Master of Science in Civil Engineering

Thesis of Master Degree

Validation study of a fixed-base driving simulator on steering behavior of drivers

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Content

Abstract

Driving simulator is a research tool for scientific research and applications in several field studies, but testing the validity is one of the first things to perform before carrying out any activity with it.

This thesis aims at validating the steering behavior of drivers based on a fixed-base driving simulator. The experiment was carried out involving 34 participants in total. They were divided into two groups according to age distribution of a group originally involved in real driving observations, and the population of the Italian licensed drivers. The data from field observations and laboratory experiments included position data, curvature of trajectories, heading angle and curvilinear abscissa. Because of the few spatial data available about trajectories of real vehicles, field predictive model was elaborated to estimate the trajectory correctly according to recorded field data (it is worth noting that the field data were recorded with high precision and accuracy GPS in RTK mode). So, predictive model was used for validation of simulator.

The three indexes include the anticipatory distance, which is the distance between steering point and starting point of curvature, the curvature of the trajectory along the circular arc of the alignment, and the curvature change rate approaching and exiting from a curve (i.e., along the segment across the straight and the circular arc).

The results demonstrated that simulator shows relative validity for the anticipation distance in situation where the radius of curve is bigger than 1000 m or lower than 450 m. However, the absolute validation was reached for the anticipatory distance when the radius of curve is around 500 m. Meanwhile, simulator showed relative validity for curvature change rate and curvature between real and simulated scenario where the simulator values are always higher than that in real scenario.

These results will provide a big support for the research work of DIATI (Department of Environment, Land and Infrastructure Engineering) and any other teams working on simulator to improve knowledge on behavioral response of drivers under a multitude of factors that may be reproduced at a simulator.

Key Words: Driving Simulator, Trajectories, Validation, Anticipatory Distance

1. Introduction

The driving simulator is a research tool that helps scientists to study practical problems belonging to different fields of applied sciences: psychologists, from general physicians, specialists (e.g., neurologists, internists, and psychiatrists), physician's assistants, nurse practitioners, clinical psychologists, neuropsychologists, occupational therapists, and students of health care as well as automotive and civil engineers.

Driving simulators are investigative tools. For example, the environmental lighting conditions between day and night, the weather conditions and the state of the pavement may be controlled and change during the experiments. In addition, the parameters related to the vehicle, such as the tires and steering characteristics, can be set configuring them to make the same as those of an existing vehicle or prototypes. In the virtual environment, new types of roads, signals and markings can also be evaluated without the influence of factors related to the real environment.

Driving simulators have advantages compared to real driving, as they provide a basic safe environment for drivers and staff involved in, and no one of them is put into a condition of danger. This makes driving simulators very useful for studying driving concern fatigue or for training drivers who are commonly subjected to high risks.

However, the driving simulator also has some disadvantages. Whatever the goodness available for the development of a simulator, its validity will always remain questionable because the complexity of the real world can never be replicated in its entirety. Despite the technological advances, simulator will always be an approximation of reality. Furthermore, the driver knows that his behavior will not directly affect his safety. Symptoms of simulator sickness may also occur in some cases. Finally, the most advanced simulators, equipped with large operation systems or high-level visualization systems, can have very high calibration costs.

1.1 The Case Study

The track here considered as the case study is a part of route next to Perugia (Italy), and composed of two road segments: the SP169_1 and the SP170_2. Years ago, a field observation was carried out using vehicles equipped with high precision and accuracy GPS in real-time kinematics (RTK) mode driven by test drivers on road sections to get geometric characteristics (1). The results provided an insight into the effects of road geometrics on driver behavior, thus now we can model that route according to these data. Figure 1 and Table 1 show the information of these two road segments.

Table 1 lists the geometric characteristics collected from the as-built alignment database for tangents, curves, and grades, the combination of which determines a high variation of steering angles along the same path.

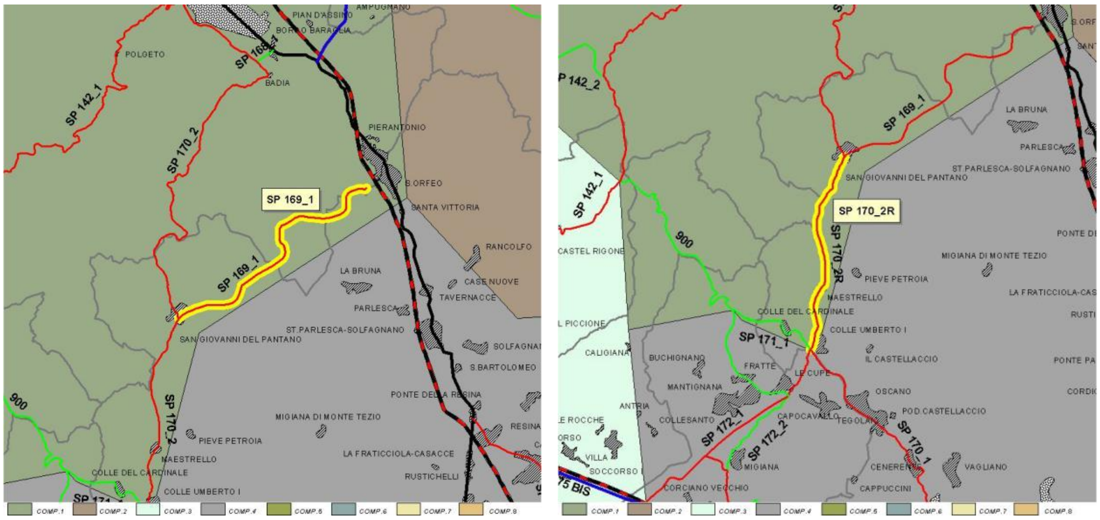


Figure 1 Location of Road SP169_1 and Road SP170_2

Table 1 Characteristics of Road SP169_1 and Road SP170_2

Road designation		SP 170_2+SP 169_1
Length [km]		13.8
Minimum radius [m]		47.8
Maximum radius [m]		1950
Maximum grade [%]		8.3
Number of curves with radius	<100 m	5
	⩾100 m, <200m	20
	⩾200 m, <400m	16
	⩾400 m, <800m	3
	⩾800 m	17
Length of grades with slope	<-5%	806.5
	⩾-5%, <-3%	1069.7
	⩾-3%, <-1%	526.0
	⩾-1%, <+1%	3061.2
	⩾+1%, <+3%	3018.0
	⩾+3%, <+5%	1133.9
	⩾+5%	0
Number of drivers		7

1.2 Research Aim

Research aim is to define the validity of driving simulator at the *Politecnico di Torino* for trajectory in aspect of steering behavior. Although it was already carried out on a section of 3 km closed to Turin (3), with this experiment one more significant case was added – 15 km – to reinforce the research on validation for different environments and road types.

To achieve this aim, there are three indexes here proposed related to steering behavior: the anticipatory distance, which is the distance between steering point and starting point of curvature, the curvature of the trajectory in the portion of circular arc of the alignment, and the curvature change rate approaching and exiting from a curve.

The object of the experiments was performed by means of a sample of 40 voluntary participants, aged between 23 and 63, and divided into 2 groups. One group consists of 7 male drivers compared with the field research group, and the second group consists of 40 drivers as planned according to the population ratio of Italy who have driving licenses.

2. Experiment Protocol

2.1 The Driving Simulator

The driving simulator used is located at the Department of Environmental, Land and Infrastructure Engineering (DIATI) of *Politecnico di Torino*. More precisely it is in the Road Safety and Driving Simulation Laboratory. It was manufactured by the French company *Oktal* (now *AV Simulation*), which deals with the design and construction of driving simulators for motor vehicles, aeronautics and railways, as well as the development of the related management programs.

The simulator uses three computers (Figure 2):

- the first, located behind the driving position, is mainly used for the management of the operating system and the simulation software;
- the second, also located on the simulator, has the task of producing the scenario in three 32-inch screens;
- the third, positioned behind the simulator, has the task of producing the scenario through Virtual Reality (VR) technology.

In particular, the simulator has a fixed base, and faithfully reproduces the driving position of the driver but is not able to provide the driver with the usual accelerations that would occur in driving in a real environment.

In order to best identify the driver in the recreated virtual environment and try to limit the distraction and effects of malaise resulting from the simulation, the laboratory walls were painted in black. The room can also be darkened by means of a curtain, and the tests are therefore carried out in a dark environment.

Figure 2 Simulator Equipment

Virtual environment is reproduced in high definition by means of three Samsung 32" Full HD screens, one located in front of the driver's seat on which the central rear-view mirror and windscreen wipers are reproduced. The remaining two are placed at the side and inclined at 25° with respect to the first in order to create a visual field of about 120° and a greater immersion in the virtual scenario. The side mirrors are also reproduced in them.

Sound effects are reproduced through 5.1 surrounding system: three are under the driver's seat, including a subwoofer, and the remaining three below the screens.

The driving position (Figure 3) simulates as much as possible that of a real car and is in fact equipped with:

- adjustable seat in eco-leather with a special safety belt;
- dashboard for ignition of the vehicle, horn and handbrake and safety key for disabling the circuit in the event of anomalies during simulation;
- display reproducing speedometer, on-board instrument lights, running gear, distance traveled and instant consumption;
- steering wheel, through which vibrations and stimuli due to the pavement are perceived, at bumps or whatever and the deviation suffered by the vehicle in the event of an impact. Equipped with the relative levers for the activation of the direction

indicators, of the low and high beam headlights, and the control of the windscreen wipers;

- seven-speed manual gearbox positioned on the right as in the usual car;
- pedal set composed of clutch, brake and gas pedal.

Figure 3 Simulator Detail

The operator-software interface takes place by means of a control station (Figure 4), from which it is possible to design and implement the scenario, start, display and suspend the simulation, and export the data of the same.

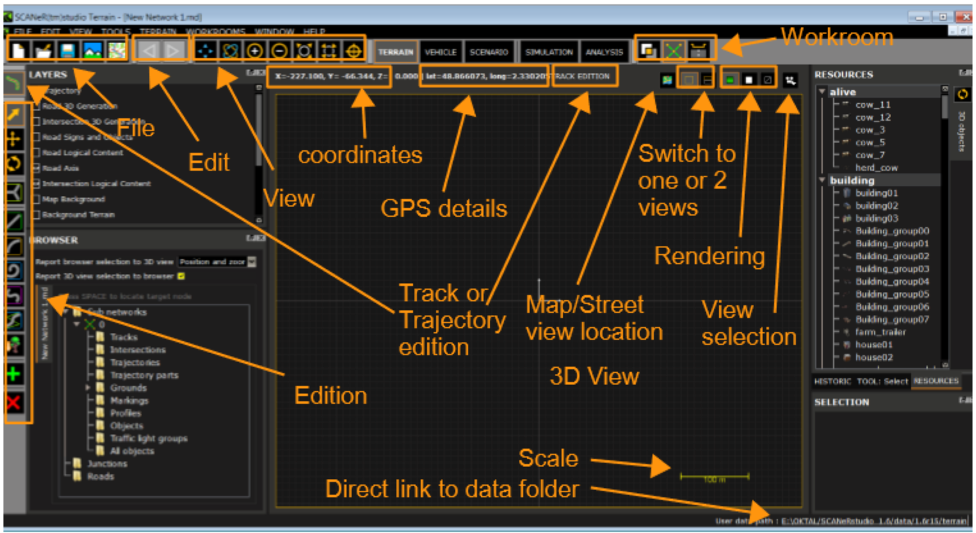


Figure 4 Software Interface in Terrain Mode

The program supplied by the manufacturer is SCANeR^{TM}studio. It allows the control all the simulation phases, from the design to data collection. In particular, it is divided into five sections, each of which is dedicated to specific functions.

The terrain mode is used to design the geometric characteristics of the route: the horizontal alignment, the elevation profile and the cross sections. Furthermore, it allows the insertion of objects of furniture implemented directly in the software or chargeable through external files.

The vehicle mode would allow you to modify or import the characteristics of the vehicle used within the simulation.

With the scenario mode the actual design of the experiment is possible, in particular in this application the traffic, environmental, and lighting conditions are defined, in addition to defining the vehicle to be used in the simulation phase. The traffic (activation, displacement, and timed deactivation of a number of autonomous vehicles) is regulated by means of simple programming scripts, realized mainly with "if-then" cycles. The vehicles that make up the traffic, chosen from a vast list of cars, are autonomous, and for each of them it is possible to define the route to follow, the type of driving (prudent, normal or aggressive), the maximum speed, the respect or less of the limits, and more.

The simulation mode is instead directed to the management and control of the driving phase, from the control station it is also possible to vary the meteorological and lighting conditions.

The last application is the analysis mode, in which the data recorded during the simulation is collected. The same can be visualized through graphs for a better interpretation and can be exported in a format compatible with Microsoft® Excel to be more easily analyzed and treated.

2.2 Design of the Experiment

2.2.1 Selection of Participants

The participants involved in the experiment were selected from professors, technical staff, graduate students, employees of *Politecnico di Torino* and a group formed by outside.

The age distribution of drivers in field research at that moment is reported in Table 2. So, all the sample staffs are male, and the average age equal to 36.14. Setting one experiment group in the same condition is needed to be as a comparison sample.

Table 2 Field Experiment Group

Number	Gender	Age
1	Male	35
2	Male	25
3	Male	30
4	Male	50
5	Male	27
6	Male	39
7	Male	47
Average	/	36.14

The age of drivers that can be selected varied between 24 and 63 years old. The sample size were 34 drivers. They were divided into 2 groups. One group had 7 participants which had the same age and gender distribution to filed sample and the other had 40 participants, including group 1, to simulate real Italy drivers' population distribution. It followed that each participant undergone only one single test, but the result of each volunteer can be used for two groups at the meantime according to our need.

Before assuming the possible distribution of the sample, a study of the Italian driver population distribution was carried out. This analysis has used information on driving licenses on the website of the Ministry of Transportation (MIT, 2017).

As the information Table 3 shows, the age between 45-64 accounts for the largest proportion and the age smaller than 25 accounts for the smallest proportion.

In Table 4, the ratio of male to female who have driving licenses is almost the same. We can keep 1:1 for male to female or a bit more males. It depends on the participants who are coming to make the best arrangement.

Table 3 Italian Drivers' distribution of Age

Licenses Population By Age			
N°	Range	Amount	%
1	<25	3 083 172	7.96
2	25-34	5 679 399	14.66
3	35-44	7 415 976	19.15
4	45-64	15 067 898	38.90
5	>65	7 484 601	19.32
	Total	38 731 046	100

Table 4 Italian Drivers' distribution of Gender

Licenses Population by Gender		
Gender	%	Amount
Male	55.14	20 583 900
Female	44.76	16 708 252
Total	99.90	37 292 152

Through the data present in MIT, there was 0.1% lost where it was not possible to assigned the class to which it belonged to.

In the meantime, because there were no participants older than 65 in database, so in Table 5, the sample falling into the age group over 65 was redistributed in the other three classes, defined as under 25, between 25 and 45, and between 45 and 65, through a calculation that follows the weighted average.

The average age of the Italian driver's population has a difference by 5.2 years as Table 6 which is not too large.

Then defined the sample class of group 1 according to the distribution of field group. In Table 7, it's the group 1's arrangement and this group was taken as one comparison with field group. Group 1 participants' distribution corresponded to field group.

Table 5 Re-Distributed Age

Re-Distributed											
Range of Age				Range of Age				Range of Age			
N°	Range	Total	%	N°	Range	Total	%	N°	Range	Total	%
1	<25	3083172	7.96	1	<25	3083172	7.96	1	<25	3083172	9.87
2	25-45	13095375	33.81	2	25-45	13095375	33.81	2	25-45	13095375	41.91
3	45-64	15067898	38.90	3	45-64	15067898	38.90	3	45-64	15067898	48.22
4	>65	7484601	19.32								

Table 6 Average Age Values

Drivers average estimated [years]	48.3
Medium (without over 65) [years]	43.1

Table 7 Group 1 Arrangement

Group 1			
N°	Range	%	Driver
1	<25	9.87	1
2	25-45	41.91	4
3	45-64	48.22	2

In Table 8, group 2's age arrangement for 40 participants initially were defined. The age distribution corresponded to the analysis we did above for Italy's distribution of drivers strictly.

Table 8 Group 2 Arrangement

Group 2			
N°	Range	%	Driver
1	<25	9.87	4
2	25-45	41.91	16
3	45-64	48.22	20

In Table 9, group 2's gender arrangement for 40 participants initially were defined. The gender distribution is also corresponded to the analysis above for Italy's distribution of drivers strictly.

Still needed to add 15 people as the backup in case that someone of group are not available. The list of groups invited can be seen in attachment. The sample in the list respects the initial hypothesis of representation of the Italian population of drivers. In fact, if we evaluate the average age of the sample (41.9), it appears to be slightly lower than the average value of the Italian driver population (43.1 years). The gender distribution of the sample (42.5% females and 57.5% males) respects the data of the Italian driver population (44.76% females and 55.14% males) (MIT, 2017).

Table 9 Group 2 Gender Distribution

Group 2		
Gender	%	Driver
Male	55.14	22
Female	44.76	18
Total	99.90	40

After completing the list of participants, they were invited to come to the laboratory to do the experiments. The invitation letter is in attachment 1. When receiving their reply, contacted them to fix the appointment of the experiment.

Finally, 34 participants in total have confirmed their willing to take part in the experiments. The list of participants is in attachment 6. Crash was happened for 4 of these 34 participants during the experiments.

2.2.2 Simulator Training

Before carrying out the experiment, it was necessary to train the participants who didn't have experience at the driving simulator. The test drivers thus had the opportunity to learn about the simulator and some important information for getting a successful outcome of the experiment.

This driving training was carried out before the test. It was important to observe the physical conditions of the participants as if the test drivers were able to withstand the fairly long simulated driving session. The influence during the simulation can produce different kinds of discomforts to the drivers: visual fatigue, dizziness and other symptoms related to simulation.

The test track for training (Figure 5) consists of the following elements: (i) a carriageway with two lanes in each direction, (ii) horizontal and vertical road signs, (iii) some public and/or private buildings, (iv) trees and other vegetation.

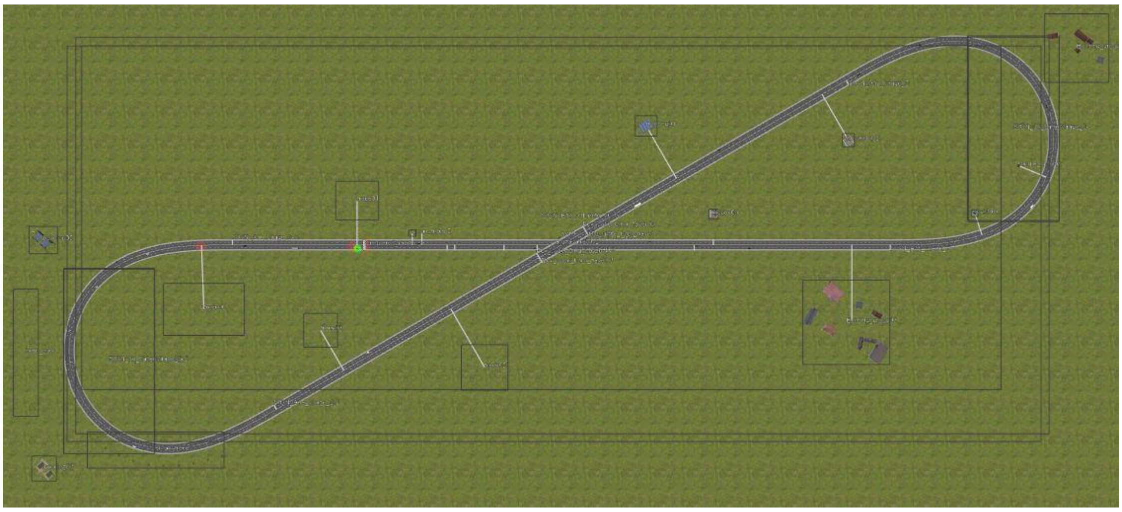


Figure 5 Test Track Used for Training

2.2.3 Experimental Arrangement

This section presents the protocol of the experiment that each participant followed from their entry into the laboratory until the end of the test. It was divided into five main phases which show the specific actions that each participant performed.

The first phase needs about 10 min. The procedure begun with the participant entering the laboratory, then the pre-test started (about 5-10 min). The participant was accommodated in the driving position for the pre-test in order to get familiar with the use of simulator. Then the participant was invited to fill in the pre-questionnaire (Attachment 2).

The second phase needed about 15 min. The participant was informed about the method of the experiment. In particular, they should be told to keep the attitude of real driving and be aware of that: the driving simulator is NOT a video game, but a research tool, therefore it was requested to drive in a realistic way.

The third phase needed about 20 min. This is the most important phase of the experiment. Participants started their driving and the data was recorded. Before that, the participant was subjected to a series of cognitive (visual and auditory) tests (Attachment 3). The participant started the driving in the direction from point of S170_2 to S169. There is the speed limit sign but drivers no need to limit the speed inside that range. On the road, some traffic flow was added in order to give a real feeling like real word, but they won't stop the drivers to let drivers drive in free flow speed conditions.

The fourth phase needs about 15 min. At the end of the third phase the experiment result was officially generated. The participant re-run the cognitive tests in the same way as in third phase in order to compare the two results obtained and to understand if there are important differences in cognitive abilities induced by the test.

In the fifth phase the participant filled the post-questionnaire (see Attachment 4).

2.3 Test Track in Simulator

2.3.1 Alignment Information Acquisition

To get the same track between simulator and real case, the model was built using SCANeR^{TM}studio version 1.7 software according to the AutoCAD information available about the real track. There were two AutoCAD files (Attachment 7) corresponded to the road SP 169_1 and SP 170_2. Figure 6 includes a small section of the horizontal alignment of SP 169_1.

The horizontal alignment information was listed into a table (Attachment 7) and inputted into SCANeR^{TM}studio 1.7 to obtain the same horizontal alignment in the simulation environment. For getting information of vertical alignment, the information was read from AutoCAD layout graph of vertical alignment (Figure 7).

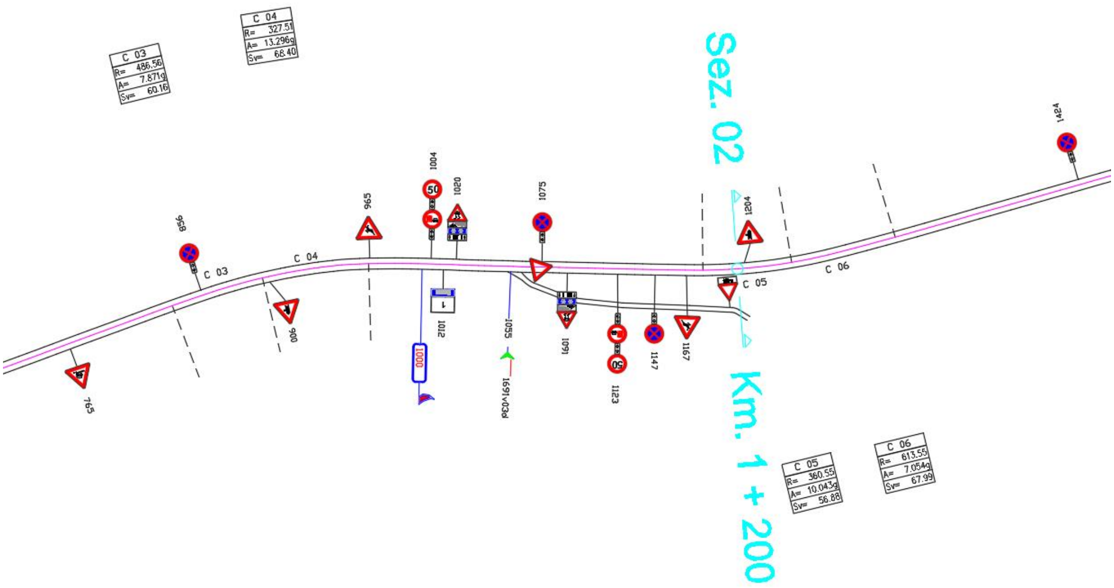


Figure 6. Part of Horizontal Layout of SP169_1

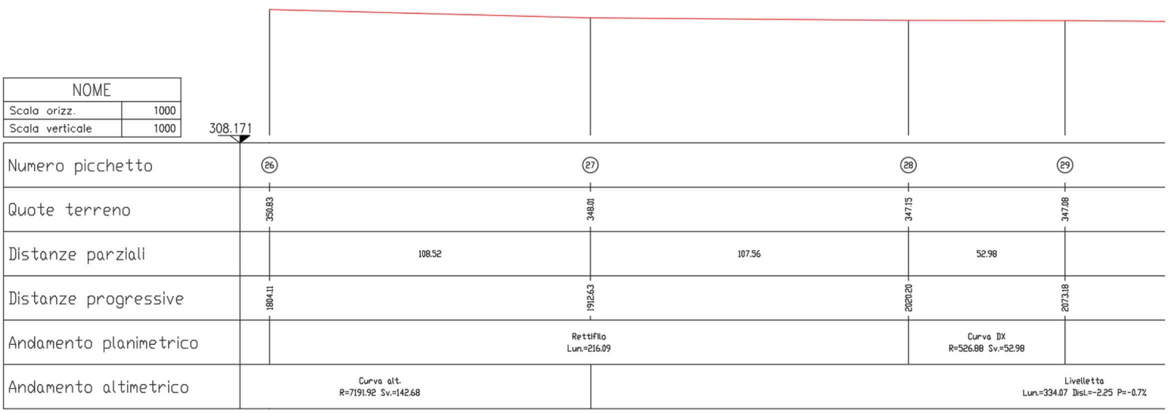


Figure 7. Part of Vertical Layout Example of SP169_1

About cross section, there was one cross section file for each km (Figure 8), so data from such source was inputted into the simulator to associate the cross sectional characteristics to the horizontal alignment.

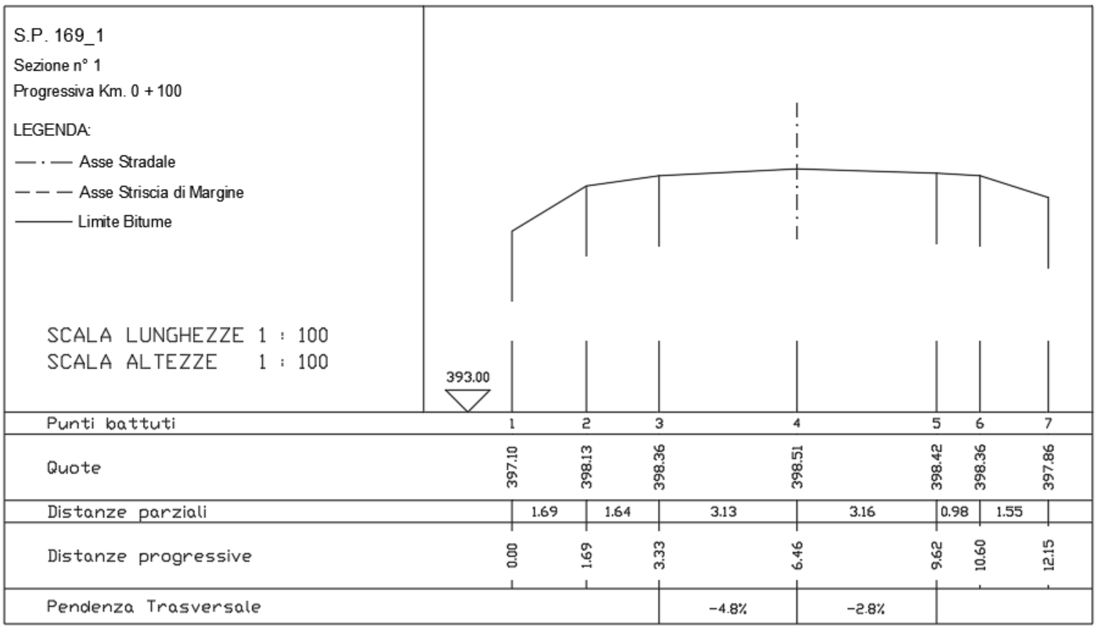


Figure 8 Cross Section Layout Example of SP 169_1 of Starting Point

2.3.2 Test Track Model and Scenarios

As the methodology to get information of test track that was presented in above, the curvature diagram of the sections for one direction was reported in Figure 9 (indicated with the letter A and B). In the diagram, a positive curvature characterizes right-hand curves, while a negative curvature indicates left-hand curves.

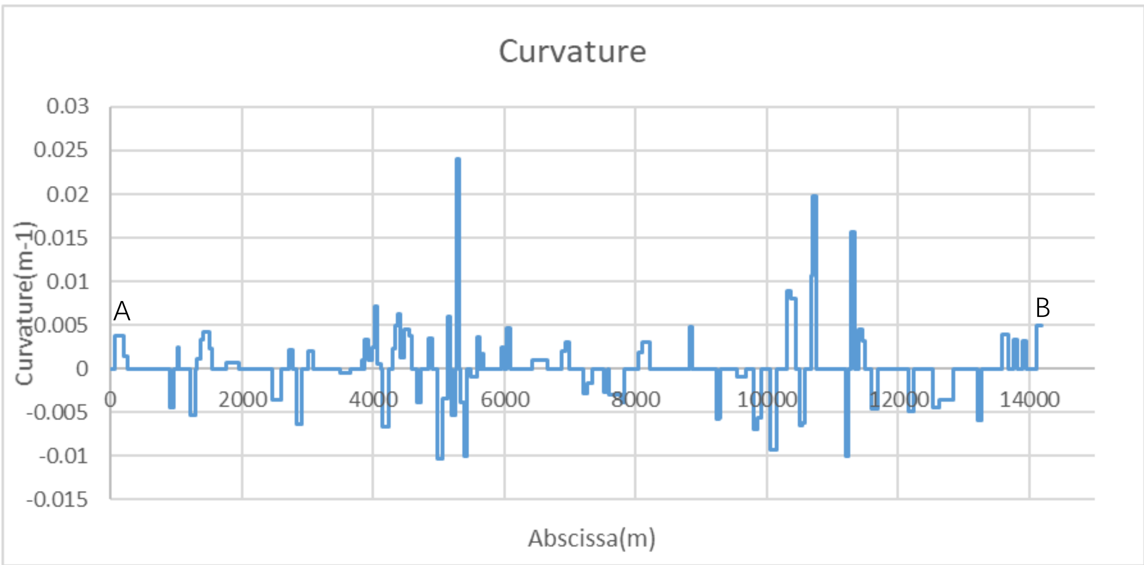


Figure 9 Alignment Curvature Diagram

Figure 10 shows parts of the road scenarios comparison implemented in the simulation software.

Figure 10 Pictures of Real (left) and Simulated (right) Scenarios

2.4 Participants Personal Data Acquisition

2.4.1 Questionnaires

During the experiment, drivers filled two questionnaires (Attachment 2 and 4) to understand the health conditions before carrying out the experiment, and to understand the sensations perceived during experiments, both of a psycho-physical nature with the quantification of any symptoms of simulator sickness perceived, and confidence with the equipment. These parameters allow researchers to have evaluations on the quality of the simulator to represent a real experience, so as to make any changes and improvements to the same in future experiences.

The pre-drive questionnaire was aimed at collecting information about the general state of health, the use of drugs or alcohol and the time in which the last meal was made. And for all participants, their states were good during experiment judged from the questionnaires. The post-drive questionnaire was used to obtain information about the driving experience with the test track. The questionnaire can be taken as a reference to improve the simulator equipment and point out the unreasonable place of test track which is useful to understand some questions related to test track during the analysis after experiments.

As regards the post-simulation questionnaire, an excellent result was noted as the disturbances for each driver were very limited. Those most frequently reported (Figure 11) were generally visual fatigue and dizziness. However, even though analyzing the response provided by the individual driver, no one has shown such levels of discomfort as to justify their exclusion from the driver sample. Therefore, it was possible to avoid having to eliminate valuable trajectories data collected by the driving simulator and useful in the analysis phase.

