used by DFO as a standalone tool.
compatUnit3		String value containing the third compatible in from the structure pattern. ”Neut” structure pattern is populated with the most common neutral structure. Note that parameter is not used by AutoDesigner and is intended for easy selection of compatible units if PoleCheck2.0 is used by DFO as a standalone tool.
compatUnit4		String value containing the fourth compatible in from the structure pattern. ”Neut” structure pattern is populated with the most common neutral structure. Note that parameter is not used by AutoDesigner and is intended for easy selection of compatible units if PoleCheck2.0 is used by DFO as a standalone tool.
compatUnit5		String value containing the fifth compatible in from the structure pattern. ”Neut” structure pattern is populated with the most common neutral structure. Note that parameter is not used by AutoDesigner and is intended for easy selection of compatible units if PoleCheck2.0 is used by DFO as a standalone tool.
loading	Yes	String value specifying ’medium’, ’heavy’ or both values seperated by a comma. Field specifies the types of loading that must be considered in the PoleCheck2.0 lookup table.
gradeInc	Yes	String value specifying 1, 2 or both values seperated by a comma. Field specifies the grade of construction of the incoming mainline span. Note that this field is typically set to 2 and only includes 1 for a limited selection of structure patterns (no provision for tap-off structures has been provided).
gradeOut	Yes	String value specifying 1, 2 or both values seperated by a comma. Field specifies the grade of construction of the outgoing mainline span. Note that this field is typically set to 2 and only includes 1 for a limited selection of structure patterns (no provision for tap-off structures has been provided).
deepSet		Integer value which is set to either 1 or 0 for all structure patterns. Pole deep-set is applied to pole uniformly for all pole configurations within PoleCheck2.0 lookup table.
topToAttach1		Floating point value representing the distance from the top of the pole to the top supporting bolt of attachment 1, where attachment 1 is defined arbitrarly by the user. Note that attachment 1 is normally the top attachment on the pole structure but in certain cases may not be such as when the source attachment is lower than the load attachment.
att1CondVertRatio		The ratio between the pole height of a set 35 ft. pole plus the difference in height between the top supporting bolt of the top attachment and the condutor elevation divided by the height of a set 35 ft. pole. Value serves as a multiplicative factor for transverse and longitudinal loads that are applied to the bolt location on the pole.
cond1		Integer flag that is set to either 1 or 0 or left blank if no incoming conductor is present on attachment.

cond2		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond3		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only.
cond4		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment.
cond5		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond6		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only.
condTypesAttach1	Yes	Lists the range of conductor types that the attachment's conductors must be evaluated for in the PoleCheck2.0 lookup table. Note that normally this field contains multiple integer numbers seperated by commas where each integer represents a conductor type as per the numbering on Table 2.3.
condTypeOutIfDiffAttach1	Yes	Lists the range of conductor types that the attachment's outgoing conductors must be evaluated for if they are not carrying a continuous tension with that of the incoming conductors. Field is left blank if outgoing conductors are continuous with the incoming span or if the outgoing conductors do not exist on the attachment. Conductor types are denoted by numbers as per Table 2.3 and are seperated by commas.
weightsAttach1		The mass of the attachments fixtures (not including conductor) in kg.
surfaceAreaEquipAtt1		Field is left blank if attachment is not defined as an equipment structure. If non-blank, the field contains the area in $m\hat{2}$ of equipment installed on the pole from the perspective of a single wind direction. If value is non-zero, it triggers the pole case generator to not consider any conductor attachment data for the attachment.
incTightAttach1		Field is set to 1 if the incoming span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no incoming mainline is present on attachment.
outTightAttach1		Field is set to 1 if the outgoing span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no ougoing mainline is present on attachment.
minDeflAttach1	Yes	Field specifies the minimum investigated deflection of the outgoing span with respect to the incoming span of attachment 1 for each conductor type specified. Deflection values for each conductor type are seperated by commas.
maxDeflAttach1	Yes	Field specifies the maximum investigated deflection of the outgoing span with respect to the incoming span of attachment 1 for each conductor type specified. Deflection values for each conductor type are seperated by commas.
terminationOrTensionChangeAttach1		Value is set to 1 if the incoming and outgoing spans on attachment contain a break in tension or if the one of the spans are not present on the attachment.

ancRefAttach1		Contains a '0', '1' or '2' value to indicate that attachment must be anchored and that the forces contributed by the structure should be applied to calculations involving the anchor number specified. A '0' value indicates that no anchor is required.
topToAttach2		Floating point value representing the distance from the top of the pole to the top supporting bolt of attachment 2, where attachment 2 is defined arbitrarly by the user. Note that if attachment 2 does not exist then this value should be left blank which flags the PoleCheck2.0 case generator to ignore all remaining data fields that are associated with attachment 2.
att2CondVertRatio		The ratio between the pole height of a set 35 ft. pole plus the difference in height between the top supporting bolt of the top attachment and the condutor elevation divided by the height of a set 35 ft. pole. Value serves as a multiplicative factor for transverse and longitudinal loads that are applied to the bolt location on the pole.
cond7		Integer flag that is set to either 1 or 0 or left blank if no incoming conductor is present on attachment.
cond8		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond9		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only.
cond10		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment.
cond11		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond12		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only.
condTypesAttach2	Yes	Lists the range of conductor types that the attachment's conductors must be evaluated for in the PoleCheck2.0 lookup table. Note that normally this field contains multiple integer numbers seperated by commas where each integer represents a conductor type as per the numbering on Table 2.3.
weightsAttach2		The mass of the attachments fixtures (not including conductor) in kg.
surfaceAreaEquipAtt2		Field is left blank if attachment is not defined as an equipment structure. If non-blank, the field contains the area in m$\hat{2}$ of equipment installed on the pole from the perspective of a single wind direction. If value is non-zero, it triggers the pole case generator to not consider any conductor attachment data for the attachment.
incTightAttach2		Field is set to 1 if the incoming span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no incoming mainline is present on attachment.
outTightAttach2		Field is set to 1 if the outgoing span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no ougoing mainline is present on attachment.

refAttachForAttach2BaseDef		Integer flag to indicate a reference attachment for the orientation of the conductor spans on the attachment. Often, this value is set to 1 indicating that all orientation values specified for the attachment are referenced to the first attachment's incoming span. If the value is set to a value other than 1 then it looks for the orientation of the outgoing span of the referenced attachment and uses it as the reference orientation for the current attachment.
deflAttach2WRTRef	Yes	Floating point value in degrees to indicate the deflection of the current span's conductor attachments with respect to the reference attachment specified. Non-zero values normally are applied to the attachment's outgoing span as a non-zero value normally indicates that the current attachment is either a tap-off or a discontinuous deflection of the mainline spans and so no incoming span exists on the current attachment. The case where the value is set to zero normally occurs when the current attachment is a lower attachment that is related to attachment 1 as part of a three phase inline tangent structure, in which case the specified deflection is applied to the incoming span of the current attachment. Note that multiple non-zero deflections may be specified with commas seperating each value.
syncAtt2DeflCondWithRef		Integer flag that is set to either 0 or 1. A flag that is set to 1 confirms that the current attachment is a lower attachment that is a part of a three phase inline tangent structure while a value of 0 confirms that the attachment has no such relationship to the first attachment and that it must be a tap-off, an equipment attachment or that it is an outgoing discontinuous span deflection with respect to the first attachment.
minDeflAttach2	Yes	Field specifies the minimum investigated deflection of the outgoing span with respect to the incoming span of the current attachment for each conductor type specified. Deflection values for each conductor type are seperated by commas.
maxDeflAttach2	Yes	Field specifies the maximum investigated deflection of the outgoing span with respect to the incoming span of the current attachment for each conductor type specified. Deflection values for each conductor type are seperated by commas.
terminationOrTensionChangeAttach2		Value is set to 1 if the incoming and outgoing spans on attachment contain a break in tension or if the one of the spans are not present on the attachment.
ancRefAttach2		Contains a '0', '1' or '2' value to indicate that attachment must be anchored and that the forces contributed by the structure should be applied to calculations involving the anchor number specified. A '0' value indicates that no anchor is required.
topToAttach3		Floating point value representing the distance from the top of the pole to the top supporting bolt of attachment 3, where attachment 3 is defined arbitrarly by the user. Note that if attachment 3 does not exist then this value should be left blank which flags the PoleCheck2.0 case generator to ignore all remaining data fields that are associated with attachment 3.
att3CondVertRatio		The ratio between the pole height of a set 35 ft. pole plus the difference in height between the top supporting bolt of the top attachment and the condutor elevation divided by the height of a set 35 ft. pole. Value serves as a multiplicative factor for transverse and longitudinal loads that are applied to the bolt location on the pole.

cond13		Integer flag that is set to either 1 or 0 or left blank if no incoming conductor is present on attachment.
cond14		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond15		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only.
cond16		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment.
cond17		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond18		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only.
condTypesAttach3	Yes	Lists the range of conductor types that the attachment's conductors must be evaluated for in the PoleCheck2.0 lookup table. Note that normally this field contains multiple integer numbers seperated by commas where each integer represents a conductor type as per the numbering on Table 2.3.
weightsAttach3		The mass of the attachments fixtures (not including conductor) in kg.
surfaceAreaEquipAtt3		Field is left blank if attachment is not defined as an equipment structure. If non-blank, the field contains the area in $m\hat{2}$ of equipment installed on the pole from the perspective of a single wind direction. If value is non-zero, it triggers the pole case generator to not consider any conductor attachment data for the attachment.
incTightAttach3		Field is set to 1 if the incoming span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no incoming mainline is present on attachment.
outTightAttach3		Field is set to 1 if the outgoing span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no ougoing mainline is present on attachment.
refAttachForAttach3BaseDefl		Integer flag to indicate a reference attachment for the orientation of the conductor spans on the attachment. Often, this value is set to 1 indicating that all orientation values specified for the attachment are referenced to the first attachment's incoming span. If the value is set to a value other than 1 then it looks for the orientation of the outgoing span of the referenced attachment and uses it as the reference orientation for the current attachment.

deflAttach3WRTRef	Yes	Floating point value in degrees to indicate the deflection of the current span's conductor attachments with respect to the reference attachment specified. Non-zero values normally are applied to the attachment's outgoing span as a non-zero value normally indicates that the current attachment is either a tap-off or a discontinuous deflection of the mainline spans and so no incoming span exists on the current attachment. The case where the value is set to zero normally occurs when the current attachment is a lower attachment that is related to attachment 1 as part of a three phase inline tangent structure, in which case the specified deflection is applied to the incoming span of the current attachment. Note that multiple non-zero deflections may be specified with commas seperating each value.
syncAtt3DeflCondWithRef		Integer flag that is set to either 0 or 1. A flag that is set to 1 confirms that the current attachment is a lower attachment that is a part of a three phase inline tangent structure while a value of 0 confirms that the attachment has no such relationship to the first attachment and that it must be a tap-off, an equipment attachment or that it is an outgoing discontinuous span deflection with respect to the first attachment.
minDeflAttach3	Yes	Field specifies the minimum investigated deflection of the outgoing span with respect to the incoming span of the current attachment for each conductor type specified. Deflection values for each conductor type are seperated by commas.
maxDeflAttach3	Yes	Field specifies the maximum investigated deflection of the outgoing span with respect to the incoming span of the current attachment for each conductor type specified. Deflection values for each conductor type are seperated by commas.
terminationOrTensionChangeAttach3		Value is set to 1 if the incoming and outgoing spans on attachment contain a break in tension or if the one of the spans are not present on the attachment.
ancRefAttach3		Contains a '0', '1' or '2' value to indicate that attachment must be anchored and that the forces contributed by the structure should be applied to calculations involving the anchor number specified. A '0' value indicates that no anchor is required.
topToAttach4		Floating point value representing the distance from the top of the pole to the top supporting bolt of attachment 4, where attachment 4 is defined arbitrarly by the user. Note that if attachment 4 does not exist then this value should be left blank which flags the PoleCheck2.0 case generator to ignore all remaining data fields that are associated with attachment 4.
att4CondVertRatio		The ratio between the pole height of a set 35 ft. pole plus the difference in height between the top supporting bolt of the top attachment and the condutor elevation divided by the height of a set 35 ft. pole. Value serves as a multiplicative factor for transverse and longitudinal loads that are applied to the bolt location on the pole.
cond19		Integer flag that is set to either 1 or 0 or left blank if no incoming conductor is present on attachment.
cond20		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.

cond21		Integer flag that is set to either 1, 0 or is left blank if no incoming conductor is present on attachment or if the incoming conductor is single phase only.
cond22		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment.
cond23		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only. Note that value may be populated if a single phase line carries a flat-spaced neutral wire on a cross-arm with the phase conductor.
cond24		Integer flag that is set to either 1, 0 or is left blank if no outgoing conductor is present on attachment or if the outgoing conductor is single phase only.
condTypesAttach4	Yes	Lists the range of conductor types that the attachment's conductors must be evaluated for in the PoleCheck2.0 lookup table. Note that normally this field contains multiple integer numbers seperated by commas where each integer represents a conductor type as per the numbering on Table 2.3.
weightsAttach4		The mass of the attachments fixtures (not including conductor) in kg.
surfaceAreaEquipAtt4		Field is left blank if attachment is not defined as an equipment structure. If non-blank, the field contains the area in $m\hat{2}$ of equipment installed on the pole from the perspective of a single wind direction. If value is non-zero, it triggers the pole case generator to not consider any conductor attachment data for the attachment.
incTightAttach4		Field is set to 1 if the incoming span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no incoming mainline is present on attachment.
outTightAttach4		Field is set to 1 if the outgoing span on the attachment is a tight-span or 0 if it is a slack-span. Field is left blank if no ougoing mainline is present on attachment.
refAttachForAttach4BaseDefl		Integer flag to indicate a reference attachment for the orientation of the conductor spans on the attachment. Often, this value is set to 1 indicating that all orientation values specified for the attachment are referenced to the first attachment's incoming span. If the value is set to a value other than 1 then it looks for the orientation of the outgoing span of the referenced attachment and uses it as the reference orientation for the current attachment.
deflAttach4WRTRef	Yes	Floating point value in degrees to indicate the deflection of the current span's conductor attachments with respect to the reference attachment specified. Non-zero values normally are applied to the attachment's outgoing span as a non-zero value normally indicates that the current attachment is either a tap-off or a discontinuous deflection of the mainline spans and so no incoming span exists on the current attachment. The case where the value is set to zero normally occurs when the current attachment is a lower attachment that is related to attachment 1 as part of a three phase inline tangent structure, in which case the specified deflection is applied to the incoming span of the current attachment. Note that multiple non-zero deflections may be specified with commas seperating each value.

syncAtt4DeflCondWithRef		Integer flag that is set to either 0 or 1. A flag that is set to 1 confirms that the current attachment is a lower attachment that is a part of a three phase inline tangent structure while a value of 0 confirms that the attachment has no such relationship to the first attachment and that it must be a tap-off, an equipment attachment or that it is an outgoing discontinuous span deflection with respect to the first attachment.
minDeflAttach4	Yes	Field specifies the minimum investigated deflection of the outgoing span with respect to the incoming span of the current attachment for each conductor type specified. Deflection values for each conductor type are seperated by commas.
maxDeflAttach4	Yes	Field specifies the maximum investigated deflection of the outgoing span with respect to the incoming span of the current attachment for each conductor type specified. Deflection values for each conductor type are seperated by commas.
terminationOrTensionChangeAttach4		Value is set to 1 if the incoming and outgoing spans on attachment contain a break in tension or if the one of the spans are not present on the attachment.
ancRefAttach4		Contains a '0', '1' or '2' value to indicate that attachment must be anchored and that the forces contributed by the structure should be applied to calculations involving the anchor number specified. A '0' value indicates that no anchor is required.
topToNeutSepAttach		Contains a floating point value representing the height from the top of the pole to the elevation of any vertically-spaced neutral attachments on the pole structure. PoleCheck2.0 assumes that all neutral attachments that are not flat-spaced are at the same elevation on the pole. Field is left blank if no vertically-spaced neutral attachments are present on the pole.
condTypeTensOrientMatchIndex1		Contains an integer value referencing a span to indicate that the designated span contains a neutral attachment vertically spaced on the pole. For example, if a value of 1 is present, this indicates that the incoming span of attachment 1 contains a neutral, a value of 4 indicates that the outgoing span of attachment 1 contains a neutral attachment, etc. Value left blank if no vertically spaced neutral attachments are present on the pole.
condTypeTensOrientMatchIndex2		Contains an integer value referencing a span to indicate that the designated span contains a neutral attachment vertically spaced on the pole. For example, if a value of 1 is present, this indicates that the incoming span of attachment 1 contains a neutral, a value of 4 indicates that the outgoing span of attachment 1 contains a neutral attachment, etc. Value left blank if no vertically spaced neutral attachments are present on the pole or if only 1 vertically-spaced neutral attachment is present.
condTypeTensOrientMatchIndex3		Contains an integer value referencing a span to indicate that the designated span contains a neutral attachment vertically spaced on the pole. For example, if a value of 1 is present, this indicates that the incoming span of attachment 1 contains a neutral, a value of 4 indicates that the outgoing span of attachment 1 contains a neutral attachment, etc. Value left blank if no vertically spaced neutral attachments are present on the pole or if only 2 vertically-spaced neutral attachments are present.

condTypeTensOrientMatchIndex4		Contains an integer value referencing a span to indicate that the designated span contains a neutral attachment vertically spaced on the pole. For example, if a value of 1 is present, this indicates that the incoming span of attachment 1 contains a neutral, a value of 4 indicates that the outgoing span of attachment 1 contains a neutral attachment, etc. Value left blank if no vertically spaced neutral attachments are present on the pole or if only 3 vertically-spaced neutral attachments are present..
ancRefDedicatedNeutAnc		Contains a '1' or '2' value to indicate that the neutral attachments specified in condTypeTensOrientMatchIndex1, condTypeTensOrientMatchIndex2, condTypeTensOrientMatchIndex3, and condTypeTensOrientMatchIndex4 must be anchored and that the forces contributed by the structure should be applied to calculations involving the anchor number specified. A blank cell indicates that no anchor is required.
exemptNeutDedicatedNeutAnc		Contains an integer value or multiple integer values seperated by a comma that corresponds to the integer values contained in condTypeTensOrientMatchIndex1, condTypeTensOrientMatchIndex2, condTypeTensOrientMatchIndex3, or condTypeTensOrientMatchIndex4. Any integer values specified in the cell exempt the corresponding neutral attachment from being associated with the anchor specified in ancRefDedicatedNeutAnc. Feature is often used when one or more of the vertically-spaced neutral attachments are being anchored by an anchor that is already anchoring one of the phase conductor spans and so a dedicated neutral anchor is not required. Value is left blank if no vertically-spaced neutral attachments are present or if vertically-spaced neutral attachments are present but there is no need to exempt any of the attachments from a dedicated neutral anchor.
typeAncOne	Yes	Contains a string listing the types of anchors to be considered for anchor 1. If multiple anchor types must be considered for all configurations in the PoleCheck2.0 lookup table, then multiple anchor names are listed with a comma seperating them. For example, 'G40A,G50A' indicates that both a G40A and G50A anchor need to be considered for anchor 1 in the PoleCheck2.0 lookup table. If value is blank, then PoleCheck2.0 case generator does not consider any subsequent columns in the PoleCheck2.0 structure list.
lenMinAncOne	Yes	Contains an integer value or multiple integer values seperated by comma characters for the minimum anchor length that must be considered for anchor 1. Multiple values are specified when multiple anchor types are specified in the typeAncOne cell.
lenMaxAncOne	Yes	Contains an integer value or multiple integer values seperated by comma characters for the maximum anchor length that must be considered for anchor 1. Multiple values are specified when multiple anchor types are specified in the typeAncOne cell.
topToAncAttach1AncOne		Contains a floating point value specifying the distance from the top of the pole to the top anchor attachment of anchor 1.
topToAncAttach2AncOne		Contains a floating point value specifying the distance from the top of the pole to the lower anchor attachment of anchor 1. Value may be left blank if anchor only has a single attachment piont on the pole.

typeAncTwo	Yes	Contains a string listing the types of anchors to be considered for anchor 2. If multiple anchor types must be considered for all configurations in the PoleCheck2.0 lookup table, then multiple anchor names are listed with a comma seperating them. For example, 'G40A,G50A' indicates that both a G40A and G50A anchor need to be considered for anchor 2 in the PoleCheck2.0 lookup table. If value is blank, then PoleCheck2.0 case generator does not consider any subsequent columns in the PoleCheck2.0 structure list.
lenMinAncTwo	Yes	Contains an integer value or multiple integer values seperated by comma characters for the minimum anchor length that must be considered for anchor 2. Multiple values are specified when multiple anchor types are specified in the typeAncOne cell.
lenMaxAncTwo	Yes	Contains an integer value or multiple integer values seperated by comma characters for the maximum anchor length that must be considered for anchor 2. Multiple values are specified when multiple anchor types are specified in the typeAncOne cell.
topToAncAttach1AncTwo		Contains a floating point value specifying the distance from the top of the pole to the top anchor attachment of anchor 2.
topToAncAttach2		AncTwoContains a floating point value specifying the distance from the top of the pole to the lower anchor attachment of anchor 2. Value may be left blank if anchor only has a single attachment piont on the pole.

Table A.12: Parameters Contained in the PoleCheck2.0 Structure List

PLS Pole FEA Case List Parameter Name	Description of Parameter
Loading	Possible values: heavy or medium loading. Value state determines the ice-loading condition to be used in evaluating transverse, vertical and longitudinal conductor loading.
GradeInc	Possible values: 1, 2 or blank. Value state determines the loading factors on the incoming mainline span to be applied to tranverse, longitudinal and vertical conductor loading as well as to the wind loading effects considered by PLS Pole on any pole and anchor structures. Specifying grade 1 results in more conservative loading factors being applied and are intended to be used for situations such as railway crossings or navigible water crossings.
GradeOut	Possible values: 1, 2 or blank. Value state determines the loading factors of any outgoing (non-tangential) spans to be applied to tranverse, longitudinal and vertical conductor loading as well as to the wind loading effects considered by PLS Pole on any pole and anchor structures.
Standard	Contains a text string that will comprise the file name for the completed PoleCheck2.0 lookup table. Note that lookup tables are divided on the basis of structure pattern and pole loading, meaning that each structure pattern that is design for use in heavy loading conditions will contain separate lookup tables for heavy and medium loading conditions.
CU#1	A text string that generally represents the first compatible unit of the structure pattern. Note that this field is not used by AutoDesigner or in the creation of the PoleCheck2.0 data tables but rather provides future functionality to enable DFO designers to utilize tables with a checkbox-style user interface that is similar to the current implementation of PoleCheck1.0.

CU#2	A text string that generally represents the second compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the ”Neut” tag is replaced with a likely neutral attachment structure.
CU#3	A text string that generally represents the third compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the ”Neut” tag is replaced with a likely neutral attachment structure.
CU#4	A text string that generally represents the fourth compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the ”Neut” tag is replaced with a likely neutral attachment structure.
CU#5	A text string that generally represents the fifth compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the ”Neut” tag is replaced with a likely neutral attachment structure.
CondTypeIncMain	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the incoming mainline span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
CondTypeOutMain	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the outgoing mainline span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
CondTypeTap1	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the first tap-off span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
CondTypeTap2	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the second tap-off span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
SpanLengthIncMain	Floating point value representing the span length in meters of the incoming mainline span.
SpanLengthOutMain	Floating point value representing the span length in meters of the outgoing mainline span. Value may be filled with a hyphon character if no outgoing mainline span is present.
SpanLengthTapOne	Floating point value representing the span length in meters of the first tap-off span. Value may be filled with a hyphon character if no tap-off spans are present.
SpanLengthTapTwo	Floating point value representing the span length in meters of the second tap-off span. Value may be filled with a hyphon character if less than 2 tap-off spans are present.
DeflectionMain	Floating point value in radians representing the orientation of the outgoing mainline span with respect to the orientation of the incoming mainline span. Note that orientation of the incoming mainline span is always assumed to be equal to zero. Value may be left blank if not outgoing mainline span is present.
DeflectionTap1	Floating point value in radians representing the orientation of the first tap-off span with respect to the orientation of the incoming mainline span. Value may be left blank if no tap-off spans are present.
DeflectionTap2	Floating point value in radians representing the orientation of the second tap-off span with respect to the orientation of the incoming mainline span. Value may be left blank if less than 2 tap-off spans are present.
anc1Length	Floating point value in meters representing the length of the first anchor. Value may be left blank if no anchors are required for structure pattern under investigation
anc2Length	Floating point value in meters representing the length of the second anchor. Value may be left blank if less than two anchors are required for structure pattern under investigation.

AncType	Data string representing the types of anchors being modelled for a given PLS Pole case. If two anchors are present than the individual anchor names are seperated buy a comma with anchor 1 always being first.
PoleBaseFile	A data string containing the file name of the templated PLS base file. file name begins with a description of the pole deep-set depth (ds0 or ds1 for a 0 meter or 1.0 meter deep-set, respectively) followed by the AncType string discussed above with all alphabetic characters shifted to lower case. Field must not be left blank.
anc1Orient	Floating point value in radians representing the orientation of the first anchor with respect to the incoming mainline span orientation. Value set to 0.0 if no anchors are present.
anc2Orient	Floating point value in radians representing the orientation of the second anchor with respect to the incoming mainline span orientation. Value is set to 0.0 if less than two anchors are present.
cond1To6Orient	The orientation in radians of the first attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Note that orientation of the attachment points in the same direction as the resolved force vector for the attachment.
cond7To12Orient	The orientation in radians of the seond attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Note that orientation of the attachment points in the same direction as the resolved force vector for the attachment.
cond13To18Orient	The orientation in radians of the third attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Note that orientation of the attachment points in the same direction as the resolved force vector for the attachment.
cond19To24Orient	The orientation in radians of the fourth attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Note that orientation of the attachment points in the same direction as the resolved force vector for the attachment.
neutCondOrient	The orientation in radians of the fifth attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Note that orientation of the attachment points in the same direction as the resolved force vector for the attachment.
topToAnc1Attach1	Floating point value in meters representing the seperation between the top of the pole structure and the top guy wire attachment on the pole for the first anchor. Value is left blank if no anchors are present on pole.
topToAnc1Attach2	Floating point value in meters representing the seperation between the top of the pole structure and the bottom guy wire attachment on the pole for the first anchor. Value is left blank if no anchors are present on pole or if anchor 1 only has a single guy wire attachment on the pole.
topToAnc2Attach1	Floating point value in meters representing the seperation between the top of the pole structure and the top guy wire attachment on the pole for the second anchor. Value is left blank if less than two anchors are present on pole.
topToAnc2Attach2	Floating point value in meters representing the seperation between the top of the pole structure and the top guy wire attachment on the pole for the second anchor. Value is left blank if less than two anchors are present on pole or if the second anchor only has a single guy wire attachment on the pole.
topToCond1To6Attach	The distance in meters from the top of the pole structure and the first attachment point on the pole structure as specified in the PoleCheck2.0 structure list.

topToCond7To12Attach	The distance in meters from the top of the pole structure and the second attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Value may be left blank if no second attachment is present for structure pattern under investigation.
topToCond13To18Attach	The distance in meters from the top of the pole structure and the third attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Value may be left blank if no third attachment is present for structure pattern under investigation.
topToCond19To24Attach	The distance in meters from the top of the pole structure and the fourth attachment point on the pole structure as specified in the PoleCheck2.0 structure list. Value may be left blank if no fourth attachment is present for structure pattern under investigation.
topToNeutCondAttach	The distance in meters from the top of the pole structure and the vertically-spaced neutral attachment point on the pole structure as per the PoleCheck2.0 structure list. Value may be left blank if no vertically-spaced neutral attachments are present on the pole.
poleWindPressureY-Wind+Y	Floating point value in Pascals representing the X component wind loading on the pole and any guy wire attachments in the case where the wind is blowing in the the positive Y direction. Note that the X axis points in the direction of the incoming mainline span while the Y axis points 90 degrees clockwise with respect to the incoming mainline attachment.
poleWindPressureX-Wind+Y	Floating point value in Pascals representing the Y component wind loading on the pole and any guy wire attachments in the case where the wind is blowing in the the positive Y direction. Note that the X axis points in the direction of the incoming mainline span while the Y axis points 90 degrees clockwise with respect to the incoming mainline attachment.
strainAtt1VertLoad-Wind+Y	Floating point value in Newtons representing the vertical load at the first attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt1YLoad-Wind+Y	Floating point value in Newtons representing the Y axis component of the force load at the first attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt1XLoad-Wind+Y	Floating point value in Newtons representing the X axis component of the force load at the first attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt2VertLoad-Wind+Y	Floating point value in Newtons representing the vertical load at the second attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt2YLoad-Wind+Y	Floating point value in Newtons representing the Y axis component of the force load at the second attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt2XLoad-Wind+Y	Floating point value in Newtons representing the X axis component of the force load at the second attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt3VertLoad-Wind+Y	Floating point value in Newtons representing the vertical load at the third attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt3YLoad-Wind+Y	Floating point value in Newtons representing the Y axis component of the force load at the third attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt3XLoad-Wind+Y	Floating point value in Newtons representing the X axis component of the force load at the third attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt4VertLoad-Wind+Y	Floating point value in Newtons representing the vertical load at the fourth attachment point in the case where the wind is blowing in the direction of the positive Y direction.

strainAtt4YLoad-Wind+Y	Floating point value in Newtons representing the Y axis component of the force load at the fourth attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAtt4XLoad-Wind+Y	Floating point value in Newtons representing the X axis component of the force load at the fourth attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAttNVertLoad-Wind+Y	Floating point value in Newtons representing the vertical load at the vertically-spaced neutral attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAttNYLoad-Wind+Y	Floating point value in Newtons representing the Y axis component of the force load at the vertically-spaced neutral attachment point in the case where the wind is blowing in the direction of the positive Y direction.
strainAttNXLoad-Wind+Y	Floating point value in Newtons representing the X axis component of the force load at the vertically-spaced neutral attachment point in the case where the wind is blowing in the direction of the positive Y direction.
	Repeat the above 17 entries for each of the remaining eight wind directions (+X+Y, +X, +X-Y, -Y, -X-Y, -X,and -X+Y)
Justification	A text string generated during the calculation of the longitudinal, vertical, and transverse force components. The strings contains equations for each of the pole's attachment points deriving the longitudinal, vertical and transverse forces. The justification string also contains a data-dump at the end of the text that provides geometric information on the attachments and anchors as well as the final loading vectors for each of the attachments where each data point is seperated by a '$' character. While the data comprising the data-dump is largely unused, the intent is to provide the necessary information to generate a 3D representation of the pole structure and applicable load vectors in a future PoleCheck2.0 output report format.

Table A.13: PoleCheck2.0 Lookup Table Columns

PoleCheck2.0 Lookup Table Column Name	Description of Column
Loading	Possible values: heavy or medium loading. Value state determines the ice-loading condition to be used in evaluating transverse, vertical and longitudinal conductor loading.
GradeInc	Possible values: 1, 2 or blank. Value state determines the loading factors on the incoming mainline span to be applied to tranverse, longitudinal and vertical conductor loading as well as to the wind loading effects considered by PLS Pole on any pole and anchor structures. Specifying grade 1 results in more conservative loading factors being applied and are intended to be used for situations such as railway crossings or navigible water crossings.
GradeOut	Possible values: 1, 2 or blank. Value state determines the loading factors of any outgoing (non-tangential) spans to be applied to tranverse, longitudinal and vertical conductor loading as well as to the wind loading effects considered by PLS Pole on any pole and anchor structures.
CU#1	A text string that generally represents the first compatible unit of the structure pattern. Note that this field is not used by AutoDesigner or in the creation of the PoleCheck2.0 data tables but rather provides future functionality to enable DFO designers to utilize tables with a checkbox-style user interface that is similar to the current implementation of PoleCheck1.0.

CU#2	A text string that generally represents the second compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the "Neut" tag is replaced with a likely neutral attachment structure.
CU#3	A text string that generally represents the third compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the "Neut" tag is replaced with a likely neutral attachment structure.
CU#4	A text string that generally represents the fourth compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the "Neut" tag is replaced with a likely neutral attachment structure.
CU#5	A text string that generally represents the fifth compatible unit of the structure pattern. In the case of a dedicated neutral attachment, the "Neut" tag is replaced with a likely neutral attachment structure.
IncomingTightSpan	Possible values: 1, 0 or blank. The data field contains an binary flag indicating whether the span on the incoming mainline attachment is slack or tight. A value of 0 indicates a slack span, a value of 1 indicates a tight span and a blank value occurs when no incoming mainline span is present.
IncomingTightSpan	Possible values: 1, 0 or blank. The data field contains an binary flag indicating whether the span on the incoming mainline attachment is slack or tight. A value of 0 indicates a slack span, a value of 1 indicates a tight span and a blank value occurs when no incoming mainline span is present.
OutgoingTightSpan	Possible values: 1, 0 or blank. The data field contains an binary flag indicating whether the span on the outgoing mainline attachment is slack or tight. A value of 0 indicates a slack span, a value of 1 indicates a tight span and a blank value occurs when no outgoing mainline span is present.
Tap1TightSpan	Possible values: 1, 0 or blank. The data field contains an binary flag indicating whether the span on the first tap-span attachment is slack or tight. A value of 0 indicates a slack span, a value of 1 indicates a tight span and a blank value occurs when no tap spans are present.
Tap2TightSpan	Possible values: 1, 0 or blank. The data field contains an binary flag indicating whether the span on the second tap-span attachment is slack or tight. A value of 0 indicates a slack span, a value of 1 indicates a tight span and a blank value occurs when less than two tap-spans are present.
CondTypeIncMain	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the incoming mainline span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
CondTypeOutMain	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the outgoing mainline span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
CondTypeTap1	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the first tap-off span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
CondTypeTap2	Possible values: 4, 6, 8, 9 or blank. The data field contains an integer value that corresponds to the conductor type of the second tap-off span. Note that numeric identifiers for conductor types correspond to those listed in Table 2.3.
SpanLengthIncMain	Floating point value representing the span length in meters of the incoming mainline span.
SpanLengthOutMain	Floating point value representing the span length in meters of the outgoing mainline span. Value may be filled with a hyphon character if no outgoing mainline span is present.

SpanLengthTapOne	Floating point value representing the span length in meters of the first tap-off span. Value may be filled with a hyphon character if no tap-off spans are present.
SpanLengthTapTwo	Floating point value representing the span length in meters of the second tap-off span. Value may be filled with a hyphon character if less than 2 tap-off spans are present.
DeflectionMain	Floating point value in radians representing the orientation of the outgoing mainline span with respect to the orientation of the incoming mainline span. Note that orientation of the incoming mainline span is always assumed to be equal to zero. Value may be left blank if not outgoing mainline span is present.
DeflectionTap1	Floating point value in radians representing the orientation of the first tap-off span with respect to the orientation of the incoming mainline span. Value may be left blank if no tap-off spans are present.
DeflectionTap2	Floating point value in radians representing the orientation of the second tap-off span with respect to the orientation of the incoming mainline span. Value may be left blank if less than 2 tap-off spans are present.
anc1Length	Floating point value in meters representing the length of the first anchor. Value may be left blank if no anchors are required for structure pattern under investigation
anc2Length	Floating point value in meters representing the length of the second anchor. Value may be left blank if less than two anchors are required for structure pattern under investigation.
AncType	Data string representing the types of anchors being modelled for a given PLS Pole case. If two anchors are present than the individual anchor names are seperated buy a comma with anchor 1 always being first.
Pole Height	Integer value in feet representing the pole height from pole butt to pole top. Values vary between 35 and 60 in 5 ft. increments. Value must not be blank.
Pole Type	Data string containin an abbreviation of the pole composition. Typically pole compositions include: western red cedar (WR), Lodgepole Pine (LP) or Douglas Fir (DF). Currently, only pole types of WR have been considered in PoleCheck2.0 as the DFO considers the WR pole composition to be the least conservative of the three.
Pole Class	Integer value ranging from 1 to 7 indicating the class of the pole. Pole class indicates the width of the pole where smaller integer values correspond to thicker poles. Note that not all pole classes are naturally occur in trees for all pole heights and PoleCheck2.0 only considers pole height and class combinations that are feasible and commercially available.
Usage	Floating point value representing the pole utilization in percent or value may be 'NA'. Value is obtained from the Optimum Pole Selector in PLS-Pole and represents the utilization of the most strained member in a pole structure after deformation due to forces applied to the pole. Values that are less than 100 represent compliant pole height, class and composition combinations while values that are over 100 or labelled 'NA' are considered to be non-compliant.

Jusification1 to Justification10	A series of text strings that are spread over the final 10 columns of the PoleCheck2.0 look-up table. The text string is subdivided to help minimize the size of the numpy array utilized in Python to store the PoleCheck2.0 data table. Furthemore the text string has had all newline characters replaced with a tag since the PoleCheck2.0 lookup table is saved in a CSV format. Note that Justification1 to Justification10 are only populated for the 35 ft. class 2 pole structure since the string is unique to a given PLS-Pole FEA case and all other pole combinations are computed by the Optimum Pole Selector during the same run. The text string is generated during the calculation of the longitudinal, vertical, and transverse force components by the PLS-Pole FEA case generator. The strings contains equations for each of the pole's attachment points deriving the longitudinal, vertical and transverse forces. The justification string also contains a data-dump at the end of the text that provides geometric information on the attachments and anchors as well as the final loading vectors for each of the attachments where each data point is seperated by a '$' character. While the data comprising the data-dump is largely unused, the intent is to provide the necessary information to generate a 3D representation of the pole structure and applicable load vectors in a future PoleCheck2.0 output report format.

Appendix B: Data Tables Pertaining to Hyperparameter Search

Table B.1: Survey CSV File and User Input for First Hyperparameter Search Test Case.

ID	Northing (UTM 11)	Easting (UTM 11)	Elevation (m)	Crossing/Asset Type	Ex. Str. Pattern	misc	Ex. Height of Attachments
9	6054750.708	411653.058	805.108	PP_			
1	6054754.509	411662.3	805.29	PP_			
1A	6054760.976	411659.632	805.463	ANC_			
2	6054716.648	411677.892	804.756	PP_			
2A	6054710.176	411680.559	804.772	ANC_			
3	6054731.38	411704.005	806.122	PP_			
3A	6054727.986	411697.887	806.122	ANC_			
4	6054787.229	411804.665	807.745	PP_			
7035	6054792.009	411814.972	808.93	RDSHL_			
7036	6054793.657	411818.437	809.275	RDCL_			
7037	6054795.779	411822.973	809.212	RDSHL_			
7100	6054800.51	411840.833	810.335	P/L_			
7109	6054812.05	411851.249	810.297	P/L_			
7111	6054815.679	411869.901	810.951	P/L_			
7118	6054827.967	411884.343	811.209	P/L_			
7038	6054812.136	411857.99	810.856	RDSHL_			
7039	6054818.985	411872.555	810.973	RDCL_			
7040	6054823.943	411883.157	811.106	RDSHL_			
5	6054833.624	411903.91	811.196	PP_			
5A	6054830.235	411906.035	811.173	ANC_			
6	6054907.14	411995.382	811.877	PP_			
6A	6054911.526	412000.821	812.248	ANC_			
7	6054923.408	412002.541	812.252	PP_			
7A	6054916.972	412005.312	812.222	ANC_			
8	6054989.555	411974.122	812.55	PP_			
8A	6054995.99	411971.36	812.531	ANC_			
User Input:							
Loading:	Medium						
Spacing:	Rural						
# Ph. Ex. Main	3						
# Ph. New Main	3						
# Ph. Ex. Tap	1						

# Ph. New Tap	1						
Grounding	Earth Return						
Min Clearance	Pedestrian						
Ex. Cond. Type	#4 ACSR						
Ex. Tap-Off Cond. Type	#4 ACSR						
New Cond. Type	1/0 ACSR						
New Tap-Off Cond. Type	1/0 ACSR						
Equip. 1	Pole 9	N390					
Equip. 2	Pole 8	N390					
Equip. 3							
Service Pt.	18						
Prelim Stk List Mod.	None						

Table B.2: Hyperparameter Search Results for Test Case 1.