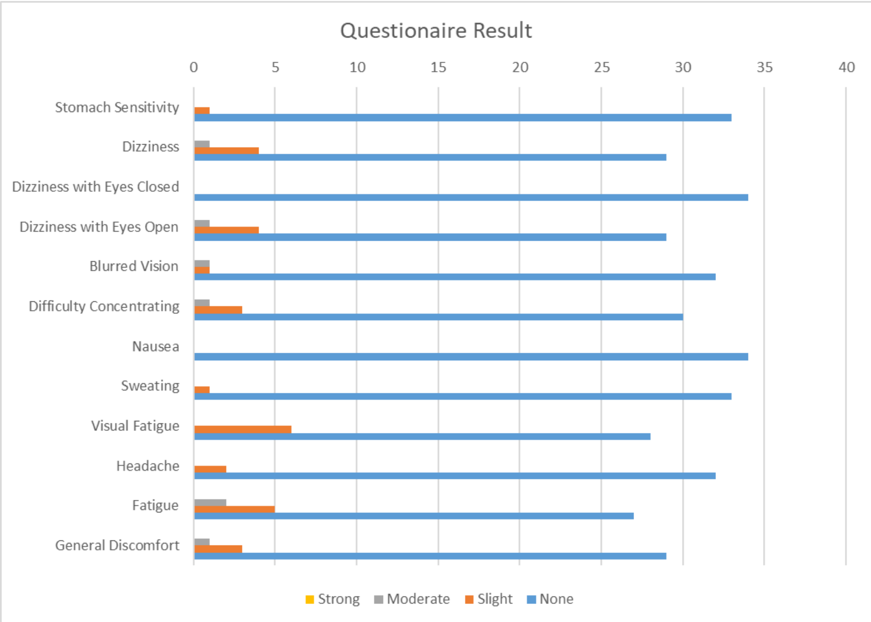


Figure 11 Post-simulation Questionnaire Result

2.4.2 Cognitive Tests

Each participant was accompanied by a cognitive test (Attachment 3) in order to have an objective comparison on the degree of attention with which the drivers prepared to carry out the experience and the test was also carried out to understand if cognitive performance could have been changed during the experiment as the result of fatigue induced by the simulation.

The cognitive tests carried out allow to measure reaction time, required by a participant to perform an action given certain stimuli. They were of two types: visual and auditory.

The visual test was carried out through the proposition of two types of stimuli: in the case of the appearance of the concentric with a red point (Figure 12 (a)), they must not take any action; the subjects must be pressed in the area indicated on the screen if the green dot is showed (Figure 12 (b));

The auditory test was carried out through the emission of a sound stimuli. The test begins with the proposition of Figure 12 (a), according to which the subjects will have to be pressed if the specific stimuli is verified by the sound emitted subsequently.

(a) (b)

Figure 12 Two Types of the Concentric

The participants were subjected to 17 visual stimuli and 17 sound stimuli, of which reaction time was recorded. The web platform (https://cognitivefun.net/test) automatically summarizes the measurements, and shows average reaction time.

3. Data Processing

3.1 Position Data Treatment

Once the data from the driving simulator was collected, there was the problem of assembling two different coordinate systems: the one in real world from the GPS instrument which worked in geographical coordinates, and the data from the simulator which operated in local coordinates. A prior conversion of the different reference systems was necessary. Two conversions need to be done: from geographic coordinates to cartographic for field research; from local coordinates to cartographic for simulator through conversion.

The criterion of least squares was used imposing that the transformation determines the minimum differences of these known points from the two reference systems. The process is expressed by the equation (1):

$$\begin{pmatrix} X_P \\ Y_P \end{pmatrix} = \begin{pmatrix} X'_0 \\ Y'_0 \end{pmatrix} + \lambda \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \begin{pmatrix} X'_P \\ Y'_P \end{pmatrix} \quad (1)$$

The X_P and Y_P coordinates represent the point in the cartographic reference system; the coordinates X'_P and Y'_P identify the point in the local and geographic reference system in which it must add the only translation of the origin of the two reference systems of X'_0 and Y'_0. And α is the rotation value α and λ is a scale factor.

Because of the impossibility of making a correlation between the real and the simulated road axes with absolute precision since different starting positions and deviations of measurement, they were treated separately. It was also necessary since each trajectory has its own length, a direct comparison between data measured on different trajectories is not possible without the use of a reference line. Then, the as-built alignment from the two environments was used as a reference element to define the curvilinear abscissa and to compare results.

From Figure 13, positions of the vehicle center (x_i, y_i) were used to derive vehicle orientation (heading angle, α_i).

$$\alpha_i = \arctan\left(\frac{x_{i+1}-x_i}{y_{i+1}-y_i}\right) \quad (2)$$

The next equations (3) and (4) are for the curvature (c) and the curvature change rate (c_r) of the driving trajectory respectively. According to the difference in two station movement, c and c_r can be calculated as follows:

$$c_i = \left(\frac{d\alpha}{ds}\right)_i = \frac{\alpha_{i+1}-\alpha_i}{s_{i+1}-s_i} \quad (3)$$

$$c_{r,i} = \left(\frac{dc}{ds}\right)_i = \frac{c_{i+1}-c_i}{s_{i+1}-s_i} \quad (4)$$

In these three equations, x and y represent the East and North coordinates of the driver's position between two points i and i+1. Abscissa "s" was recorded along direction of the centerline of test track. Curvature was assumed positive in the case of a rightward curve, while c_r was considered as absolute terms. (3)

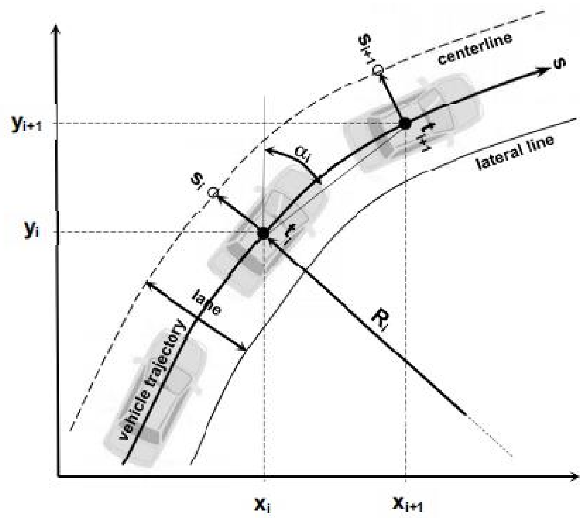


Figure 13 Description of Position Data

Not only for the heading angle but also for the result gotten from these three equations, there were Gaussian noise appeared for the position system. In order to remove the noise, it was necessary to filter the heading angle, curvature and curvature change rate by using abscissa progressively increased for each 1 meter. In this case, the local noise component in the data can be reduced without affecting the actual information content of the trajectory geometry.

3.2 Predictive Model of the Trajectory Curvature

It presented the mathematical model used in Excel for processing the data obtained from field original data and to develop a predictive trajectory curvature for drivers in real scenarios since the sample size of field research is small, so there must be deviations in this case. Even though researchers have removed the parts of data which were affected by surrounding, there were still deviations influenced by drivers' habits for this small sample size. So, at that time the spatial data points collected in the investigation have also been used to calibrate a model that could be used to predict the trajectory curvature (c_T). Considerations in field research suggested that drivers anticipated the steering action when passing a curve. Although this action resulted primarily from a visual interpretation of the geometrics of the road environment ahead of drivers, it was also influenced by the geometry of the elements just passed. So, it was thought to develop this model for making a comparison between predictive trajectory data and data obtained from the curvature values of the road axis in the real and simulated scenarios.

Based on the above considerations, a discrete model structure was proposed for field research reflecting general driver behavior affected by the road characteristics in terms of test track. The model was structured as a moving average with weighted factors that decrease as the distance from the point under consideration increases. The curvature at a generic point i of vehicle trajectories ($c_{T,i}$) was supposed to depend on the horizontal alignment curvature. The horizontal alignment curvature values are defined for a certain distance along the road center line. The equation for the model is as follows (1):

$$c_{T,i} = \frac{\sum_{h=i-n}^{h=i+n} c_{AB,h} \cdot p_h}{\sum_{h=i-n}^{h=i+n} p_h} \tag{5}$$

where $c_{AB,h}$ indicates the horizontal alignment curvature at a generic point h located in a range across the i-th point, p_h represents a weighted factor as a function of the distance from the generic h-th point, n is the number of points preceding and following the *i*-th assumed to estimate the trajectory curvature c_T step by step.

3.3 The *T*-test Statistics

It is a parametric statistical test with the aim of validating if the mean value of a distribution deviates significantly from a certain reference value.

Also, the *t*-test is used when it needs to verify the hypothesis that the mean value of the population does not differ significantly from a certain constant value μ_0. If in the survey you want to evaluate the following null hypothesis:

$$H_0: \mu = \mu_0 \tag{6}$$

in front of the bidirectional alternative hypothesis:

$$H_1: \mu \neq \mu_0 \tag{7}$$

The *t* parameter is calculated as follows:

$$t = \frac{X-\mu_0}{\sigma/\sqrt{n-1}} \text{ with } X = \sum_{n=1}^{N} \frac{x_i}{N} \tag{8}$$

x_i: sample value;

n: sample size;

σ: standard deviation.

The sample mean is normally distributed if the population is normal and, due to the central limit theorem, which allows to prove the convergence of the distribution in a Gaussian, it may be stated that the sample mean tend to normal as *n* goes to infinity. It can then be approximated to a normal distribution for high *n* values.

Standardizing respect to μ_0 it is obtained the normal average standard 0 and variance 1. Since the sample size and the standard deviation are known, the rejected test region is composed by:

$$P(z < -z_{\frac{\alpha}{2}} \ or \ z > z_{\frac{\alpha}{2}}) = \alpha \tag{9}$$

where α represents the level of significance of the test. This parameter provides an indication of the opening of the acceptance-rejection area of the statistical test.

Then t-test was used to evaluate the data belonging to the same population, which was obtained from the real and simulated scenarios. t-test was performed to verify the null hypothesis H_0, which determines whether the compared datasets are part of the same population (i.e. the means and standard deviations of the two datasets are comparable, thus demonstrating that simulator reaches an absolute validation).

4. Data Analysis

To achieve the aim of trajectories' validation, three indexes of comparison between real environment and simulator which were proposed related to steering behavior has been taken into consideration:

- the anticipatory distance (d_a) between the positions where drivers initiated the steering maneuver before the TS points (TS means starting point of transition);
- the curvature (c) along the circular portion of the curve where the drivers reach the highest curvature point;
- the curvature change rate (c_r) of trajectories along transition and reverse spirals.

Figure 14 illustrates the general trend observed in the data: most of drivers anticipate the action of the steering wheel in the position (A) before the point (D) where the curvature actually changes (TS points). Then drivers pass the point (B) getting the highest curvature. Furthermore, different drivers adopted different c and c_r values. This is supported by the paper of Doi et al. (4).

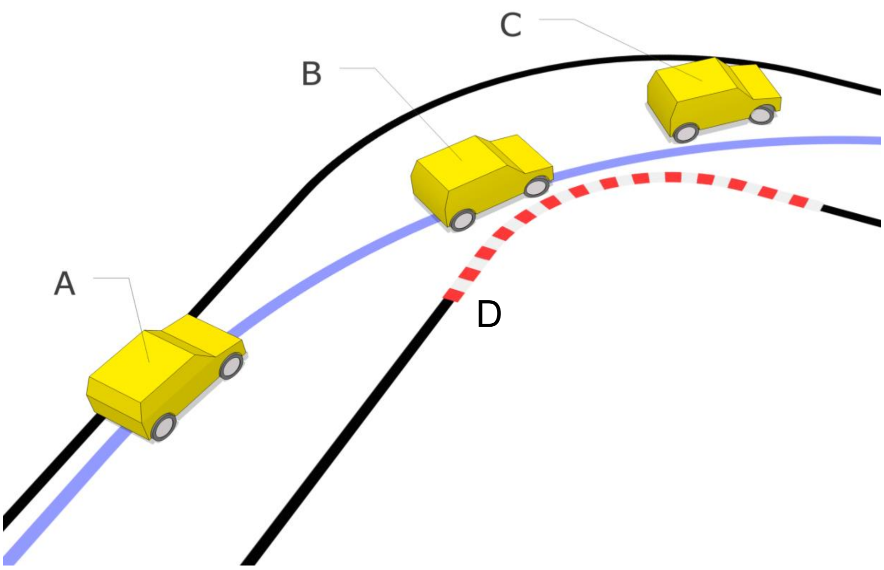
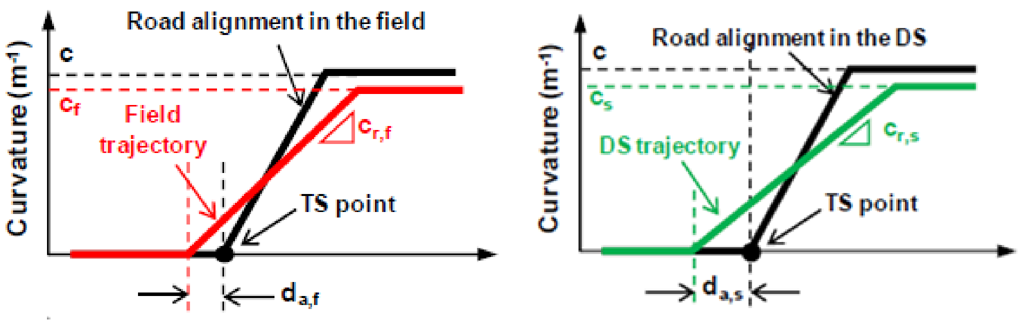


Figure 14 Steering Behavior

Figure 15 introduces one general case that was considered in data analysis: the road sections across the TS point. The case includes two graphs (3):

a. the first shows the curvature observed in the field (red line) compared with the field road alignment curvature (black line);

b. the second shows differences between the trajectory curvature (green line) and the road curvature in the DS model (black line again). It is worth noting that the curvature profiles illustrating the field alignment and the alignment in the simulated model have the same value.



(A) (B)

Figure 15 Curvature Profiles (3)

As the group arrangement divided in before, there were two groups to do the experiments. The first group had 7 males with the age distribution imitating field group's age distribution. The second group had 34 participants with the age distribution imitating the Italian drivers' age distribution.

Then using the average curvature values of each group for abscissa to get the distance d_a, the curvature c and the curvature change rate (c_r). Here showed one example for group 1, group 2 from 1 km to 2 km (Figure 16). There are two TS points. Then we interpolated the data in the TS point to get the result of d_a, c, c_r.

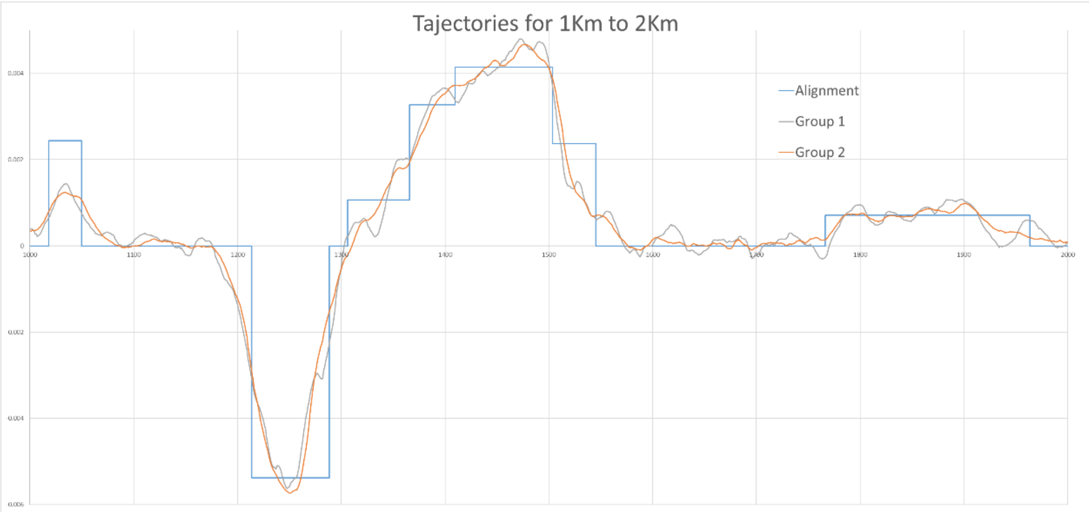


Figure 16 Group 2 Recording Curvature

Table 10 shows the result of d_a, c, c_r corresponded to above graphs. From preliminary analysis, it showed a good absolute validation result.

Table 10 Result of Example Segment from 1 km to 2 km

Group	1		2	
	First TS Point	Second TS Point	First TS Point	Second TS Point
Distance d_a (m)	37.84	13.17	63.38	64.25
Curvature c (1/m)	-0.00538	-0.00430	0.00546	0.00418
CCR c_r	-7.81E-05	2.05E-05	-5.76E-05	8.55E-06

Then all the data was elaborated in this way for group 1, 2, field data and predictive model of field data.

5 Results and Discussion

5.1 Anticipatory Distance (d_a)

According to the method of treatment described above, data were elaborated. Here, and in further analysis, collected data were depicted with box-plots, showing the mean and median values, the 1st and 3rd quartile. The statistical tests were also conducted consisting of field and simulated sample data (t-Test). Specifically, t-value obtained assuming one-tailed and two-tailed between samples. A level of significance for statistical tests was assumed equal to 5%. The null hypothesis H_0 is accepted if the value of t is less than the critical t values of two tails, otherwise the null hypothesis H_0 is rejected. Finally, the t-test was performed to verify the null hypothesis H_0, which determines whether the compared datasets are part of the same population (i.e. the means and standard deviations of the two datasets are comparable, thus demonstrating that DS reaches an absolute validation). Otherwise, in the case of a rejection of the H_0 hypothesis, data were analyzed to evaluate the direction and the magnitude of the difference between samples (i.e. assessing if a relative validity was obtained).

For field group's result, the abscissa interval of drivers' position was 25 m and the interval of points for the horizontal alignment was 10 m. Thus, it was in a low precision to define a precise anticipatory distance. There must be measurement deviations in filed. And the cumulative deviations became bigger and bigger in magnitude of 10^{+1} for anticipatory distance. It caused field anticipatory distance d_a is always bigger than simulator's result. Meanwhile, the sample size is also too small to be representative. Therefore, to solve this problem, field predictive model was elaborated which was much more precise with estimating the trajectory correctly according to recorded data. Therefore, here predictive model was used for validation aims with simulator.

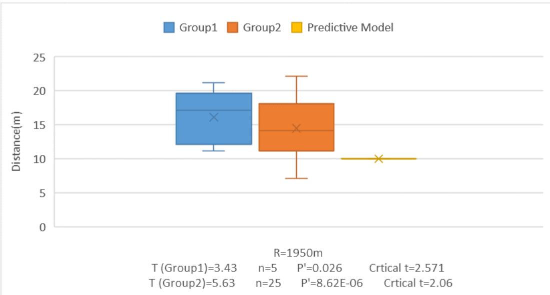
Table 11 has summarized the all box plot results for comparisons of anticipatory distance between simulator and real scenario (Attachment 10). It revealed that mean (and median) values of d_a in the simulated scenario are always higher than those in the predictive field model for the portions where curve radius is bigger than 1000 m (100% for group 1 and group 2). Meanwhile, mean (and median) values of d_a in the simulated scenario are always lower than those in the predictive field model for curves whose radius are lower than 450 m (75% for group 1 and 90% for group 2). Statistical *t*-tests revealed that the H_o was always rejected for entering maneuvers ($t >$ critical t). This result makes it possible to determine the relative validity of the simulator for these specific conditions. A detailed examination reveals that observational data values collected on the simulator are consistently higher and lower than those from real driving scenarios for curves of these ranges. However, mean (and median) values of d_a in the simulated scenario are equal to those in the predictive field model for the radius approaching 500 m (100% for group 1 and group 2). Statistical *t*-tests revealed that the H_o was always accepted for entering maneuvers ($t <$ critical t). So absolute validity was reached for this situation. Figure 17 presents some representative graphs of results for sections with different radius.

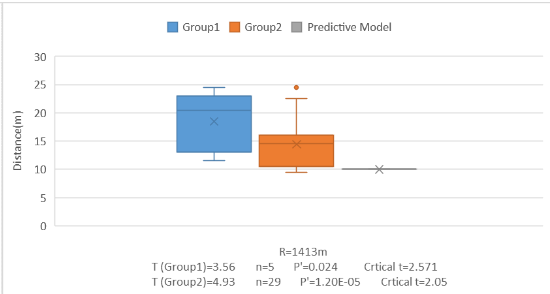
The difference between simulator and field for small and big curve radius may be attributed to at least two factors: the less detailed nature of the virtual environment with respect to the real one, and the limited quality of the visual hardware employed. These two factors curb the sense of depth perceived by a driver looking at the simulator screens when the steering radius is big or small. The fact that drivers involved in experiments at the simulator underestimate and overestimate distances, implies an accentuation of the drivers' anticipatory behavior with respect to the same event in real driving. (3)

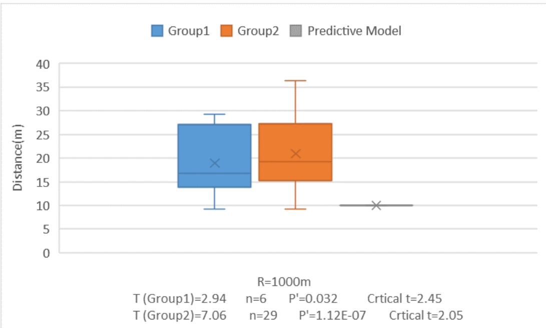
Table 11 Validation Results for Anticipation Distance

Road Element	No. of Sections	Group 1			Group 2		
		Absoulute Validation	Relative Validation		Absoulute Validation	Relative Validation	
			$d_S > d_R$	$d_S < d_R$		$d_S > d_R$	$d_S < d_R$
Curve (R≥1000m)	5	0 (0%)	5 (100%)	0 (0%)	0 (0%)	5 (100%)	0 (0%)
Curve (R≅500m)	4	4 (100%)	0 (0%)	0 (0%)	4 (100%)	0 (0%)	0 (0%)
Curve (R<450m)	20	5 (25%)	0 (0%)	15 (75%)	2 (10%)	0 (0%)	18 (90%)

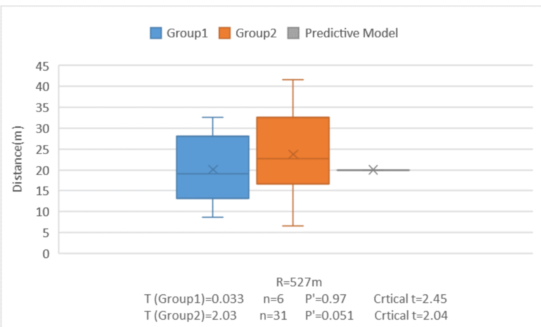
R ≥ 1000 m

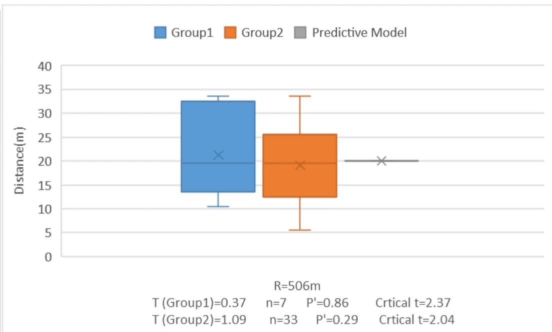


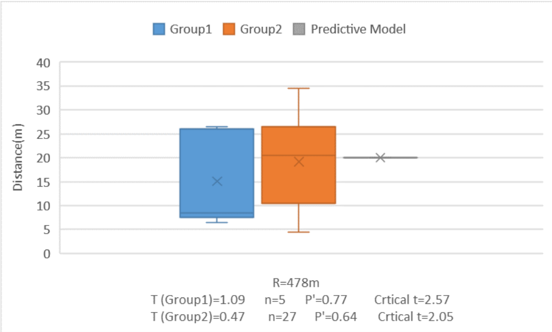




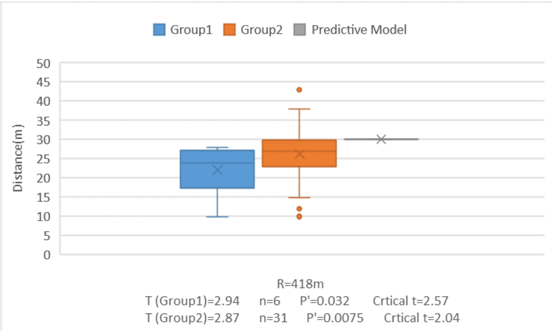
R around 500 m

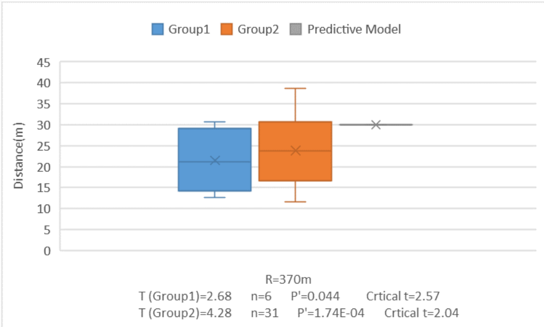


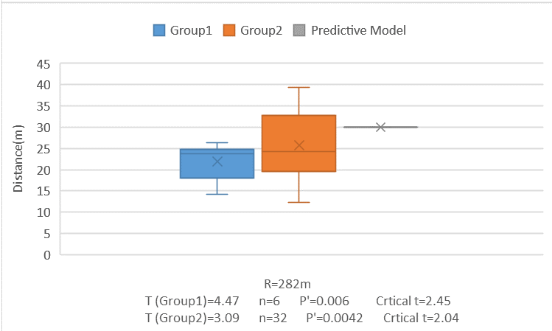


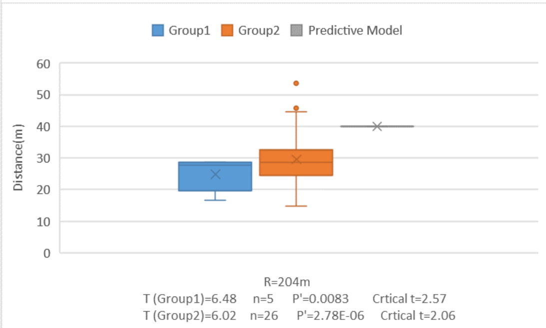


R < 450 m









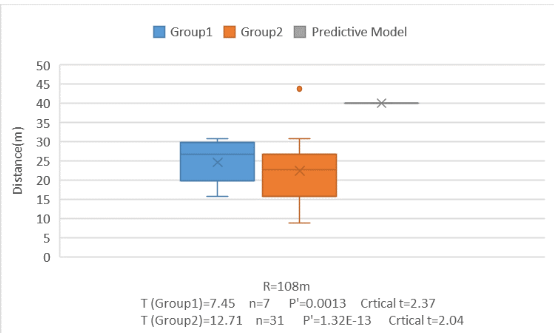


Figure 17 Box Plots of Comparison for Anticipatory Distance between Simulator (Group1 & Group2) and Real Scenario (Predictive field model)

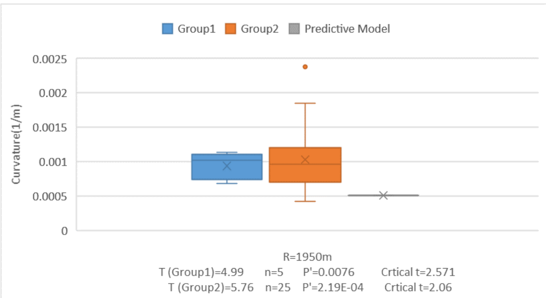
5.2 Curvature (*c*) Along Circular Arc

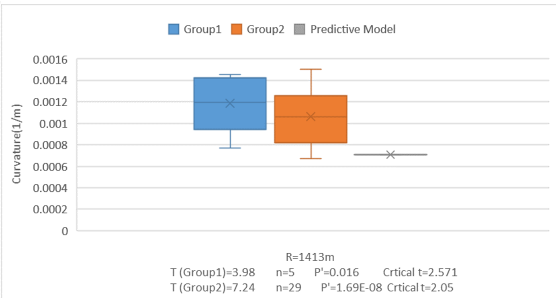
Results for curvature *c* are reported in Figure 18 (arranged according to radius from big to small). The T-test revealed all curvature data to be normally distributed with a level of significance of 5%. Table 12 has summarized the all box plot results for comparisons of curvature between simulator and real scenario (Attachment 11). The result shows that mean (and median) values of d_a in the simulated scenario were always higher than those in the predictive field model (over 90% for all cases). Statistical t-tests revealed that the H_o was always rejected for entering maneuvers (T > critical t). This result determined the relative validity of the simulator for curvature. Figure 18 presents some representative graphs of results for sections with different radius.

It revealed that most drivers adopted trajectories with a lower radius than that in real scenario. The difference between simulator and field may also be attributed to the less detailed nature of the virtual environment with respect to the real one. The less nature information lets drivers overestimate the curvature in simulator to be sure they can pass the curve safely.

Table 12 Validation Results for Curvature

Road Element	No. of Sections	Group 1			Group 2		
		Absoulute Validation	Relative Validation		Absoulute Validation	Relative Validation	
			$c_S > c_R$	$c_S < c_R$		$c_S > c_R$	$c_S < c_R$
Curve (R>1000m)	5	0 (0%)	5 (100%)	0 (0%)	0 (0%)	5 (100%)	0 (0%)
Curve (R≅500m)	4	0 (0%)	4 (100%)	0 (0%)	0 (0%)	4 (100%)	0 (0%)
Curve (R<450m)	20	2 (90%)	18 (90%)	0 (0%)	0 (0%)	20 (100%)	0 (0%)





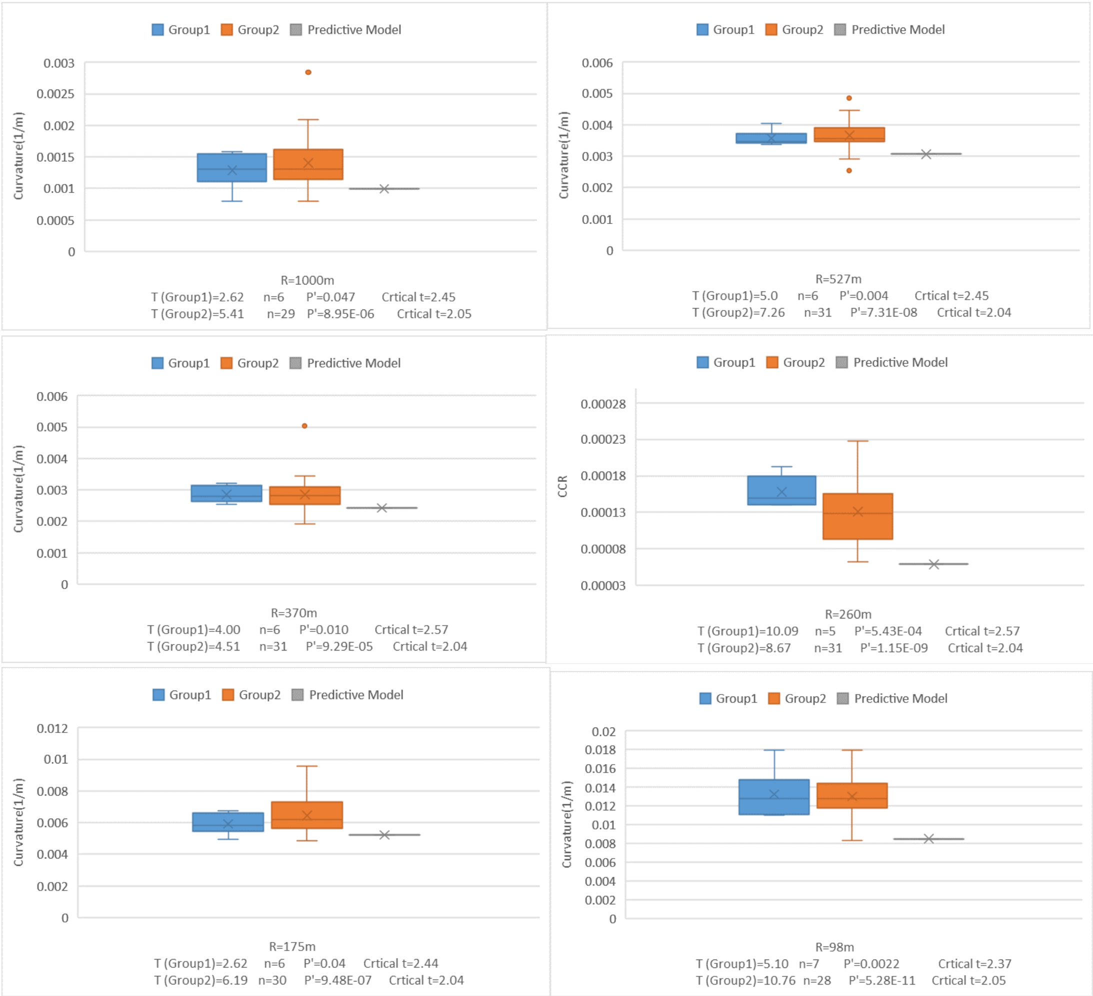


Figure 18 Box Plots of Comparison for Curvature between Simulator (Group1 & Group2) and Real Scenario (Predictive field model)

5.3 Curvature Change Rate (c_r) at TS Entering Points

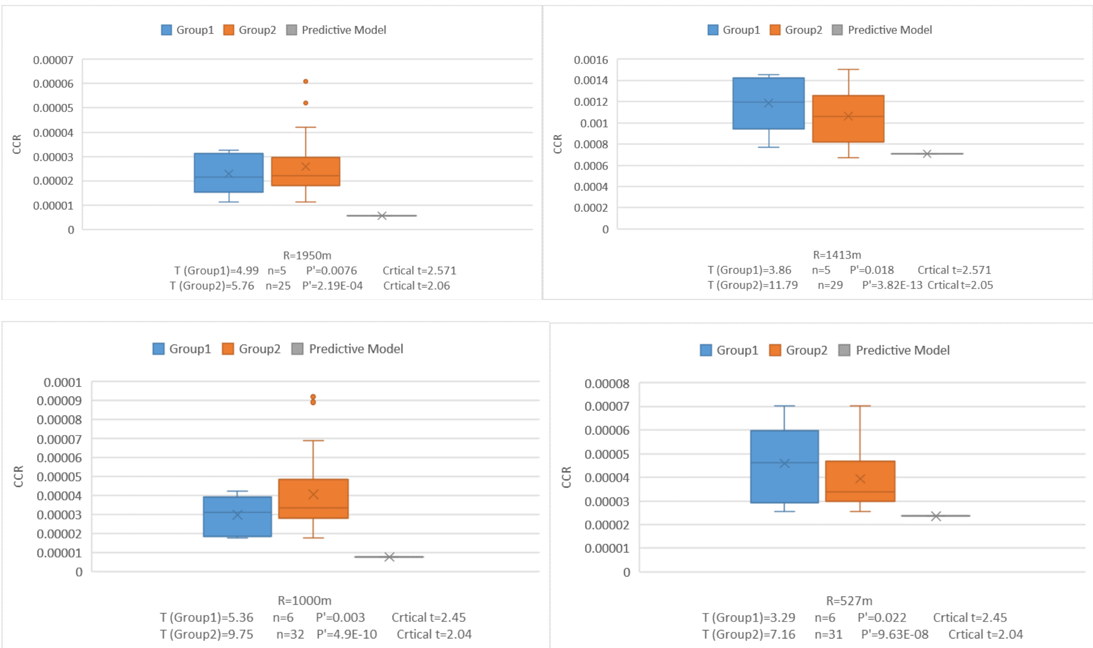
Figure 19 shows the results for c_r when approaching the curves. Mean values and median of the sample were compared with the curvature change rate in real scenario. Again, the T-test revealed that collected data were normally distributed with a level of significance of 5%

Table 13 has summarized the all box plot results for comparisons of curvature change rate between simulator and real scenario (Attachment 12). For most drivers in simulator, c_r was always higher than the values in real scenario (over 90% for all cases). Statistical t-tests revealed that the H_o was always rejected for entering maneuvers (T > critical t). This result determined the relative validity of the simulator for curvature. Figure 19 presents some representative graphs of results for sections with different radius.