No.	Population Size	Crossover Rate	Mutation Rate	Min. Cost	Computation Time
1	5120	0.6	0.0005	$25633.05	5.03 min
2	5120	0.6	0.001	$25633.05	4.53 min
3	5120	0.6	0.005	$25570.19	5.33 min
4	5120	0.6	0.01	$25570.19	5.3 min
5	5120	0.6	0.015	$25570.19	5.51 min
6	5120	0.6	0.02	$25633.05	5.09 min
7	5120	0.6	0.025	$25570.19	5.23 min
8	5120	0.6	0.03	$25570.19	5.07 min
9	5120	0.6	0.035	$25570.19	5.13 min
10	5120	0.6	0.04	$25570.19	5.57 min
11	5120	0.65	0.0005	$25633.05	5.58 min
12	5120	0.65	0.001	$25633.05	4.87 min
13	5120	0.65	0.005	$25570.19	5.43 min
14	5120	0.65	0.01	$25570.19	5.31 min
15	5120	0.65	0.015	$25633.05	5.28 min
16	5120	0.65	0.02	$25570.19	5.57 min
17	5120	0.65	0.025	$25570.19	5.3 min
18	5120	0.65	0.03	$25570.19	5.73 min
19	5120	0.65	0.035	$25570.19	5.76 min
20	5120	0.65	0.04	$25633.05	5.02 min
21	5120	0.7	0.0005	$25633.05	5.13 min
22	5120	0.7	0.001	$25633.05	5.44 min
23	5120	0.7	0.005	$25633.05	5.23 min
24	5120	0.7	0.01	$25570.19	6.08 min
25	5120	0.7	0.015	$25633.05	5.46 min
26	5120	0.7	0.02	$25570.19	6.47 min
27	5120	0.7	0.025	$25570.19	5.58 min
28	5120	0.7	0.03	$25570.19	6.5 min
29	5120	0.7	0.035	$25633.05	5.72 min
30	5120	0.7	0.04	$25570.19	6.04 min
31	5120	0.75	0.0005	$25570.19	5.84 min
32	5120	0.75	0.001	$25633.05	5.54 min
33	5120	0.75	0.005	$25633.05	5.52 min
34	5120	0.75	0.01	$25633.05	5.89 min
35	5120	0.75	0.015	$25570.19	5.88 min
36	5120	0.75	0.02	$25633.05	5.54 min

37	5120	0.75	0.025	$25570.19	5.97 min
38	5120	0.75	0.03	$25570.19	6.8 min
39	5120	0.75	0.035	$25570.19	6.5 min
40	5120	0.75	0.04	$25633.05	5.56 min
41	5120	0.8	0.0005	$25633.05	5.82 min
42	5120	0.8	0.001	$25633.05	5.6 min
43	5120	0.8	0.005	$25570.19	5.67 min
44	5120	0.8	0.01	$25633.05	6.01 min
45	5120	0.8	0.015	$25570.19	6.67 min
46	5120	0.8	0.02	$25633.05	5.67 min
47	5120	0.8	0.025	$25570.19	6.49 min
48	5120	0.8	0.03	$25633.05	6.61 min
49	5120	0.8	0.035	$25633.05	5.8 min
50	5120	0.8	0.04	$25633.05	5.98 min
51	5120	0.85	0.0005	$25633.05	5.88 min
52	5120	0.85	0.001	$25570.19	6.77 min
53	5120	0.85	0.005	$25570.19	6.06 min
54	5120	0.85	0.01	$25570.19	6.58 min
55	5120	0.85	0.015	$25570.19	6.9 min
56	5120	0.85	0.02	$25633.05	6.24 min
57	5120	0.85	0.025	$25570.19	6.78 min
58	5120	0.85	0.03	$25570.19	6.53 min
59	5120	0.85	0.035	$25570.19	6.98 min
60	5120	0.85	0.04	$25570.19	6.47 min
61	5120	0.9	0.0005	$25570.19	7.43 min
62	5120	0.9	0.001	$25633.05	6.16 min
63	5120	0.9	0.005	$25633.05	6.15 min
64	5120	0.9	0.01	$25570.19	6.71 min
65	5120	0.9	0.015	$25570.19	7.04 min
66	5120	0.9	0.02	$25633.05	6.34 min
67	5120	0.9	0.025	$25633.05	6.17 min
68	5120	0.9	0.03	$25570.19	7.1 min
69	5120	0.9	0.035	$25570.19	6.88 min
70	5120	0.9	0.04	$25570.19	7.1 min
71	5120	0.95	0.0005	$25633.05	6.45 min
72	5120	0.95	0.001	$25570.19	6.63 min
73	5120	0.95	0.005	$25570.19	6.91 min
74	5120	0.95	0.01	$25633.05	6.86 min
75	5120	0.95	0.015	$25633.05	6.27 min
76	5120	0.95	0.02	$25633.05	6.41 min
77	5120	0.95	0.025	$25570.19	6.94 min
78	5120	0.95	0.03	$25570.19	7.51 min
79	5120	0.95	0.035	$25570.19	7.33 min
80	5120	0.95	0.04	$25570.19	7.91 min
81	2560	0.6	0.0005	$25570.19	2.44 min
82	2560	0.6	0.001	$25570.19	2.45 min
83	2560	0.6	0.005	$25633.05	2.51 min
84	2560	0.6	0.01	$25633.05	2.58 min
85	2560	0.6	0.015	$25633.05	2.66 min
86	2560	0.6	0.02	$25633.05	2.65 min
87	2560	0.6	0.025	$25633.05	2.78 min
88	2560	0.6	0.03	$25633.05	2.72 min
89	2560	0.6	0.035	$25633.05	2.52 min
90	2560	0.6	0.04	$25570.19	2.68 min
91	2560	0.65	0.0005	$25689.69	2.89 min
92	2560	0.65	0.001	$25633.05	2.75 min
93	2560	0.65	0.005	$25570.19	2.73 min
94	2560	0.65	0.01	$25570.19	2.95 min

95	2560	0.65	0.015	$25633.05	2.46 min
96	2560	0.65	0.02	$25570.19	3.31 min
97	2560	0.65	0.025	$25633.05	2.89 min
98	2560	0.65	0.03	$25570.19	2.75 min
99	2560	0.65	0.035	$25633.05	2.73 min
100	2560	0.65	0.04	$25633.05	2.86 min
101	2560	0.7	0.0005	$25633.05	2.49 min
102	2560	0.7	0.001	$25570.19	3.38 min
103	2560	0.7	0.005	$25633.05	2.86 min
104	2560	0.7	0.01	$25633.05	2.86 min
105	2560	0.7	0.015	$25633.05	2.64 min
106	2560	0.7	0.02	$25633.05	2.87 min
107	2560	0.7	0.025	$25570.19	3.23 min
108	2560	0.7	0.03	$25633.05	2.86 min
109	2560	0.7	0.035	$25570.19	3.03 min
110	2560	0.7	0.04	$25570.19	2.88 min
111	2560	0.75	0.0005	$25633.05	2.94 min
112	2560	0.75	0.001	$25633.05	3.02 min
113	2560	0.75	0.005	$25633.05	3.02 min
114	2560	0.75	0.01	$25570.19	3.09 min
115	2560	0.75	0.015	$25570.19	3.11 min
116	2560	0.75	0.02	$25570.19	3.19 min
117	2560	0.75	0.025	$25570.19	2.93 min
118	2560	0.75	0.03	$25633.05	2.79 min
119	2560	0.75	0.035	$25633.05	3.1 min
120	2560	0.75	0.04	$25633.05	2.96 min
121	2560	0.8	0.0005	$25633.05	2.99 min
122	2560	0.8	0.001	$25633.05	3.02 min
123	2560	0.8	0.005	$25633.05	3.06 min
124	2560	0.8	0.01	$25570.19	2.94 min
125	2560	0.8	0.015	$25570.19	3.27 min
126	2560	0.8	0.02	$25570.19	3.35 min
127	2560	0.8	0.025	$25633.05	3.02 min
128	2560	0.8	0.03	$25633.05	2.69 min
129	2560	0.8	0.035	$25633.05	3.39 min
130	2560	0.8	0.04	$25570.19	3.31 min
131	2560	0.85	0.0005	$25633.05	3.01 min
132	2560	0.85	0.001	$25633.05	3.27 min
133	2560	0.85	0.005	$25633.05	3.02 min
134	2560	0.85	0.01	$25570.19	3.46 min
135	2560	0.85	0.015	$25570.19	3.35 min
136	2560	0.85	0.02	$25633.05	2.86 min
137	2560	0.85	0.025	$25633.05	3.01 min
138	2560	0.85	0.03	$25570.19	3.28 min
139	2560	0.85	0.035	$25570.19	3.28 min
140	2560	0.85	0.04	$25570.19	3.53 min
141	2560	0.9	0.0005	$25633.05	3.33 min
142	2560	0.9	0.001	$25570.19	3.25 min
143	2560	0.9	0.005	$25633.05	3.23 min
144	2560	0.9	0.01	$25570.19	3.42 min
145	2560	0.9	0.015	$25633.05	3.07 min
146	2560	0.9	0.02	$25633.05	3.25 min
147	2560	0.9	0.025	$25570.19	3.77 min
148	2560	0.9	0.03	$25570.19	3.15 min
149	2560	0.9	0.035	$25570.19	3.51 min
150	2560	0.9	0.04	$25633.05	3.15 min
151	2560	0.95	0.0005	$25633.05	3.09 min
152	2560	0.95	0.001	$25570.19	3.56 min

153	2560	0.95	0.005	$25570.19	3.37 min
154	2560	0.95	0.01	$25633.05	3.28 min
155	2560	0.95	0.015	$25633.05	3.29 min
156	2560	0.95	0.02	$25570.19	3.38 min
157	2560	0.95	0.025	$25570.19	4.39 min
158	2560	0.95	0.03	$25633.05	3.29 min
159	2560	0.95	0.035	$25570.19	3.47 min
160	2560	0.95	0.04	$25633.05	3.16 min
161	1280	0.6	0.0005	$25633.05	1.35 min
162	1280	0.6	0.001	$25570.19	1.61 min
163	1280	0.6	0.005	$25633.05	1.32 min
164	1280	0.6	0.01	$25633.05	1.5 min
165	1280	0.6	0.015	$25633.05	1.4 min
166	1280	0.6	0.02	$25633.05	1.77 min
167	1280	0.6	0.025	$25633.05	1.54 min
168	1280	0.6	0.03	$25570.19	1.56 min
169	1280	0.6	0.035	$25570.19	1.46 min
170	1280	0.6	0.04	$25633.05	1.3 min
171	1280	0.65	0.0005	$25633.05	1.34 min
172	1280	0.65	0.001	$25633.05	1.33 min
173	1280	0.65	0.005	$25718.17	1.37 min
174	1280	0.65	0.01	$25633.05	1.48 min
175	1280	0.65	0.015	$25633.05	1.25 min
176	1280	0.65	0.02	$25570.19	1.47 min
177	1280	0.65	0.025	$25633.05	1.37 min
178	1280	0.65	0.03	$25633.05	1.41 min
179	1280	0.65	0.035	$25570.19	1.6 min
180	1280	0.65	0.04	$25633.05	1.52 min
181	1280	0.7	0.0005	$25633.05	1.47 min
182	1280	0.7	0.001	$25570.19	1.62 min
183	1280	0.7	0.005	$25633.05	1.59 min
184	1280	0.7	0.01	$25570.19	1.39 min
185	1280	0.7	0.015	$25633.05	1.48 min
186	1280	0.7	0.02	$25633.05	1.73 min
187	1280	0.7	0.025	$25570.19	1.55 min
188	1280	0.7	0.03	$25633.05	1.56 min
189	1280	0.7	0.035	$25633.05	1.63 min
190	1280	0.7	0.04	$25570.19	1.63 min
191	1280	0.75	0.0005	$25633.05	1.7 min
192	1280	0.75	0.001	$25689.69	1.51 min
193	1280	0.75	0.005	$25570.19	1.67 min
194	1280	0.75	0.01	$25633.05	1.59 min
195	1280	0.75	0.015	$25633.05	1.51 min
196	1280	0.75	0.02	$25570.19	1.63 min
197	1280	0.75	0.025	$25633.05	1.62 min
198	1280	0.75	0.03	$25633.05	1.59 min
199	1280	0.75	0.035	$25633.05	1.58 min
200	1280	0.75	0.04	$25570.19	1.95 min
201	1280	0.8	0.0005	$25633.05	1.54 min
202	1280	0.8	0.001	$25570.19	2.28 min
203	1280	0.8	0.005	$25633.05	2.23 min
204	1280	0.8	0.01	$25633.05	1.37 min
205	1280	0.8	0.015	$25950.93	1.66 min
206	1280	0.8	0.02	$25633.05	1.53 min
207	1280	0.8	0.025	$25570.19	1.37 min
208	1280	0.8	0.03	$25570.19	1.58 min
209	1280	0.8	0.035	$25633.05	1.65 min
210	1280	0.8	0.04	$25570.19	1.67 min

211	1280	0.85	0.0005	$25570.19	1.82 min
212	1280	0.85	0.001	$25655.31	1.82 min
213	1280	0.85	0.005	$25633.05	1.48 min
214	1280	0.85	0.01	$25633.05	1.76 min
215	1280	0.85	0.015	$25633.05	1.55 min
216	1280	0.85	0.02	$25633.05	1.61 min
217	1280	0.85	0.025	$25633.05	1.7 min
218	1280	0.85	0.03	$25570.19	1.91 min
219	1280	0.85	0.035	$25633.05	1.73 min
220	1280	0.85	0.04	$25633.05	1.7 min
221	1280	0.9	0.0005	$25633.05	1.85 min
222	1280	0.9	0.001	$25633.05	1.72 min
223	1280	0.9	0.005	$25655.31	1.9 min
224	1280	0.9	0.01	$25570.19	1.68 min
225	1280	0.9	0.015	$25633.05	1.72 min
226	1280	0.9	0.02	$25570.19	1.85 min
227	1280	0.9	0.025	$25570.19	1.76 min
228	1280	0.9	0.03	$25570.19	2.22 min
229	1280	0.9	0.035	$25633.05	1.76 min
230	1280	0.9	0.04	$25633.05	1.9 min
231	1280	0.95	0.0005	$25889.18	1.69 min
232	1280	0.95	0.001	$25633.05	1.65 min
233	1280	0.95	0.005	$25570.19	1.75 min
234	1280	0.95	0.01	$25633.05	1.6 min
235	1280	0.95	0.015	$25570.19	1.74 min
236	1280	0.95	0.02	$25633.05	1.73 min
237	1280	0.95	0.025	$25633.05	1.75 min
238	1280	0.95	0.03	$25633.05	1.92 min
239	1280	0.95	0.035	$25570.19	1.98 min
240	1280	0.95	0.04	$25633.05	1.75 min
241	640	0.6	0.0005	$26167.45	0.62 min
242	640	0.6	0.001	$25911.44	0.69 min
243	640	0.6	0.005	$25633.05	1.17 min
244	640	0.6	0.01	$25570.19	0.83 min
245	640	0.6	0.015	$25718.17	0.85 min
246	640	0.6	0.02	$25718.17	0.85 min
247	640	0.6	0.025	$25696.56	0.83 min
248	640	0.6	0.03	$25633.05	0.92 min
249	640	0.6	0.035	$25759.42	0.75 min
250	640	0.6	0.04	$25633.05	0.98 min
251	640	0.65	0.0005	$25734.21	0.73 min
252	640	0.65	0.001	$25752.55	0.58 min
253	640	0.65	0.005	$25570.19	0.98 min
254	640	0.65	0.01	$25633.05	0.8 min
255	640	0.65	0.015	$25655.31	1.1 min
256	640	0.65	0.02	$25633.05	0.9 min
257	640	0.65	0.025	$25718.17	1.1 min
258	640	0.65	0.03	$25633.05	0.74 min
259	640	0.65	0.035	$25633.05	0.8 min
260	640	0.65	0.04	$25633.05	0.88 min
261	640	0.7	0.0005	$25655.31	0.8 min
262	640	0.7	0.001	$25752.55	0.78 min
263	640	0.7	0.005	$25570.19	1.33 min
264	640	0.7	0.01	$25633.05	0.98 min
265	640	0.7	0.015	$25570.19	0.95 min
266	640	0.7	0.02	$25655.31	1.0 min
267	640	0.7	0.025	$25633.05	0.86 min
268	640	0.7	0.03	$25570.19	1.03 min

269	640	0.7	0.035	$25633.05	0.86 min
270	640	0.7	0.04	$25718.17	0.82 min
271	640	0.75	0.0005	$25797.07	0.72 min
272	640	0.75	0.001	$25633.05	0.73 min
273	640	0.75	0.005	$25633.05	0.84 min
274	640	0.75	0.01	$25570.19	0.82 min
275	640	0.75	0.015	$25781.68	0.92 min
276	640	0.75	0.02	$25633.05	0.81 min
277	640	0.75	0.025	$25655.31	1.13 min
278	640	0.75	0.03	$25633.05	0.78 min
279	640	0.75	0.035	$25759.42	0.89 min
280	640	0.75	0.04	$25759.42	0.99 min
281	640	0.8	0.0005	$25655.31	0.9 min
282	640	0.8	0.001	$25689.69	1.03 min
283	640	0.8	0.005	$25933.04	0.9 min
284	640	0.8	0.01	$25633.05	1.02 min
285	640	0.8	0.015	$25570.19	0.81 min
286	640	0.8	0.02	$25570.19	0.96 min
287	640	0.8	0.025	$25570.19	0.86 min
288	640	0.8	0.03	$25633.05	0.81 min
289	640	0.8	0.035	$25950.93	0.82 min
290	640	0.8	0.04	$25570.19	0.9 min
291	640	0.85	0.0005	$25655.31	0.87 min
292	640	0.85	0.001	$25633.05	0.91 min
293	640	0.85	0.005	$25655.31	0.92 min
294	640	0.85	0.01	$25570.19	1.02 min
295	640	0.85	0.015	$25633.05	0.96 min
296	640	0.85	0.02	$25570.19	0.98 min
297	640	0.85	0.025	$25570.19	0.98 min
298	640	0.85	0.03	$25633.05	0.87 min
299	640	0.85	0.035	$25570.19	0.96 min
300	640	0.85	0.04	$25633.05	1.11 min
301	640	0.9	0.0005	$25633.05	0.91 min
302	640	0.9	0.001	$25570.19	0.97 min
303	640	0.9	0.005	$25592.45	0.97 min
304	640	0.9	0.01	$25570.19	1.04 min
305	640	0.9	0.015	$25633.05	0.89 min
306	640	0.9	0.02	$25633.05	0.88 min
307	640	0.9	0.025	$25633.05	0.93 min
308	640	0.9	0.03	$25950.93	0.94 min
309	640	0.9	0.035	$25718.17	1.09 min
310	640	0.9	0.04	$25570.19	1.02 min
311	640	0.95	0.0005	$25633.05	0.81 min
312	640	0.95	0.001	$25759.42	0.9 min
313	640	0.95	0.005	$25633.05	0.9 min
314	640	0.95	0.01	$25759.42	1.05 min
315	640	0.95	0.015	$25633.05	0.97 min
316	640	0.95	0.02	$25633.05	1.18 min
317	640	0.95	0.025	$25570.19	1.06 min
318	640	0.95	0.03	$25759.42	0.95 min
319	640	0.95	0.035	$25633.05	0.95 min
320	640	0.95	0.04	$25889.18	1.23 min
321	320	0.6	0.0005	$26258.24	0.5 min
322	320	0.6	0.001	$26024.53	0.36 min
323	320	0.6	0.005	$25788.28	0.52 min
324	320	0.6	0.01	$25889.01	0.41 min
325	320	0.6	0.015	$25513.55	0.48 min
326	320	0.6	0.02	$25853.24	0.64 min

327	320	0.6	0.025	$25592.45	0.5 min
328	320	0.6	0.03	$25558.06	0.5 min
329	320	0.6	0.035	$25788.28	0.47 min
330	320	0.6	0.04	$25832.8	0.45 min
331	320	0.65	0.0005	$25495.2	0.48 min
332	320	0.65	0.001	$26066.67	0.41 min
333	320	0.65	0.005	$25602.58	0.48 min
334	320	0.65	0.01	$25885.35	0.98 min
335	320	0.65	0.015	$25810.54	0.49 min
336	320	0.65	0.02	$25513.55	0.55 min
337	320	0.65	0.025	$26168.13	0.47 min
338	320	0.65	0.03	$25513.55	0.54 min
339	320	0.65	0.035	$25513.55	0.41 min
340	320	0.65	0.04	$25513.55	0.54 min
341	320	0.7	0.0005	$737600.98	0.49 min
342	320	0.7	0.001	$26167.07	0.48 min
343	320	0.7	0.005	$25643.18	0.6 min
344	320	0.7	0.01	$25632.88	0.52 min
345	320	0.7	0.015	$25450.69	0.63 min
346	320	0.7	0.02	$25725.42	0.95 min
347	320	0.7	0.025	$735733.69	0.67 min
348	320	0.7	0.03	$25950.48	0.5 min
349	320	0.7	0.035	$25747.68	0.49 min
350	320	0.7	0.04	$25513.55	0.58 min
351	320	0.75	0.0005	$26333.53	0.41 min
352	320	0.75	0.001	$26298.25	0.34 min
353	320	0.75	0.005	$25535.8	0.47 min
354	320	0.75	0.01	$25513.55	0.54 min
355	320	0.75	0.015	$25513.55	0.54 min
356	320	0.75	0.02	$25513.55	0.55 min
357	320	0.75	0.025	$736503.35	0.67 min
358	320	0.75	0.03	$25725.42	0.53 min
359	320	0.75	0.035	$25610.79	0.53 min
360	320	0.75	0.04	$25682.23	0.46 min
361	320	0.8	0.0005	$25730.12	0.45 min
362	320	0.8	0.001	$26656.63	0.41 min
363	320	0.8	0.005	$25677.57	0.49 min
364	320	0.8	0.01	$25535.8	0.51 min
365	320	0.8	0.015	$25513.55	0.55 min
366	320	0.8	0.02	$25513.55	0.48 min
367	320	0.8	0.025	$25513.55	0.67 min
368	320	0.8	0.03	$25450.69	0.6 min
369	320	0.8	0.035	$25450.69	0.61 min
370	320	0.8	0.04	$25788.28	0.59 min
371	320	0.85	0.0005	$26255.25	0.42 min
372	320	0.85	0.001	$25689.69	0.6 min
373	320	0.85	0.005	$25576.41	0.46 min
374	320	0.85	0.01	$25716.62	0.61 min
375	320	0.85	0.015	$25450.69	0.72 min
376	320	0.85	0.02	$25513.55	0.63 min
377	320	0.85	0.025	$25788.28	0.56 min
378	320	0.85	0.03	$25513.55	0.63 min
379	320	0.85	0.035	$25513.55	0.67 min
380	320	0.85	0.04	$25450.69	0.69 min
381	320	0.9	0.0005	$25610.79	0.52 min
382	320	0.9	0.001	$25958.52	0.55 min
383	320	0.9	0.005	$25610.62	0.59 min
384	320	0.9	0.01	$25513.55	0.41 min

385	320	0.9	0.015	$25513.55	0.58 min
386	320	0.9	0.02	$25725.42	0.58 min
387	320	0.9	0.025	$25513.55	0.54 min
388	320	0.9	0.03	$25885.35	0.59 min
389	320	0.9	0.035	$25610.79	0.65 min
390	320	0.9	0.04	$25535.8	0.55 min
391	320	0.95	0.0005	$25655.31	0.44 min
392	320	0.95	0.001	$25655.31	0.39 min
393	320	0.95	0.005	$25535.8	0.63 min
394	320	0.95	0.01	$25513.55	0.52 min
395	320	0.95	0.015	$25769.67	0.67 min
396	320	0.95	0.02	$25450.69	0.67 min
397	320	0.95	0.025	$25450.69	0.7 min
398	320	0.95	0.03	$25513.55	0.48 min
399	320	0.95	0.035	$25610.79	0.67 min
400	320	0.95	0.04	$25832.8	0.64 min
401	160	0.6	0.0005	$25917.92	0.17 min
402	160	0.6	0.001	$739054.29	0.15 min
403	160	0.6	0.005	$25938.83	0.39 min
404	160	0.6	0.01	$26630.26	0.25 min
405	160	0.6	0.015	$25574.85	0.26 min
406	160	0.6	0.02	$25745.09	0.3 min
407	160	0.6	0.025	$736053.73	0.4 min
408	160	0.6	0.03	$26254.23	0.18 min
409	160	0.6	0.035	$25610.79	0.29 min
410	160	0.6	0.04	$25592.45	0.46 min
411	160	0.65	0.0005	$26975.12	0.25 min
412	160	0.65	0.001	$737138.43	0.23 min
413	160	0.65	0.005	$26603.84	0.17 min
414	160	0.65	0.01	$25851.17	0.21 min
415	160	0.65	0.015	$26044.41	0.24 min
416	160	0.65	0.02	$25917.92	0.39 min
417	160	0.65	0.025	$25558.06	0.32 min
418	160	0.65	0.03	$25871.4	0.36 min
419	160	0.65	0.035	$25547.93	0.39 min
420	160	0.65	0.04	$26408.51	0.23 min
421	160	0.7	0.0005	$27202.51	0.17 min
422	160	0.7	0.001	$26727.75	0.27 min
423	160	0.7	0.005	$25655.31	0.41 min
424	160	0.7	0.01	$25889.74	0.32 min
425	160	0.7	0.015	$25535.8	0.46 min
426	160	0.7	0.02	$25832.8	0.39 min
427	160	0.7	0.025	$25788.28	0.35 min
428	160	0.7	0.03	$25610.62	0.27 min
429	160	0.7	0.035	$25602.58	0.33 min
430	160	0.7	0.04	$25632.88	0.28 min
431	160	0.75	0.0005	$26066.92	0.2 min
432	160	0.75	0.001	$25659.23	0.19 min
433	160	0.75	0.005	$27431.8	0.31 min
434	160	0.75	0.01	$26772.02	0.32 min
435	160	0.75	0.015	$25558.06	0.37 min
436	160	0.75	0.02	$25610.79	0.34 min
437	160	0.75	0.025	$26732.7	0.3 min
438	160	0.75	0.03	$25610.62	0.33 min
439	160	0.75	0.035	$25513.55	0.37 min
440	160	0.75	0.04	$26440.91	0.27 min
441	160	0.8	0.0005	$26653.45	0.21 min
442	160	0.8	0.001	$26629.89	0.25 min

443	160	0.8	0.005	$736188.21	0.29 min
444	160	0.8	0.01	$25974.39	0.38 min
445	160	0.8	0.015	$26667.24	0.26 min
446	160	0.8	0.02	$26066.67	0.38 min
447	160	0.8	0.025	$25558.06	0.3 min
448	160	0.8	0.03	$25632.88	0.29 min
449	160	0.8	0.035	$26648.87	0.38 min
450	160	0.8	0.04	$25832.8	0.25 min
451	160	0.85	0.0005	$26585.98	0.19 min
452	160	0.85	0.001	$25784.95	0.21 min
453	160	0.85	0.005	$736730.07	0.26 min
454	160	0.85	0.01	$26395.3	0.37 min
455	160	0.85	0.015	$25472.94	0.26 min
456	160	0.85	0.02	$25558.06	0.42 min
457	160	0.85	0.025	$25602.58	0.35 min
458	160	0.85	0.03	$25558.06	0.34 min
459	160	0.85	0.035	$25885.35	0.41 min
460	160	0.85	0.04	$26471.38	0.35 min
461	160	0.9	0.0005	$27135.73	0.31 min
462	160	0.9	0.001	$26085.04	0.19 min
463	160	0.9	0.005	$25730.67	0.39 min
464	160	0.9	0.01	$26577.5	0.29 min
465	160	0.9	0.015	$25725.42	0.39 min
466	160	0.9	0.02	$735853.2	0.43 min
467	160	0.9	0.025	$25513.55	0.35 min
468	160	0.9	0.03	$25547.93	0.32 min
469	160	0.9	0.035	$25602.58	0.3 min
470	160	0.9	0.04	$25788.28	0.33 min
471	160	0.95	0.0005	$27700.71	0.24 min
472	160	0.95	0.001	$26049.37	0.29 min
473	160	0.95	0.005	$27082.69	0.19 min
474	160	0.95	0.01	$736350.73	0.24 min
475	160	0.95	0.015	$25655.14	0.39 min
476	160	0.95	0.02	$25952.13	0.27 min
477	160	0.95	0.025	$25788.28	0.35 min
478	160	0.95	0.03	$25667.43	0.56 min
479	160	0.95	0.035	$26484.34	0.28 min
480	160	0.95	0.04	$26440.91	0.37 min
481	80	0.6	0.0005	$28337.4	0.06 min
482	80	0.6	0.001	$29805.38	0.07 min
483	80	0.6	0.005	$26136.54	0.21 min
484	80	0.6	0.01	$1446280.32	0.2 min
485	80	0.6	0.015	$737150.04	0.09 min
486	80	0.6	0.02	$26962.97	0.12 min
487	80	0.6	0.025	$26913.32	0.15 min
488	80	0.6	0.03	$736120.34	0.12 min
489	80	0.6	0.035	$25682.23	0.21 min
490	80	0.6	0.04	$27307.92	0.14 min
491	80	0.65	0.0005	$739017.29	0.07 min
492	80	0.65	0.001	$739335.18	0.08 min
493	80	0.65	0.005	$737367.13	0.17 min
494	80	0.65	0.01	$738741.64	0.17 min
495	80	0.65	0.015	$1447101.57	0.16 min
496	80	0.65	0.02	$26489.41	0.09 min
497	80	0.65	0.025	$26587.34	0.16 min
498	80	0.65	0.03	$26098.46	0.18 min
499	80	0.65	0.035	$26044.41	0.21 min
500	80	0.65	0.04	$738633.45	0.18 min

501	80	0.7	0.0005	$741174.34	0.08 min
502	80	0.7	0.001	$28038.31	0.1 min
503	80	0.7	0.005	$736385.17	0.24 min
504	80	0.7	0.01	$26419.0	0.12 min
505	80	0.7	0.015	$28258.28	0.11 min
506	80	0.7	0.02	$26134.23	0.2 min
507	80	0.7	0.025	$736480.36	0.18 min
508	80	0.7	0.03	$26346.12	0.15 min
509	80	0.7	0.035	$26648.87	0.17 min
510	80	0.7	0.04	$26974.39	0.15 min
511	80	0.75	0.0005	$28168.88	0.07 min
512	80	0.75	0.001	$737175.72	0.1 min
513	80	0.75	0.005	$738874.9	0.14 min
514	80	0.75	0.01	$26968.09	0.16 min
515	80	0.75	0.015	$25597.11	0.22 min
516	80	0.75	0.02	$26463.17	0.19 min
517	80	0.75	0.025	$736469.01	0.16 min
518	80	0.75	0.03	$25911.27	0.23 min
519	80	0.75	0.035	$735841.07	0.23 min
520	80	0.75	0.04	$25810.54	0.18 min
521	80	0.8	0.0005	$28615.96	0.12 min
522	80	0.8	0.001	$28567.26	0.15 min
523	80	0.8	0.005	$27460.41	0.14 min
524	80	0.8	0.01	$26789.28	0.22 min
525	80	0.8	0.015	$736676.03	0.29 min
526	80	0.8	0.02	$737584.95	0.16 min
527	80	0.8	0.025	$736822.61	0.32 min
528	80	0.8	0.03	$25836.45	0.15 min
529	80	0.8	0.035	$25592.45	0.21 min
530	80	0.8	0.04	$736531.87	0.19 min
531	80	0.85	0.0005	$739900.02	0.06 min
532	80	0.85	0.001	$29914.7	0.1 min
533	80	0.85	0.005	$26772.47	0.23 min
534	80	0.85	0.01	$26641.61	0.1 min
535	80	0.85	0.015	$25889.01	0.22 min
536	80	0.85	0.02	$26526.4	0.1 min
537	80	0.85	0.025	$26471.38	0.19 min
538	80	0.85	0.03	$736409.28	0.18 min
539	80	0.85	0.035	$27430.81	0.3 min
540	80	0.85	0.04	$736637.68	0.16 min
541	80	0.9	0.0005	$738151.26	0.1 min
542	80	0.9	0.001	$28977.7	0.16 min
543	80	0.9	0.005	$737708.64	0.12 min
544	80	0.9	0.01	$736356.04	0.2 min
545	80	0.9	0.015	$26368.36	0.23 min
546	80	0.9	0.02	$736518.78	0.21 min
547	80	0.9	0.025	$26615.13	0.19 min
548	80	0.9	0.03	$25933.52	0.2 min
549	80	0.9	0.035	$25970.47	0.21 min
550	80	0.9	0.04	$25610.79	0.23 min
551	80	0.95	0.0005	$739069.8	0.11 min
552	80	0.95	0.001	$739505.42	0.1 min
553	80	0.95	0.005	$26676.72	0.26 min
554	80	0.95	0.01	$28402.14	0.11 min
555	80	0.95	0.015	$26217.22	0.17 min
556	80	0.95	0.02	$26040.9	0.2 min
557	80	0.95	0.025	$26240.83	0.16 min
558	80	0.95	0.03	$26729.36	0.22 min

559	80	0.95	0.035	$25982.88	0.18 min
560	80	0.95	0.04	$25893.66	0.2 min
561	40	0.6	0.0005	$1450158.09	0.04 min
562	40	0.6	0.001	$742201.71	0.03 min
563	40	0.6	0.005	$1450537.74	0.03 min
564	40	0.6	0.01	$737695.7	0.08 min
565	40	0.6	0.015	$2159821.75	0.05 min
566	40	0.6	0.02	$26316.11	0.1 min
567	40	0.6	0.025	$738139.5	0.12 min
568	40	0.6	0.03	$27731.36	0.08 min
569	40	0.6	0.035	$26818.06	0.13 min
570	40	0.6	0.04	$25810.54	0.12 min
571	40	0.65	0.0005	$1452515.51	0.05 min
572	40	0.65	0.001	$740115.97	0.05 min
573	40	0.65	0.005	$740617.92	0.05 min
574	40	0.65	0.01	$739552.74	0.05 min
575	40	0.65	0.015	$28367.38	0.09 min
576	40	0.65	0.02	$1447488.72	0.1 min
577	40	0.65	0.025	$735886.21	0.12 min
578	40	0.65	0.03	$736523.08	0.13 min
579	40	0.65	0.035	$736223.0	0.07 min
580	40	0.65	0.04	$736342.52	0.09 min
581	40	0.7	0.0005	$737560.5	0.04 min
582	40	0.7	0.001	$1450413.7	0.06 min
583	40	0.7	0.005	$1451517.79	0.05 min
584	40	0.7	0.01	$28205.6	0.08 min
585	40	0.7	0.015	$738643.28	0.09 min
586	40	0.7	0.02	$736829.85	0.14 min
587	40	0.7	0.025	$1447180.08	0.08 min
588	40	0.7	0.03	$738898.07	0.09 min
589	40	0.7	0.035	$27519.84	0.11 min
590	40	0.7	0.04	$25974.56	0.17 min
591	40	0.75	0.0005	$742012.66	0.05 min
592	40	0.75	0.001	$742476.62	0.05 min
593	40	0.75	0.005	$740965.96	0.1 min
594	40	0.75	0.01	$1447560.7	0.09 min
595	40	0.75	0.015	$739254.36	0.08 min
596	40	0.75	0.02	$736069.77	0.17 min
597	40	0.75	0.025	$740821.39	0.13 min
598	40	0.75	0.03	$736876.66	0.06 min
599	40	0.75	0.035	$736062.48	0.17 min
600	40	0.75	0.04	$739230.27	0.04 min
601	40	0.8	0.0005	$31157.91	0.05 min
602	40	0.8	0.001	$740271.38	0.04 min
603	40	0.8	0.005	$737545.61	0.08 min
604	40	0.8	0.01	$1451040.43	0.04 min
605	40	0.8	0.015	$26647.28	0.08 min
606	40	0.8	0.02	$25911.44	0.15 min
607	40	0.8	0.025	$26727.76	0.11 min
608	40	0.8	0.03	$26749.24	0.21 min
609	40	0.8	0.035	$26477.14	0.09 min
610	40	0.8	0.04	$25912.0	0.16 min
611	40	0.85	0.0005	$29670.16	0.04 min
612	40	0.85	0.001	$29488.3	0.05 min
613	40	0.85	0.005	$739867.51	0.07 min
614	40	0.85	0.01	$740855.74	0.06 min
615	40	0.85	0.015	$27472.19	0.07 min
616	40	0.85	0.02	$736871.83	0.13 min

617	40	0.85	0.025	$1446898.66	0.15 min
618	40	0.85	0.03	$736604.52	0.12 min
619	40	0.85	0.035	$736057.65	0.15 min
620	40	0.85	0.04	$737674.14	0.05 min
621	40	0.9	0.0005	$2870859.43	0.04 min
622	40	0.9	0.001	$740076.82	0.05 min
623	40	0.9	0.005	$28445.69	0.07 min
624	40	0.9	0.01	$26847.06	0.11 min
625	40	0.9	0.015	$1447754.44	0.1 min
626	40	0.9	0.02	$26104.5	0.13 min
627	40	0.9	0.025	$25757.22	0.11 min
628	40	0.9	0.03	$737039.91	0.08 min
629	40	0.9	0.035	$1446183.08	0.12 min
630	40	0.9	0.04	$25961.88	0.13 min
631	40	0.95	0.0005	$1450275.66	0.04 min
632	40	0.95	0.001	$1453386.75	0.06 min
633	40	0.95	0.005	$740279.9	0.11 min
634	40	0.95	0.01	$26567.26	0.09 min
635	40	0.95	0.015	$26370.46	0.12 min
636	40	0.95	0.02	$737706.02	0.12 min
637	40	0.95	0.025	$737505.35	0.1 min
638	40	0.95	0.03	$737760.12	0.08 min
639	40	0.95	0.035	$27230.14	0.12 min
640	40	0.95	0.04	$26396.39	0.15 min
641	20	0.6	0.0005	$2161185.61	0.02 min
642	20	0.6	0.001	$1452063.94	0.03 min
643	20	0.6	0.005	$2159736.3	0.01 min
644	20	0.6	0.01	$1451726.8	0.04 min
645	20	0.6	0.015	$738397.14	0.09 min
646	20	0.6	0.02	$1448244.75	0.08 min
647	20	0.6	0.025	$1447941.76	0.06 min
648	20	0.6	0.03	$739003.02	0.02 min
649	20	0.6	0.035	$1448503.11	0.02 min
650	20	0.6	0.04	$1447742.84	0.08 min
651	20	0.65	0.0005	$2165444.3	0.01 min
652	20	0.65	0.001	$3586996.59	0.01 min
653	20	0.65	0.005	$885467.51	0.02 min
654	20	0.65	0.01	$739283.46	0.04 min
655	20	0.65	0.015	$1449738.88	0.05 min
656	20	0.65	0.02	$28617.63	0.03 min
657	20	0.65	0.025	$1447475.89	0.06 min
658	20	0.65	0.03	$1447990.39	0.07 min
659	20	0.65	0.035	$739755.59	0.04 min
660	20	0.65	0.04	$1449869.84	0.03 min
661	20	0.7	0.0005	$3589877.39	0.02 min
662	20	0.7	0.001	$3585071.25	0.01 min
663	20	0.7	0.005	$2160551.59	0.02 min
664	20	0.7	0.01	$2161651.31	0.05 min
665	20	0.7	0.015	$1449809.93	0.02 min
666	20	0.7	0.02	$1448953.9	0.04 min
667	20	0.7	0.025	$737707.72	0.05 min
668	20	0.7	0.03	$737758.73	0.05 min
669	20	0.7	0.035	$741084.71	0.06 min
670	20	0.7	0.04	$738480.49	0.03 min
671	20	0.75	0.0005	$1452299.51	0.02 min
672	20	0.75	0.001	$2873321.76	0.02 min
673	20	0.75	0.005	$3582529.29	0.05 min
674	20	0.75	0.01	$1452084.19	0.04 min