It showed that in simulator, drivers compensate for less errors made when anticipating the curvature change at TS points than that in real scenario. It causes a higher angular speed of the steering wheel in simulator compared with real scenario. The difference could be attributed to the less traffic in simulator. This gives people a free turn and a higher turn speed to complete steering action faster than that in real scenario.

Table 13 Validation Results for Curvature Change Rate

Road Element	No. of Sections	Group 1			Group 2		
		Absoulute Validation	Relative Validation		Absoulute Validation	Relative Validation	
			$C_S > C_R$	$C_S < C_R$		$C_S > C_R$	$C_S < C_R$
Curve (R>1000m)	5	0 (0%)	5 (100%)	0 (0%)	0 (0%)	5 (100%)	0 (0%)
Curve (R≅500m)	4	0 (0%)	4 (100%)	0 (0%)	0 (0%)	4 (100%)	0 (0%)
Curve (R<450m)	20	2 (90%)	18 (90%)	0 (0%)	0 (0%)	20 (100%)	0 (0%)



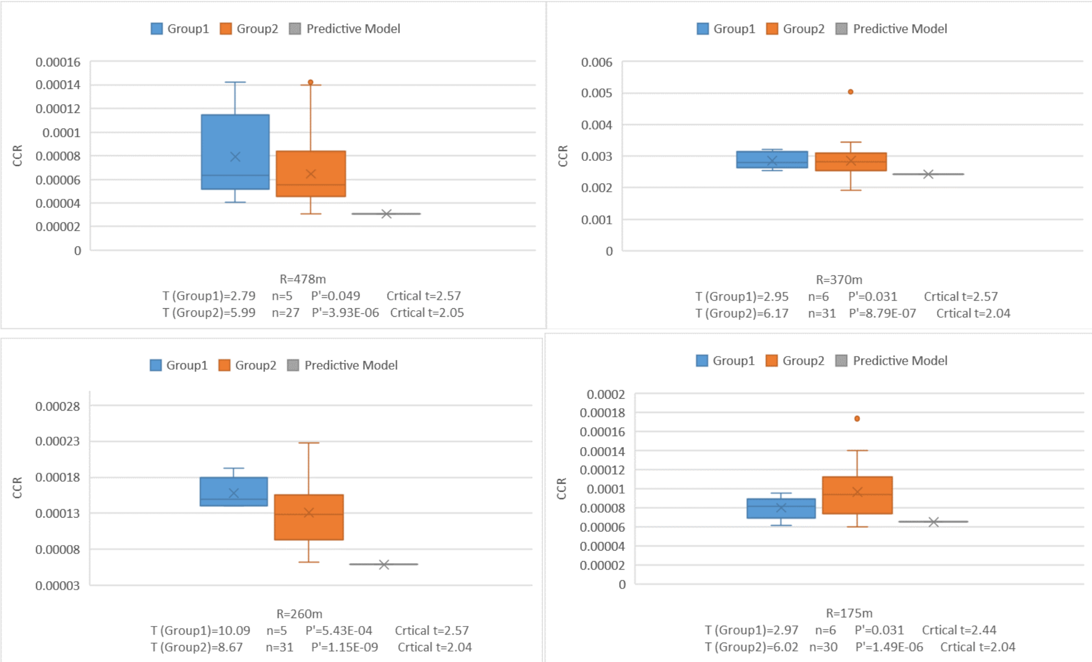


Figure 19 Plots of Comparison for Curvature Change Rate between Simulator (Group1 & Group2) and Real Scenario (Predictive field model)

6. Conclusion

This thesis has conducted the comparison for anticipation distance, curvature along circular arc and curvature change rate between along transitions between straight and curves of data coming from the real word and the simulator for validation purposes. Although it was already carried out on a section of 3 km closed to Turin, with this experiment one more significant case (15 km) was added to reinforce the research on validation for different environments and road types. To achieve this aim, first it was necessary to get a precise simulator model including alignment information and scenarios. Then, participants were divided into some groups according to the aims. For trajectory validation, fundamental understanding of the correlation was needed between the steering behavior of drivers in the field and at the simulator. For data treatment, a filtering method through enlarging the interval of abscissa was used to remove noise caused from the positioning system used for vehicle tracking. A predictive field model was also elaborated to conduct the validation with simulator because of the few spatial data points of original field recordings.

The main results of this research follows:

- the validity of the anticipatory distance (d_a) depends on the curve radius. There is an absolute validity between simulator and real scenario when radius of curve approaches 500 meters (supported by 100% of results of two groups where the radius approaches 500 m), otherwise it shows a relative validity in cases where radius was bigger than 1000 m or lower than 450 m (supported by over than 75% of results in these cases). This finding is attributable to the variable nature of driver perception of the egocentric distance with respect to the point of curvature change;
- curvature (c) values recorded at the simulator are always higher than those in the field (supported by over than 90% of results of two groups), thus suggesting a relative validity for the simulator used in this research. The difference between simulator and field may also be attributed to the lower detailed nature of the virtual environment with respect to the real one;

- there is a relative validation for curvature change rate (c_r) according to box plots graphs and statistical analysis result. Values obtained at the simulator are always higher than those from the real scenario (supported by over than 90% of results of two groups). It means a higher angular speed is happened in simulator to complete steering action faster than real scenario.

In future, there is also a need to assess the potential for alternative visual equipment (i.e., virtual headset) to compensate for the limited sense of depth that drivers experience with the simulator screens.

7. References

(1) Cerni, G., & Bassani, M. (2017). Naturalistic driving data collection to investigate into the effects of road geometrics on track behaviour. Transportation Research Part C: Emerging Technologies, 77, 1-15.

(2) Cina A. Dal GPS al GNSS (Global Navigation Satellite System) per la Geomatica (in Italian). Celid, Torino, Italy, 2014.

(3) Catani L., & Bassani M. (2019, January). Anticipatory Distance, Curvature, And Curvature Change Rate In Compound Curve Negotiation: A Comparison Between Real And Simulated Driving. In *Proceedings of the 98th Transportation Research Board Annual Meeting, Washington, D.C*.

(4) Doi, M., Zeng, K., Wada, T., Doi, S. I., Tsuru, N., Isaji, K., & Morikawa, S. (2013, October). Steering-assist control system on curved road using car-to-car communication. In *16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013)* (pp. 1-6). IEEE.

Attachments

Attachment 1 Invitation Letter

prof. Marco BASSANI

PRESENTAZIONE DELL'ATTIVITA' DI RICERCA

Torino, giugno 2019

Gentilissimo/a,

ti contatto in quanto risulti componente del gruppo di *test driver* che supporta le attività del *Laboratorio di Sicurezza Stradale e Simulazione di Guida* del Politecnico di Torino (Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture - DIATI).

Nelle prossime settimane abbiamo in programma un nuovo esperimento che necessita del tuo supporto. Esso riguarda il **confronto tra guida reale e guida simulata**. La sperimentazione in oggetto prevede in giorni e orari a te più comodi, una eventuale prima seduta di addestramento di circa 15 (quindici) minuti, nel corso della quale prenderai confidenza con il simulatore, a cui seguirà, se ritieni anche in altro giorno, il vero e proprio esperimento (in questo caso non più di trenta minuti).

Ti segnalo che:

- **se tu avessi già guidato al simulatore sarà sufficiente che tu venga solo per l'esperimento, quindi una sola volta;**
- **se fossi interessato/a a partecipare ti chiederei cortesemente di scrivermi una email di conferma;**
- **se tu avessi già compilato i moduli nelle pagine successive in recenti esperimenti, non è il caso che tu li ricompili nuovamente, abbiamo bisogno solo di un tuo messaggio di conferma di partecipazione.**

Qualora disponibile, ti chiederei di seguire alcune utili raccomandazioni che troverai nel questionario nelle pagine successive, così da non alterare l'esito dell'esperimento.

Al ricevimento della tua documentazione o messaggio di accettazione, sarai contattato telefonicamente dall'ing. **Laura Alunni** (telefono: 347-2209386) per definire nel dettaglio l'appuntamento.

I dati raccolti saranno diffusi in forma aggregata e del tutto anonima (v. "Informativa sulla privacy", pagina 4). I risultati saranno divulgati per soli scopi scientifici senza fini di lucro, e potranno essere presentati in convegni, pubblicati su tesi di Laurea, o in articoli di riviste scientifiche sempre in forma aggregata e rigorosamente anonima.

L'accesso ai locali del Laboratorio ti sarà consentito solamente se accompagnato/a da personale autorizzato. Preciso, infine, che la partecipazione a questa attività è del tutto volontaria, e non è soggetta ad alcun compenso.

Ti ringrazio in anticipo per l'attenzione che presterai a questa iniziativa, e della gentile disponibilità che ci vorrai riservare,

QUESTIONARIO PER ATTIVITA' DI RICERCA CON L'USO DEL SIMULATORE DI GUIDA

Nome e Cognome ……………………………………………………………………………………………

Sesso ☐ M ☐ F

Anno di nascita ………………

Telefono (cellulare) ……………………………………… e-mail ……………………………………………………………

Livello di istruzione ☐ licenza media inferiore ☐ qualifica professionale triennale
☐ diploma scuole superiori ☐ laurea 1° livello o diploma universitario
☐ laurea 2° livello o vecchio ordinamento
☐ specializzazioni/master post laurea 2° livello/dottorato

Anno di conseguimento della patente di guida ………………

km percorsi in un anno (media) ………………

n° di incidenti in cui si è stati coinvolti ………………

Familiarità con l'uso di software di guida (es. videogiochi) ☐ SI ☐ NO

Utilizzi dispositivi per la correzione visiva? ☐ SI ☐ NO

Se si, quali? ☐ Occhiali ☐ Lenti a contatto

Precedenti episodi di crisi epilettiche? ☐ SI ☐ NO
(o epilessie in trattamento farmacologico)

Raccomandazioni da seguire prima di effettuare le guide al simulatore:

- chi li utilizza, indossi le lenti a contatto, il sistema di tracciamento oculare non consente di tenere i propri occhiali,
- consumare pasto (colazione e/o pranzo) leggeri prima della guida,
- non assumere bevande alcoliche e/o eccitanti (caffè, *energy drink*, o simili) almeno 2 ore prima.

Il sottoscritto si rende disponibile a effettuare l'addestramento e il test con il simulatore di guida presso il *Laboratorio di Sicurezza Stradale e Simulazione di Guida* – DIATI (ingresso 2, piano terreno):

il giorno lunedì – martedì – mercoledì – giovedì – venerdì alle ore 9 - 12 12 - 15 15 - 18 oppure
il giorno lunedì – martedì – mercoledì – giovedì – venerdì alle ore 9 - 12 12 - 15 15 - 18 oppure
il giorno lunedì – martedì – mercoledì – giovedì – venerdì alle ore 9 - 12 12 - 15 15 - 18
(cerchiare o spuntare il giorno e l'orario preferiti)

Luogo e data …………………………………… Firma ……………………………………………….

Informativa resa ai sensi degli articoli 13-14 del GDPR 2016/679 (General Data Protection Regulation)

Gentile Signore/a,

ai sensi dell'art. 13 del Regolamento UE 2016/679 ed in relazione alle informazioni di cui si entrerà in possesso, ai fini della tutela delle persone e altri soggetti in materia di trattamento di dati personali, si informa quanto segue:

1. FINALITÀ DEL TRATTAMENTO

I dati da Lei forniti saranno utilizzati per scopi di ricerca scientifica, consentendo ai soggetti autorizzati al trattamento di costruire un campione di guidatori con caratteristiche idonee all'attività in esame.

2. MODALITÀ DEL TRATTAMENTO

Il trattamento dei dati sarà effettuato sia manualmente, con supporti cartacei, sia con l'ausilio di mezzi informatizzati. I dati saranno conservati sia in archivi cartacei sia in archivi elettronici. In ogni caso il trattamento dei dati avverrà con logiche strettamente correlate alle finalità indicate e con modalità che garantiscano la sicurezza e la riservatezza dei dati medesimi, attraverso l'adozione di misure idonee ad impedire l'alterazione, la cancellazione, la distruzione, l'accesso non autorizzato o il trattamento non consentito o non conforme alle finalità della raccolta.

3. CONFERIMENTO DEI DATI

Il conferimento dei dati per le finalità di cui al punto 1 sono obbligatori e l'eventuale rifiuto dell'autorizzazione comporta l'esclusione dall'attività di ricerca.

4. COMUNICAZIONE E DIFFUSIONE DEI DATI

I dati forniti saranno comunicati ai soggetti autorizzati: ricercatori, responsabili e incaricati del trattamento. In ogni caso, i dati forniti non saranno soggetti a comunicazione né a diffusione. Come espresso all'art. 162 del Regolamento UE n. 2016/679, "*La finalità statistica implica che il risultato del trattamento per finalità statistiche non siano dati personali, ma dati aggregati, e che tale risultato o i dati personali non siano utilizzati a sostegno di misure o decisioni riguardanti persone fisiche specifiche*".

5. TITOLARE DEL TRATTAMENTO

Il titolare del trattamento dei dati personali è il prof. Marco Bassani, Politecnico di Torino, Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture, corso Duca degli Abruzzi, 24 – 10129 Torino.

6. DIRITTI DELL'INTERESSATO

In ogni momento, Lei potrà esercitare, ai sensi degli articoli dal 15 al 22 del Regolamento UE n. 2016/679, il diritto di:

a) chiedere la conferma dell'esistenza o meno di propri dati personali;
b) ottenere le indicazioni circa le finalità del trattamento, le categorie dei dati personali e, quando possibile, il periodo di conservazione;
c) ottenere la limitazione del trattamento;
d) ottenere la rettifica e la cancellazione dei dati.

Può esercitare i Suoi diritti con richiesta scritta inviata al titolare del trattamento, all'indirizzo mail marco.bassani@polito.it, oppure marco.bassani@pec.polito.it.

Io sottoscritto/a dichiaro di aver ricevuto l'informativa che precede.

Torino, lì ……………………… Firma ………………………………………………………………………….

Io sottoscritto/a alla luce dell'informativa ricevuta

◻ esprimo il consenso ◻ NON esprimo il consenso al trattamento dei miei dati personali e, espressamente, al trattamento di eventuali dati sensibili, per il conseguimento delle su esposte finalità.

◻ esprimo il consenso ◻ NON esprimo il consenso al trattamento dei risultati delle esperienze di guida svolte e alla loro pubblicazione su tesi di Laurea Magistrale e/o pubblicazioni scientifiche in forma aggregata e rigorosamente anonima.

Attachment 2 Pre-Questionnaire

prof. Marco BASSANI

QUESTIONARIO PER ATTIVITA' DI RICERCA CON L'USO DEL SIMULATORE DI GUIDA

QUESTIONARIO PRE-GUIDA

Nome e Cognome .... Numero identificativo del TD ....

Giorno .... Ora ....

È attualmente in buona salute? ☐ SI ☐ NO

Se no, di cosa soffre? ....

Ha assunto medicinali nelle precedenti 24h? ☐ SI ☐ NO

Se si, quali? (è sufficiente la categoria) ....

È affetto da malattie croniche (asma, diabete, ansia, allergia…)? ☐ SI ☐ NO

Se sì, quali? ....

Precedenti episodi di crisi epilettica (o epilessia in trattamento farmacologico) ☐ SI ☐ NO

Quanto tempo fa ha consumato l'ultimo pasto (colazione e/o pranzo)? ....ore ....minuti

Come lo definirebbe? ☐ Abbondante ☐ Moderato ☐ Leggero

Ha assunto bevande alcoliche e/o eccitanti (caffè, energy drink) nelle ultime 2 h? ☐ SI ☐ NO

Ha assunto bevande alcoliche nelle precedenti 24h? ☐ SI ☐ NO

Quante ore ha è dormito la notte precedente? ....

Utilizza dispositivi per la correzione visiva? ☐ SI ☐ NO

Attualmente li indossa? ☐ SI ☐ NO

Se si, quali? ☐ Occhiali ☐ Lenti a contatto

Attachment 3 Visual and Auditory Tests

prof. Marco BASSANI

QUESTIONARIO PER ATTIVITA' DI RICERCA CON L'USO DEL SIMULATORE DI GUIDA

MONITORAGGIO PERFORMANCE: TEST COGNITIVI

Nome e Cognome…………………………………………………………………..… Numero identificativo del TD………..

ORA Pre-Guida …………………... ORA Post-Guida ……………………...

n. Prova	PRE-GUIDA		POST-GUIDA	
	Test Visivo	Test Uditivo	Test Visivo	Test Uditivo
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
Tempo Medio				

Attachment 4 Post-Questionnaire

prof. Marco BASSANI

QUESTIONARIO PER ATTIVITA' DI RICERCA CON L'USO DEL SIMULATORE DI GUIDA

QUESTIONARIO DI POST-SIMULAZIONE

Nome e Cognome .... Numero identificativo del TD ....

Giorno .... Ora ....

Indicare se attualmente percepisce uno o più dei seguenti sintomi[1]:

- Generale disagio	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Fatica	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Mal di testa	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Stanchezza visiva	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Difficoltà nella messa a fuoco	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Incremento di salivazione	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Incremento di sudorazione	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Nausea	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Difficoltà di concentrazione	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Intontimento	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Visione offuscata	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Capogiro (a occhi aperti)	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Capogiro (a occhi chiusi)	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Vertigini	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Sensibilità di stomaco	☐ per nulla	☐ lieve	☐ moderato	☐ intenso
- Disturbi digestivi	☐ per nulla	☐ lieve	☐ moderato	☐ intenso

- Altro ....

Esprimere un giudizio sull'interazione con i dispositivi audio-visivi e meccanici del simulatore di guida:

- Riproduzione del campo visivo	☐ pessimo	☐ buono	☐ ottimo
- Percezione degli specchietti	☐ pessimo	☐ buono	☐ ottimo
- Veridicità degli effetti sonori	☐ pessimo	☐ buono	☐ ottimo
- Veridicità della strumentazione di bordo	☐ pessimo	☐ buono	☐ ottimo
- Risposta del volante	☐ pessimo	☐ buono	☐ ottimo
- Risposta del cambio	☐ pessimo	☐ buono	☐ ottimo
- Percezione dell'acceleratore	☐ pessimo	☐ buono	☐ ottimo
- Percezione del freno	☐ pessimo	☐ buono	☐ ottimo

Di quali elementi/strumenti si è servito per valutare la velocità di marcia?

☐ Contachilometri ☐ Monitor laterali

☐ Altro: ....

[1] *Simulator Sickness Questionnaire*

Familiarità con l'uso di software di guida (es. videogiochi)? ☐ SI ☐ NO
Se SI, ha avuto un approccio simile?

☐ per nulla ☐ poco-lieve ☐ abbastanza-moderata ☐ molto

Consigli e suggerimenti per le esperienze di ricerca future
……….
……….
……….
……….

In relazione all'esperienza avuta, parteciperebbe ad altri esperimenti di simulazione?

☐ SI ☐ NO

Quanto hanno influito i seguenti aspetti sulla sua esperienza di guida?

- Presenza della videocamera ☐ per nulla ☐ lieve ☐ moderato ☐ intenso
- Occhiali per il tracciamento oculare ☐ per nulla ☐ lieve ☐ moderato ☐ intenso

Da quali elementi è stato condizionato il suo comportamento di guida (velocità e traiettoria)?

☐ Presenza della segnaletica orizzontale ☐ Presenza delle barriere di sicurezza
☐ Presenza di elementi sulla banchina ☐ Presenza dei lavori in corso
☐
Altro ………
……
……

Sulla base della precedente domanda, le è rimasta impressa una situazione particolare? ☐ SI ☐ NO
Se SI, ne fornisca una breve descrizione.
……….
……….
……….
……….

Ha rilevato difficoltà nel guidare e nel controllare il veicolo?
☐ SI ☐ NO
Se SI, per quale motivo?
……….
……….
……….
……
……….

Attachment 5 List of Invited Participants (For Privacy reason, the names of participants are removed)

Group 1				
ID			Sex	Age
47			M	23
59			M	37
63			M	29
29			M	52
74			M	27
26			M	40
32			M	45

Group 2				
ID			Sex	Age
60			M	23
19			F	25
39			F	33
15			F	29
73			M	32
90			F	40
71			M	32
25			F	30
85			M	46
20			M	58
43			F	25
57			M	63
21			F	51
35			M	56
11			F	56
44			M	49
24			M	61
41			M	50
34			M	45
51			F	30
52			F	36
56			F	24
83			M	29
55			M	43
36			F	25
78			M	52
33			M	51
7			F	49
22			F	47
88			F	64
82			F	56
6			F	57
23			M	56
BACKUP LIST				
36			F	25
84			F	23
2			M	24
87			F	24

53			M	30
54			M	30
79			F	30
68			F	37
13			F	35
30			M	57
77			M	46
72			M	46
76			M	51
5			M	56
12			M	51

Group1	
Average Age	36.14
Gender	All Male

Group 1+2	
Average Age	41.9
Gender	17 Female 23 Male

Attachment 6 Final List of Coming Participants

No.	Name	Surname	Gender	Age
1			M	46
2			M	45
3			F	47
4			F	56
5			M	45
6			F	29
7			M	56
8			F	51
9			M	25
10			F	49
11			M	58
12			M	27
13			M	29
14			M	56
15			M	29
16			F	27
17			F	24
18			M	61
19			F	33
20			F	57
21			M	36
22			F	30
23			M	52
24			M	51
25			M	52
26			M	30
27			F	29
28			M	50
29			M	37
30			M	28
31			F	31
32			M	29
33			M	57
34			F	40

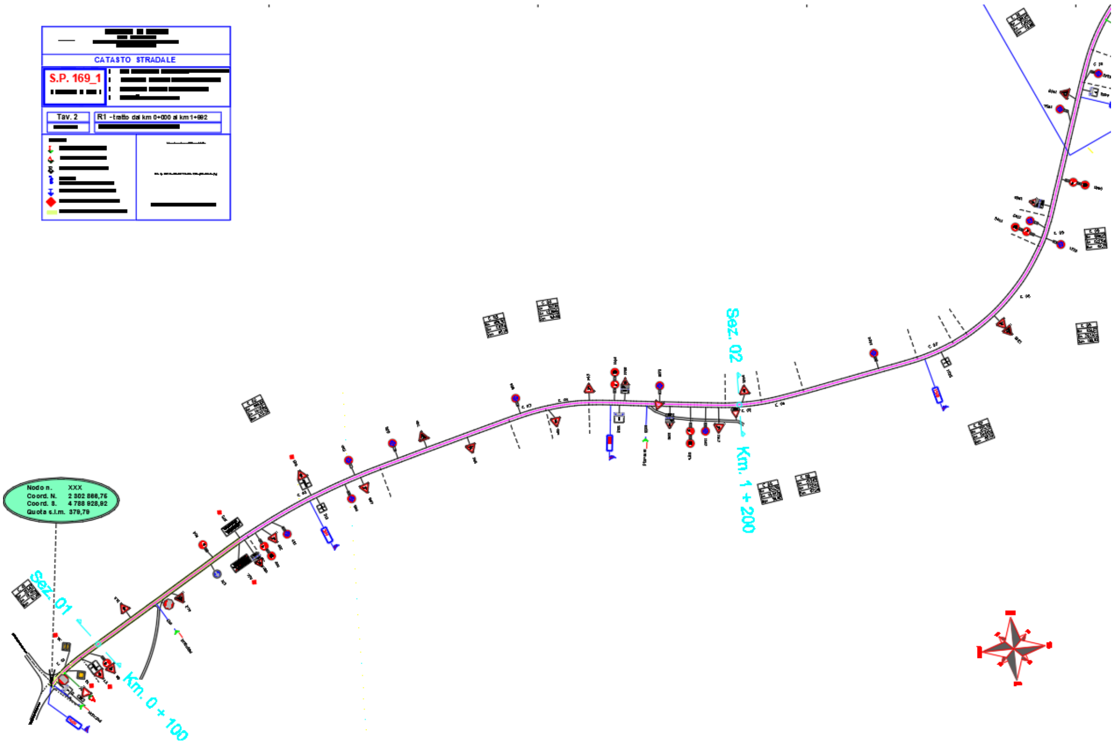
Range	Number
UNDER 25	3
25-45(NOT INCLUDE 45)	14
OVER 45	17

Gender	Number
MALE	21
FEMALE	13

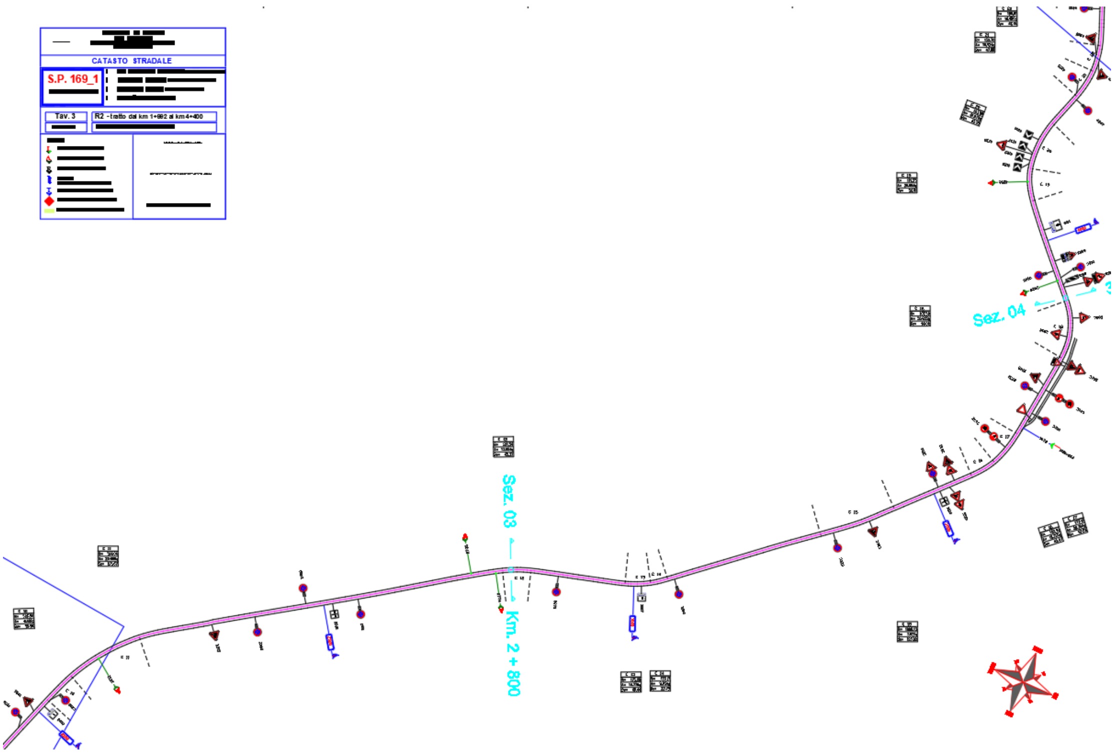
Attachment 7 Information of Road Elements