675	20	0.75	0.015	$27792.96	0.08 min
676	20	0.75	0.02	$1448256.39	0.04 min
677	20	0.75	0.025	$740493.24	0.06 min
678	20	0.75	0.03	$1450277.21	0.06 min
679	20	0.75	0.035	$2869857.5	0.03 min
680	20	0.75	0.04	$741336.33	0.04 min
681	20	0.8	0.0005	$2162767.65	0.02 min
682	20	0.8	0.001	$2878720.02	0.02 min
683	20	0.8	0.005	$1450614.13	0.02 min
684	20	0.8	0.01	$739164.88	0.04 min
685	20	0.8	0.015	$2162332.31	0.05 min
686	20	0.8	0.02	$1450026.36	0.08 min
687	20	0.8	0.025	$1451211.14	0.04 min
688	20	0.8	0.03	$1451293.07	0.05 min
689	20	0.8	0.035	$2162011.22	0.04 min
690	20	0.8	0.04	$741378.94	0.04 min
691	20	0.85	0.0005	$32397.32	0.02 min
692	20	0.85	0.001	$744411.18	0.02 min
693	20	0.85	0.005	$2875213.76	0.02 min
694	20	0.85	0.01	$740118.31	0.04 min
695	20	0.85	0.015	$2160461.44	0.04 min
696	20	0.85	0.02	$2161134.39	0.06 min
697	20	0.85	0.025	$735903.93	0.1 min
698	20	0.85	0.03	$1449296.73	0.03 min
699	20	0.85	0.035	$29259.04	0.04 min
700	20	0.85	0.04	$1450792.39	0.12 min
701	20	0.9	0.0005	$3017157.83	0.02 min
702	20	0.9	0.001	$2163586.88	0.02 min
703	20	0.9	0.005	$1453654.79	0.03 min
704	20	0.9	0.01	$1448595.22	0.05 min
705	20	0.9	0.015	$739394.77	0.05 min
706	20	0.9	0.02	$2159410.18	0.05 min
707	20	0.9	0.025	$1448428.28	0.08 min
708	20	0.9	0.03	$2157800.75	0.07 min
709	20	0.9	0.035	$21609068.25	0.07 min
710	20	0.9	0.04	$1448435.55	0.06 min
711	20	0.95	0.0005	$741772.89	0.02 min
712	20	0.95	0.001	$742209.81	0.03 min
713	20	0.95	0.005	$2167546.2	0.02 min
714	20	0.95	0.01	$2160092.44	0.07 min
715	20	0.95	0.015	$1451605.5	0.07 min
716	20	0.95	0.02	$26856.35	0.09 min
717	20	0.95	0.025	$743194.53	0.04 min
718	20	0.95	0.03	$26230.48	0.11 min
719	20	0.95	0.035	$740677.87	0.05 min
720	20	0.95	0.04	$1447680.28	0.05 min
721	10	0.6	0.0005	$2165424.89	0.01 min
722	10	0.6	0.001	$5869373.43	0.01 min
723	10	0.6	0.005	$3020295.87	0.01 min
724	10	0.6	0.01	$2166654.16	0.02 min
725	10	0.6	0.015	$2303841.47	0.01 min
726	10	0.6	0.02	$2165546.19	0.02 min
727	10	0.6	0.025	$3584341.56	0.01 min

Table B.3: Survey CSV File and User Input for Second Hyperparameter Search Test Case.

ID	Northing (UTM 11)	Easting (UTM 11)	Elevation (m)	Crossing/Asset Type	Ex. Str. Pattern	misc	Ex. Height of Attachments
496287	6114160.556	373388.604	702.158	EXPP_35_5_04_	N12_	496287	HOA=8.3M_-
496288	6114252.287	373391.065	703.981	EXPP_35_5_04_	N12_	496288	HOA=7.9M_-
646820	6114306.08	373392.432	704.701	EXPP_40_5_06_	N42_N390_E12_S99785_	646820	HOA=9.5M_-
2	6114417.878	373394.462	706.098	PP_40_			
3	6114529.45	373397.681	707.709	PP_40_			
7000	6114534.352	373397.832	708.027	APSH_			
7001	6114537.868	373397.934	708.111	APCL_			
7002	6114541.58	373398.041	708.076	APSH_			
4	6114586.931	373399.347	708.981	PP_45_			
4A	6114593.927	373399.541	709.312	ANC_			
7016	6114587.208	373389.142	708.444	RDSHL_			
7017	6114587.384	373384.929	708.525	RDCL_			
7018	6114587.574	373376.472	708.381	RDSHL_			
7105	6114589.469	373369.851	707.471	PED_			
5	6114588.049	373360.396	707.639	PP_50_			
6	6114578.009	373349.756	707.786	PP_55_			
6A	6114577.855	373355.244	707.773	ANC_			
6B	6114577.814	373356.745	707.809	ANC_			
7003	6114578.594	373329.129	707.613	APSH_			
7004	6114578.745	373324.335	707.555	APCL_			
7005	6114578.884	373319.609	707.439	APSH_			
7	6114579.799	373287.81	706.984	PP_50_			
7006	6114579.945	373282.805	706.79	APSH_			
7007	6114580.127	373276.15	706.53	APCL_			
7008	6114580.298	373269.855	706.116	APSH_			
7009	6114582.005	373211.316	705.025	APSH_			
7010	6114582.145	373206.006	705.055	APCL_			
7011	6114582.301	373200.1	704.863	APSH_			
8	6114582.614	373189.879	704.159	PP_55_			
8A	6114582.774	373182.879	703.94	ANC_			
8B	6114589.614	373189.879	703.861	ANC_			
7019	6114573.442	373191.177	704.684	RDSHL_			
7020	6114567.939	373191.989	704.794	RDCL_			
7021	6114563.231	373192.651	704.695	RDSHL_			
9	6114553.681	373194.026	703.939	PP_55_			
10	6114543.05	373204.064	704.208	PP_55_			
10A	6114548.545	373204.234	704.337	ANC_			
10B	6114550.041	373204.264	704.325	ANC_			
11	6114443.023	373201.176	701.276	PP_55_			
11A	6114443.023	373196.024	701.168	ANC_			
11B	6114436.027	373200.97	701.15	ANC_			
7022	6114442.757	373211.218	703.154	RDSHL_			
7023	6114442.611	373215.413	703.245	RDCL_			
7024	6114442.431	373221.356	703.153	RDSHL_			
7108	6114442.695	373228.97	702.106	PED_			
12	6114442.181	373229.952	702.09	PP_55_			
12A	6114442.181	373236.114	702.11	ANC_			
12B	6114449.188	373230.162	702.169	ANC_			
13	6114422.692	373229.4	701.828	PP_50_			
13A	6114417.204	373229.229	701.757	ANC_			

13B	6114415.71	373229.189	701.731	ANC_			
4	6114586.931	373399.347	708.981	PP_45_			
496292	6114637.841	373402.096	709.692	EXPP_40_-4_04_	R212_	496292	HOA=7.8M_-
496293	6114726.451	373404.499	705.988	EXPP_35_-5_04_	R212_	496293	HOA=8.0M_-
496294	6114828.317	373407.438	702.25	EXPP_35_-5_04_	R212_	496294	HOA=8.1M_-
User Input:							
Loading:	Medium						
Spacing:	Urban						
# Ph. Ex. Main	3						
# Ph. New Main	3						
# Ph. Ex. Tap	1						
# Ph. New Tap	1						
Grounding	Multi-Ground Neut.						
Min Clearance	Pedestrian						
Ex. Cond. Type	#4 ACSR						
Ex. Tap-Off Cond. Type	#4 ACSR						
New Cond. Type	1/0 ACSR						
New Tap-Off Cond. Type	1/0 ACSR						
Equip. 1							
Equip. 2							
Equip. 3							
Service Pt.	9						
Prelim Stk List Mod.	Terminate Neut at Pole 6						

Table B.4: Hyperparameter Search Results for Test Case 2.

No.	Population Size	Crossover Rate	Mutation Rate	Min. Cost	Computation Time
1	5120	0.6	0.0005	$33243.99	9.65 min
2	5120	0.6	0.001	$33288.51	10.32 min
3	5120	0.6	0.005	$33243.99	10.02 min
4	5120	0.6	0.01	$33243.99	10.41 min
5	5120	0.6	0.015	$33243.99	10.42 min
6	5120	0.6	0.02	$33243.99	9.28 min
7	5120	0.6	0.025	$33243.99	10.6 min
8	5120	0.6	0.03	$33243.99	10.25 min
9	5120	0.6	0.035	$33243.99	12.19 min
10	5120	0.6	0.04	$33243.99	11.21 min
11	5120	0.65	0.0005	$33243.99	9.19 min
12	5120	0.65	0.001	$33565.02	9.89 min
13	5120	0.65	0.005	$33243.99	10.05 min
14	5120	0.65	0.01	$33243.99	10.84 min
15	5120	0.65	0.015	$33243.99	9.61 min
16	5120	0.65	0.02	$33243.99	10.39 min
17	5120	0.65	0.025	$33243.99	10.82 min

18	5120	0.65	0.03	$33243.99	10.82 min
19	5120	0.65	0.035	$33243.99	10.98 min
20	5120	0.65	0.04	$33243.99	10.84 min
21	5120	0.7	0.0005	$33266.25	10.39 min
22	5120	0.7	0.001	$33243.99	11.96 min
23	5120	0.7	0.005	$33243.99	10.58 min
24	5120	0.7	0.01	$33243.99	12.05 min
25	5120	0.7	0.015	$33243.99	12.73 min
26	5120	0.7	0.02	$33243.99	11.27 min
27	5120	0.7	0.025	$33243.99	10.41 min
28	5120	0.7	0.03	$33243.99	12.0 min
29	5120	0.7	0.035	$33243.99	11.9 min
30	5120	0.7	0.04	$33243.99	12.07 min
31	5120	0.75	0.0005	$33243.99	14.17 min
32	5120	0.75	0.001	$33243.99	11.85 min
33	5120	0.75	0.005	$33243.99	11.98 min
34	5120	0.75	0.01	$33243.99	14.11 min
35	5120	0.75	0.015	$33243.99	12.27 min
36	5120	0.75	0.02	$33243.99	11.41 min
37	5120	0.75	0.025	$33243.99	12.38 min
38	5120	0.75	0.03	$33243.99	14.27 min
39	5120	0.75	0.035	$33243.99	12.66 min
40	5120	0.75	0.04	$33243.99	10.72 min
41	5120	0.8	0.0005	$33243.99	10.41 min
42	5120	0.8	0.001	$33243.99	12.18 min
43	5120	0.8	0.005	$33243.99	11.28 min
44	5120	0.8	0.01	$33243.99	11.72 min
45	5120	0.8	0.015	$33243.99	10.56 min
46	5120	0.8	0.02	$33243.99	12.86 min
47	5120	0.8	0.025	$33243.99	10.7 min
48	5120	0.8	0.03	$33243.99	11.67 min
49	5120	0.8	0.035	$33243.99	13.28 min
50	5120	0.8	0.04	$33243.99	12.3 min
51	5120	0.85	0.0005	$33243.99	11.08 min
52	5120	0.85	0.001	$33243.99	11.37 min
53	5120	0.85	0.005	$33243.99	13.34 min
54	5120	0.85	0.01	$33243.99	11.36 min
55	5120	0.85	0.015	$33243.99	11.63 min
56	5120	0.85	0.02	$33243.99	11.92 min
57	5120	0.85	0.025	$33243.99	12.19 min
58	5120	0.85	0.03	$33243.99	11.56 min
59	5120	0.85	0.035	$33243.99	12.64 min
60	5120	0.85	0.04	$33243.99	12.24 min
61	5120	0.9	0.0005	$33243.99	12.53 min
62	5120	0.9	0.001	$33243.99	13.62 min
63	5120	0.9	0.005	$33243.99	12.81 min
64	5120	0.9	0.01	$33243.99	13.01 min
65	5120	0.9	0.015	$33243.99	12.09 min
66	5120	0.9	0.02	$33243.99	12.89 min
67	5120	0.9	0.025	$33243.99	13.9 min
68	5120	0.9	0.03	$33243.99	13.46 min
69	5120	0.9	0.035	$33243.99	13.54 min
70	5120	0.9	0.04	$33243.99	13.88 min
71	5120	0.95	0.0005	$33243.99	12.36 min
72	5120	0.95	0.001	$33243.99	12.89 min
73	5120	0.95	0.005	$33243.99	12.68 min
74	5120	0.95	0.01	$33243.99	13.47 min
75	5120	0.95	0.015	$33243.99	13.02 min

76	5120	0.95	0.02	$33243.99	12.85 min
77	5120	0.95	0.025	$33243.99	12.62 min
78	5120	0.95	0.03	$33243.99	14.97 min
79	5120	0.95	0.035	$33243.99	13.88 min
80	5120	0.95	0.04	$33243.99	12.53 min
81	2560	0.6	0.0005	$33360.71	5.24 min
82	2560	0.6	0.001	$33565.02	5.02 min
83	2560	0.6	0.005	$33243.99	5.56 min
84	2560	0.6	0.01	$33243.99	5.0 min
85	2560	0.6	0.015	$33243.99	5.31 min
86	2560	0.6	0.02	$33243.99	5.62 min
87	2560	0.6	0.025	$33243.99	5.11 min
88	2560	0.6	0.03	$33243.99	5.63 min
89	2560	0.6	0.035	$33243.99	5.23 min
90	2560	0.6	0.04	$33243.99	6.4 min
91	2560	0.65	0.0005	$33266.25	5.17 min
92	2560	0.65	0.001	$33325.76	4.97 min
93	2560	0.65	0.005	$33243.99	5.46 min
94	2560	0.65	0.01	$33243.99	5.19 min
95	2560	0.65	0.015	$33243.99	5.68 min
96	2560	0.65	0.02	$33243.99	5.58 min
97	2560	0.65	0.025	$33243.99	5.3 min
98	2560	0.65	0.03	$33243.99	6.08 min
99	2560	0.65	0.035	$33243.99	5.81 min
100	2560	0.65	0.04	$33243.99	5.94 min
101	2560	0.7	0.0005	$33325.76	5.3 min
102	2560	0.7	0.001	$33243.99	6.19 min
103	2560	0.7	0.005	$33243.99	5.62 min
104	2560	0.7	0.01	$33243.99	7.28 min
105	2560	0.7	0.015	$33243.99	6.09 min
106	2560	0.7	0.02	$33243.99	6.93 min
107	2560	0.7	0.025	$33325.76	6.67 min
108	2560	0.7	0.03	$33243.99	5.38 min
109	2560	0.7	0.035	$33243.99	5.6 min
110	2560	0.7	0.04	$33243.99	6.18 min
111	2560	0.75	0.0005	$33571.68	5.39 min
112	2560	0.75	0.001	$33243.99	6.78 min
113	2560	0.75	0.005	$33243.99	6.48 min
114	2560	0.75	0.01	$33243.99	6.27 min
115	2560	0.75	0.015	$33243.99	5.91 min
116	2560	0.75	0.02	$33243.99	5.95 min
117	2560	0.75	0.025	$33243.99	6.08 min
118	2560	0.75	0.03	$33243.99	6.36 min
119	2560	0.75	0.035	$33243.99	6.45 min
120	2560	0.75	0.04	$33243.99	6.18 min
121	2560	0.8	0.0005	$33243.99	5.77 min
122	2560	0.8	0.001	$33243.99	8.27 min
123	2560	0.8	0.005	$33243.99	6.98 min
124	2560	0.8	0.01	$33243.99	6.97 min
125	2560	0.8	0.015	$33243.99	5.95 min
126	2560	0.8	0.02	$33243.99	6.21 min
127	2560	0.8	0.025	$33278.94	6.17 min
128	2560	0.8	0.03	$33243.99	6.32 min
129	2560	0.8	0.035	$33243.99	6.34 min
130	2560	0.8	0.04	$33243.99	6.83 min
131	2560	0.85	0.0005	$33243.99	5.99 min
132	2560	0.85	0.001	$33243.99	6.33 min
133	2560	0.85	0.005	$33243.99	6.82 min

134	2560	0.85	0.01	$33243.99	7.45 min
135	2560	0.85	0.015	$33243.99	6.74 min
136	2560	0.85	0.02	$33243.99	6.13 min
137	2560	0.85	0.025	$33243.99	7.59 min
138	2560	0.85	0.03	$33243.99	6.19 min
139	2560	0.85	0.035	$33243.99	6.86 min
140	2560	0.85	0.04	$33243.99	6.51 min
141	2560	0.9	0.0005	$33243.99	6.61 min
142	2560	0.9	0.001	$33243.99	7.78 min
143	2560	0.9	0.005	$33243.99	6.73 min
144	2560	0.9	0.01	$33243.99	7.12 min
145	2560	0.9	0.015	$33243.99	8.3 min
146	2560	0.9	0.02	$33243.99	6.87 min
147	2560	0.9	0.025	$33243.99	6.78 min
148	2560	0.9	0.03	$33243.99	6.81 min
149	2560	0.9	0.035	$33243.99	7.71 min
150	2560	0.9	0.04	$33243.99	6.25 min
151	2560	0.95	0.0005	$33278.94	6.52 min
152	2560	0.95	0.001	$33243.99	6.62 min
153	2560	0.95	0.005	$33243.99	5.89 min
154	2560	0.95	0.01	$33243.99	6.82 min
155	2560	0.95	0.015	$33243.99	7.18 min
156	2560	0.95	0.02	$33243.99	7.29 min
157	2560	0.95	0.025	$33243.99	7.19 min
158	2560	0.95	0.03	$33243.99	7.5 min
159	2560	0.95	0.035	$33243.99	7.86 min
160	2560	0.95	0.04	$33243.99	7.07 min
161	1280	0.6	0.0005	$33838.45	2.66 min
162	1280	0.6	0.001	$33323.46	3.36 min
163	1280	0.6	0.005	$33565.02	3.2 min
164	1280	0.6	0.01	$33243.99	3.39 min
165	1280	0.6	0.015	$33243.99	3.42 min
166	1280	0.6	0.02	$33278.94	3.18 min
167	1280	0.6	0.025	$33562.12	3.03 min
168	1280	0.6	0.03	$33243.99	3.81 min
169	1280	0.6	0.035	$33243.99	3.67 min
170	1280	0.6	0.04	$33325.76	3.57 min
171	1280	0.65	0.0005	$33412.68	2.97 min
172	1280	0.65	0.001	$33450.64	3.68 min
173	1280	0.65	0.005	$33527.16	3.75 min
174	1280	0.65	0.01	$33266.25	3.41 min
175	1280	0.65	0.015	$33243.99	3.69 min
176	1280	0.65	0.02	$33243.99	3.8 min
177	1280	0.65	0.025	$33243.99	3.61 min
178	1280	0.65	0.03	$33278.94	3.37 min
179	1280	0.65	0.035	$33243.99	3.49 min
180	1280	0.65	0.04	$33278.94	2.68 min
181	1280	0.7	0.0005	$33764.18	2.63 min
182	1280	0.7	0.001	$33243.99	3.22 min
183	1280	0.7	0.005	$33243.99	3.6 min
184	1280	0.7	0.01	$33243.99	3.17 min
185	1280	0.7	0.015	$33527.16	4.07 min
186	1280	0.7	0.02	$33243.99	3.89 min
187	1280	0.7	0.025	$33278.94	3.66 min
188	1280	0.7	0.03	$33243.99	3.21 min
189	1280	0.7	0.035	$33527.16	3.5 min
190	1280	0.7	0.04	$33278.94	2.74 min
191	1280	0.75	0.0005	$33351.37	2.79 min