Horizontal Layout SP169_1

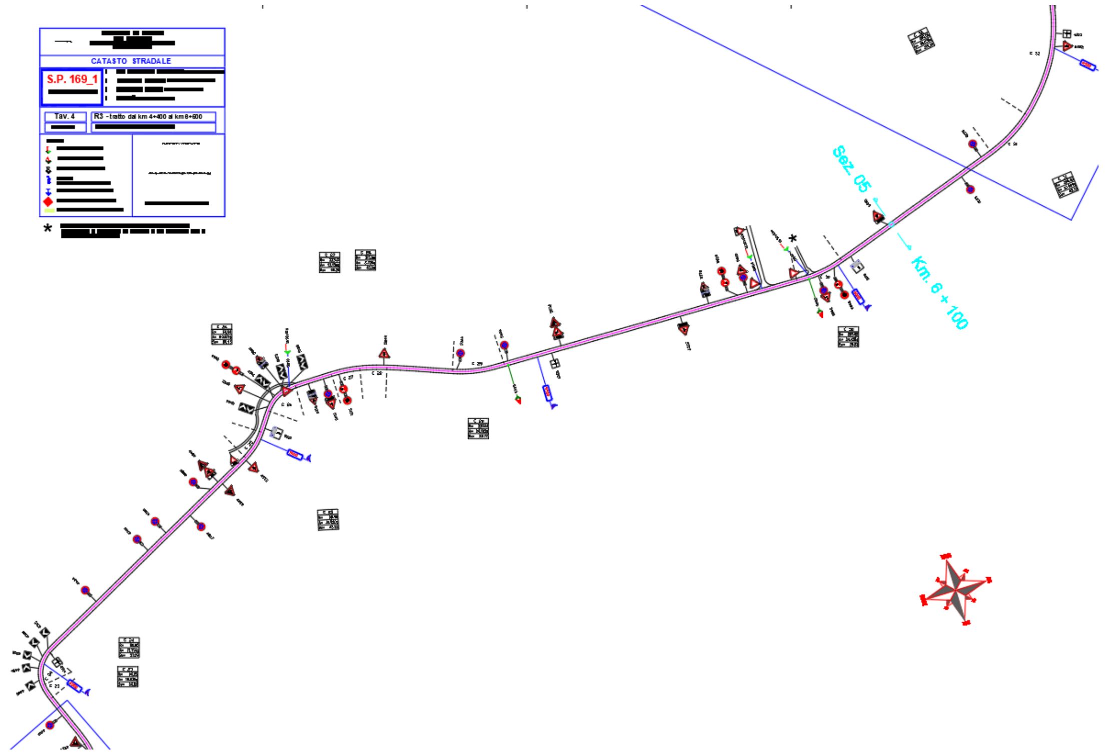
R1 Part



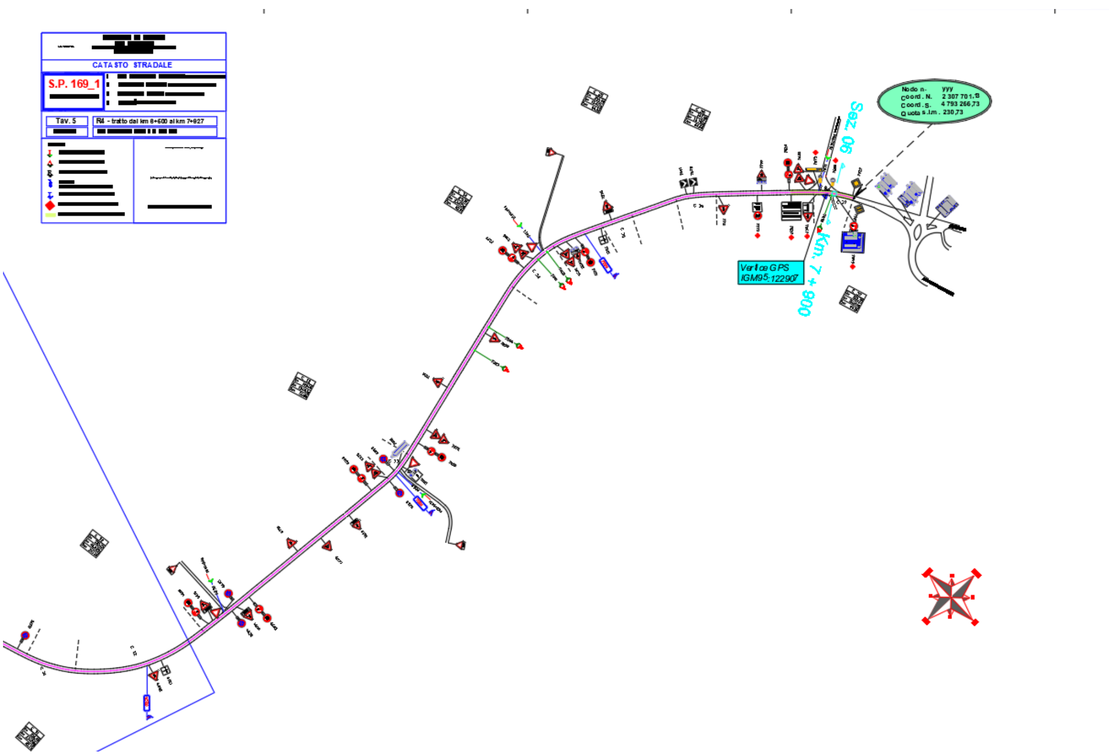
R2 Part



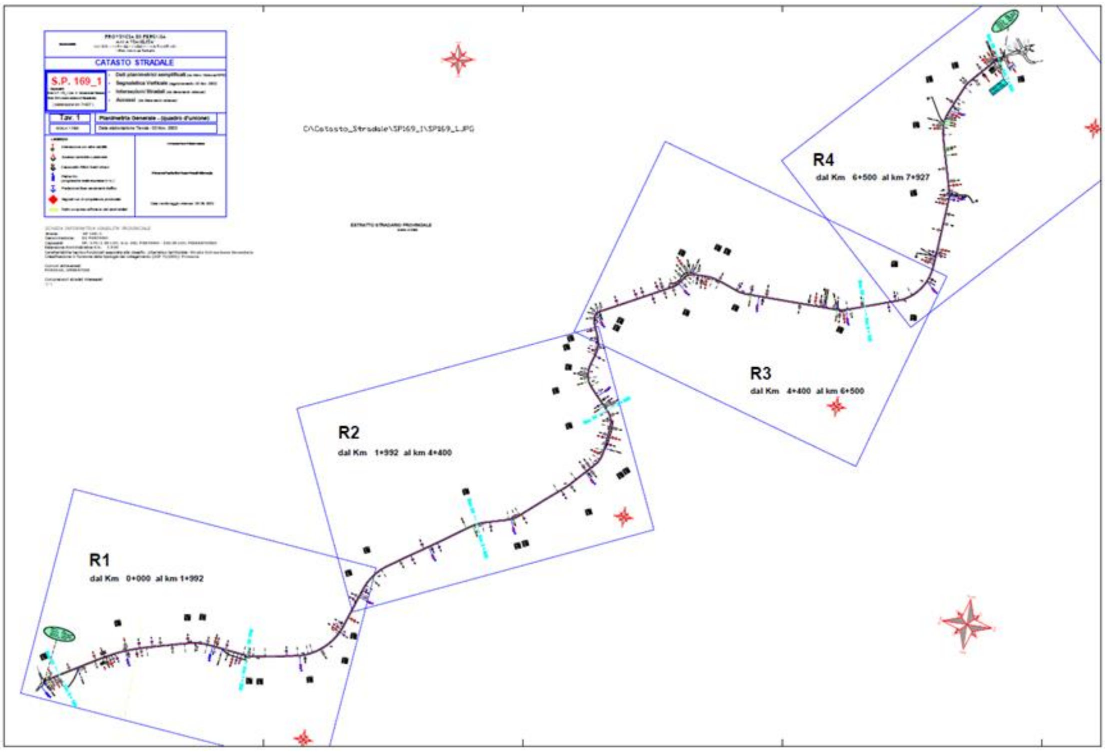
R3 Part



R4 Part

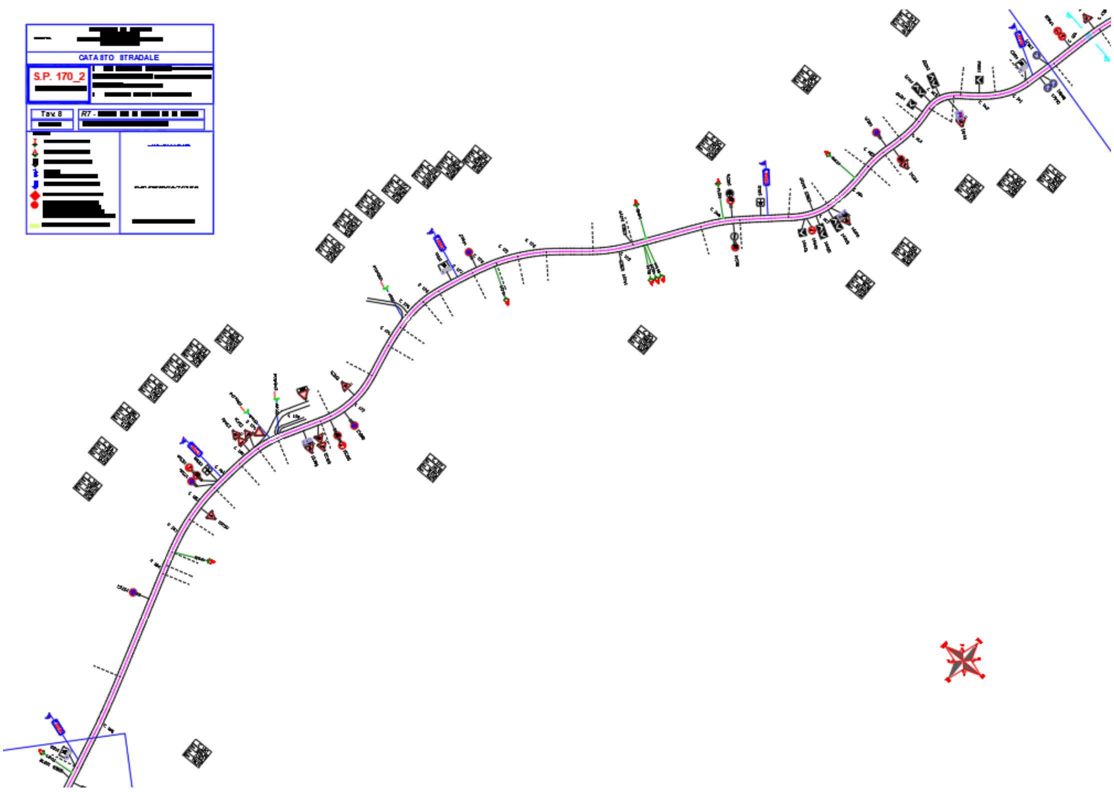


Master Plan of SP169_1

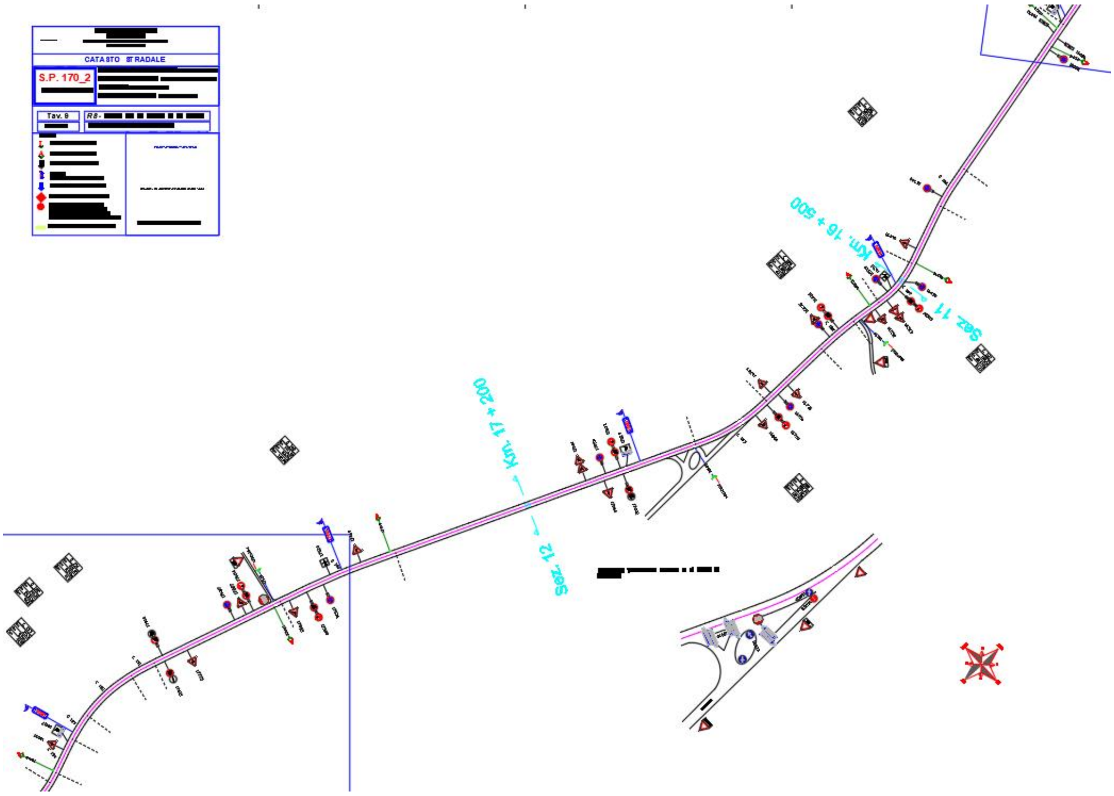


Horizontal Layout SP170_2

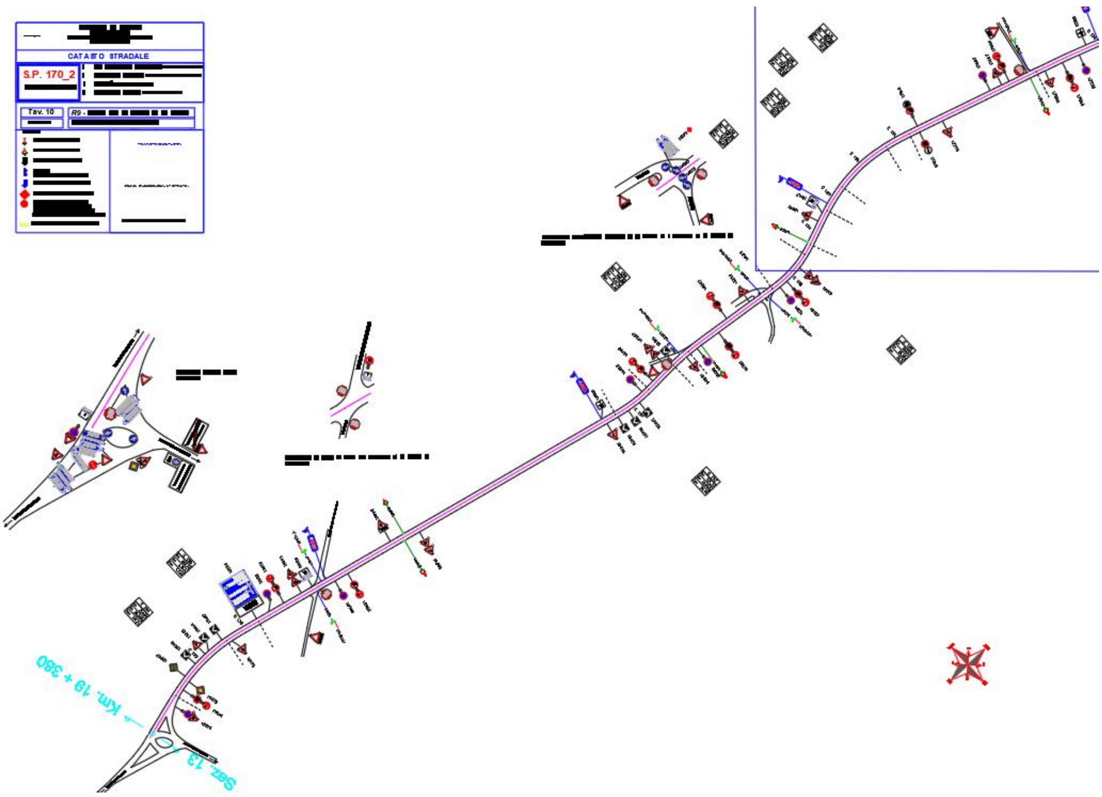
R1 Part



R2 Part



R3 Part



Horizontal Information From SP170_2 to SP169_1

Element Id	Length	R	Direction	Curvature Real	elemento	Progressiva
0	0.00			0.00E+00		0.00
1	77.75			0.00E+00	R	74.84
2	119.23	269.08	DX	3.72E-03	C	194.07
3	57.98	688.34	DX	1.45E-03	C	252.05
4	645.86			0.00E+00	R	897.91
5	65.99	-225.77	SX	-4.43E-03	C	963.90
6	54.03			0.00E+00	R	1017.93
7	31.98	409.46	DX	2.44E-03	C	1049.91
8	163.93			0.00E+00	R	1213.84
9	74.71	-185.87	SX	-5.38E-03	C	1288.55
10	17.60			0.00E+00	R	1306.15
11	59.43	936.83	DX	1.07E-03	C	1365.58
12	44.11	305.5	DX	3.27E-03	C	1409.69
13	94.01	241.21	DX	4.15E-03	C	1503.70
14	41.40	422.06	DX	2.37E-03	C	1545.10
15	221.40			0.00E+00	R	1766.50
16	196.96	1413.49	DX	7.07E-04	C	1963.46
17	502.81			0.00E+00	R	2466.27
18	132.07	-282.34	SX	-3.54E-03	C	2598.34
19	119.18			0.00E+00	R	2717.52
20	67.19	477.81	DX	2.09E-03	C	2784.71
21	49.61			0.00E+00	R	2834.32
22	81.27	-158.35	SX	-6.32E-03	C	2915.59
23	100.93			0.00E+00	R	3016.52
24	69.42	506.23	DX	1.98E-03	C	3085.94
25	411.20			0.00E+00	R	3497.14
26	158.14	-1949.69	SX	-5.13E-04	C	3655.28
27	175.61			0.00E+00	R	3830.89
28	14.16	1000.21	DX	1.00E-03	C	3845.05
29	22.56			0.00E+00	R	3867.61
30	63.06	305.54	DX	3.27E-03	C	3930.67
31	55.23	975.11	DX	1.03E-03	C	3985.90
32	37.30	419.15	DX	2.39E-03	C	4023.20
33	34.93	139.06	DX	7.19E-03	C	4058.13
34	72.87	1880.04	DX	5.32E-04	C	4131.00
35	17.71			0.00E+00	R	4148.71
36	93.22	-151.32	SX	-6.61E-03	C	4241.93
37	53.24			0.00E+00	R	4295.17
38	34.75	440.41	DX	2.27E-03	C	4329.92
39	53.80	200.97	DX	4.98E-03	C	4383.72

40	29.72	159.12	DX	6.28E-03	C	4413.44
41	61.08	770.59	DX	1.30E-03	C	4474.52
42	40.16	220.49	DX	4.54E-03	C	4514.68
43	35.29	220.49	DX	4.54E-03	C	4549.97
44	45.42	264.39	DX	3.78E-03	C	4595.39
45	73.66			0.00E+00	R	4669.05
46	63.97	-260.62	SX	-3.84E-03	C	4733.02
47	110.54			0.00E+00	R	4843.56
48	62.41	289.66	DX	3.45E-03	C	4905.97
49	76.50			0.00E+00	R	4982.47
50	67.04	-96.78	SX	-1.03E-02	C	5049.51
51	88.06	-286.2	SX	-3.49E-03	C	5137.57
52	32.82	169.31	DX	5.91E-03	C	5170.39
53	34.29			0.00E+00	R	5204.68
54	39.91	-185.44	SX	-5.39E-03	C	5244.59
55	26.22			0.00E+00	R	5270.81
56	46.70	41.53	DX	2.41E-02	C	5317.51
57	10.35			0.00E+00	R	5327.86
58	55.09	-260.02	SX	-3.85E-03	C	5382.95
59	55.03	-99.82	SX	-1.00E-02	C	5437.98
60	51.29			0.00E+00	R	5489.27
61	89.66	-1154.99	SX	-8.66E-04	C	5578.93
62	43.68	273.27	DX	3.66E-03	C	5622.61
63	44.40			0.00E+00	R	5667.01
64	9.68	600.34	DX	1.67E-03	C	5676.69
65	281.19			0.00E+00	R	5957.88
66	45.90	418.31	DX	2.39E-03	C	6003.78
67	25.59			0.00E+00	R	6029.37
68	65.48	213.67	DX	4.68E-03	C	6094.85
69	322.00			0.00E+00	R	6416.85
70	233.76	994.86	DX	1.01E-03	C	6650.61
71	214.43			0.00E+00	R	6865.04
72	60.16	486.56	DX	2.06E-03	C	6925.20
73	68.40	327.57	DX	3.05E-03	C	6993.60
74	213.10			0.00E+00	R	7206.70
75	56.88	-360.55	SX	-2.77E-03	C	7263.58
76	67.99	-613.55	SX	-1.63E-03	C	7331.57
77	185.11			0.00E+00	R	7516.68
78	60.84	-370.79	SX	-2.70E-03	C	7577.52
79	25.70			0.00E+00	R	7603.22
80	180.93	-330.67	SX	-3.02E-03	C	7784.15
81	49.35	-259.03	SX	-3.86E-03	C	7833.50
82	216.12			0.00E+00	R	8049.62

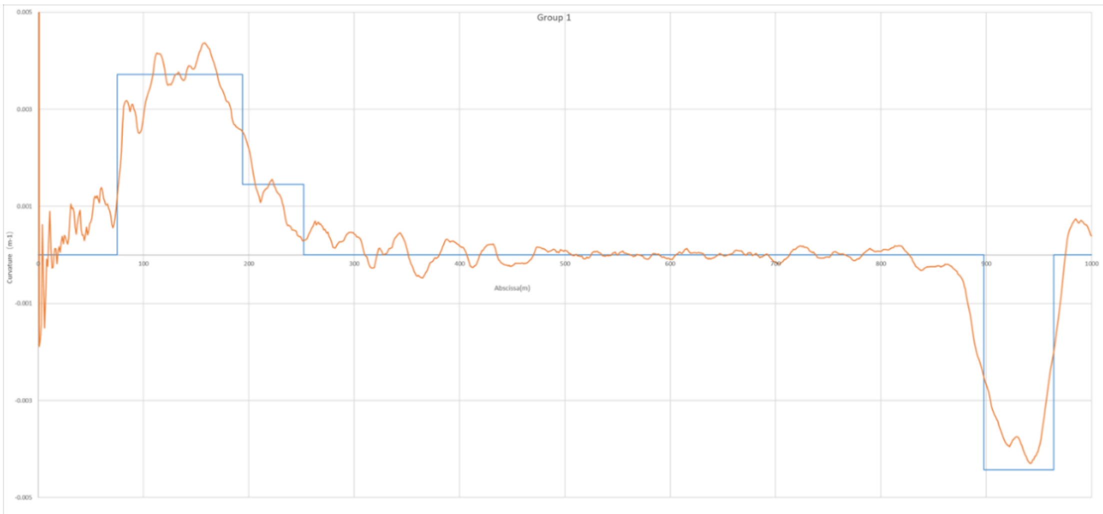
83	52.98	526.94	DX	1.90E-03	C	8102.60
84	125.67	324.04	DX	3.09E-03	C	8228.27
85	586.26			0.00E+00	R	8814.53
86	45.37	211.54	DX	4.73E-03	C	8859.90
87	367.58			0.00E+00	R	9227.48
88	40.66	-175.20	SX	-5.71E-03	C	9268.14
89	27.79	-177.71	SX	-5.63E-03	C	9295.93
90	253.36			0.00E+00	R	9549.29
91	123.82	-1000.13	SX	-1.00E-03	C	9673.11
92	133.55			0.00E+00	R	9806.66
93	42.07	-142.99	SX	-6.99E-03	C	9848.73
94	57.83	-177.41	SX	-5.64E-03	C	9906.56
95	139.22			0.00E+00	R	10045.78
96	94.02	-107.59	SX	-9.29E-03	C	10139.80
97	167.23			0.00E+00	R	10307.03
98	52.01	111.55	DX	8.96E-03	C	10359.04
99	81.75	123.99	DX	8.07E-03	C	10440.79
100	57.11			0.00E+00	R	10497.90
101	47.80	-152.70	SX	-6.55E-03	C	10545.70
102	42.15	-160.81	SX	-6.22E-03	C	10587.85
103	90.63			0.00E+00	R	10678.48
104	24.62	94.25	DX	1.06E-02	C	10703.10
105	57.06	50.60	DX	1.98E-02	C	10760.16
106	439.35			0.00E+00	R	11199.51
107	48.22	-98.96	SX	-1.01E-02	C	11247.73
108	35.67			0.00E+00	R	11283.40
109	60.93	64.04	DX	1.56E-02	C	11344.33
110	60.03			0.00E+00	R	11404.36
111	46.25	223.81	DX	4.47E-03	C	11450.61
112	43.29	315.86	DX	3.17E-03	C	11493.90
113	104.16			0.00E+00	R	11598.06
114	83.77	-220.51	SX	-4.53E-03	C	11681.83
115	483.85			0.00E+00	R	12165.68
116	78.28	-203.82	SX	-4.91E-03	C	12243.96
117	293.68			0.00E+00	R	12537.64
118	82.15	-226.49	SX	-4.42E-03	C	12619.79
119	219.24	-280.05	SX	-3.57E-03	C	12839.03
120	381.67			0.00E+00	R	13220.70
121	50.68	-169.06	SX	-5.92E-03	C	13271.38
122	314.28			0.00E+00	R	13585.66
123	92.91	251.95	DX	3.97E-03	C	13678.57
124	84.05			0.00E+00	R	13762.62
125	58.22	298.49	DX	3.35E-03	C	13820.84

126	74.80			0.00E+00	R	13895.64
127	64.68	307.46	DX	3.25E-03	C	13960.32
128	155.05			0.00E+00	R	14115.37
129	64.26	202.38	DX	4.94E-03	C	14179.63

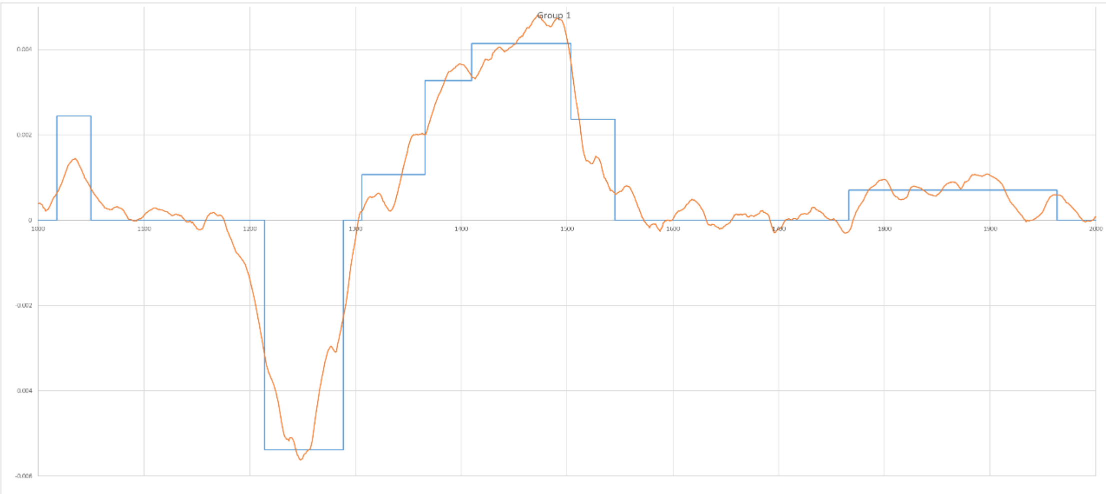
Attachment 8 Results from The Driving Simulator (average data of all participants)

Group 1

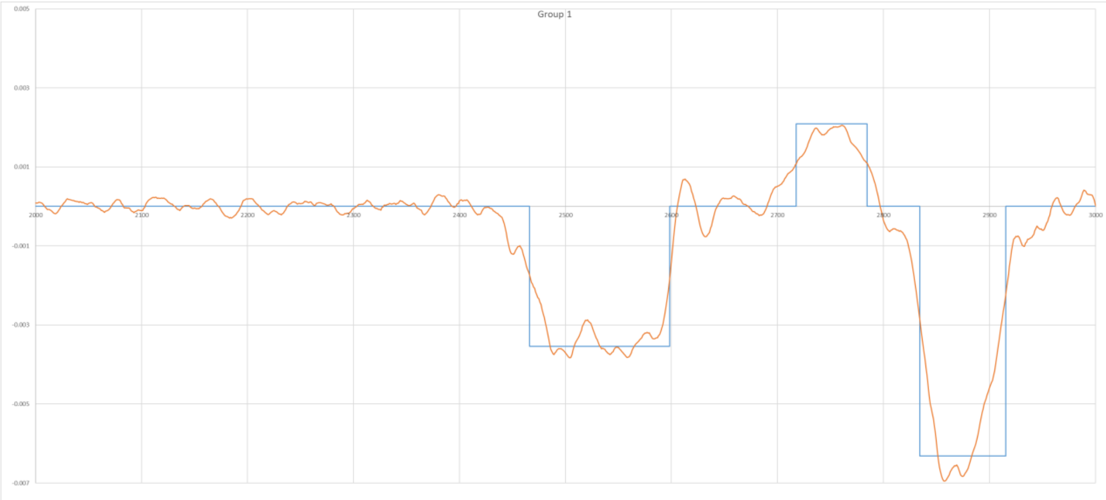
0-1Km



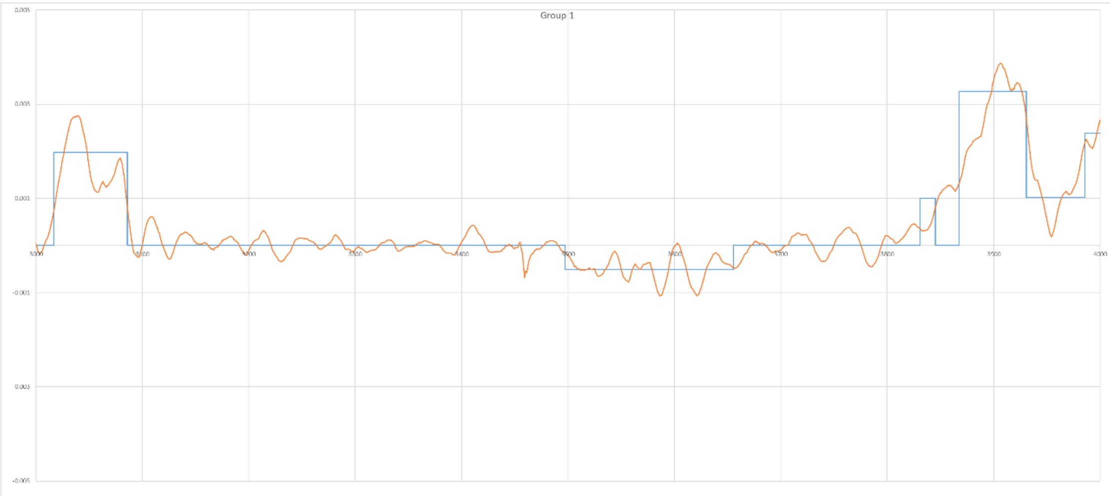
1Km-2Km



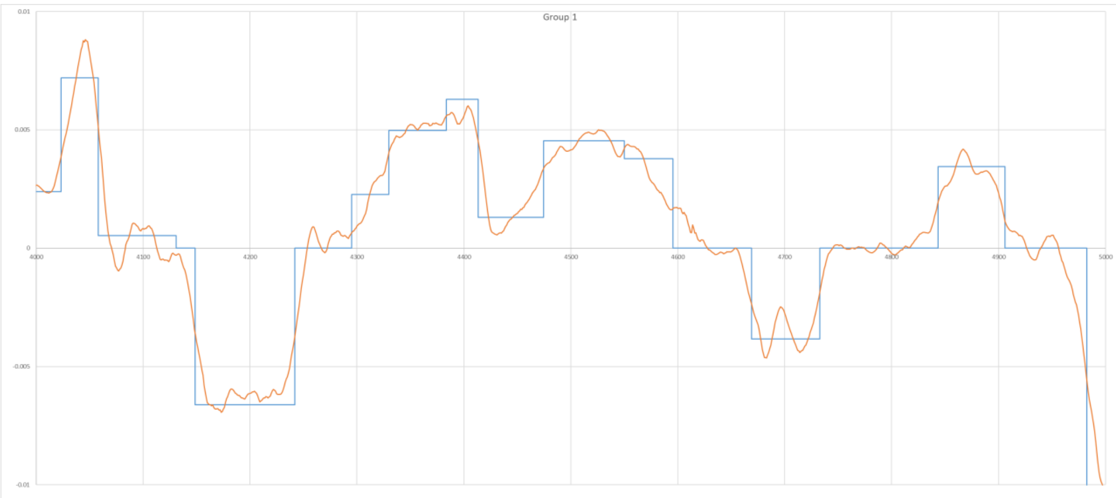
2Km-3KM



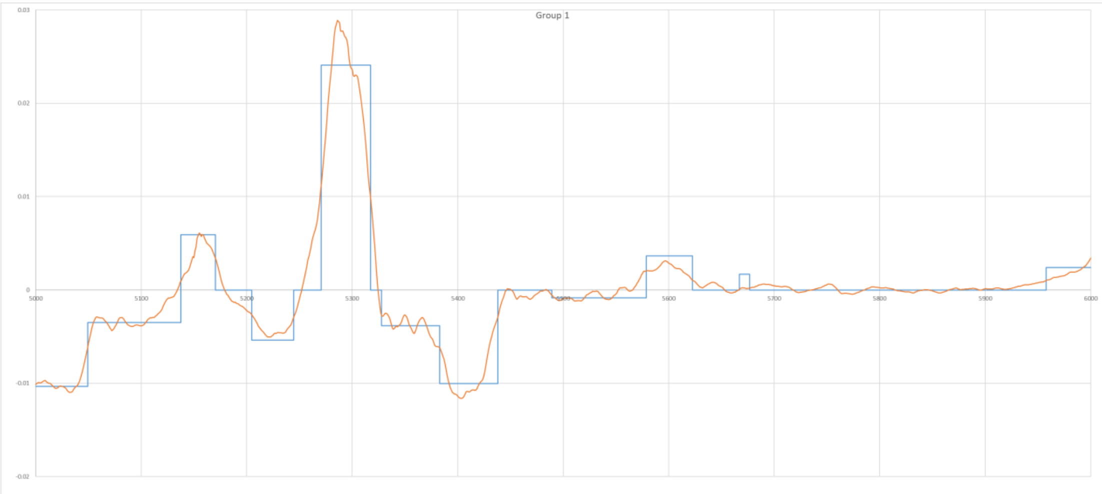
3Km-4Km



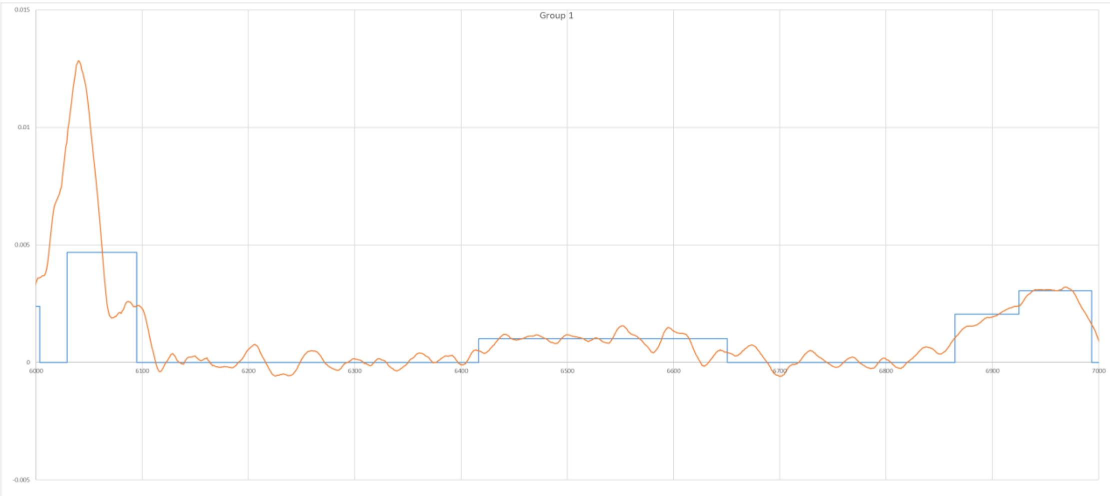
4Km-5Km



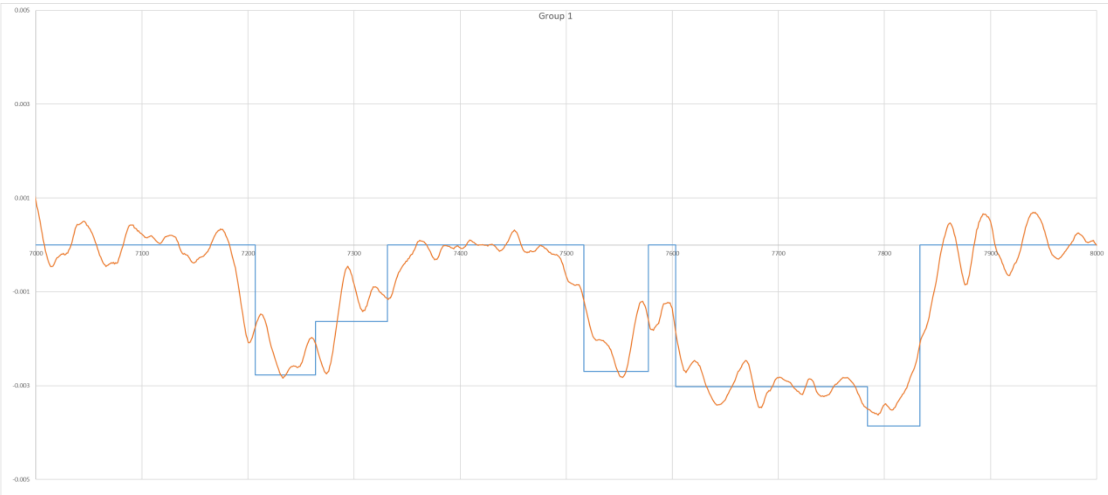
5Km-6Km



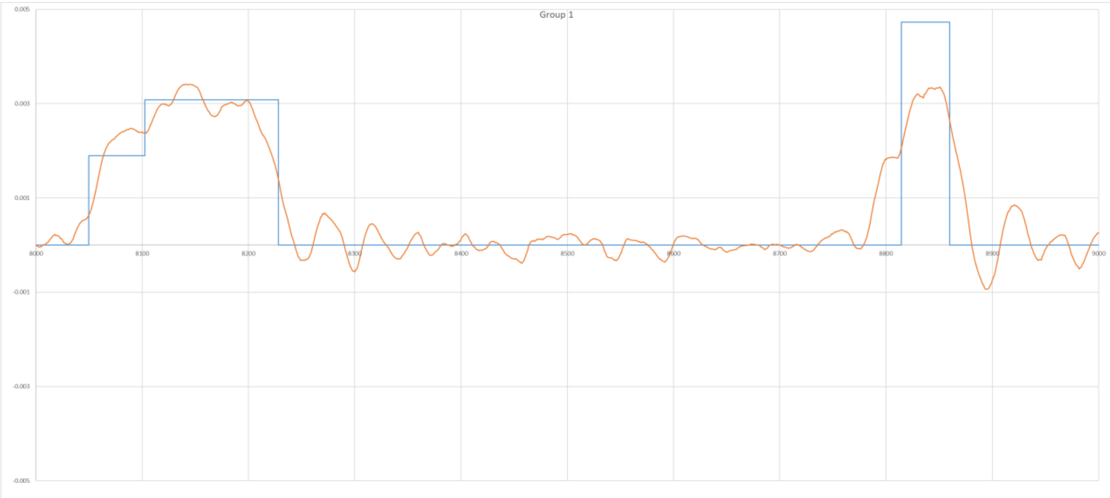
6Km-7Km



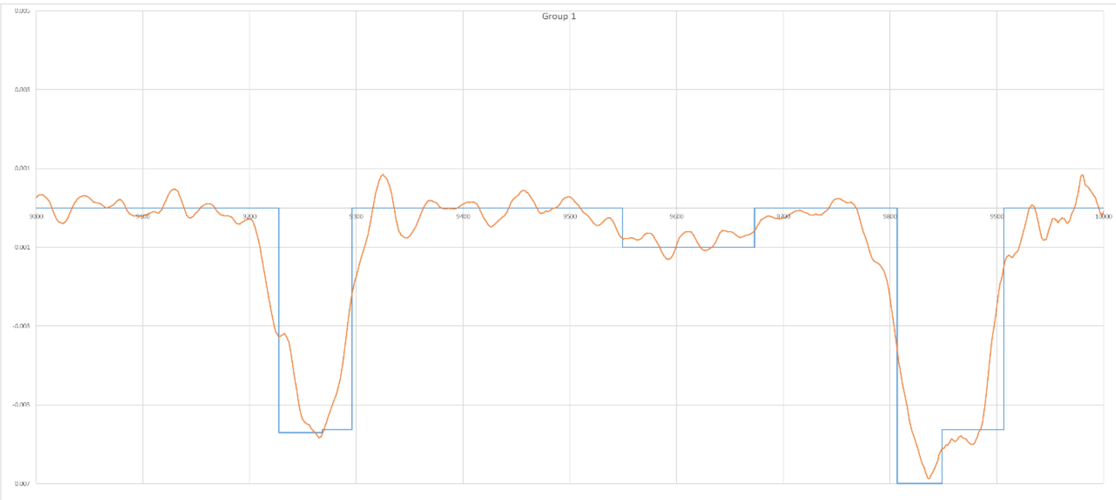
7Km-8Km



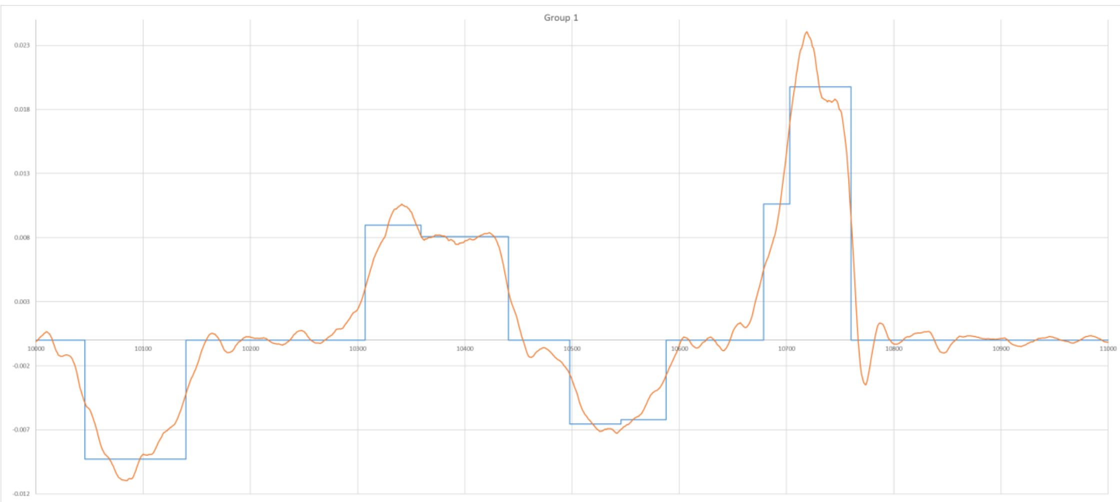
8Km-9Km



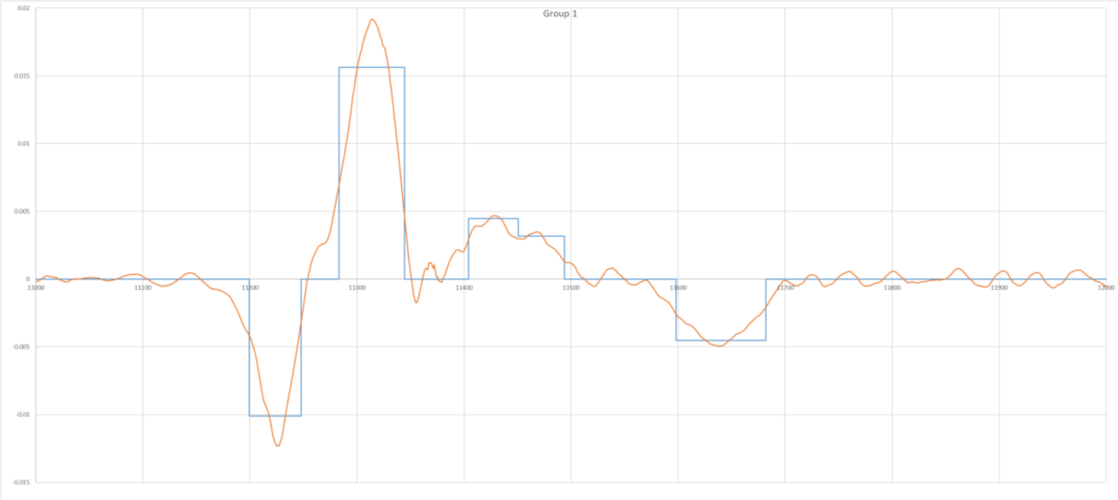
9Km-10Km



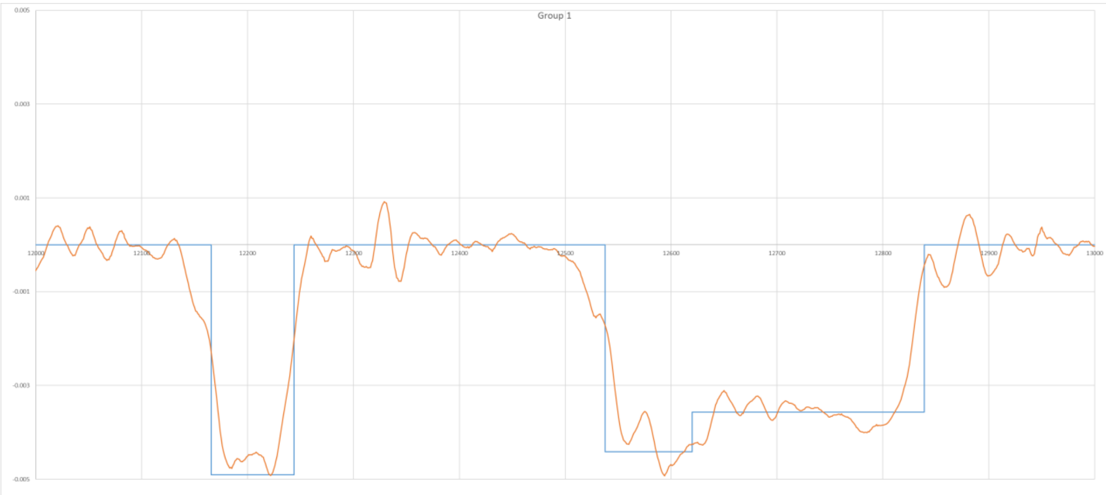
10Km-11Km



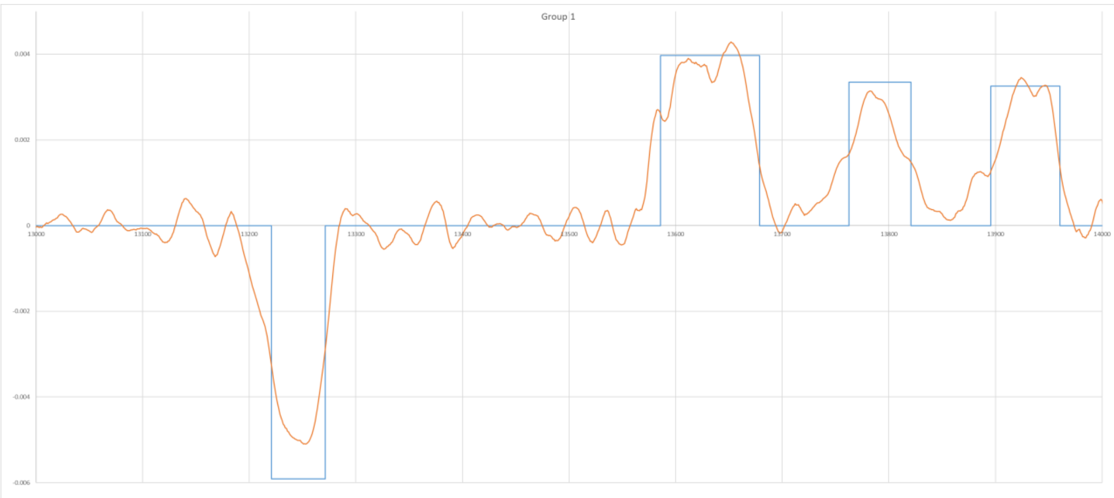
11Km-12Km



12Km-13Km

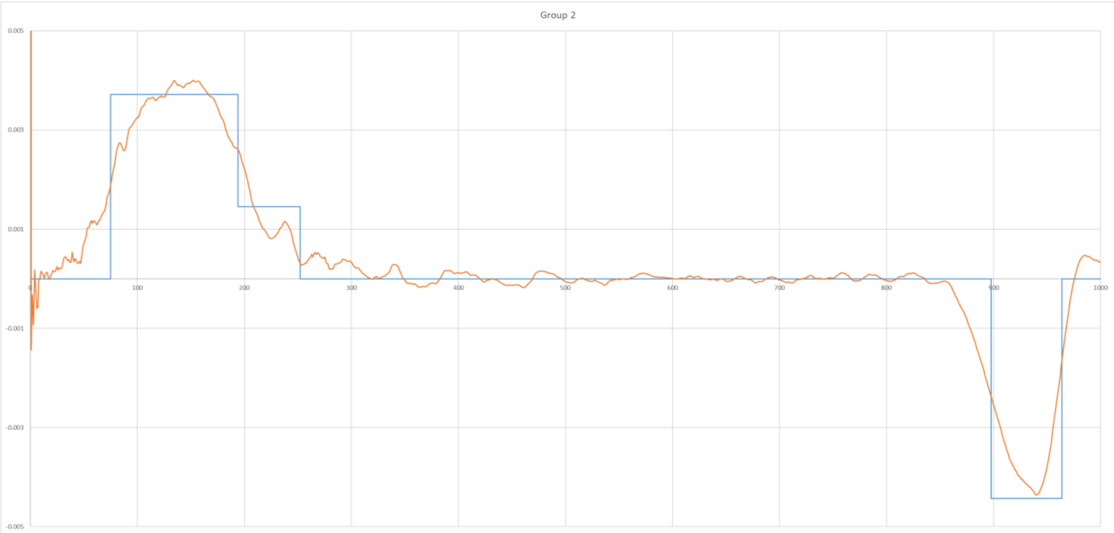


13Km-14Km

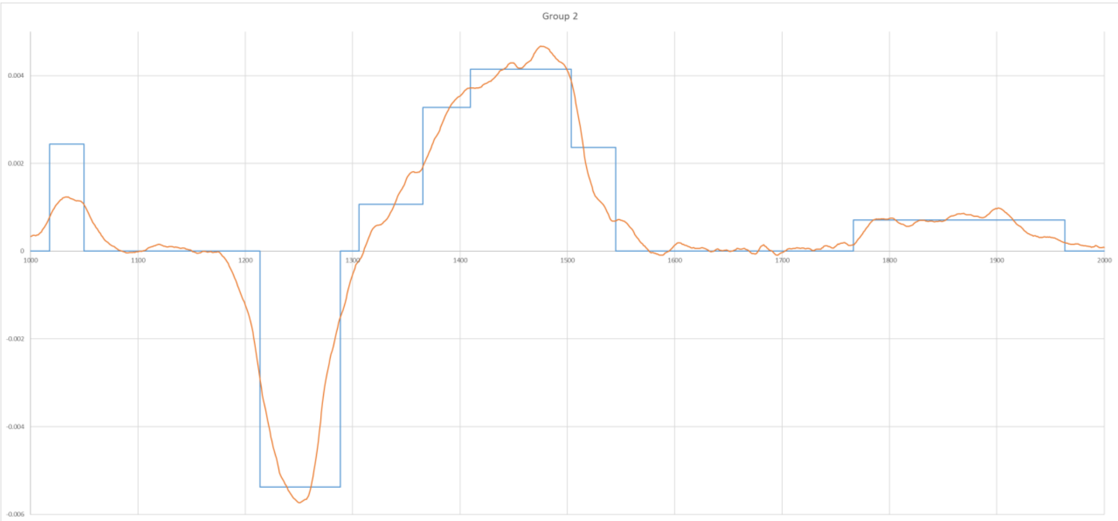


Group 2

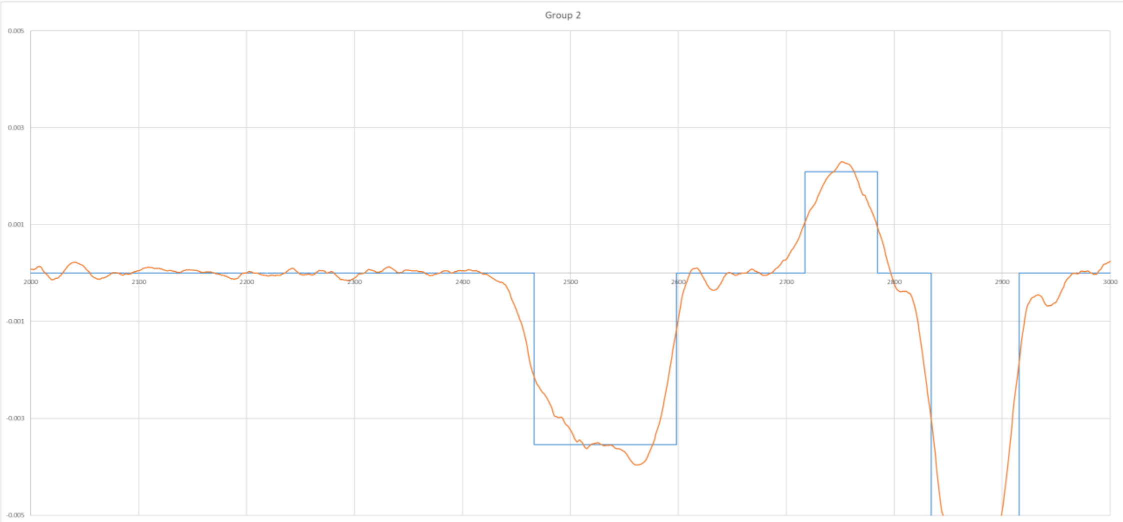
0-1Km



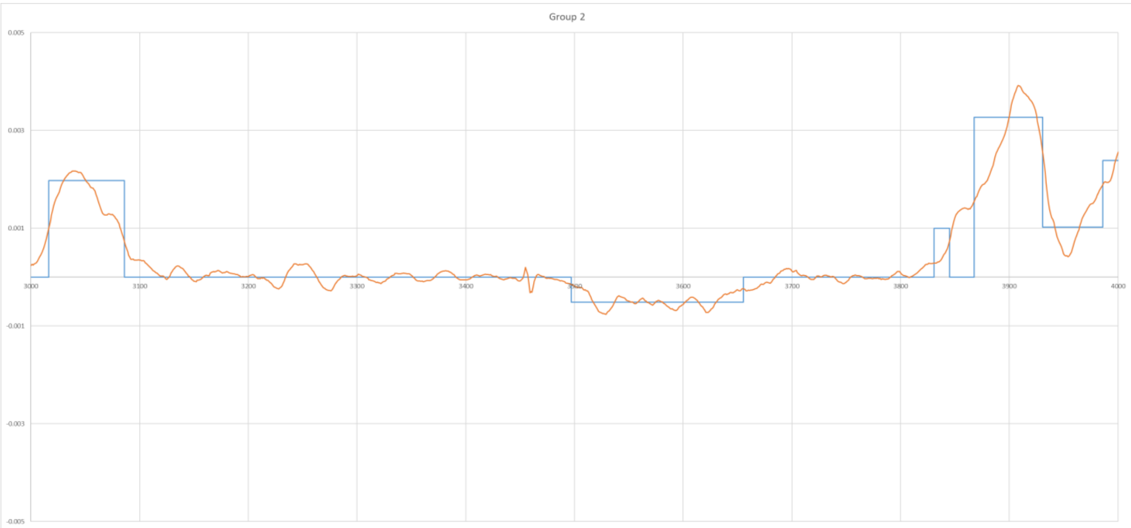
1Km-2Km



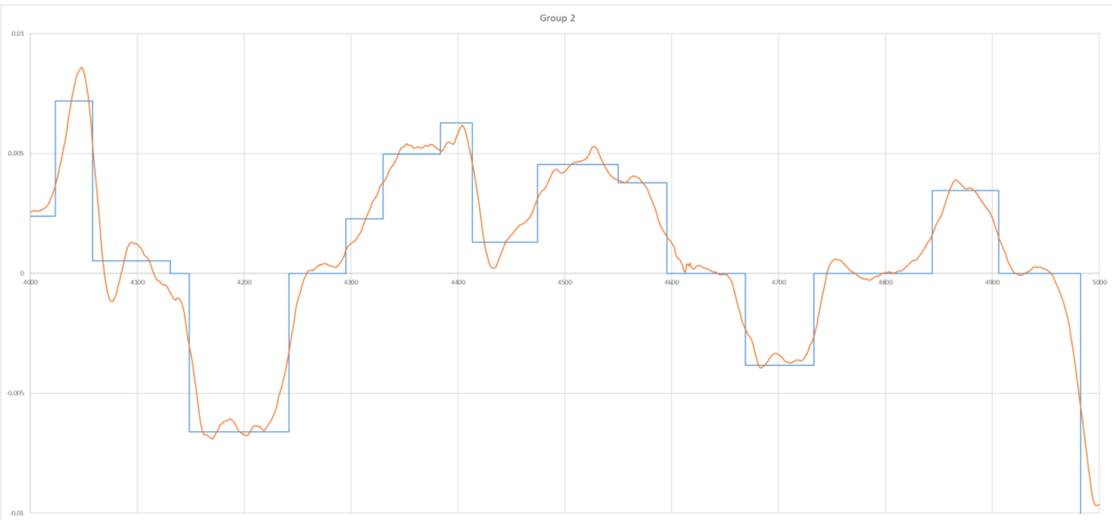
2Km-3Km



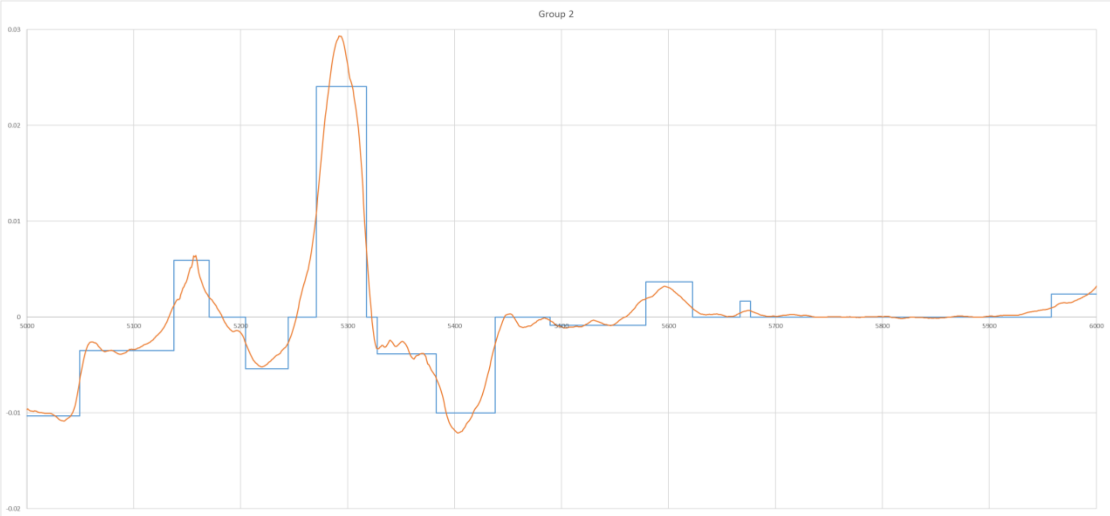
3Km-4Km



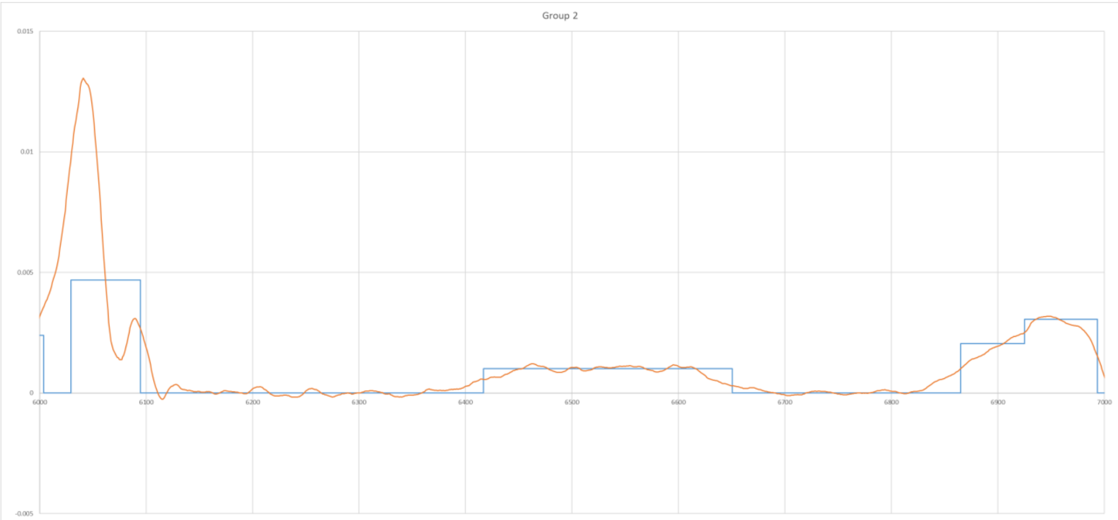
4Km-5Km



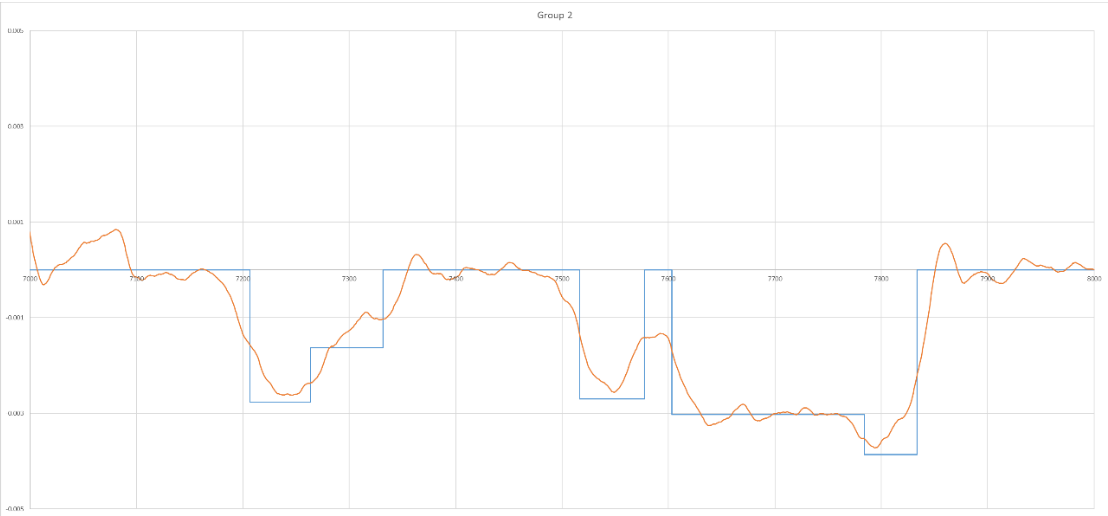
5Km-6Km



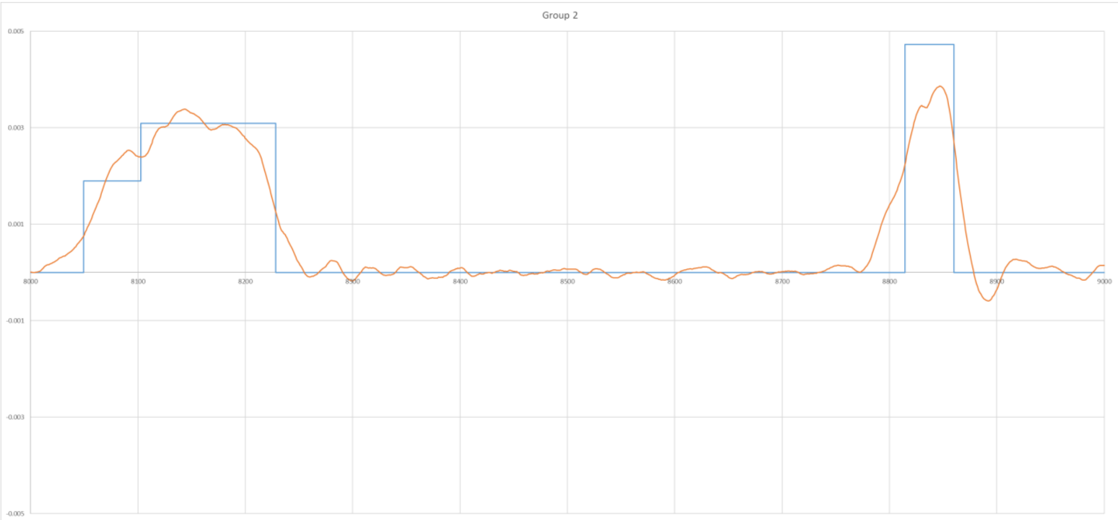
6Km-7Km



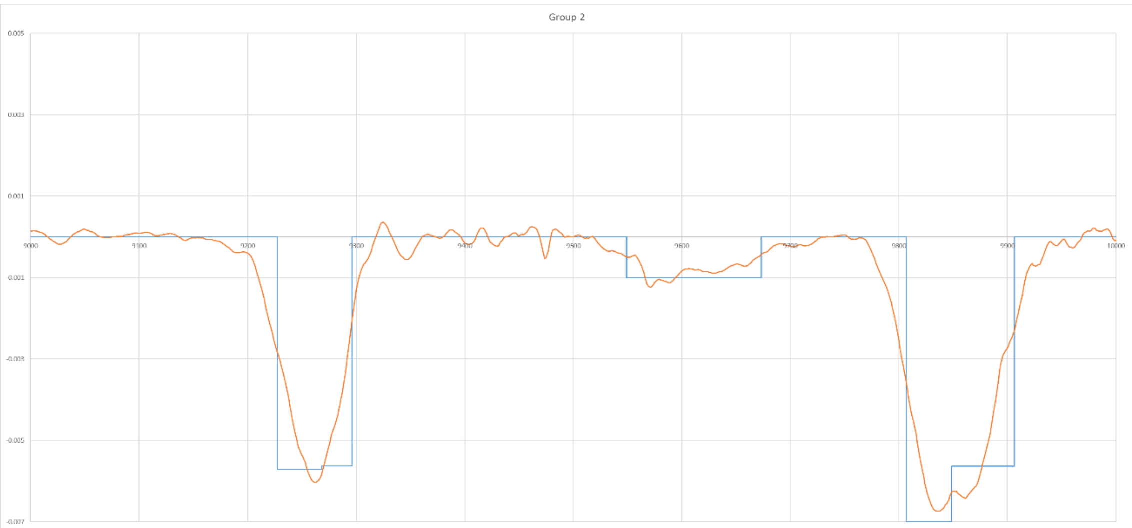
7Km-8Km



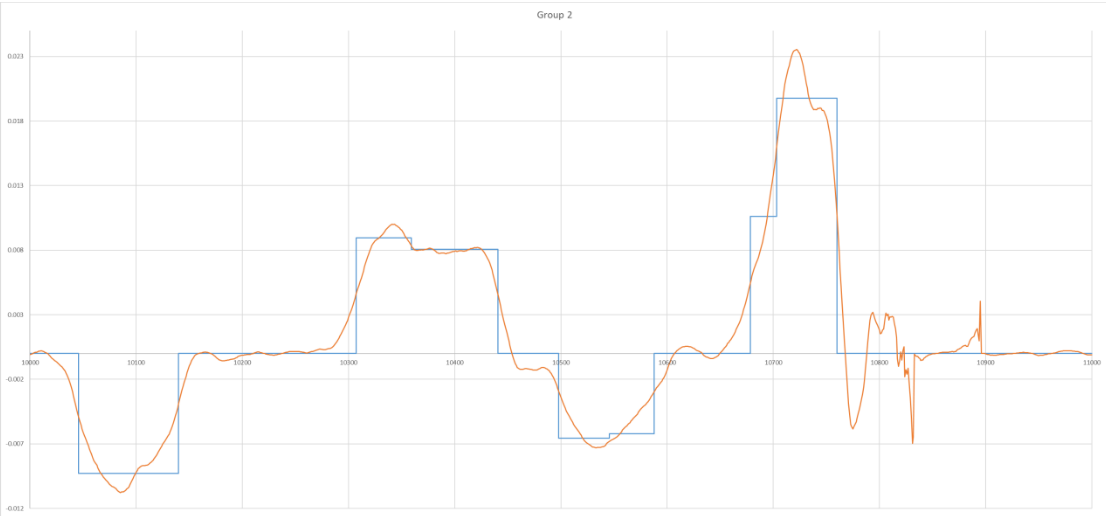
8Km-9Km



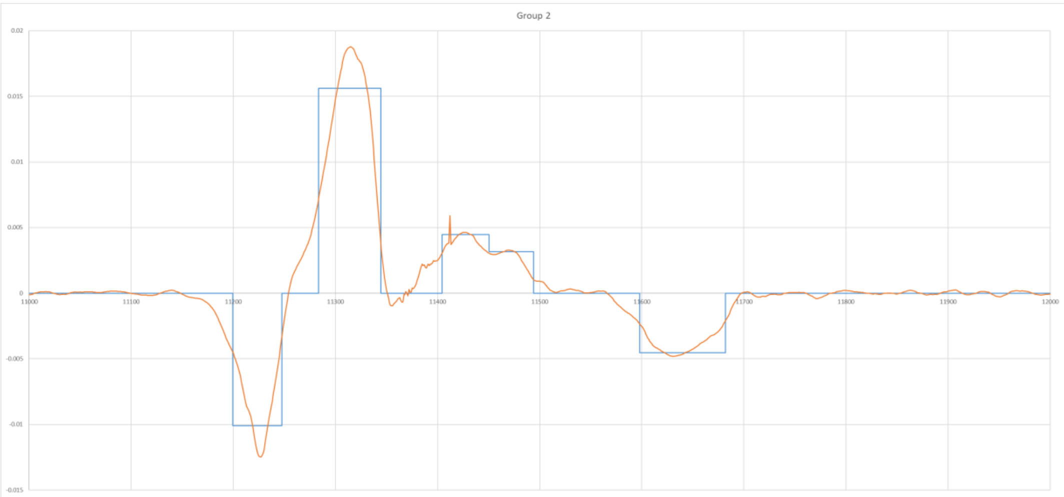
9Km-10Km



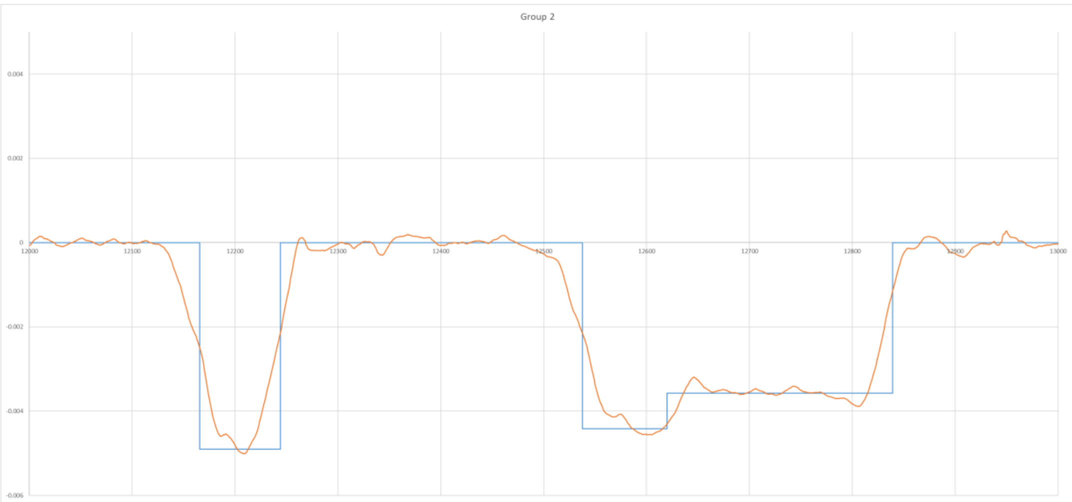
10Km-11Km



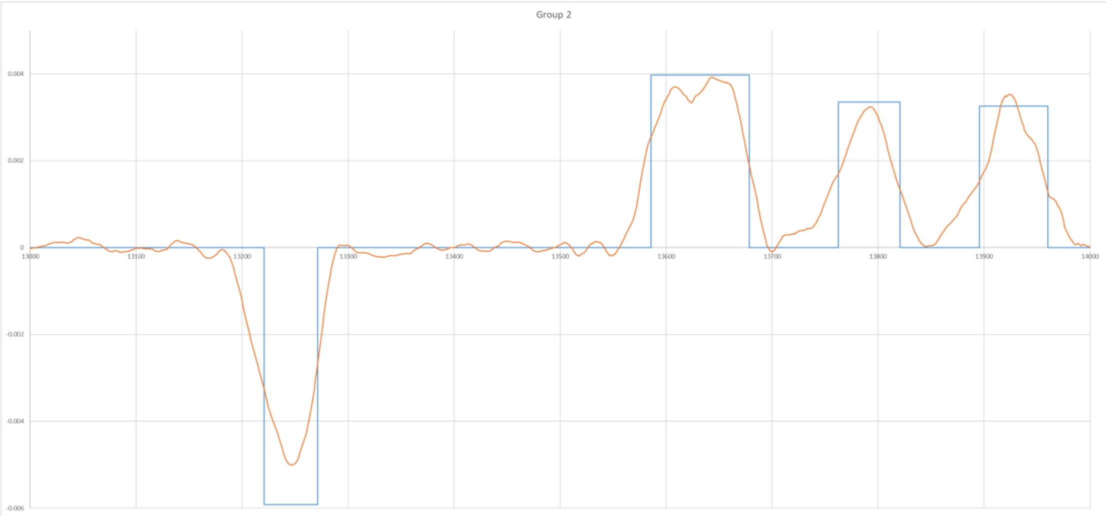
11Km-12Km



12Km-13Km



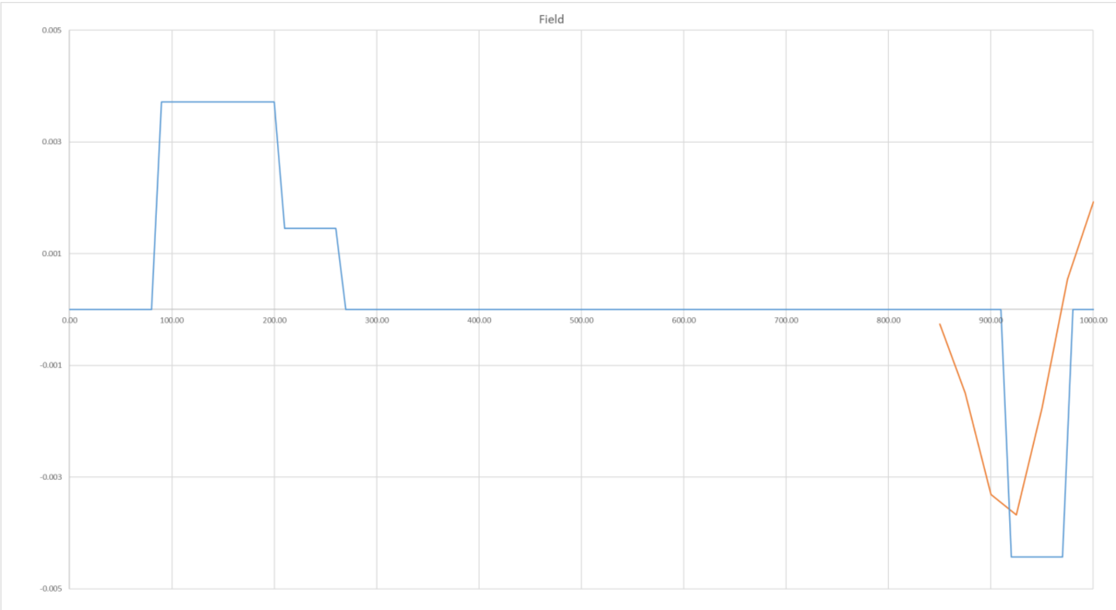
13Km-14Km



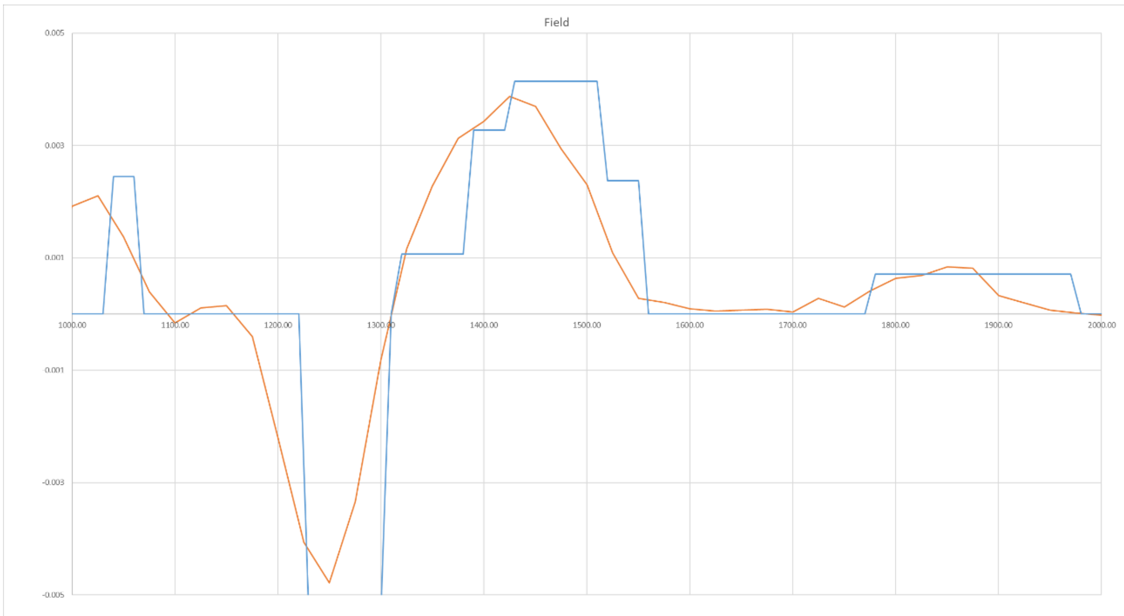
Group 2
0.004
0.002
0
-0.002
-0.004
-0.006
13000
13100
13200
13300
13400
13500
13600
13700
13800
13900
14000