192	1280	0.75	0.001	$33243.99	3.49 min
193	1280	0.75	0.005	$33243.99	3.13 min
194	1280	0.75	0.01	$33243.99	3.7 min
195	1280	0.75	0.015	$33243.99	3.32 min
196	1280	0.75	0.02	$33243.99	3.48 min
197	1280	0.75	0.025	$33243.99	4.37 min
198	1280	0.75	0.03	$33243.99	4.36 min
199	1280	0.75	0.035	$33243.99	4.1 min
200	1280	0.75	0.04	$33243.99	3.52 min
201	1280	0.8	0.0005	$33445.09	2.72 min
202	1280	0.8	0.001	$33278.94	3.14 min
203	1280	0.8	0.005	$33243.99	3.27 min
204	1280	0.8	0.01	$33243.99	3.69 min
205	1280	0.8	0.015	$33243.99	3.74 min
206	1280	0.8	0.02	$33243.99	3.46 min
207	1280	0.8	0.025	$33243.99	3.94 min
208	1280	0.8	0.03	$33243.99	3.39 min
209	1280	0.8	0.035	$33243.99	3.48 min
210	1280	0.8	0.04	$33243.99	3.41 min
211	1280	0.85	0.0005	$33266.25	3.44 min
212	1280	0.85	0.001	$33341.8	3.55 min
213	1280	0.85	0.005	$33243.99	3.94 min
214	1280	0.85	0.01	$33243.99	3.62 min
215	1280	0.85	0.015	$33608.93	3.58 min
216	1280	0.85	0.02	$33243.99	4.11 min
217	1280	0.85	0.025	$33243.99	4.5 min
218	1280	0.85	0.03	$33278.94	3.51 min
219	1280	0.85	0.035	$33243.99	3.88 min
220	1280	0.85	0.04	$33243.99	3.6 min
221	1280	0.9	0.0005	$33763.83	3.36 min
222	1280	0.9	0.001	$33323.46	3.46 min
223	1280	0.9	0.005	$33278.94	3.66 min
224	1280	0.9	0.01	$33243.99	3.59 min
225	1280	0.9	0.015	$33243.99	4.05 min
226	1280	0.9	0.02	$33243.99	4.92 min
227	1280	0.9	0.025	$33243.99	3.61 min
228	1280	0.9	0.03	$33243.99	4.14 min
229	1280	0.9	0.035	$33243.99	4.42 min
230	1280	0.9	0.04	$33243.99	3.69 min
231	1280	0.95	0.0005	$33325.76	4.14 min
232	1280	0.95	0.001	$33243.99	3.32 min
233	1280	0.95	0.005	$33243.99	3.55 min
234	1280	0.95	0.01	$33278.94	3.47 min
235	1280	0.95	0.015	$33243.99	4.32 min
236	1280	0.95	0.02	$33243.99	4.0 min
237	1280	0.95	0.025	$33243.99	4.47 min
238	1280	0.95	0.03	$33243.99	4.18 min
239	1280	0.95	0.035	$33243.99	3.34 min
240	1280	0.95	0.04	$33243.99	4.92 min
241	640	0.6	0.0005	$35197.99	1.58 min
242	640	0.6	0.001	$33707.36	2.3 min
243	640	0.6	0.005	$34125.7	1.6 min
244	640	0.6	0.01	$33816.44	1.54 min
245	640	0.6	0.015	$33816.44	1.54 min
246	640	0.6	0.02	$33243.99	2.26 min
247	640	0.6	0.025	$33266.25	1.77 min
248	640	0.6	0.03	$33278.94	2.06 min
249	640	0.6	0.035	$33243.99	1.83 min

250	640	0.6	0.04	$33243.99	2.26 min
251	640	0.65	0.0005	$33650.14	1.93 min
252	640	0.65	0.001	$34612.1	1.54 min
253	640	0.65	0.005	$33278.94	2.33 min
254	640	0.65	0.01	$33565.02	1.88 min
255	640	0.65	0.015	$33243.99	1.81 min
256	640	0.65	0.02	$33243.99	1.89 min
257	640	0.65	0.025	$33243.99	2.02 min
258	640	0.65	0.03	$33243.99	2.09 min
259	640	0.65	0.035	$33325.76	2.14 min
260	640	0.65	0.04	$33243.99	1.76 min
261	640	0.7	0.0005	$34294.41	1.36 min
262	640	0.7	0.001	$34437.24	1.39 min
263	640	0.7	0.005	$33562.12	1.71 min
264	640	0.7	0.01	$33243.99	1.66 min
265	640	0.7	0.015	$33341.06	2.21 min
266	640	0.7	0.02	$33243.99	2.11 min
267	640	0.7	0.025	$33243.99	2.2 min
268	640	0.7	0.03	$33278.94	1.49 min
269	640	0.7	0.035	$33266.25	2.42 min
270	640	0.7	0.04	$33243.99	1.86 min
271	640	0.75	0.0005	$746118.65	1.35 min
272	640	0.75	0.001	$34278.74	2.03 min
273	640	0.75	0.005	$33341.06	2.2 min
274	640	0.75	0.01	$33325.76	2.14 min
275	640	0.75	0.015	$33243.99	2.31 min
276	640	0.75	0.02	$33599.98	1.99 min
277	640	0.75	0.025	$33243.99	2.67 min
278	640	0.75	0.03	$33278.94	2.5 min
279	640	0.75	0.035	$33323.46	1.93 min
280	640	0.75	0.04	$33278.94	2.01 min
281	640	0.8	0.0005	$33445.83	1.67 min
282	640	0.8	0.001	$33593.94	2.79 min
283	640	0.8	0.005	$33243.99	1.63 min
284	640	0.8	0.01	$33278.94	1.72 min
285	640	0.8	0.015	$33565.02	2.09 min
286	640	0.8	0.02	$33278.94	2.24 min
287	640	0.8	0.025	$33243.99	1.82 min
288	640	0.8	0.03	$33527.16	2.14 min
289	640	0.8	0.035	$33816.44	2.26 min
290	640	0.8	0.04	$33243.99	2.15 min
291	640	0.85	0.0005	$34009.41	1.61 min
292	640	0.85	0.001	$33739.18	1.56 min
293	640	0.85	0.005	$33243.99	2.0 min
294	640	0.85	0.01	$33565.02	2.28 min
295	640	0.85	0.015	$33527.16	1.8 min
296	640	0.85	0.02	$33565.02	2.49 min
297	640	0.85	0.025	$33243.99	2.86 min
298	640	0.85	0.03	$33325.76	2.35 min
299	640	0.85	0.035	$33278.94	3.08 min
300	640	0.85	0.04	$33243.99	2.58 min
301	640	0.9	0.0005	$33449.75	1.92 min
302	640	0.9	0.001	$33266.25	2.26 min
303	640	0.9	0.005	$33243.99	2.07 min
304	640	0.9	0.01	$33243.99	2.05 min
305	640	0.9	0.015	$33243.99	2.26 min
306	640	0.9	0.02	$33243.99	1.88 min
307	640	0.9	0.025	$33278.94	1.93 min

308	640	0.9	0.03	$33278.94	2.07 min
309	640	0.9	0.035	$33325.76	2.24 min
310	640	0.9	0.04	$33243.99	2.32 min
311	640	0.95	0.0005	$34294.12	1.69 min
312	640	0.95	0.001	$33798.0	1.88 min
313	640	0.95	0.005	$33243.99	1.86 min
314	640	0.95	0.01	$33325.76	2.02 min
315	640	0.95	0.015	$33243.99	2.04 min
316	640	0.95	0.02	$33243.99	1.71 min
317	640	0.95	0.025	$33243.99	2.38 min
318	640	0.95	0.03	$33243.99	2.91 min
319	640	0.95	0.035	$33278.94	2.07 min
320	640	0.95	0.04	$33243.99	2.33 min
321	320	0.6	0.0005	$36940.66	0.56 min
322	320	0.6	0.001	$747995.05	0.67 min
323	320	0.6	0.005	$34700.7	1.21 min
324	320	0.6	0.01	$34251.57	1.19 min
325	320	0.6	0.015	$33860.96	1.18 min
326	320	0.6	0.02	$1453059.9	0.85 min
327	320	0.6	0.025	$33243.99	1.34 min
328	320	0.6	0.03	$33816.44	1.0 min
329	320	0.6	0.035	$33819.82	1.14 min
330	320	0.6	0.04	$33527.16	1.54 min
331	320	0.65	0.0005	$748524.11	0.59 min
332	320	0.65	0.001	$35357.36	1.2 min
333	320	0.65	0.005	$33370.27	1.14 min
334	320	0.65	0.01	$33457.78	1.02 min
335	320	0.65	0.015	$33624.24	1.3 min
336	320	0.65	0.02	$33681.74	1.17 min
337	320	0.65	0.025	$33333.03	1.1 min
338	320	0.65	0.03	$33243.99	1.33 min
339	320	0.65	0.035	$33278.94	1.2 min
340	320	0.65	0.04	$33301.2	1.42 min
341	320	0.7	0.0005	$34660.95	0.7 min
342	320	0.7	0.001	$36018.25	0.73 min
343	320	0.7	0.005	$34335.5	1.27 min
344	320	0.7	0.01	$33527.16	1.16 min
345	320	0.7	0.015	$33527.16	1.63 min
346	320	0.7	0.02	$33898.21	1.24 min
347	320	0.7	0.025	$33243.99	1.52 min
348	320	0.7	0.03	$34056.62	0.9 min
349	320	0.7	0.035	$33781.49	1.19 min
350	320	0.7	0.04	$33278.94	1.43 min
351	320	0.75	0.0005	$39204.64	0.6 min
352	320	0.75	0.001	$33913.81	1.1 min
353	320	0.75	0.005	$33904.94	1.22 min
354	320	0.75	0.01	$33885.52	1.12 min
355	320	0.75	0.015	$33310.77	0.78 min
356	320	0.75	0.02	$33360.71	1.39 min
357	320	0.75	0.025	$33278.94	1.16 min
358	320	0.75	0.03	$33781.49	1.29 min
359	320	0.75	0.035	$33243.99	1.32 min
360	320	0.75	0.04	$33832.96	0.97 min
361	320	0.8	0.0005	$35496.02	0.8 min
362	320	0.8	0.001	$34997.32	0.69 min
363	320	0.8	0.005	$743276.55	1.27 min
364	320	0.8	0.01	$34357.76	1.15 min
365	320	0.8	0.015	$33325.76	1.69 min

366	320	0.8	0.02	$33842.52	1.16 min
367	320	0.8	0.025	$1452928.07	0.87 min
368	320	0.8	0.03	$33278.94	1.07 min
369	320	0.8	0.035	$33243.99	1.05 min
370	320	0.8	0.04	$33438.13	1.43 min
371	320	0.85	0.0005	$35377.41	0.74 min
372	320	0.85	0.001	$36718.25	0.98 min
373	320	0.85	0.005	$34478.62	1.16 min
374	320	0.85	0.01	$33797.56	1.63 min
375	320	0.85	0.015	$33243.99	1.33 min
376	320	0.85	0.02	$33325.76	1.6 min
377	320	0.85	0.025	$33341.06	1.25 min
378	320	0.85	0.03	$33243.99	1.32 min
379	320	0.85	0.035	$34704.4	1.21 min
380	320	0.85	0.04	$743358.32	1.11 min
381	320	0.9	0.0005	$34057.28	1.08 min
382	320	0.9	0.001	$34213.47	1.03 min
383	320	0.9	0.005	$34864.96	1.35 min
384	320	0.9	0.01	$33243.99	1.64 min
385	320	0.9	0.015	$33562.12	1.65 min
386	320	0.9	0.02	$33243.99	1.33 min
387	320	0.9	0.025	$33243.99	1.48 min
388	320	0.9	0.03	$33527.16	1.45 min
389	320	0.9	0.035	$1452808.55	1.12 min
390	320	0.9	0.04	$33341.06	1.25 min
391	320	0.95	0.0005	$35493.47	0.84 min
392	320	0.95	0.001	$34405.25	0.96 min
393	320	0.95	0.005	$33608.93	1.25 min
394	320	0.95	0.01	$33266.25	1.38 min
395	320	0.95	0.015	$33599.98	1.64 min
396	320	0.95	0.02	$33243.99	1.26 min
397	320	0.95	0.025	$33562.12	1.54 min
398	320	0.95	0.03	$33360.71	1.19 min
399	320	0.95	0.035	$33795.71	1.11 min
400	320	0.95	0.04	$33562.12	1.25 min
401	160	0.6	0.0005	$893812.12	0.31 min
402	160	0.6	0.001	$1459452.56	0.59 min
403	160	0.6	0.005	$1454694.27	0.39 min
404	160	0.6	0.01	$745178.71	0.43 min
405	160	0.6	0.015	$33266.25	0.74 min
406	160	0.6	0.02	$33778.81	0.74 min
407	160	0.6	0.025	$33662.1	0.65 min
408	160	0.6	0.03	$2163841.94	0.57 min
409	160	0.6	0.035	$745915.65	0.5 min
410	160	0.6	0.04	$34437.24	0.62 min
411	160	0.65	0.0005	$751138.38	0.24 min
412	160	0.65	0.001	$36459.23	0.31 min
413	160	0.65	0.005	$1456959.63	0.88 min
414	160	0.65	0.01	$35074.59	0.69 min
415	160	0.65	0.015	$744453.63	0.78 min
416	160	0.65	0.02	$33323.46	0.72 min
417	160	0.65	0.025	$33781.49	0.72 min
418	160	0.65	0.03	$1453532.36	0.47 min
419	160	0.65	0.035	$34043.94	0.65 min
420	160	0.65	0.04	$34357.76	0.75 min
421	160	0.7	0.0005	$2165564.92	0.34 min
422	160	0.7	0.001	$37834.8	0.36 min
423	160	0.7	0.005	$745283.33	0.43 min

424	160	0.7	0.01	$1452741.77	0.86 min
425	160	0.7	0.015	$33407.84	0.57 min
426	160	0.7	0.02	$743895.82	0.72 min
427	160	0.7	0.025	$1452786.29	0.51 min
428	160	0.7	0.03	$1453097.76	0.6 min
429	160	0.7	0.035	$34800.58	0.78 min
430	160	0.7	0.04	$744584.37	0.48 min
431	160	0.75	0.0005	$36543.51	0.32 min
432	160	0.75	0.001	$747113.91	0.45 min
433	160	0.75	0.005	$34580.49	0.67 min
434	160	0.75	0.01	$34305.89	0.74 min
435	160	0.75	0.015	$1453085.06	0.68 min
436	160	0.75	0.02	$33829.43	0.54 min
437	160	0.75	0.025	$33726.26	0.91 min
438	160	0.75	0.03	$743830.13	0.94 min
439	160	0.75	0.035	$1453271.23	0.55 min
440	160	0.75	0.04	$33986.68	0.64 min
441	160	0.8	0.0005	$1456674.47	0.35 min
442	160	0.8	0.001	$34548.5	0.51 min
443	160	0.8	0.005	$34905.32	0.65 min
444	160	0.8	0.01	$743786.44	0.62 min
445	160	0.8	0.015	$33983.04	0.6 min
446	160	0.8	0.02	$33949.9	0.84 min
447	160	0.8	0.025	$33781.49	0.82 min
448	160	0.8	0.03	$33879.3	0.9 min
449	160	0.8	0.035	$33654.06	1.0 min
450	160	0.8	0.04	$33669.05	0.66 min
451	160	0.85	0.0005	$2165578.28	0.28 min
452	160	0.85	0.001	$747786.65	0.57 min
453	160	0.85	0.005	$33901.17	0.63 min
454	160	0.85	0.01	$743956.86	0.61 min
455	160	0.85	0.015	$1453893.87	0.69 min
456	160	0.85	0.02	$33763.83	0.79 min
457	160	0.85	0.025	$1453849.35	0.6 min
458	160	0.85	0.03	$33781.49	0.82 min
459	160	0.85	0.035	$33243.99	0.73 min
460	160	0.85	0.04	$33646.79	0.72 min
461	160	0.9	0.0005	$1453350.45	0.4 min
462	160	0.9	0.001	$749205.77	0.36 min
463	160	0.9	0.005	$1453386.59	0.77 min
464	160	0.9	0.01	$33243.99	0.79 min
465	160	0.9	0.015	$33653.45	0.74 min
466	160	0.9	0.02	$744738.36	0.67 min
467	160	0.9	0.025	$34292.51	0.59 min
468	160	0.9	0.03	$33863.26	0.8 min
469	160	0.9	0.035	$33668.76	0.8 min
470	160	0.9	0.04	$33301.2	0.84 min
471	160	0.95	0.0005	$36151.41	0.45 min
472	160	0.95	0.001	$747434.68	0.58 min
473	160	0.95	0.005	$34631.18	0.96 min
474	160	0.95	0.01	$33565.02	0.83 min
475	160	0.95	0.015	$744585.27	0.82 min
476	160	0.95	0.02	$33975.64	0.98 min
477	160	0.95	0.025	$33738.5	0.68 min
478	160	0.95	0.03	$33926.05	0.97 min
479	160	0.95	0.035	$1453295.34	0.96 min
480	160	0.95	0.04	$34664.0	0.64 min
481	80	0.6	0.0005	$1463383.27	0.1 min

482	80	0.6	0.001	$749176.57	0.14 min
483	80	0.6	0.005	$746907.44	0.36 min
484	80	0.6	0.01	$35447.63	0.43 min
485	80	0.6	0.015	$1454220.01	0.33 min
486	80	0.6	0.02	$2164940.45	0.26 min
487	80	0.6	0.025	$33966.23	0.43 min
488	80	0.6	0.03	$34046.72	0.46 min
489	80	0.6	0.035	$34015.15	0.46 min
490	80	0.6	0.04	$33820.26	0.46 min
491	80	0.65	0.0005	$2173932.83	0.12 min
492	80	0.65	0.001	$1458946.17	0.21 min
493	80	0.65	0.005	$41806.83	0.26 min
494	80	0.65	0.01	$34579.46	0.33 min
495	80	0.65	0.015	$35754.36	0.32 min
496	80	0.65	0.02	$2163139.89	0.53 min
497	80	0.65	0.025	$2876107.69	0.41 min
498	80	0.65	0.03	$36348.51	0.41 min
499	80	0.65	0.035	$743298.81	0.46 min
500	80	0.65	0.04	$1453352.55	0.34 min
501	80	0.7	0.0005	$750806.6	0.24 min
502	80	0.7	0.001	$1458279.08	0.17 min
503	80	0.7	0.005	$35788.82	0.4 min
504	80	0.7	0.01	$34429.34	0.38 min
505	80	0.7	0.015	$1452991.48	0.3 min
506	80	0.7	0.02	$1453295.34	0.41 min
507	80	0.7	0.025	$1453428.11	0.4 min
508	80	0.7	0.03	$35538.04	0.28 min
509	80	0.7	0.035	$34586.86	0.41 min
510	80	0.7	0.04	$1453692.09	0.33 min
511	80	0.75	0.0005	$2168075.32	0.13 min
512	80	0.75	0.001	$1459431.04	0.13 min
513	80	0.75	0.005	$35568.48	0.24 min
514	80	0.75	0.01	$1453172.83	0.45 min
515	80	0.75	0.015	$744173.86	0.56 min
516	80	0.75	0.02	$34074.37	0.42 min
517	80	0.75	0.025	$2164113.43	0.41 min
518	80	0.75	0.03	$1453803.38	0.33 min
519	80	0.75	0.035	$34442.88	0.41 min
520	80	0.75	0.04	$744004.42	0.49 min
521	80	0.8	0.0005	$41730.26	0.17 min
522	80	0.8	0.001	$1463896.98	0.25 min
523	80	0.8	0.005	$747251.66	0.43 min
524	80	0.8	0.01	$35269.35	0.44 min
525	80	0.8	0.015	$744005.61	0.39 min
526	80	0.8	0.02	$1453609.56	0.34 min
527	80	0.8	0.025	$33348.01	0.44 min
528	80	0.8	0.03	$34470.08	0.37 min
529	80	0.8	0.035	$34284.31	0.37 min
530	80	0.8	0.04	$744025.55	0.39 min
531	80	0.85	0.0005	$2169264.59	0.15 min
532	80	0.85	0.001	$2878848.46	0.13 min
533	80	0.85	0.005	$2165127.42	0.4 min
534	80	0.85	0.01	$1453769.36	0.47 min
535	80	0.85	0.015	$2162774.33	0.39 min
536	80	0.85	0.02	$36259.36	0.26 min
537	80	0.85	0.025	$744681.22	0.38 min
538	80	0.85	0.03	$34393.8	0.47 min
539	80	0.85	0.035	$743880.77	0.39 min

540	80	0.85	0.04	$1453414.67	0.57 min
541	80	0.9	0.0005	$752090.65	0.14 min
542	80	0.9	0.001	$1458066.93	0.13 min
543	80	0.9	0.005	$1454797.54	0.47 min
544	80	0.9	0.01	$33870.52	0.35 min
545	80	0.9	0.015	$36010.01	0.18 min
546	80	0.9	0.02	$35241.15	0.51 min
547	80	0.9	0.025	$2163762.56	0.41 min
548	80	0.9	0.03	$2163547.91	0.45 min
549	80	0.9	0.035	$34344.54	0.36 min
550	80	0.9	0.04	$1453314.23	0.5 min
551	80	0.95	0.0005	$1604743.47	0.16 min
552	80	0.95	0.001	$2170276.53	0.23 min
553	80	0.95	0.005	$38048.47	0.27 min
554	80	0.95	0.01	$33872.92	0.62 min
555	80	0.95	0.015	$2163987.2	0.33 min
556	80	0.95	0.02	$33426.18	0.58 min
557	80	0.95	0.025	$35063.13	0.4 min
558	80	0.95	0.03	$34102.66	0.46 min
559	80	0.95	0.035	$744550.77	0.44 min
560	80	0.95	0.04	$744492.83	0.67 min
561	40	0.6	0.0005	$3601307.44	0.05 min
562	40	0.6	0.001	$3606714.23	0.06 min
563	40	0.6	0.005	$2170405.05	0.12 min
564	40	0.6	0.01	$2171802.06	0.17 min
565	40	0.6	0.015	$2166461.43	0.14 min
566	40	0.6	0.02	$35131.06	0.31 min
567	40	0.6	0.025	$747558.3	0.08 min
568	40	0.6	0.03	$747477.61	0.32 min
569	40	0.6	0.035	$746010.23	0.18 min
570	40	0.6	0.04	$2163877.41	0.22 min
571	40	0.65	0.0005	$2183449.3	0.06 min
572	40	0.65	0.001	$3033606.95	0.1 min
573	40	0.65	0.005	$1459834.92	0.12 min
574	40	0.65	0.01	$2174957.65	0.15 min
575	40	0.65	0.015	$2166316.82	0.23 min
576	40	0.65	0.02	$745022.03	0.2 min
577	40	0.65	0.025	$2166556.16	0.13 min
578	40	0.65	0.03	$745367.38	0.2 min
579	40	0.65	0.035	$744873.17	0.28 min
580	40	0.65	0.04	$2164150.55	0.28 min
581	40	0.7	0.0005	$3037001.38	0.05 min
582	40	0.7	0.001	$3027798.69	0.08 min
583	40	0.7	0.005	$2171638.22	0.11 min
584	40	0.7	0.01	$1454116.05	0.26 min
585	40	0.7	0.015	$747301.7	0.25 min
586	40	0.7	0.02	$744915.72	0.22 min
587	40	0.7	0.025	$746319.68	0.21 min
588	40	0.7	0.03	$2169787.33	0.16 min
589	40	0.7	0.035	$1453797.23	0.27 min
590	40	0.7	0.04	$35890.95	0.22 min
591	40	0.75	0.0005	$2886145.55	0.05 min
592	40	0.75	0.001	$758614.28	0.06 min
593	40	0.75	0.005	$3593016.5	0.12 min
594	40	0.75	0.01	$2876727.88	0.25 min
595	40	0.75	0.015	$1459342.58	0.15 min
596	40	0.75	0.02	$1458987.4	0.28 min
597	40	0.75	0.025	$745020.19	0.26 min

598	40	0.75	0.03	$35699.79	0.19 min
599	40	0.75	0.035	$3591865.46	0.11 min
600	40	0.75	0.04	$35400.44	0.2 min
601	40	0.8	0.0005	$2891464.69	0.07 min
602	40	0.8	0.001	$2174844.75	0.13 min
603	40	0.8	0.005	$2165490.9	0.24 min
604	40	0.8	0.01	$746642.71	0.33 min
605	40	0.8	0.015	$36759.63	0.17 min
606	40	0.8	0.02	$2170176.82	0.12 min
607	40	0.8	0.025	$1462956.65	0.18 min
608	40	0.8	0.03	$746873.83	0.24 min
609	40	0.8	0.035	$35743.66	0.2 min
610	40	0.8	0.04	$2166607.8	0.11 min
611	40	0.85	0.0005	$755950.01	0.07 min
612	40	0.85	0.001	$3029696.99	0.1 min
613	40	0.85	0.005	$1464134.95	0.12 min
614	40	0.85	0.01	$37672.98	0.21 min
615	40	0.85	0.015	$1454337.47	0.28 min
616	40	0.85	0.02	$2165927.53	0.16 min
617	40	0.85	0.025	$3588448.48	0.15 min
618	40	0.85	0.03	$2166305.59	0.17 min
619	40	0.85	0.035	$34287.83	0.32 min
620	40	0.85	0.04	$37032.26	0.09 min
621	40	0.9	0.0005	$2174122.41	0.08 min
622	40	0.9	0.001	$1464289.1	0.08 min
623	40	0.9	0.005	$2883706.31	0.2 min
624	40	0.9	0.01	$2165128.54	0.37 min
625	40	0.9	0.015	$747674.71	0.2 min
626	40	0.9	0.02	$36371.36	0.31 min
627	40	0.9	0.025	$34573.6	0.28 min
628	40	0.9	0.03	$1601834.34	0.18 min
629	40	0.9	0.035	$35064.25	0.2 min
630	40	0.9	0.04	$1453727.55	0.24 min
631	40	0.95	0.0005	$2174640.7	0.1 min
632	40	0.95	0.001	$2174212.05	0.09 min
633	40	0.95	0.005	$1456322.66	0.28 min
634	40	0.95	0.01	$2317575.85	0.19 min
635	40	0.95	0.015	$746203.24	0.17 min
636	40	0.95	0.02	$2165606.79	0.23 min
637	40	0.95	0.025	$2875069.13	0.19 min
638	40	0.95	0.03	$1453279.27	0.35 min
639	40	0.95	0.035	$747265.85	0.24 min
640	40	0.95	0.04	$35751.73	0.3 min
641	20	0.6	0.0005	$5016345.87	0.02 min
642	20	0.6	0.001	$6019053.73	0.02 min
643	20	0.6	0.005	$4309732.99	0.11 min
644	20	0.6	0.01	$2171472.94	0.15 min
645	20	0.6	0.015	$2882629.0	0.07 min
646	20	0.6	0.02	$5011695.04	0.05 min
647	20	0.6	0.025	$2167330.31	0.12 min
648	20	0.6	0.03	$2885036.94	0.05 min
649	20	0.6	0.035	$37744.33	0.15 min
650	20	0.6	0.04	$3022275.09	0.07 min
651	20	0.65	0.0005	$6449215.88	0.02 min
652	20	0.65	0.001	$5311679.3	0.03 min
653	20	0.65	0.005	$5014351.27	0.02 min
654	20	0.65	0.01	$1454436.2	0.12 min
655	20	0.65	0.015	$1465432.28	0.1 min

656	20	0.65	0.02	$3024311.9	0.05 min
657	20	0.65	0.025	$2168650.83	0.07 min
658	20	0.65	0.03	$2879411.17	0.12 min
659	20	0.65	0.035	$1456447.88	0.07 min
660	20	0.65	0.04	$1460596.37	0.06 min
661	20	0.7	0.0005	$4594297.8	0.02 min
662	20	0.7	0.001	$5027504.27	0.03 min
663	20	0.7	0.005	$3029257.75	0.03 min
664	20	0.7	0.01	$1611794.36	0.09 min
665	20	0.7	0.015	$3883884.23	0.04 min
666	20	0.7	0.02	$2178549.07	0.06 min
667	20	0.7	0.025	$2884838.66	0.07 min
668	20	0.7	0.03	$2166543.3	0.15 min
669	20	0.7	0.035	$1454866.55	0.16 min
670	20	0.7	0.04	$1455634.9	0.17 min
671	20	0.75	0.0005	$4451001.01	0.03 min
672	20	0.75	0.001	$2882099.83	0.06 min
673	20	0.75	0.005	$3023584.34	0.13 min
674	20	0.75	0.01	$6307981.11	0.04 min
675	20	0.75	0.015	$4304771.57	0.09 min
676	20	0.75	0.02	$2170666.79	0.08 min
677	20	0.75	0.025	$1457102.36	0.23 min
678	20	0.75	0.03	$2169420.99	0.16 min
679	20	0.75	0.035	$1457977.28	0.1 min
680	20	0.75	0.04	$750478.96	0.1 min
681	20	0.8	0.0005	$2890954.68	0.03 min
682	20	0.8	0.001	$5452491.15	0.03 min
683	20	0.8	0.005	$2318869.66	0.05 min
684	20	0.8	0.01	$2882611.23	0.08 min
685	20	0.8	0.015	$1606001.38	0.1 min
686	20	0.8	0.02	$746312.01	0.14 min
687	20	0.8	0.025	$747572.02	0.12 min
688	20	0.8	0.03	$2164391.64	0.08 min
689	20	0.8	0.035	$1461240.03	0.11 min
690	20	0.8	0.04	$2167514.73	0.1 min
691	20	0.85	0.0005	$7876117.35	0.03 min
692	20	0.85	0.001	$4311753.69	0.03 min
693	20	0.85	0.005	$4449387.42	0.03 min
694	20	0.85	0.01	$2171308.4	0.11 min
695	20	0.85	0.015	$2166001.74	0.1 min
696	20	0.85	0.02	$2880025.94	0.11 min
697	20	0.85	0.025	$35869.64	0.11 min
698	20	0.85	0.03	$3588668.43	0.14 min
699	20	0.85	0.035	$1457973.15	0.05 min
700	20	0.85	0.04	$890622.84	0.12 min
701	20	0.9	0.0005	$5165235.07	0.03 min
702	20	0.9	0.001	$6440305.7	0.03 min
703	20	0.9	0.005	$4452968.34	0.08 min
704	20	0.9	0.01	$2877694.33	0.23 min
705	20	0.9	0.015	$1458148.58	0.1 min
706	20	0.9	0.02	$747068.98	0.15 min
707	20	0.9	0.025	$3588788.85	0.08 min
708	20	0.9	0.03	$1455320.69	0.19 min
709	20	0.9	0.035	$2163799.07	0.19 min
710	20	0.9	0.04	$2170882.93	0.08 min
711	20	0.95	0.0005	$5170729.17	0.04 min
712	20	0.95	0.001	$2882758.02	0.03 min
713	20	0.95	0.005	$4734446.6	0.03 min

714	20	0.95	0.01	$1454425.46	0.11 min
715	20	0.95	0.015	$3599373.59	0.05 min
716	20	0.95	0.02	$3590621.05	0.05 min
717	20	0.95	0.025	$1457666.2	0.06 min
718	20	0.95	0.03	$2876228.03	0.16 min
719	20	0.95	0.035	$892085.82	0.13 min
720	20	0.95	0.04	$1460199.48	0.11 min
721	10	0.6	0.0005	$9445526.1	0.01 min
722	10	0.6	0.001	$6877525.5	0.01 min
723	10	0.6	0.005	$5876762.68	0.01 min
724	10	0.6	0.01	$7158793.03	0.01 min

Table B.5: Survey CSV File and User Input for Third Hyperparameter Search Test Case.

ID	Northing (UTM 11)	Easting (UTM 11)	Elevation (m)	Crossing/Asset Type	Ex. Str. Pattern	misc	Ex. Height of Attachments
222039	5911023.565	512023.5	625.364	EXPP_	N52_N0C_-E12	222039	HOA 12.70 10.3
222040	5910974.713	512023.699	626.734	EXPP_45_-3_79	N12_N86_-N0C	222040	HOA 11.1 8.09
600	5910943.768	512023.91	627.043	OG_	PARKING LOT		
607	5910900.762	512022.505	629.475	BRUSH_			
606	5910900.71	512026.57	628.722	BRUSH_			
1	5910892.946	512022.958	629.31	PP_45_			
605	5910884.916	512025.915	628.847	BRUSH_			
604	5910883.764	512022.347	629.086	BRUSH_			
386699	5910871.019	512023.129	629.182	EXPP_45_-3_99	N12_N86_-E12_R0	386699	HOA 10.52
386699A	5910864.019	512023.129	629.182	EXANC_	G40_		
386700	5910807.587	512022.958	630.279	EXPP_45_-4_80	N12	386700	HOA 11.14
386701	5910704.968	512023.241	630.437	EXPP_45_-4_90	N12	386701	HOA 9.67
19	5910592.988	512023.491	626.949	PP_45_			
601	5910550.652	512023.645	628.144	APSH_			
602	5910546.427	512023.511	628.083	APCL_			OIL
603	5910542.236	512023.612	628.055	APSH_			
386703	5910502.845	512023.854	627.301	EXPP_40_-3_91	N12_-R154F_E12	386703	HOA 10.00 9.00
386703A	5910500.359	512022.572	627.196	EXANC_			
386704	5910407.141	512019.375	622.668	EXPP_	N12	386704	HOA 11.45
1	5910892.946	512022.958	629.31	PP_45_			
2	5910892.687	512014.353	628.968	PP_45_			
2A	5910892.896	512021.328	629.239	ANC_			
2B	5910892.838	512019.355	629.2	ANC_			
608	5910891.282	511967.712	627.059	OG_			
3	5910889.634	511914.428	626.701	PP_45_			
609	5910888.014	511860.853	626.591	OG_			
4	5910886.585	511814.478	626.319	PP_45_			
4A	5910886.356	511807.485	626.208	ANC_			
4B	5910886.448	511809.504	626.276	ANC_			
5	5910876.575	511814.502	626.916	PP_45_			
5A	5910983.594	511814.49	626.483	ANC_			
5B	5910981.58	511814.505	626.603	ANC_			
610	5910845.684	511814.5	628.517	OG_			
6	5910827.494	511814.526	629.555	PP_45_			

611	5910790.678	511814.543	630.368	OG_			
7	5910776.137	511814.54	630.524	PP_45_			
7A	5910769.111	511814.552	630.662	ANC_			
7B	5910771.131	511814.543	630.651	ANC_			
8	5910764.932	511814.545	630.554	PP_45_			
612	5910765.35	511859.647	630.258	OG_			
9	5910765.778	511905.126	629.845	PP_45_			
9A	5910765.842	511912.132	629.736	ANC_			
9B	5910765.839	511910.113	629.793	ANC_			
8	5910764.932	511814.545	630.554	PP_45_			
613	5910764.571	511776.597	629.553	OG_			
10	5910764.232	511739.595	628.49	PP_45_			
614	5910763.868	511701.389	627.068	OG_			
11	5910763.565	511669.477	625.579	PP_50_			
617	5910754.591	511666.158	625.485	P/LGAS_			
616	5910773.457	511665.835	625.123	P/LGAS_			
615	5910763.516	511665.764	625.501	P/LGAS_			
618	5910763.441	511656.647	625.144	RDSHL_			
619	5910763.37	511650.592	625.3	RDCL_			
620	5910763.294	511644.709	625.161	RDSHL_			
622	5910753.004	511637.638	625.361	P/LGAS_			
621	5910763.275	511637.357	625.341	P/LGAS_			
623	5910778.384	511637.342	624.95	P/LGAS_			
12	5910763.166	511633.494	625.236	PP_50_			
624	5910762.877	511600.658	624.006	OG_			
13	5910762.629	511568.92	622.862	PP_45_			
14	5910762.373	511540.111	621.617	PP_45_			
15	5910762.065	511503.97	620.529	PP_45_			
15A	5910761.995	511496.961	619.718	ANC_			
15B	5910762.014	511498.982	619.765	ANC_			
14	5910762.373	511540.111	621.617	PP_45_			
16	5910772.356	511540.097	621.668	PP_45_			
16A	5910765.375	511540.117	621.581	ANC_			
16B	5910767.369	511540.102	621.509	ANC_			
625	5910808.301	511540.095	621.455	OG_			
17	5910849.681	511540.079	621.263	PP_45_			
626	5910887.645	511540.049	620.585	OG_			
18	5910910.654	511540.052	620.287	PP_45_			
18A	5910917.638	511540.05	620.166	ANC_			
18B	5910915.664	511540.048	620.242	ANC_			
19	5910592.988	512023.491	626.949	PP_45_			
20	5910592.888	512013.488	627.752	PP_45_			
20A	5910592.95	512020.479	627.331	ANC_			
20B	5910592.909	512018.494	627.319	ANC_			
627	5910592.521	511973	626.679	OG_			
21	5910591.999	511918.828	625.6	PP_45_			
628	5910591.641	511878.164	625.962	OG_			
22	5910591.261	511838.866	625.187	PP_45_			
629	5910590.798	511789.191	624.808	OG_			
23	5910590.312	511738.924	624.538	PP_45_			
630	5910589.894	511696.93	624.665	OG_			
24	5910589.679	511672.35	624.543	PP_45_			
24A	5910589.615	511665.367	624.482	ANC_			
24B	5910589.633	511667.375	624.494	ANC_			
25	5910573.311	511672.517	625.462	PP_45_			

25A	5910573.311	511679.5					
6025A	5910573.334	511677.508	625.686	ANC_			
6025B	5910573.353	511679.514	625.82	ANC_			
631	5910570.551	511637.457	626.006	P/LGAS_			
632	5910581.787	511637.286	625.042	P/LGAS_			
26	5910572.928	511633.535	625.599	PP_45_			
633	5910570.14	511592.939	626.148	OG_			
27	5910572.145	511550.507	626.026	PP_45_			
634	5910569.353	511509.412	625.897	OG_			
28	5910571.38	511468.483	625.705	PP_45_			
28A	5910571.325	511463.457	625.69	ANC_			
28B	5910571.306	511461.479	625.661	ANC_			
User Input:							
Loading:	Medium						
Spacing:	Urban						
# Ph. Ex. Main	3						
# Ph. New Main	3						
# Ph. Ex. Tap	3						
# Ph. New Tap	3						
Grounding	Multi-Ground Neut.						
Min Clearance	Pedestrian						
Ex. Cond. Type	1/0 ACSR						
Ex. Tap-Off Cond. Type	1/0 ACSR						
New Cond. Type	1/0 ACSR						
New Tap-Off Cond. Type	1/0 ACSR						
Equip. 1							
Equip. 2							
Equip. 3							
Service Pt.	20						
Prelim Stk List Mod.	None						