Field Data

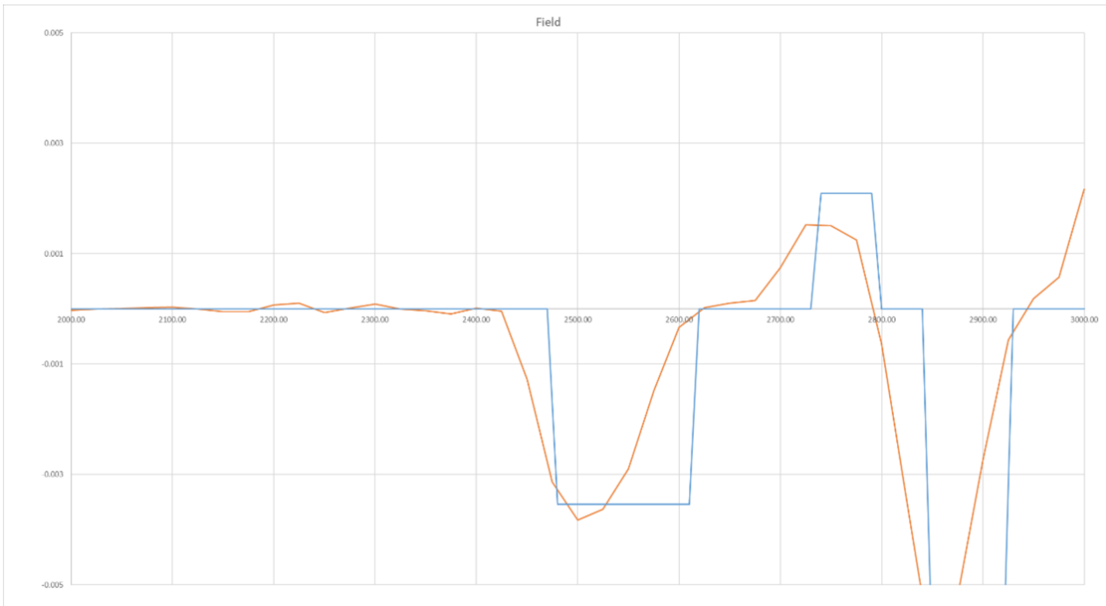
0-1Km



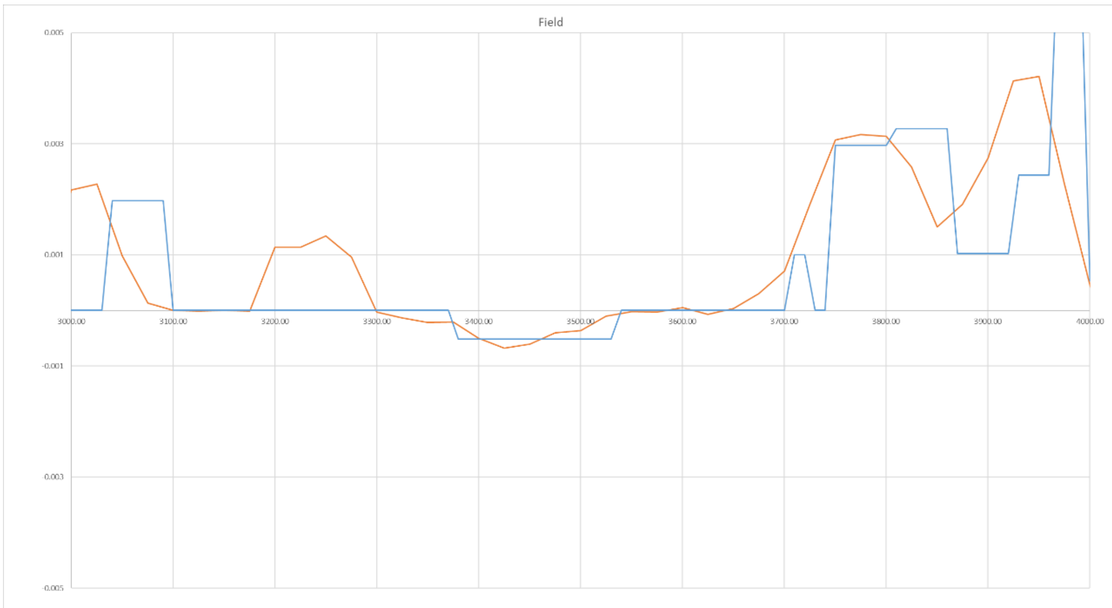
1Km-2Km



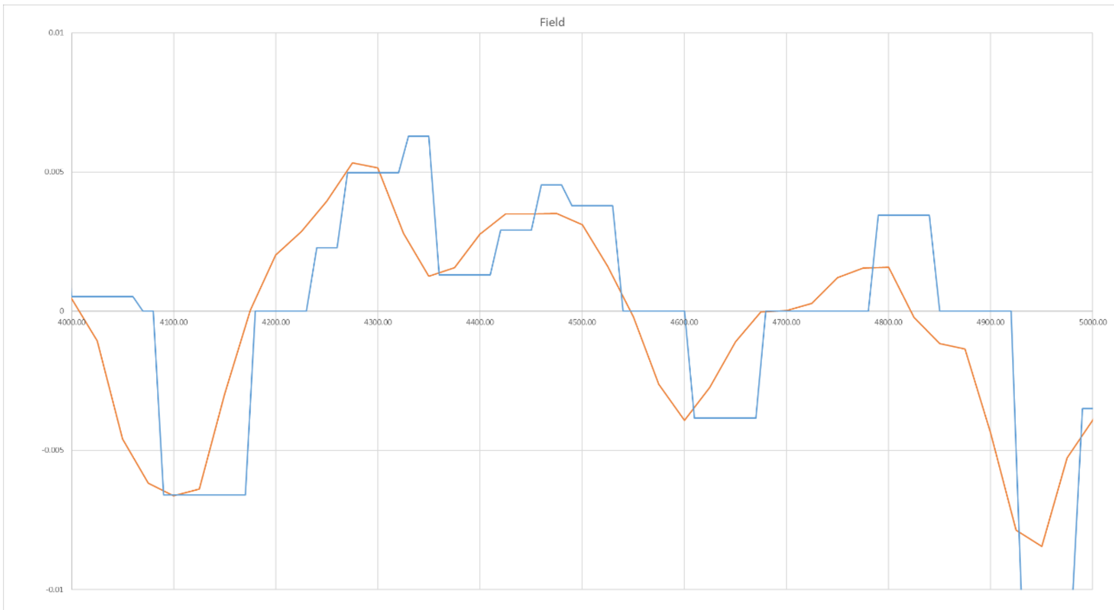
2Km-3Km



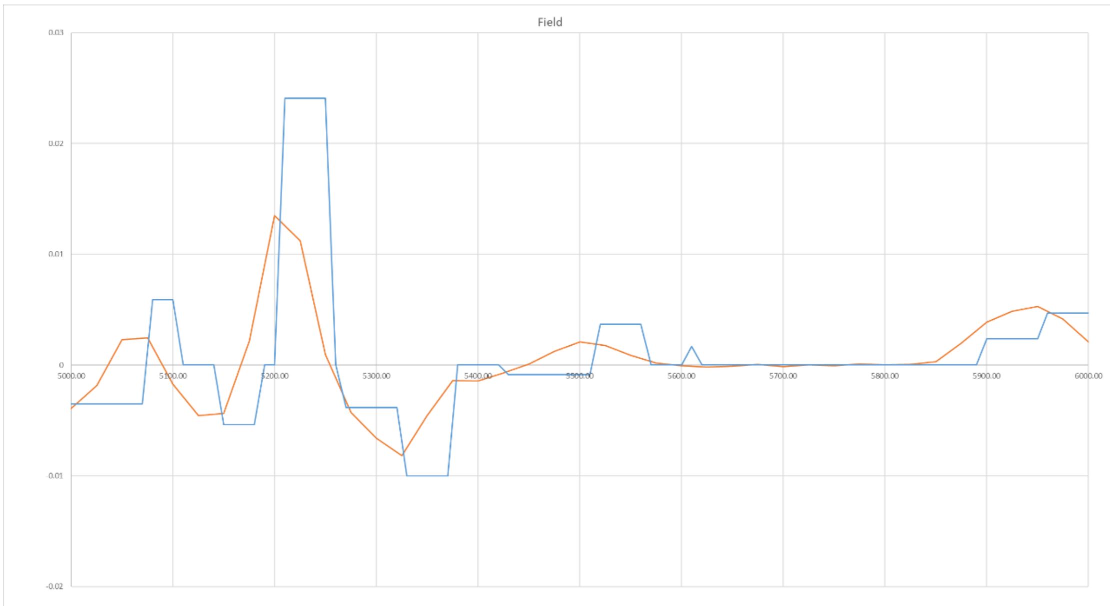
3Km-4Km



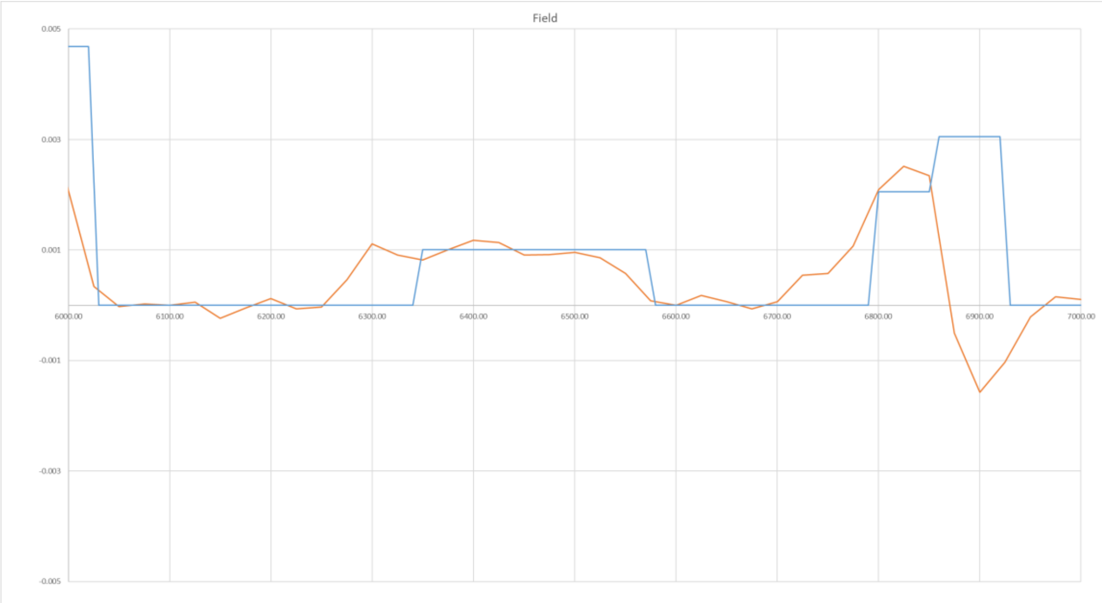
4Km-5Km



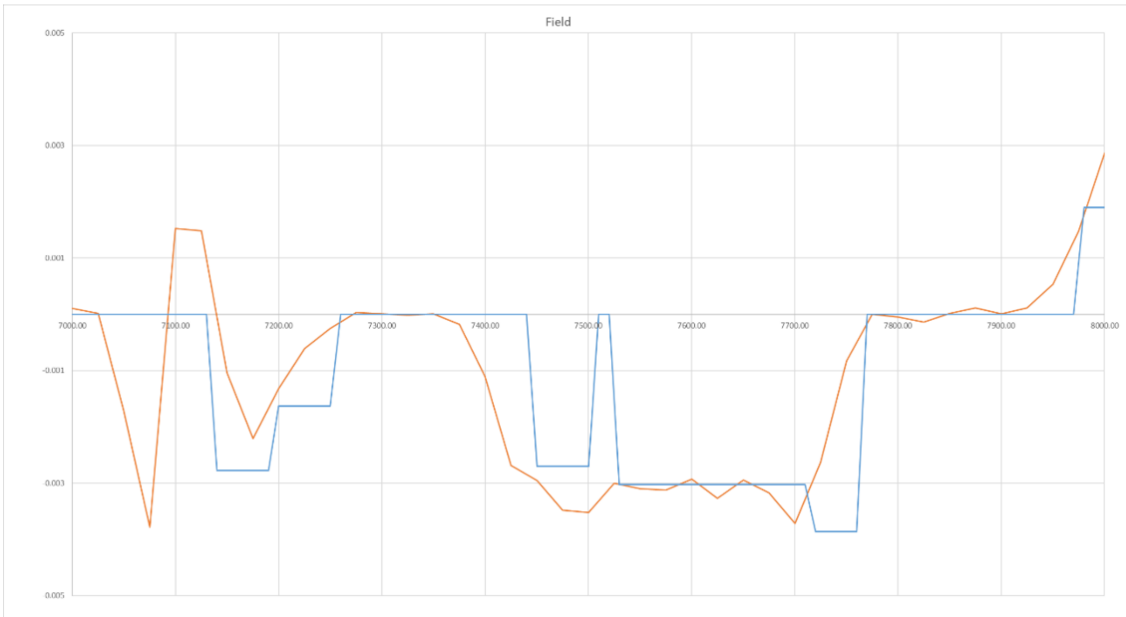
5Km-6Km



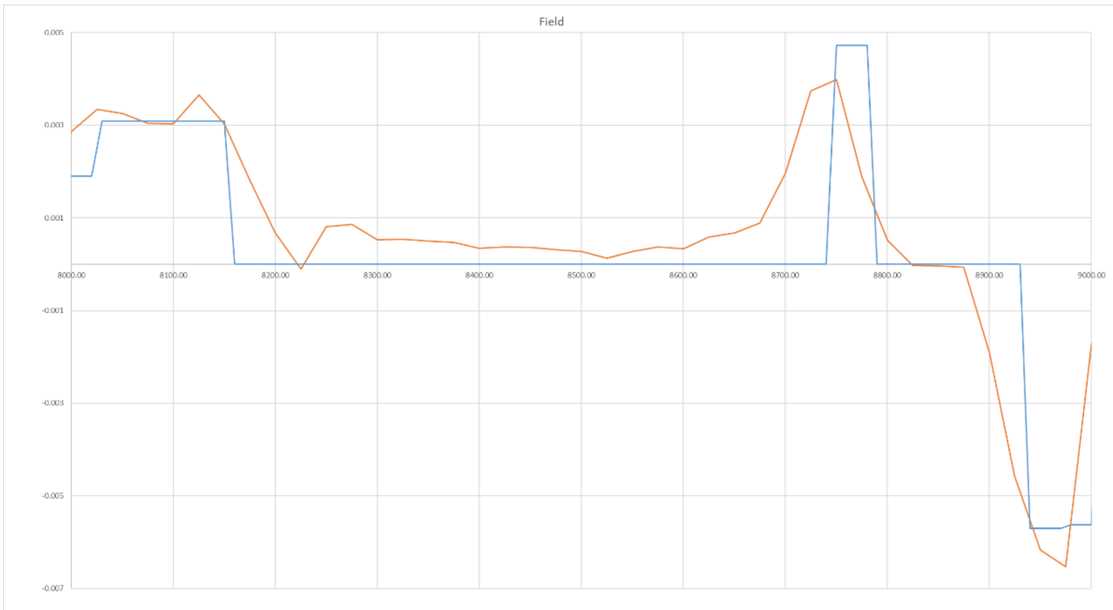
6Km-7Km



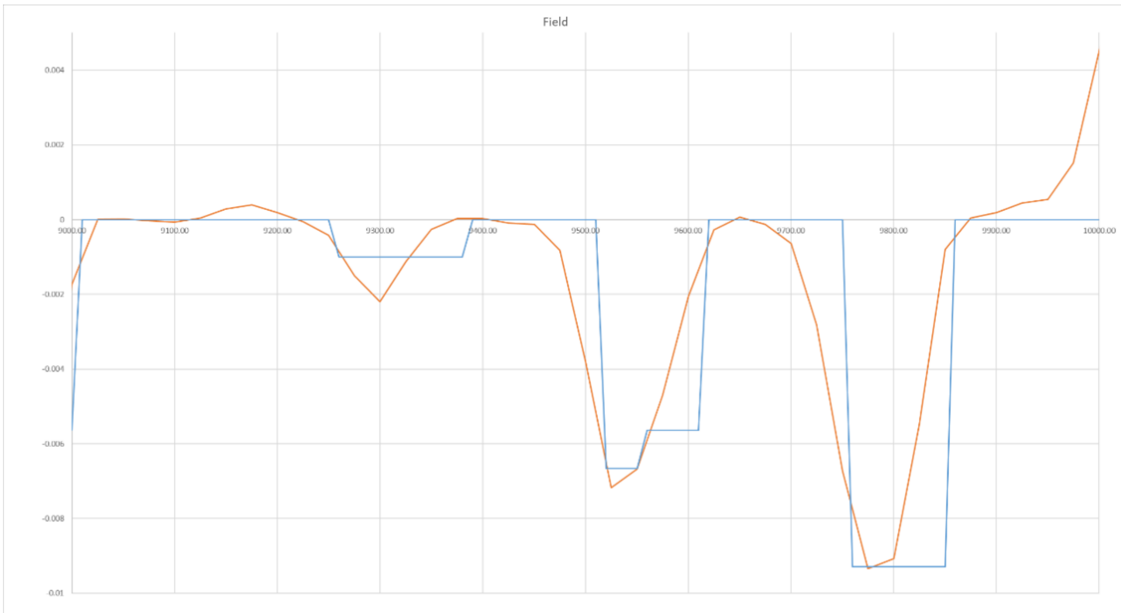
7Km-8Km



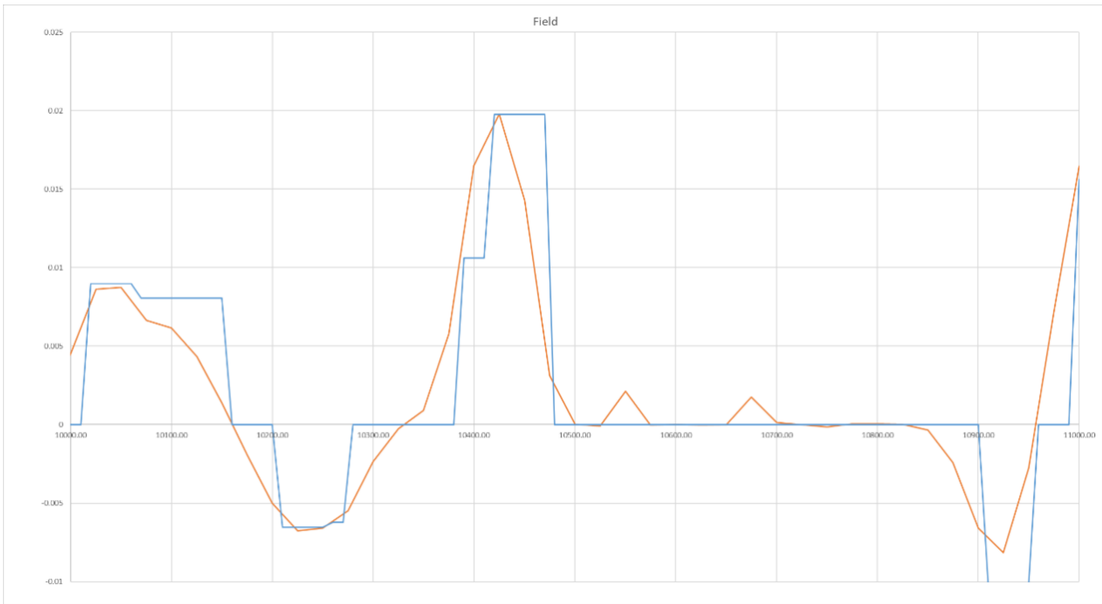
8Km-9Km



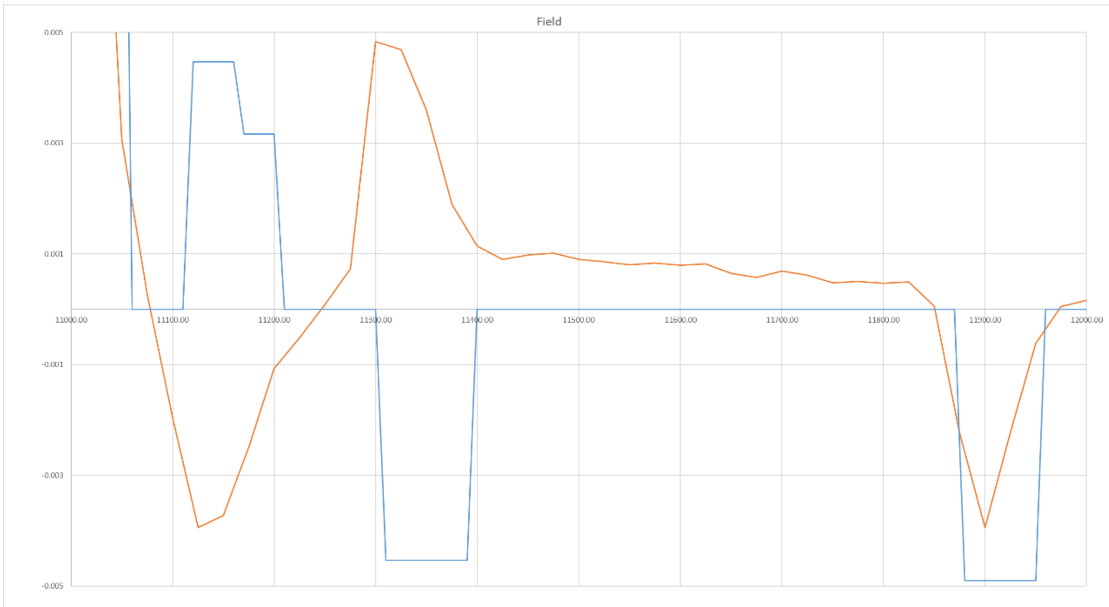
9Km-10Km



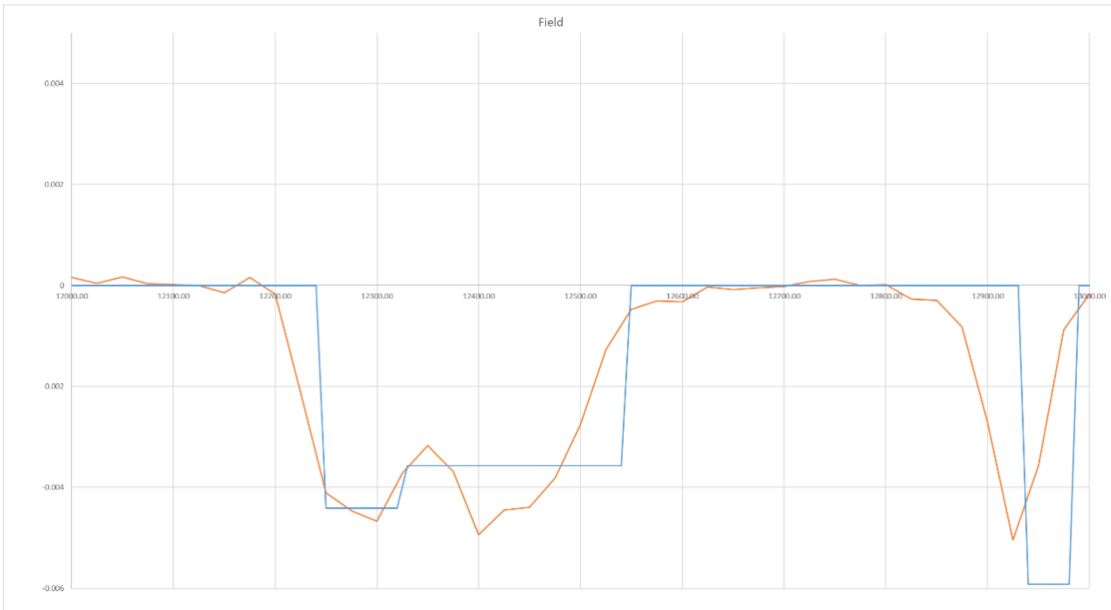
10Km-11Km



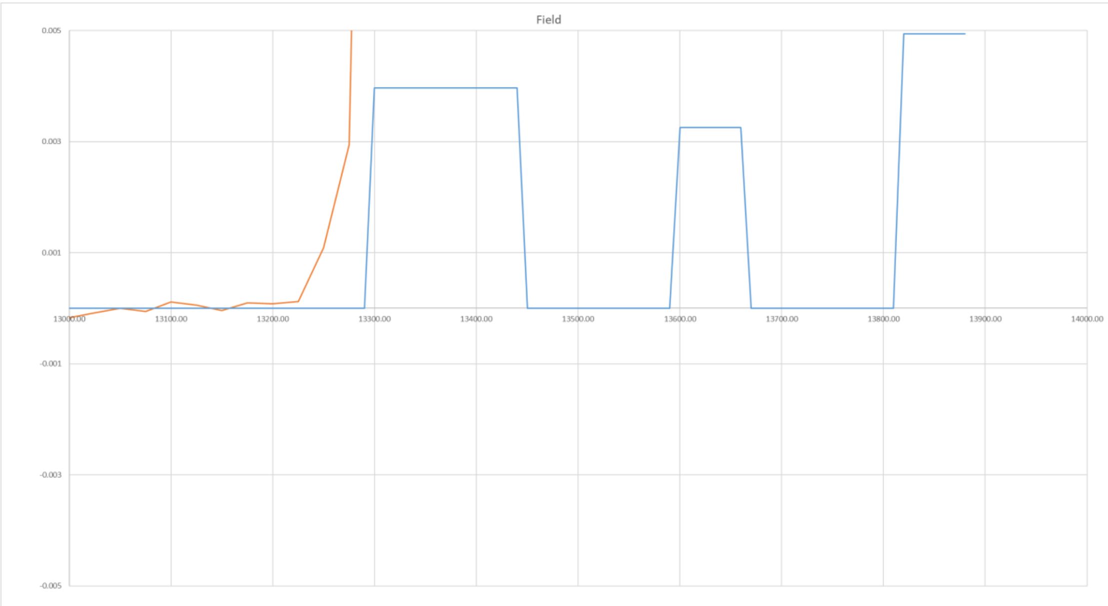
11Km-12Km



12Km-13Km



13Km-14Km



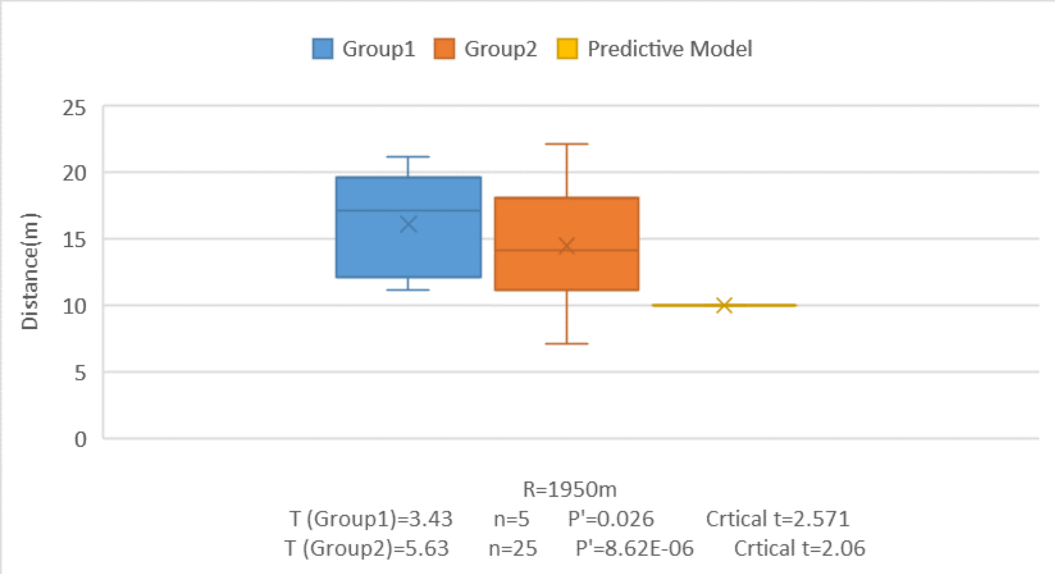
Attachment 9 Results Data Table

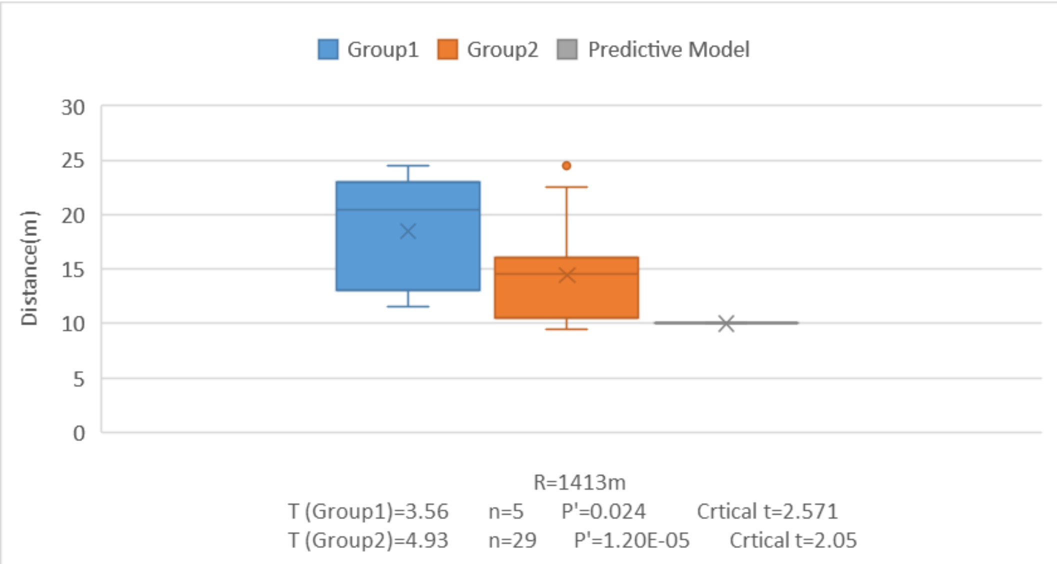
Station Abscissa (m)				
No.	**Group 1**	**Group 2**	**Field**	**Field Model**
1	826.7876	835.602		880
2	1175.999	1150.461	1156.691	1180
3	1753.333	1702.252	1700	1760
4	2426	2417.48	2405.665	2440
5	2690.156	2685.84	2623.571	2710
6	3007.562	2988.169	2943.917	3010
7	3490.689	3472.701	3299.305	3360
8	3794.64	3809.045	3641.12	3690
9	4629	4642.946	4547.115	4580
10	4810.936	4797.317	4691.342	4750
11	5896.439	5893.054	5800	5860
12	6404.763	6358.749	6251.723	6330
13	6819.733	6816.274	6687.669	6770
14	7182.437	7164.733	7092.794	7100
15	7476.754	7461.974	7351.254	7410
16	8027.949	8004.571	7901.111	7950
17	8778.718	8772	8600	8710
18	9167.465	9154	8823.622	8890
19	9509.682	9518.331	9219.848	9240
20	9768.006	9753.12	9405.52	9470
21	10015.46	10016.33	9658.146	9700
22	10269.17	10261	9873.649	9970
23	10454.12	10453.93	10160.46	10190
24	10647.31	10649.77	10330.44	10340
25	11153.81	11148.3	10826.06	10850
26	11380.23	11371.41	11077.88	11100
27	11569	11566.03	11246.48	11260
28	12135.03	12117.81	11841.06	11840
29	12477	12473.44	12186.87	12210
30	13188.11	13156.8	12801.34	12890
31	13557.18	13555.64	13157.3	13260

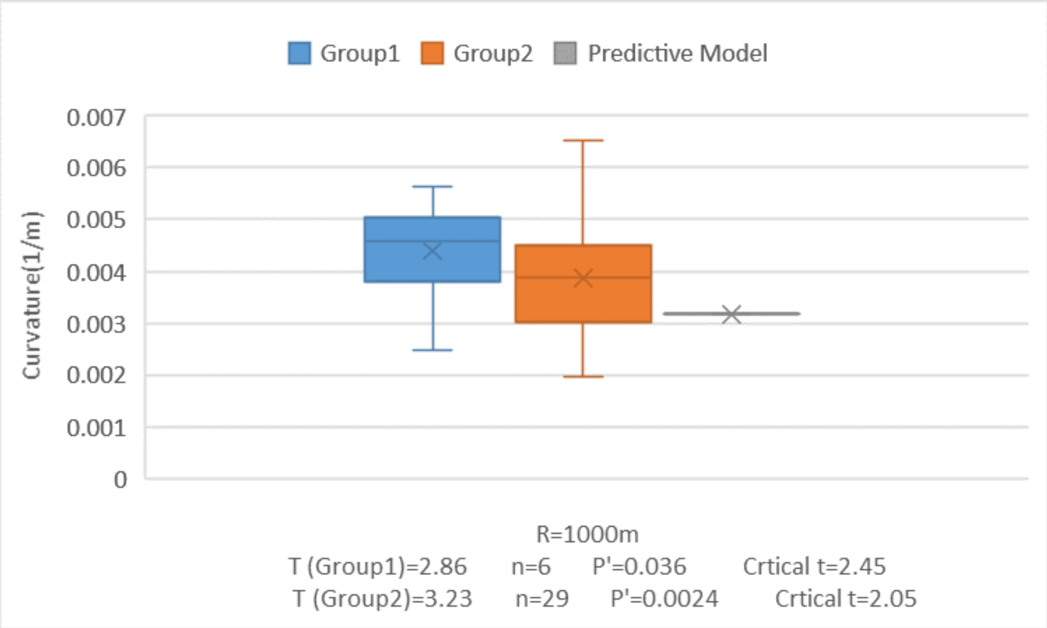
Anticipation Distance(m)				
No.	Group 1	Group 2	Field	Field Model
1	71.12131256	62.30686		30.00
2	37.83956691	63.37799	63.30925	40.00
3	13.16616374	64.24725	70	10.00
4	40.26889	48.7887	64.33515	30.00
5	27.36251713	31.67852	106.4291	20.00
6	8.956406135	28.34981	86.08301	20.00
7	6.44985376	24.43835	70.69518	10.00
8	36.24927006	21.84401	58.87971	10.00
9	40.04889	26.10301	52.88514	20.00
10	32.62323695	46.24147	88.65778	30.00
11	61.44018205	64.82471	90	30.00
12	12.08621176	58.09939	88.27696	10.00
13	45.30555863	48.7652	102.3306	20.00
14	24.26227151	41.96628	37.20604	30.00
15	39.92508012	54.70486	88.74561	30.00
16	21.67029963	45.0477	68.88906	20.00
17	35.81120767	42.52889	140	30.00
18	60.01429658	73.47889	106.3784	40.00
19	39.60726443	30.95745	30.1524	10.00
20	38.65331558	53.53884	104.48	40.00
21	30.32103908	29.44759	91.85402	50.00
22	37.86052826	46.02889	136.3509	40.00
23	43.7761718	43.9668	39.53596	10.00
24	31.17350328	28.71009	49.56139	40.00
25	45.70386475	51.20943	73.94255	50.00
26	24.12795921	32.94781	32.12057	10.00
27	29.05889	32.02515	53.52028	40.00
28	30.65284429	47.87165	28.94325	30.00
29	60.63889	64.19544	53.12563	30.00
30	32.59163769	63.89889	128.6556	40.00
31	28.47442775	30.02128	132.7004	30.00

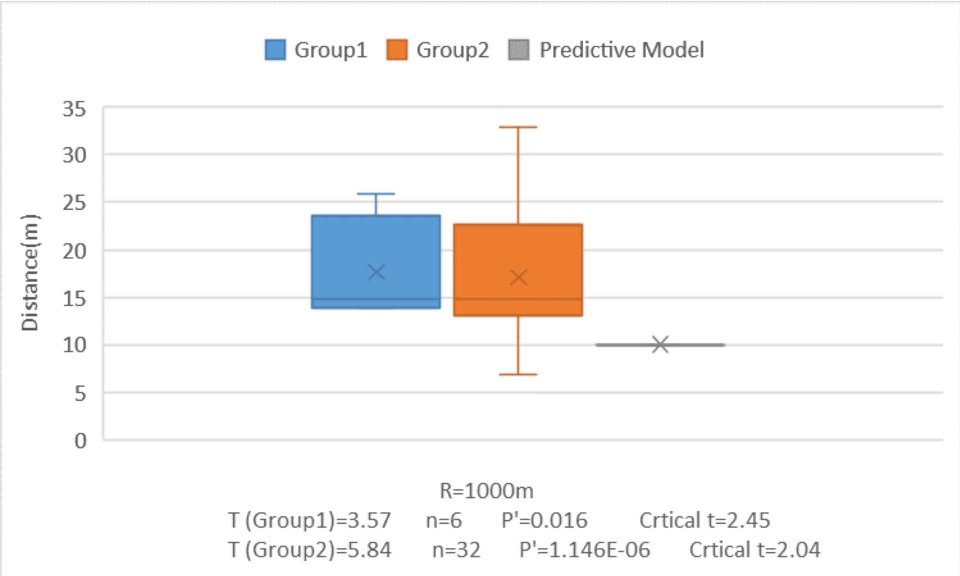
CCR(1/m)				
No.	**Group 1**	**Group 2**	**Field**	**Field Model**
1	-3.73E-05	-4.175E-05	-4.57E-05	-6.4617E-05
2	-7.81E-05	-5.764E-05	-5.13E-05	-5.62974E-05
3	2.047E-05	8.5518E-06	5.621E-06	6.42521E-06
4	-5.95E-05	-3.721E-05	-4.05E-05	-3.19458E-05
5	4.238E-05	3.5285E-05	1.503E-05	3.07961E-05
6	8.481E-05	4.1067E-05	2.803E-05	3.45614E-05
7	-1.75E-05	-1.353E-05	-5.43E-06	-5.67691E-06
8	3.446E-05	3.8009E-05	2.368E-05	2.43746E-05
9	-8.58E-05	-9.592E-05	-7.4E-05	-5.86404E-05
10	7.272E-05	5.5533E-05	1.447E-05	4.31997E-05
11	8.854E-05	8.7125E-05	3.533E-05	3.65728E-05
12	7.67E-06	7.4287E-06	7.961E-06	7.72961E-06
13	2.131E-05	2.3471E-05	1.832E-05	2.63974E-05
14	-5.61E-05	-3.569E-05	-2.69E-05	-3.65822E-05
15	-3.71E-05	-2.899E-05	-2.37E-05	-3.462E-05
16	2.935E-05	2.4045E-05	1.634E-05	2.35777E-05
17	5.261E-05	4.8925E-05	2.659E-05	5.90882E-05
18	-5.84E-05	-5.536E-05	-4.32E-05	-6.51051E-05
19	-1.57E-05	-2.289E-05	-2.73E-05	-1.23698E-05
20	-9.96E-05	-8.133E-05	-6E-05	-7.5206E-05
21	-0.00016	-0.0001517	-8E-05	-9.0041E-05
22	0.0001425	0.0001199	4.963E-05	9.41434E-05
23	-9.92E-05	-9.094E-05	-0.000105	0.000119415
24	0.0003355	0.0003206	0.0002093	0.000180663
25	-0.000168	-0.0001587	-8.23E-05	0.000106262
26	9.363E-05	8.343E-05	8.369E-05	8.08394E-05
27	-6.87E-05	-7.409E-05	-9.04E-05	-4.82917E-05
28	-5.66E-05	-5.344E-05	-6.69E-05	-6.57092E-05
29	-4.21E-05	-3.545E-05	-4.13E-05	-4.7763E-05
30	-7.57E-05	-5.547E-05	-4.08E-05	-7.04215E-05

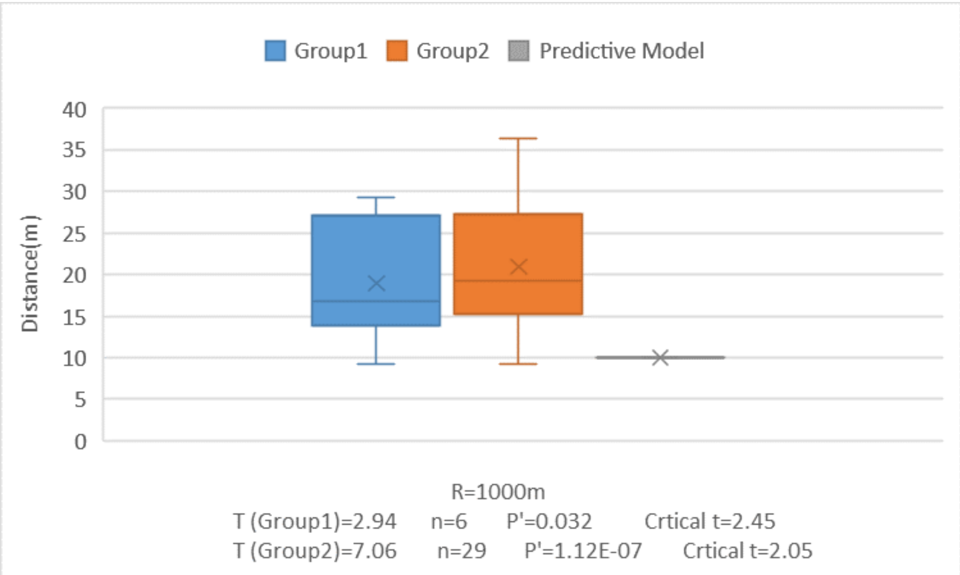
Attachment 10 Anticipation Distance

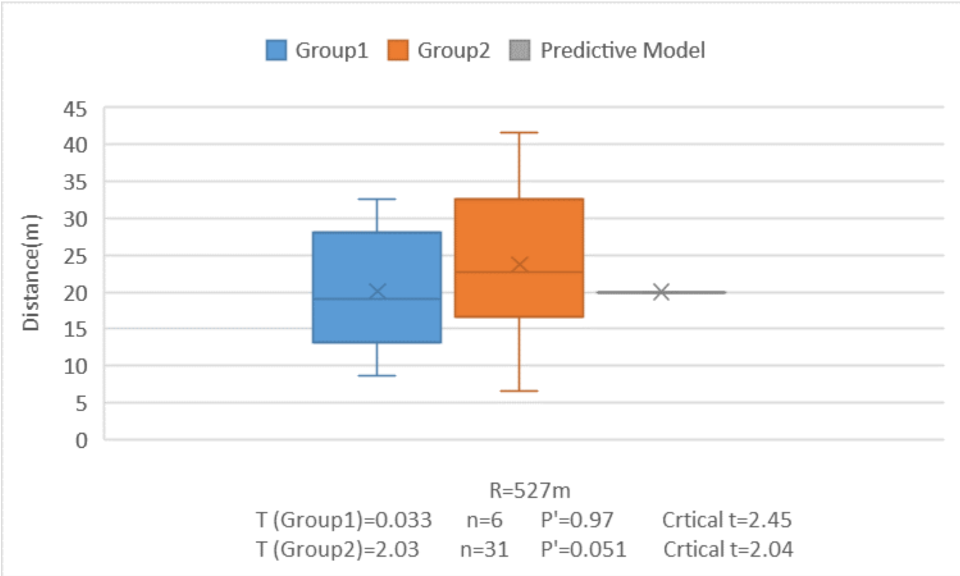


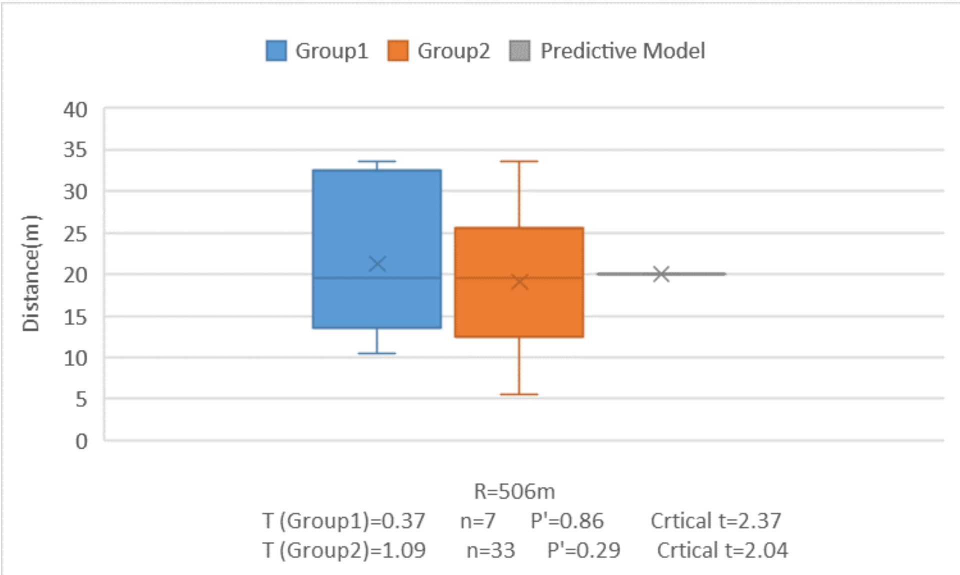


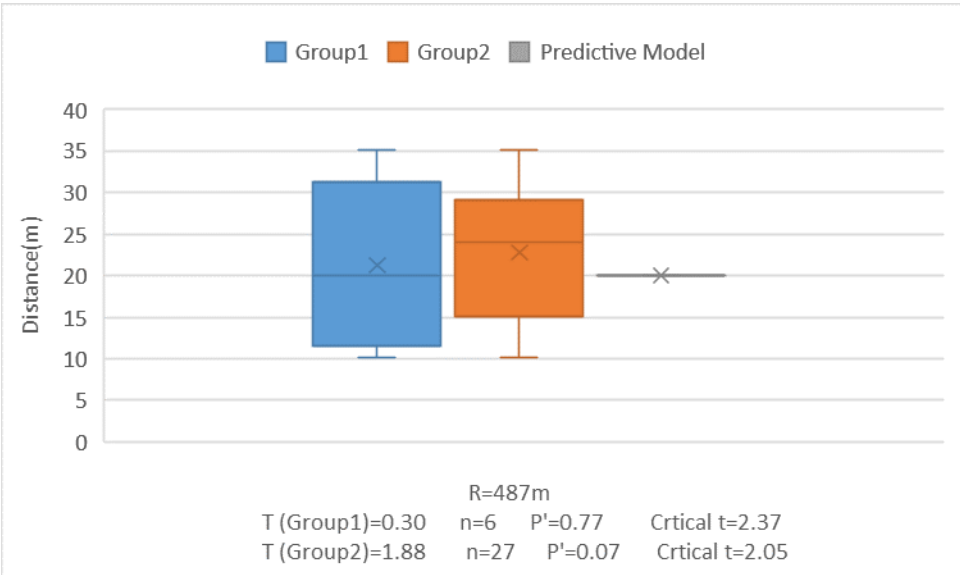

Group1 Group2 Predictive Model
Curvature(1/m)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
R=1000m
T (Group1)=2.86 n=6 P'=0.036 Crtical t=2.45
T (Group2)=3.23 n=29 P'=0.0024 Crtical t=2.05

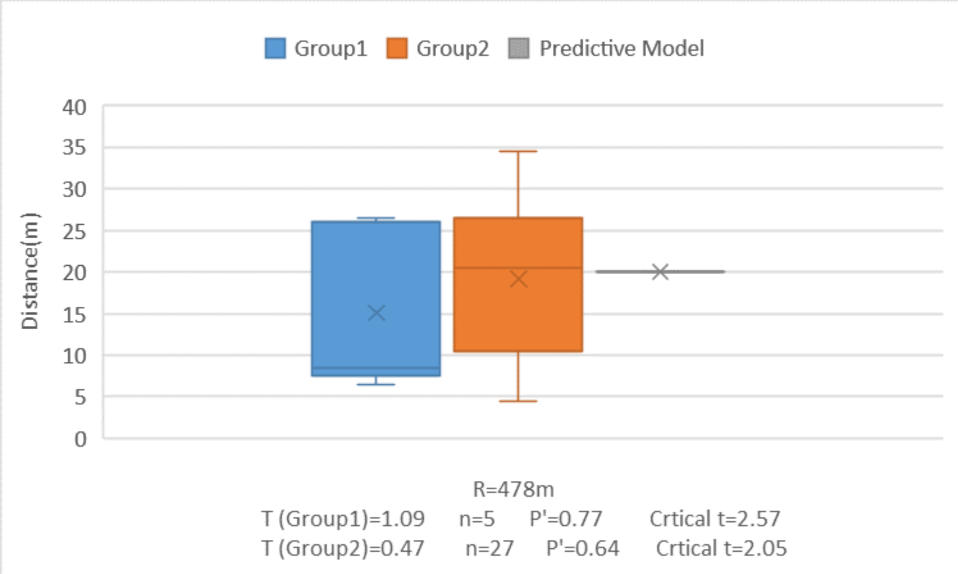

Group1 Group2 Predictive Model
Distance(m)
35
30
25
20
15
10
5
0
R=1000m
T (Group1)=3.57 n=6 P'=0.016 Crtical t=2.45
T (Group2)=5.84 n=32 P'=1.146E-06 Crtical t=2.04

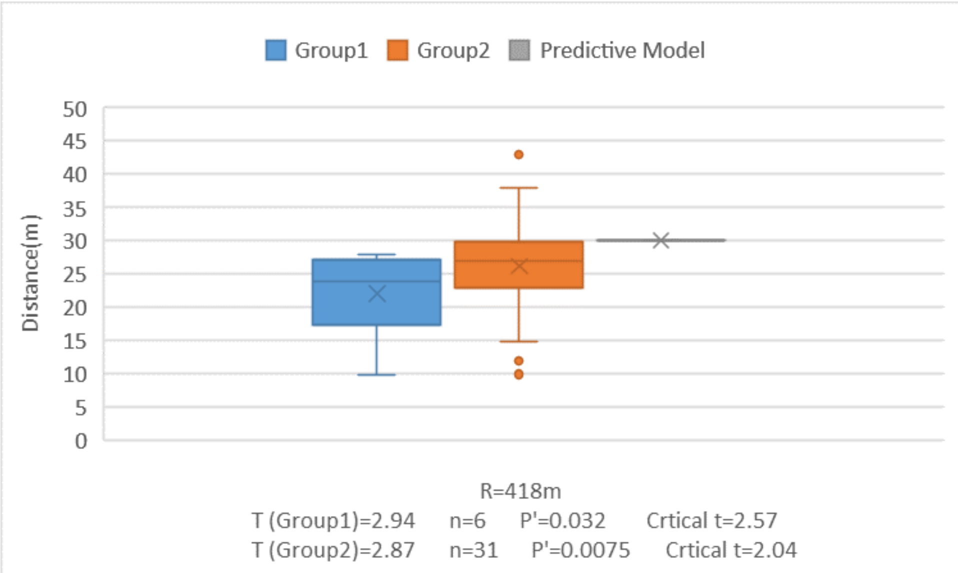

Group1 Group2 Predictive Model
Distance(m)
40
35
30
25
20
15
10
5
0
R=1000m
T (Group1)=2.94 n=6 P'=0.032 Crtical t=2.45
T (Group2)=7.06 n=29 P'=1.12E-07 Crtical t=2.05

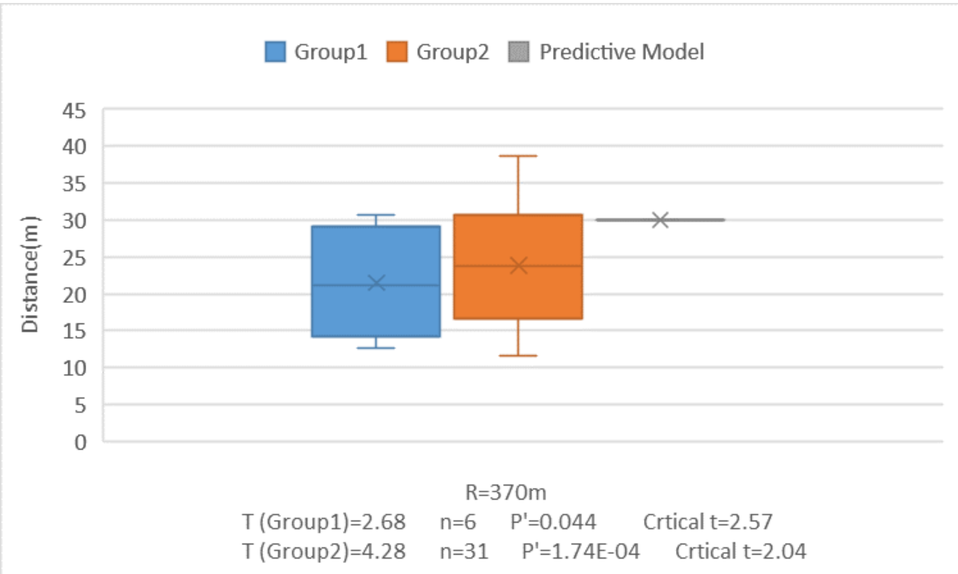

Group1
Group2
Predictive Model
Distance(m)
45
40
35
30
25
20
15
10
5
0
R=527m
T (Group1)=0.033 n=6 P'=0.97 Crtical t=2.45
T (Group2)=2.03 n=31 P'=0.051 Crtical t=2.04

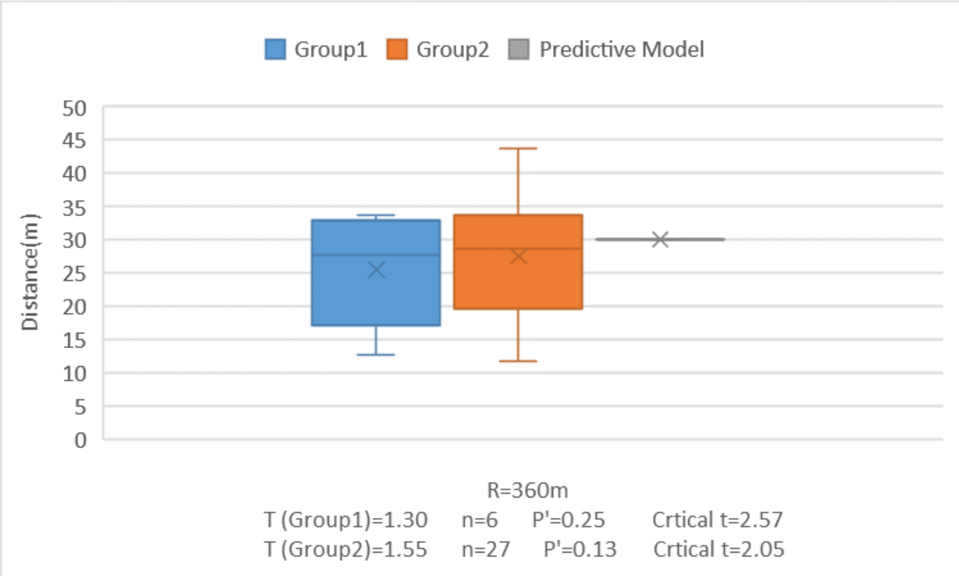

Group1
Group2
Predictive Model
Distance(m)
40
35
30
25
20
15
10
5
0
R=506m
T (Group1)=0.37 n=7 P'=0.86 Crtical t=2.37
T (Group2)=1.09 n=33 P'=0.29 Crtical t=2.04