Appendix C: Data Tables Pertaining to Final Evaluation of PoleCheck2.0 and AutoDesigner

Table C.1: PoleCheck1.0 vs. PoleCheck2.0 Pole Utilization Evaluation - Raw Data

Structure Pattern	Loading	Ruling Span	Deflection	Anchor Structure	Anchor Length 1	Anchor Length 2	Conductor Type (ACSR)	Pole Height	Pole Composition	Pole Class	Pole Utilization PC1	Pole Utilization PC2	Percent Difference
N32													
N32	Heavy	91.8m	90°	G40,G40	6.0m	6.0m	1/0	40 ft.	WR	3	30.36%	30.13%	-0.756%
N32	Heavy	71.4m	90°	G40,G40	10.0m	10.0m	266MCM	50 ft.	WR	3	39.88%	42.4%	6.32%
N32	Heavy	71.4m	90°	G40,G40	8.0m	8.0m	477MCM	35 ft.	WR	2	30.31%	31.46%	3.66%
N32	Heavy	91.8m	90°	G40,G40	8.0m	10.0m	1/0	55 ft.	WR	1	22.10%	22.50%	1.80%
N32	Heavy	71.4m	90°	G40,G40	6.0m	10.0m	477MCM	35 ft.	WR	4	69.97%	68.6%	-1.96%
N32	Medium	112.2m	90°	G40,G40	5.0m	5.0m	1/0	45 ft.	WR	1	12.28%	19.46%	5.85%
N32	Medium	112.2m	90°	G40,G40	5.0m	5.0m	1/0	45 ft.	WR	2	15.03%	23.34%	55.3%
N32	Medium	112.2m	90°	G40,G40	5.0m	5.0m	1/0	45 ft.	WR	3	24.18%	28.51%	17.9%
N42													
N42	Heavy	103.5m		G50	7.0m		1/0	45 ft.	WR	3	109.09%	117.54%	7.74%
N42	Heavy	80.5m		G50	11.0m		477MCM	50 ft.	WR	2	142.63%	193.07%	35.4%
N42	Heavy	103.5m		G50	9.0m		1/0	40 ft.	WR	1	30.48%	31.32%	2.76%
N42	Heavy	80.5m		G50	11.0m		266MCM	50 ft.	WR	2	75.92%	110.87%	46.0%
N42	Heavy	103.5m		G50	5.0m		1/0	40 ft.	WR	3	107.24%	116.03%	8.20%
N42	Medium	112.2m		G40	9.0m		1/0	45 ft.	WR	5	74.81%	92.84%	24.1%
N42	Medium	86.7m		G40	9.0m		477MCM	35 ft.	WR	2	24.38%	26.39%	8.24%
N42	Medium	86.7m		G40	11.0m		477MCM	60 ft.	WR	1	45.22%	57.75%	27.7%
N11													
N11	Medium	126.5m	6°	G40	3.0m		1/0	50 ft.	WR	4	32.97%	40.25%	18.1%
N11	Medium	126.5m	6°	G40	3.0m		1/0	60 ft.	WR	3	31.29%	34.82%	11.3%
N11	Medium	126.5m	6°	G40	3.0m		266MCM	40 ft.	WR	5	31.51%	45.2%	43.4%
N11	Medium	97.75m	9°	G40	3.0m		477MCM	40 ft.	WR	5	33.94%	44.79%	32.0%
N11	Medium	97.75m	9°	G40	3.0m		477MCM	50 ft.	WR	1	11.73%	16.61%	41.6%
N11	Medium	97.75m	9°	G40	7.0m		477MCM	55 ft.	WR	3	18.92%	26.19%	38.4%
N12,N55													
N12,N55	Heavy	91.8m	90°	G40	4.0m		1/0	45 ft.	WR	1	45.65%	46.77%	2.45%
N12,N55	Heavy	91.8m	90°	G40	4.0m		1/0	45 ft.	WR	2	94.98%	84.98%	-10.5%

N12,N55	Heavy	91.8m	120°	G40	4.0m		1/0	45 ft.	WR	1	91.31%	83.85%	-8.17%
N12,N55	Heavy	91.8m	120°	G40	4.0m		1/0	45 ft.	WR	2	178.5%	173.1%	-3.03%
N12,N55	Heavy	91.8m	90°	G40	6.0m		1/0	45 ft.	WR	1	33.02%	42.45%	28.6%
N12,N55	Heavy	91.8m	90°	G40	6.0m		1/0	45 ft.	WR	2	52.79%	55.08%	4.34%
N12,N55	Heavy	91.8m	90°	G40	6.0m		1/0	45 ft.	WR	3	120.94%	109.34%	-9.59%
N12,N55	Heavy	91.8m	120°	G40	6.0m		1/0	45 ft.	WR	1	68.94%	62.13%	-9.88%
N12,N55	Heavy	71.4m	120°	G50	8.0m		266MCM	40 ft.	WR	1	45.36%	53.45%	17.8%
N12,N55	Heavy	71.4m	120°	G50	8.0m		266MCM	40 ft.	WR	2	59.21%	68.76%	13.9%
N12,N55	Heavy	71.4m	120°	G50	8.0m		266MCM	40 ft.	WR	3	89.80%	121.09%	34.8%
N12,N55	Heavy	71.4m	90°	G50	10.0m		477MCM	45 ft.	WR	1	60.61%	63.12%	4.14%
N12,N55	Heavy	71.4m	90°	G50	10.0m		477MCM	45 ft.	WR	2	76.02%	79.03%	3.96%
N12,N55	Heavy	71.4m	90°	G50	10.0m		477MCM	45 ft.	WR	3	97.18%	185.28%	90.7%
N12,N55	Medium	112.2m	120°	G40	4.0m		1/0	45 ft.	WR	1	36.59%	36.05%	-2.77%
N12,N55	Medium	112.2m	120°	G40	4.0m		1/0	45 ft.	WR	2	51.99%	52.28%	0.56%
N12,N55	Medium	112.2m	120°	G40	4.0m		1/0	45 ft.	WR	3	88.21%	92.01%	4.31%
N12,N55	Medium	112.2m	90°	G50	10.0m		266MCM	55 ft.	WR	1	41.03%	47.55%	15.9%
N12,N55	Medium	112.2m	90°	G50	10.0m		266MCM	55 ft.	WR	2	58.43%	75.29%	28.9%
N12,N55	Medium	112.2m	90°	G50	10.0m		266MCM	55 ft.	WR	3	175.25%	265.9%	51.7%
N12													
N12	Medium	126.5m	4°				1/0	60 ft.	WR	1	45.26%	45.13%	0.287%
N12	Medium	126.5m	4°				1/0	60 ft.	WR	2	56.17%	56.37%	0.356%
N12	Medium	126.5m	4°				1/0	60 ft.	WR	3	71.17%	71.5%	0.464%
N11H													
N11H	Heavy	103.5m	20°	G40	3.0m		1/0	60 ft.	WR	1	17.85%	20.51%	14.9%
N11H	Heavy	103.5m	20°	G40	3.0m		1/0	60 ft.	WR	2	22.52%	170.38%	657%
N11H	Heavy	81.5m	9°	G40	3.0m		477	60 ft.	WR	1	18.54%	17.55%	-5.34%
N11H	Heavy	81.5m	9°	G40	3.0m		477	60 ft.	WR	2	21.83%	21.96%	0.596%

Table C.2: Survey CSV File and User Input for First Final Evaluation Case.

ID	Northing (UTM 11)	Easting (UTM 11)	Elevation (m)	Crossing/Asset Type	Ex. Str. Pattern	misc	Ex. Height of Attachments
383074	5951633.856	394649.56	667.283	EXPP_40_-5_01_	N12	383074	HOA 9.65
383073	5951546.107	394647.669	666.051	EXPP_40_-5_01_	N12	383073	HOA 9.53
1	5951443.336	394645.097	664.761	PP_			
1A	5951443.16	394652.084	664.962	ANC_			
383071	5951359.376	394643.394	665.767	EXPP_35_-5_02_	N12_	383071	HOA 8.11
383070	5951277.131	394640.393	664.501	EXPP_40_-5_02_	N12_	383070	HOA 9.54
1	5951443.336	394645.097	664.761	PP_			
7000	5951443.457	394639.846	665.584	RDSHL_			
7001	5951443.526	394636.623	665.777	RDCL_			
7002	5951443.615	394632.844	665.708	RDSHL_			
7003	5951445.3	394577.075	664.091	CREEKTOB_-			
7004	5951445.849	394562.657	664.536	CREEKTOB_-			
2	5951445.632	394548.69	665.162	PP_			
3	5951447.887	394453.749	665.617	PP_			
7005	5951448.618	394423.653	665.877	APCL_-FIELD_			

4	5951450.163	394358.793	666.551	PP_			
5	5951452.448	394262.523	667.143	PP_			
5A	5951452.601	394255.539	667.2	ANC_			
809026	5951453.972	394190.997	668.48	EXPP_40_-6_13_	R112	809026	HOW 10.47 8.69
942486	5951456.017	394106.736	668.395	EXPP_40_-6_13_	R112	942486	HOW 10.54 8.76
809027	5951457.788	394019.615	668.804	EXPP_40_-6_10_	R112	809027	HOW 10.60 8.81
5	5951452.448	394262.523	667.143	PP_			
5A	5951452.601	394255.539	667.2	ANC_			
7006	5951443.069	394262.294	667.728	RDSHL_			
7007	5951439.494	394262.225	667.801	RDCL_			
7008	5951435.842	394262.145	667.766	RDSHL_			
7010	5951432.575	394261.908	667.339	TELE_			
6	5951427.454	394261.925	667.661	PP_			
User Input:							
Loading:	Heavy						
Spacing:	Rural						
# Ph. Ex. Main	3						
# Ph. New Main	3						
# Ph. Ex. Tap	1						
# Ph. New Tap	3						
Grounding	Earth Return System						
Min Clearance	Agricultural						
Ex. Cond. Type	1/0 ACSR						
Ex. Tap-Off Cond. Type	#4 ACSR						
New Cond. Type	1/0 ACSR						
New Tap-Off Cond. Type	1/0 ACSR						
Equip. 1	Pole 6	N86					
Equip. 2							
Equip. 3							
Service Pt.	19						
Prelim Stk List Mod.	None						

Table C.3: Survey CSV File and User Input for Second Final Evaluation Case.

851751	6083199.606	618992.051	1024.034	EXPP_40_-5_	N12H_	851751	
1	6083137.122	618998.876	1019.198	PP_			
851728	6083121.91	619000.537	1020.05	EXPP_40_-3_	N42_N390_	851728	
851728A	6083116.737	619001.109	1020.177	EXANC_	G40_		
1	6083137.122	618998.876	1019.198	PP_			
1A	6083134.894	618991.714	1019.289	ANC_7.5_			
7059	6083139.916	619005.095	1019.607	RDSHL_			
7066	6083140.452	619012.014	1019.59	RDSHL_			

6002	6083152.36	619021.46	1018.9	P/L_			
6003	6083144.452	619022.443	1018.9	P/L_			
6004	6083136.278	619023.305	1018.9	P/L_			
6005	6083152.722	619022.291	1018.9	P/L_			
6006	6083144.715	619023.287	1018.9	P/L_			
6007	6083136.411	619024.166	1018.9	P/L_			
2	6083149.002	619037.071	1019.423	PP_			
3	6083165.243	619089.283	1016.255	PP_			
3A	6083167.47	619096.445	1016.325	ANC_7.5_			
4	6083158.558	619091.362	1016.366	PP_			
4A	6083156.331	619084.201	1017.775	ANC_7.5_			
5	6083174.954	619144.073	1014.815	PP_			
5B	6083182.115	619141.845	1014.701	ANC_7.5_			
5A	6083177.181	619151.234	1014.603	ANC_7.5_			
6	6083143.239	619153.938	1015.159	PP_			
6A	6083136.078	619156.166	1015.757	ANC_7.5_			
7	6083137.094	619166.311	1015.431	PP_			
7A	6083134.541	619159.259	1015.503	ANC_7.5_			
8	6083170.157	619257.652	1015.072	PP_			
8B	6083176.797	619254.167	1015.398	ANC_7.5_			
8A	6083172.709	619264.705	1015.3	ANC_7.5_			
9	6083142.417	619272.212	1012.964	PP_			
9A	6083135.776	619275.697	1012.873	ANC_7.5_			
10	6083126.3	619283.734	1011.284	PP_			
10A	6083131.747	619278.578	1012.291	ANC			
11	6083076.7	619330.688	1000.606	PP_			
12	6083027.1	619377.643	998.829	PP_			
13	6082976.938	619425.13	1003.804	PP_			
13A	6082971.492	619430.286	1005.505	ANC_7.5_			
User Input:							
Loading:	Heavy						
Spacing:	Rural						
# Ph. Ex. Main	3						
# Ph. New Main	3						
# Ph. Ex. Tap	1						
# Ph. New Tap	3						
Grounding	Earth Return System						
Min Clearance	Pedestrian						
Ex. Cond. Type	1/0 ACSR						
Ex. Tap-Off Cond. Type	1/0 ACSR						
New Cond. Type	1/0 ACSR						
New Tap-Off Cond. Type	1/0 ACSR						
Equip. 1	Pole 13	N390					
Equip. 2							
Equip. 3							
Service Pt.	18						
Prelim Stk List Mod.	None						

Table C.4: Survey CSV File and User Input for Third Final Evaluation Case.

324928	5681030.065	399105.142	896.389	EXPP_40_-4_	N12_	324928	HOA_9.40_
324929	5681028.346	399183.549	899.63	EXPP_35_-3_	N12_	324929	HOA_8.33_
7002	5681027.467	399223.32	899.482	P/L_			HPPL
7003	5681013.277	399229.81	899.842	P/L_			HPPL
324930	5681026.401	399281.252	899.729	EXPP_45_-2_	N12_	324930	HOA_11.05_
1	5681026.072	399297.36	900.452	PP_			
7004	5681025.77	399302.411	901.249	RDSHL_			
7005	5681025.726	399305.946	901.466	RDCL_			
7006	5681025.746	399310.311	901.481	RDSHL_			
324931	5681024.051	399394.54	905.856	EXPP_40_-4_	N12_	324931	HOA_9.51_
324932	5681023.588	399451.921	911.314	EXPP_35_-3_	N12_	324932	HOA_8.0_
1	5681026.072	399297.36	900.452	PP_			
2	5681039.102	399304.77	900.287	PP_			
2A	5681030.399	399299.834	900.216	ANC_			
7109	5681064.63	399319.327	902.845	OG_			
3	5681073.999	399324.645	902.388	PP_			
7007	5681090.046	399334.009	899.743	P/L_			
4	5681144.194	399364.651	899.649	PP_			
5	5681214.387	399404.662	901.052	PP_			
5A	5681219.592	399398.444	900.528	ANC_			
6	5681260.148	399459.482	900.252	PP_			
8435	5681261.379	399462.756	899.509	RDSHL_			
8431	5681276.838	399479.17	898.644	RDSHL_			
7	5681319.397	399530.476	894.27	PP_			
7009	5681350.753	399572.293	891.666	P/L_			
7012	5681367.124	399591.416	893.071	P/L_			
8	5681378.658	399601.455	892.971	PP_			
7110	5681407.217	399635.7	895.439	OG_			
9	5681445.051	399680.986	893.43	PP_			
9A	5681451.465	399688.655	893.455	ANC_			
10	5681465.441	399688.951	892.624	PP_			
10A	5681455.433	399689.149	893.278	ANC_			
11	5681518.894	399690.056	888.603	PP_			
7111	5681560.08	399687.444	886.791	P/L_			HPPL
12	5681573.991	399691.193	886.486	PP_			
12A	5681583.984	399691.399	886.486	ANC_			
12B	5681571.452	399684.139	886.486	ANC_			
13	5681590.818	399737.957	883.408	PP_			
14	5681609.28	399789.185	881.624	PP_			
14A	5681612.681	399798.592	879.762	ANC_			
15	5681621.994	399800.378	878.455	PP_			
15A	5681613.173	399798.687	879.715	ANC_			
16	5681690.072	399813.404	864.711	PP_			
17	5681758.138	399826.439	873.242	PP_			
7032	5681769.127	399834.111	873.797	PP_			
7015	5681789	399847.528	875.173	TOP OF DRAW	NORTH		
18	5681826.284	399839.491	877.839	PP_			
7113	5681866.249	399849.472	878.57	OG_			
19	5681913.57	399861.254	876.197	PP_			
7014	5681999.242	399876.661	878.249U	P/L_			

20	5682007.848	399879.279	878.867	PP_			
7114	5682029.065	399883.312	879.805	OG_			
21	5682073.201	399891.785	877.192	PP_			
22	5682138.578	399904.269	878.451	PP_			
22A	5682141.195	399896.649	878.702	ANC_			
23	5682193.93	399932.731	877.937	PP_			
23A	5682086.93	400280.731	877.937	ANC_			
23B	5682203.285	399926.316	876.271	ANC_			
7115	5682195.096	399943.436	878.98	RDSHL_			
7116	5682195.562	399947.723	878.883	RDCL_			
7117	5682196.062	399952.369	878.721	RDSHL_			
24	5682200.454	399992.365	876.194	PP_			
25	5682209.251	400073.01	873.777	PP_			
26	5682218.078	400153.629	873.509	PP_			
27	5682226.903	400234.225	871.99	PP_			
27A	5682227.967	400244.145	872.642	ANC_			
28	5682212.218	400259.561	871.989	PP_			
28A	5682212.395	400249.569	872.569	ANC_			
29	5682210.968	400324.013	869.161	PP_			
7119	5682218.313	400369.773	866.599	P/L_			HPPL
7118	5682210.058	400373.318	866.035	P/L_			HPPL
30	5682209.744	400388.487	864.935	PP_			
30A	5682201.708	400390.465	864.172	ANC_			
31	5682236.123	400436.588	862.887	PP_			
31A	5682240.924	400445.349	862.317	ANC_			
32	5682241.672	400459.101	860.693	PP_			
32A	5682241.854	400449.11	862.109	ANC_			
33	5682240.576	400514.434	858.137	PP_			
33A	5682240.412	400524.433	858.464	ANC_			
33B	5682230.57	400514.274	857.283	ANC_			
7120	5682249.183	400514.597	859.263	RDSHL_			
7121	5682251.365	400514.65	859.362	RDCL_			
7122	5682252.926	400514.629	859.335	RDSHL_			
34	5682330.299	400516.13	861.885	PP_			
34A	5682332.287	400508.144	861.78	ANC_			
35	5682392.618	400548.13	861.771	PP_			
36	5682454.905	400580.121	859.888	PP_			
36A	5682463.8	400584.668	859.362	ANC_			
37	5682468.152	400580.232	859.46	PP_	XMER		
User Input:							
Loading:	Heavy						
Spacing:	Rural						
# Ph. Ex. Main	3						
# Ph. New Main	3						
# Ph. Ex. Tap	3						
# Ph. New Tap	3						
Grounding	Earth Return System						
Min Clearance	Pedestrian						
Ex. Cond. Type	1/0 ACSR						
Ex. Tap-Off Cond. Type	1/0 ACSR						
New Cond. Type	1/0 ACSR						

New Tap-Off Cond. Type	1/0 ACSR						
Equip. 1	Pole 37	N86					
Equip. 2							
Equip. 3							
Service Pt.	4						
Prelim Stk List Mod.	None						