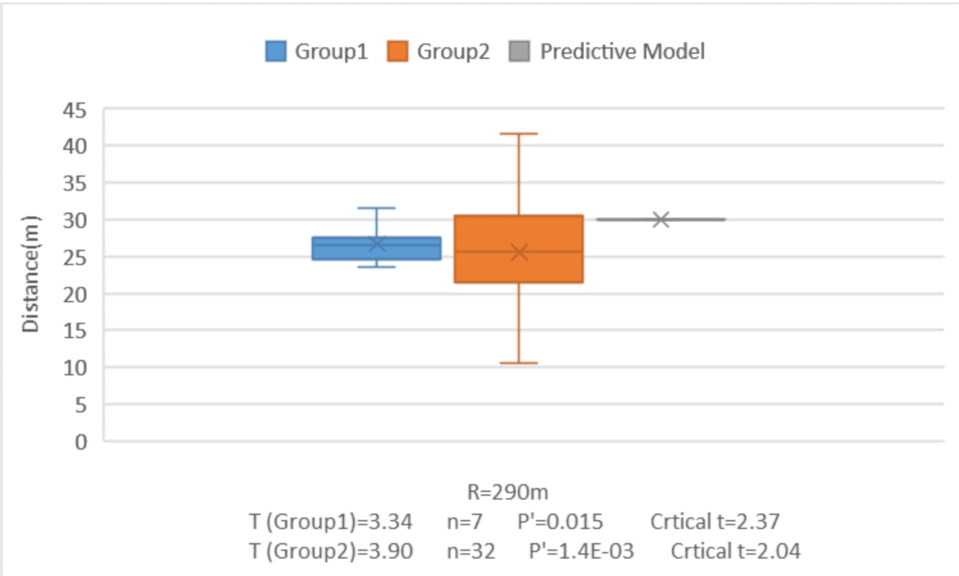

Group1
Group2
Predictive Model
Distance(m)
40
35
30
25
20
15
10
5
0
R=487m
T (Group1)=0.30 n=6 P'=0.77 Crtical t=2.37
T (Group2)=1.88 n=27 P'=0.07 Crtical t=2.05

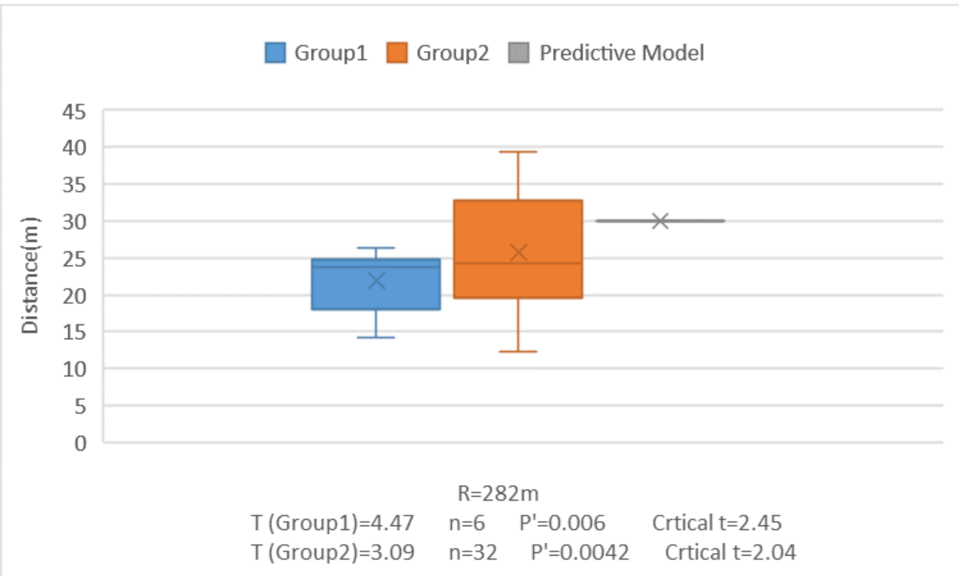

Group1 Group2 Predictive Model
Distance(m)
40
35
30
25
20
15
10
5
0
R=478m
T (Group1)=1.09 n=5 P'=0.77 Crtical t=2.57
T (Group2)=0.47 n=27 P'=0.64 Crtical t=2.05

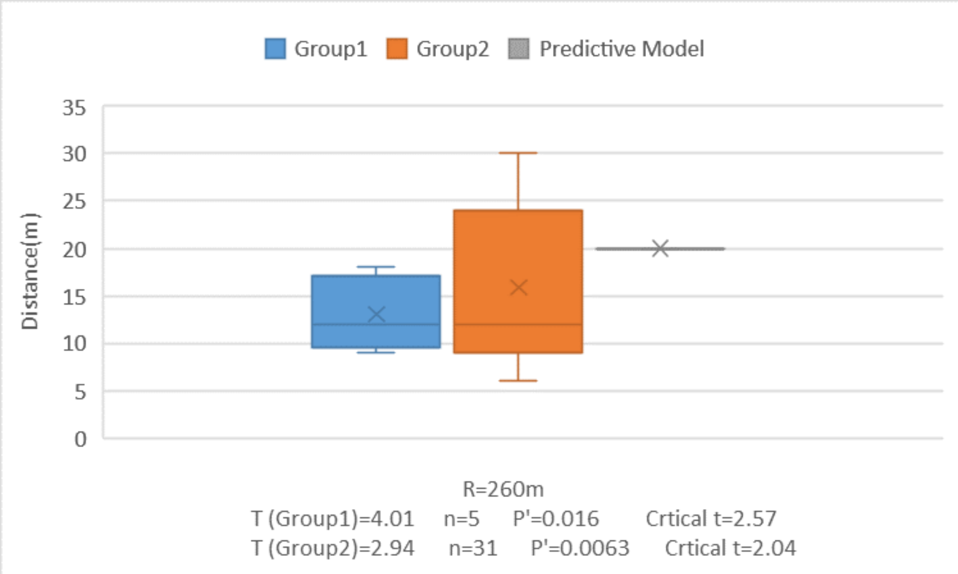

Group1 Group2 Predictive Model
Distance(m)
50
45
40
35
30
25
20
15
10
5
0
R=418m
T (Group1)=2.94 n=6 P'=0.032 Crtical t=2.57
T (Group2)=2.87 n=31 P'=0.0075 Crtical t=2.04

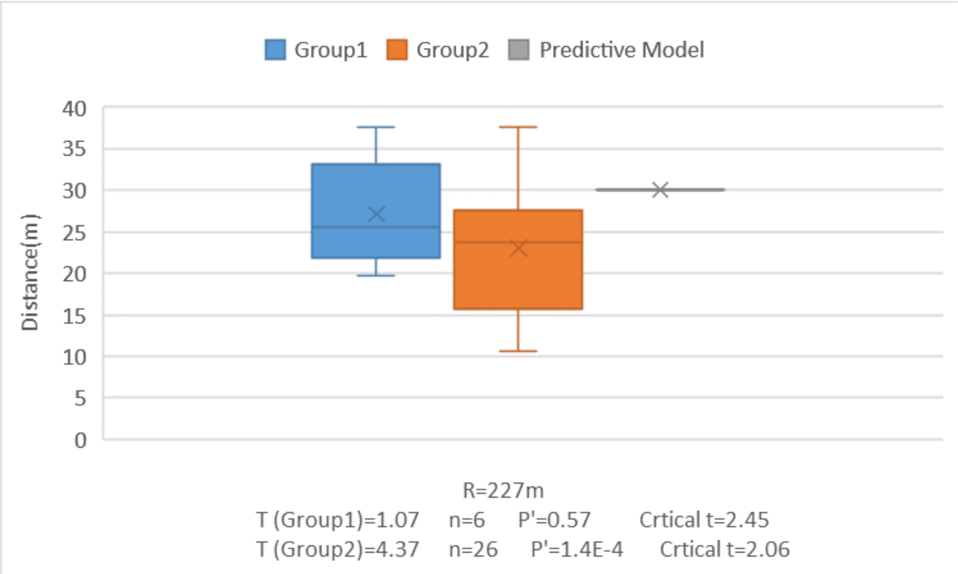

Group1 Group2 Predictive Model
Distance(m)
45
40
35
30
25
20
15
10
5
0
R=370m
T (Group1)=2.68 n=6 P'=0.044 Crtical t=2.57
T (Group2)=4.28 n=31 P'=1.74E-04 Crtical t=2.04

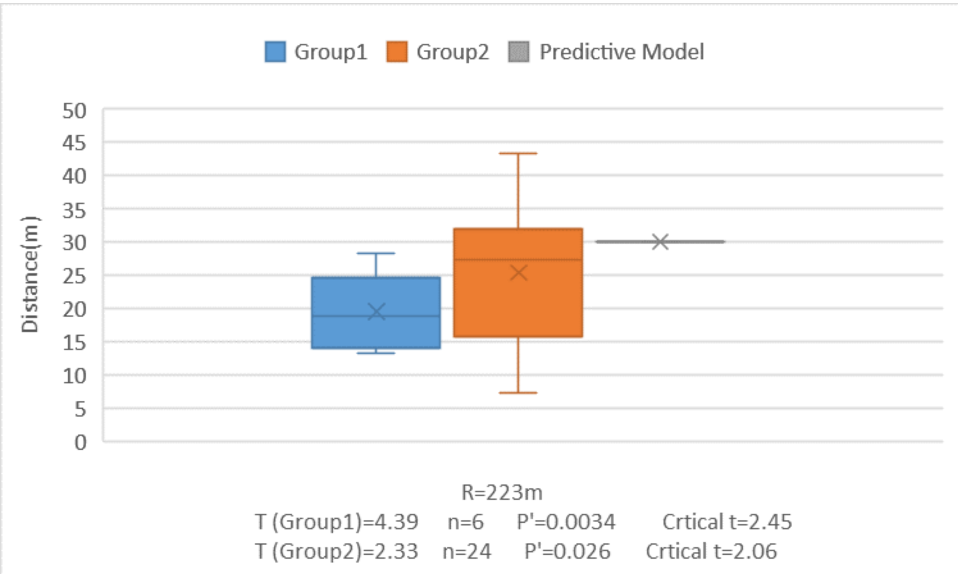

Group1 Group2 Predictive Model
Distance(m)
50
45
40
35
30
25
20
15
10
5
0
R=360m
T (Group1)=1.30 n=6 P'=0.25 Crtical t=2.57
T (Group2)=1.55 n=27 P'=0.13 Crtical t=2.05

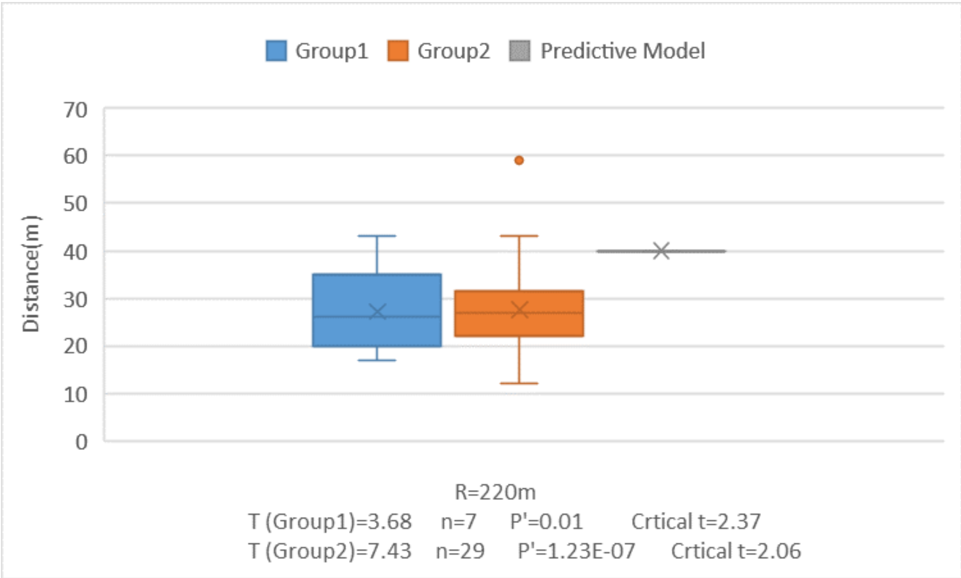

Group1 Group2 Predictive Model
Distance(m)
45
40
35
30
25
20
15
10
5
0
R=290m
T (Group1)=3.34 n=7 P'=0.015 Crtical t=2.37
T (Group2)=3.90 n=32 P'=1.4E-03 Crtical t=2.04

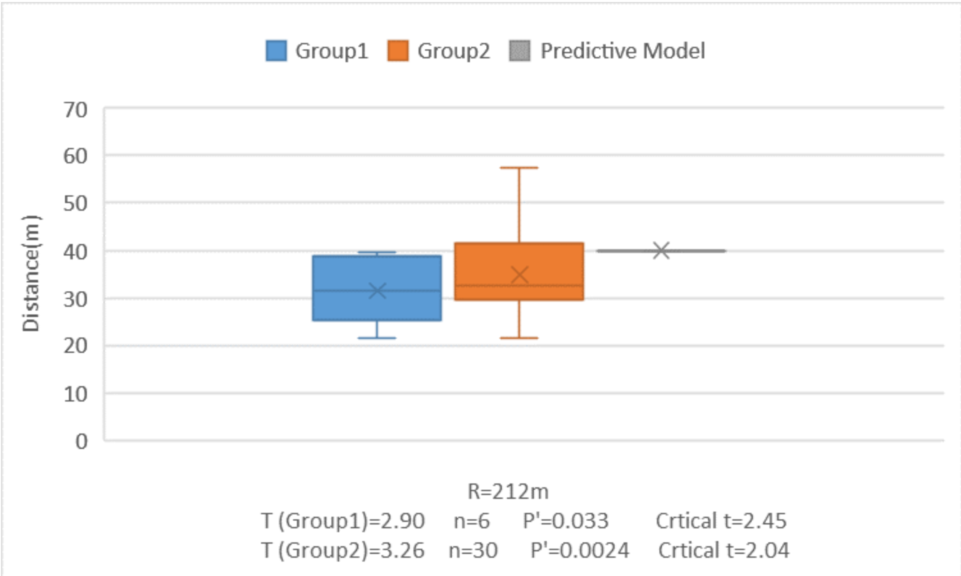

Group1 Group2 Predictive Model
Distance(m)
45
40
35
30
25
20
15
10
5
0
R=282m
T (Group1)=4.47 n=6 P'=0.006 Crtical t=2.45
T (Group2)=3.09 n=32 P'=0.0042 Crtical t=2.04

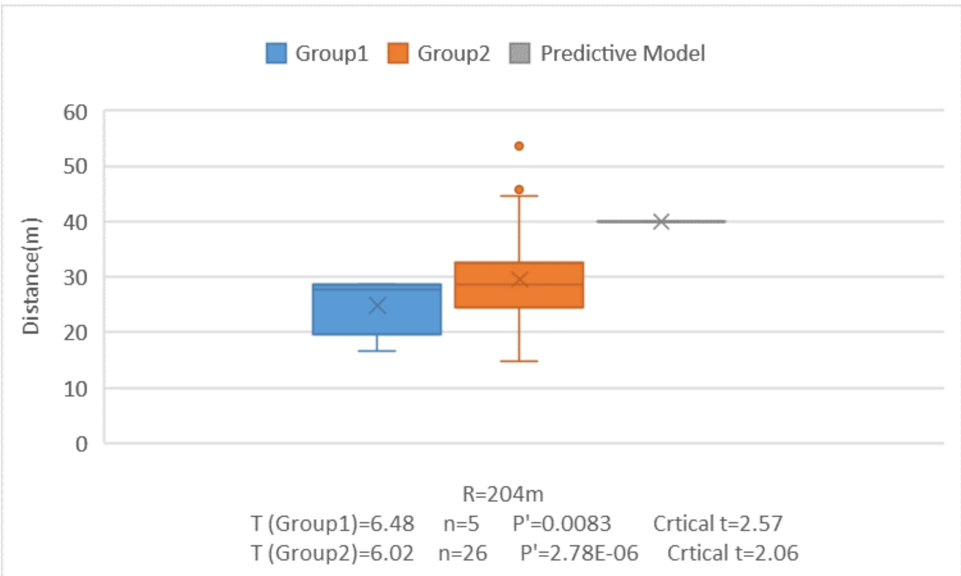

Group1
Group2
Predictive Model
Distance(m)
35
30
25
20
15
10
5
0
R=260m
T (Group1)=4.01 n=5 P'=0.016 Crtical t=2.57
T (Group2)=2.94 n=31 P'=0.0063 Crtical t=2.04

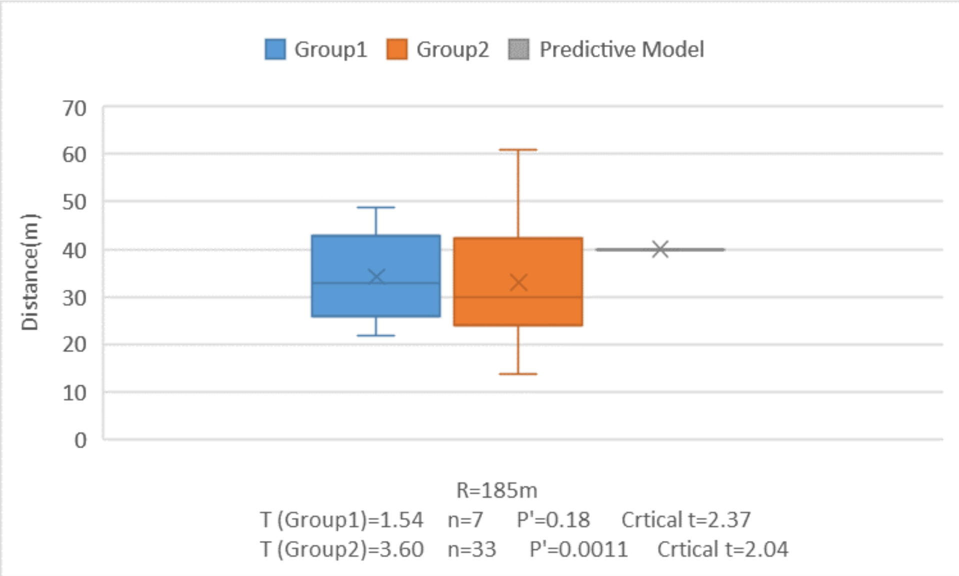

Group1
Group2
Predictive Model
Distance(m)
40
35
30
25
20
15
10
5
0
R=227m
T (Group1)=1.07 n=6 P'=0.57 Crtical t=2.45
T (Group2)=4.37 n=26 P'=1.4E-4 Crtical t=2.06

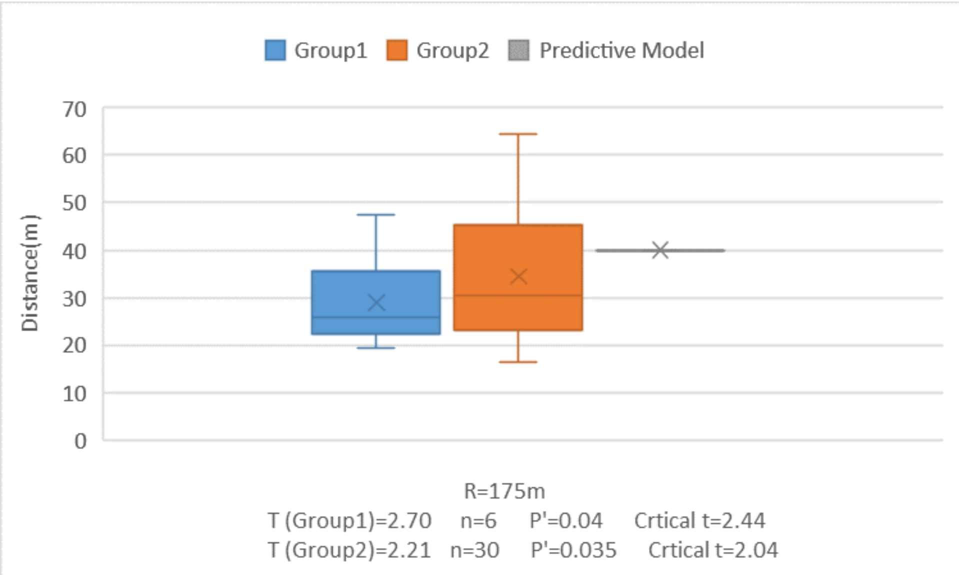

Group1
Group2
Predictive Model
Distance(m)
50
45
40
35
30
25
20
15
10
5
0
R=223m
T (Group1)=4.39 n=6 P'=0.0034 Crtical t=2.45
T (Group2)=2.33 n=24 P'=0.026 Crtical t=2.06

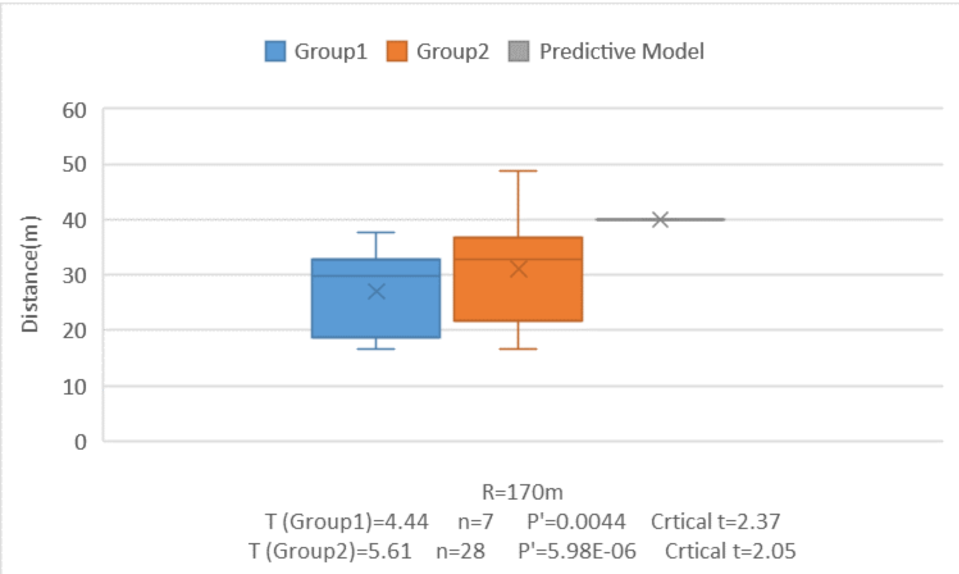

Group1 Group2 Predictive Model
Distance(m)
70
60
50
40
30
20
10
0
R=220m
T (Group1)=3.68 n=7 P'=0.01 Crtical t=2.37
T (Group2)=7.43 n=29 P'=1.23E-07 Crtical t=2.06

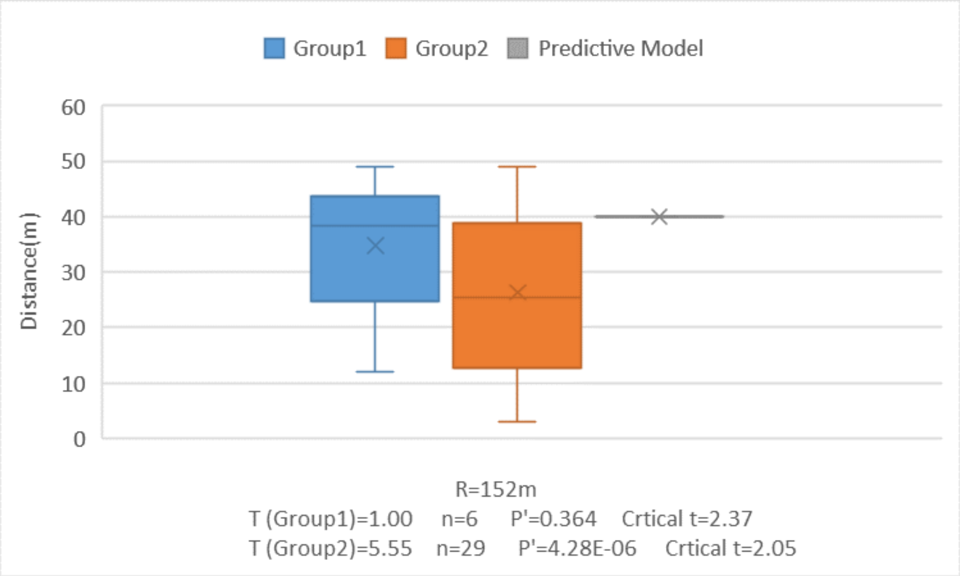

Group1 Group2 Predictive Model
Distance(m)
70
60
50
40
30
20
10
0
R=212m
T (Group1)=2.90 n=6 P'=0.033 Crtical t=2.45
T (Group2)=3.26 n=30 P'=0.0024 Crtical t=2.04

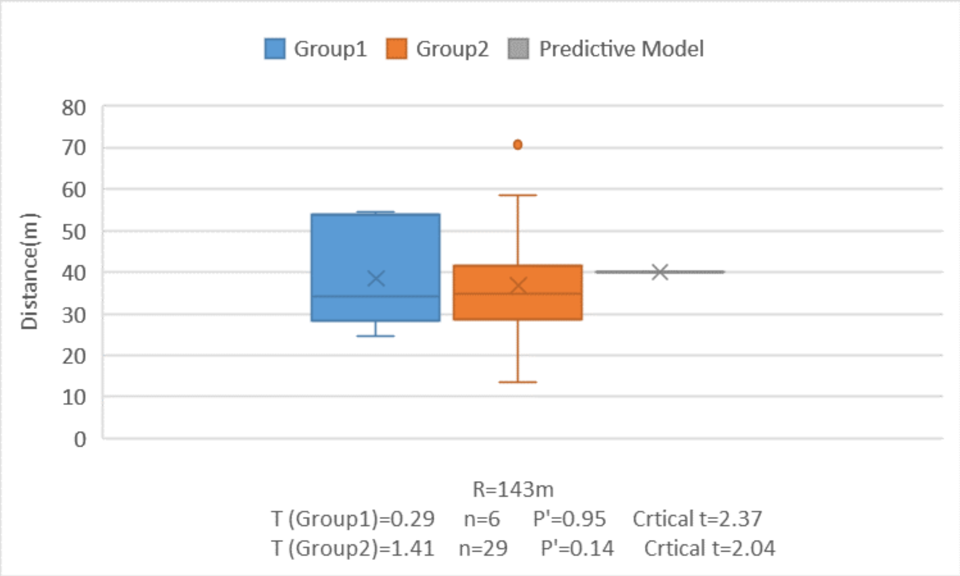

Group1 Group2 Predictive Model
Distance(m)
60
50
40
30
20
10
0
R=204m
T (Group1)=6.48 n=5 P'=0.0083 Crtical t=2.57
T (Group2)=6.02 n=26 P'=2.78E-06 Crtical t=2.06

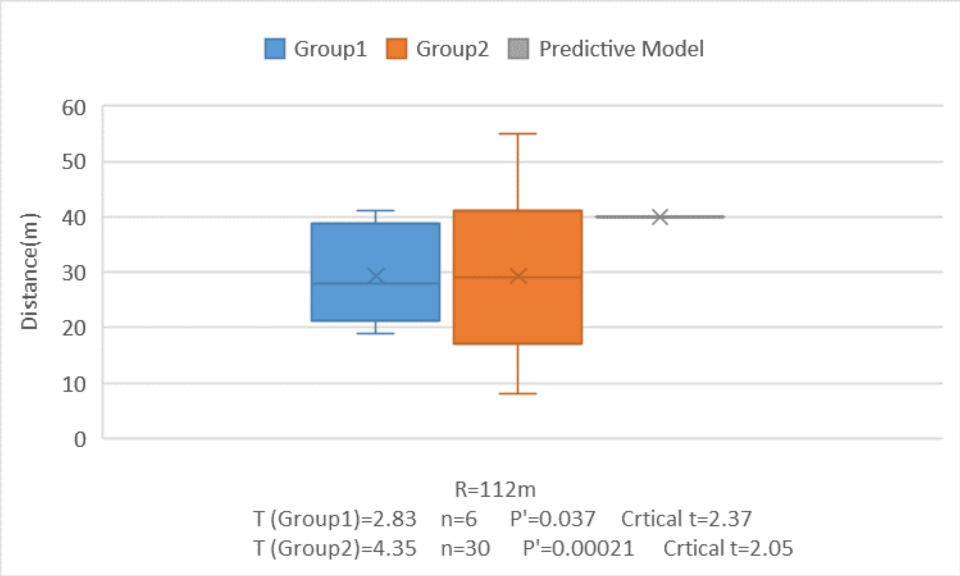

Group1
Group2
Predictive Model
Distance(m)
70
60
50
40
30
20
10
0
R=185m
T (Group1)=1.54 n=7 P'=0.18 Crtical t=2.37
T (Group2)=3.60 n=33 P'=0.0011 Crtical t=2.04

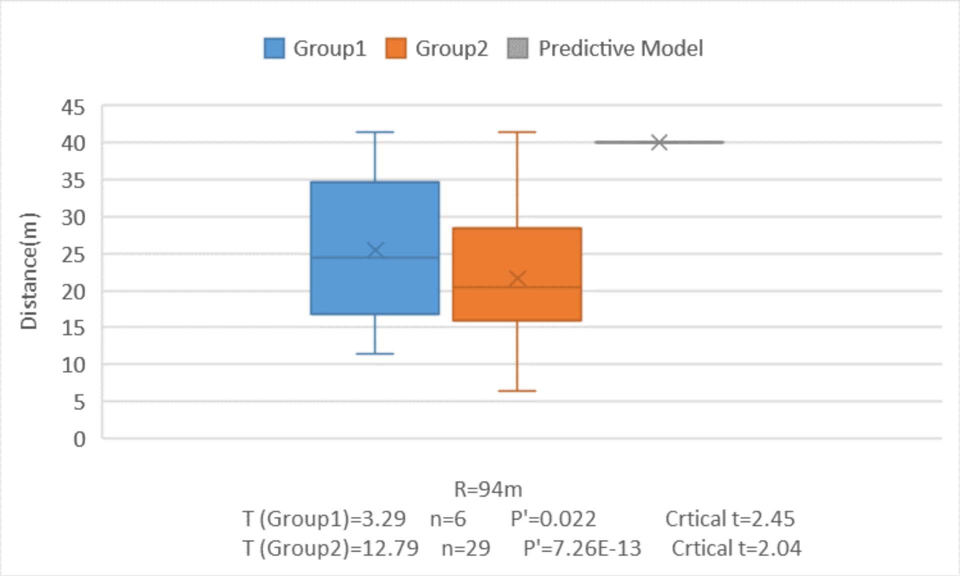

Group1
Group2
Predictive Model
Distance(m)
70
60
50
40
30
20
10
0
R=175m
T (Group1)=2.70 n=6 P'=0.04 Crtical t=2.44
T (Group2)=2.21 n=30 P'=0.035 Crtical t=2.04

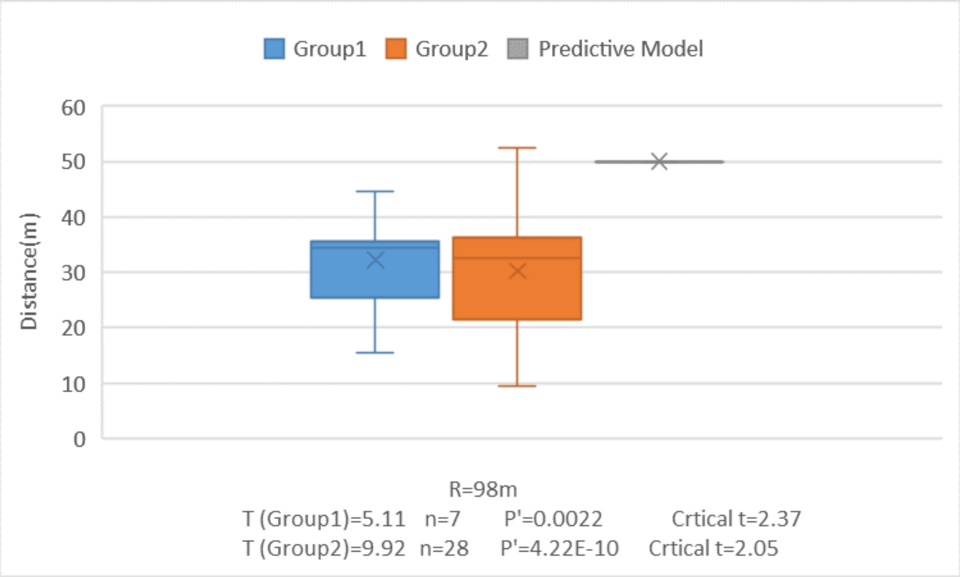

Group1
Group2
Predictive Model
Distance(m)
60
50
40
30
20
10
0
R=170m
T (Group1)=4.44 n=7 P'=0.0044 Crtical t=2.37
T (Group2)=5.61 n=28 P'=5.98E-06 Crtical t=2.05


Group1 Group2 Predictive Model
Distance(m)
60
50
40
30
20
10
0
R=152m
T (Group1)=1.00 n=6 P'=0.364 Crtical t=2.37
T (Group2)=5.55 n=29 P'=4.28E-06 Crtical t=2.05

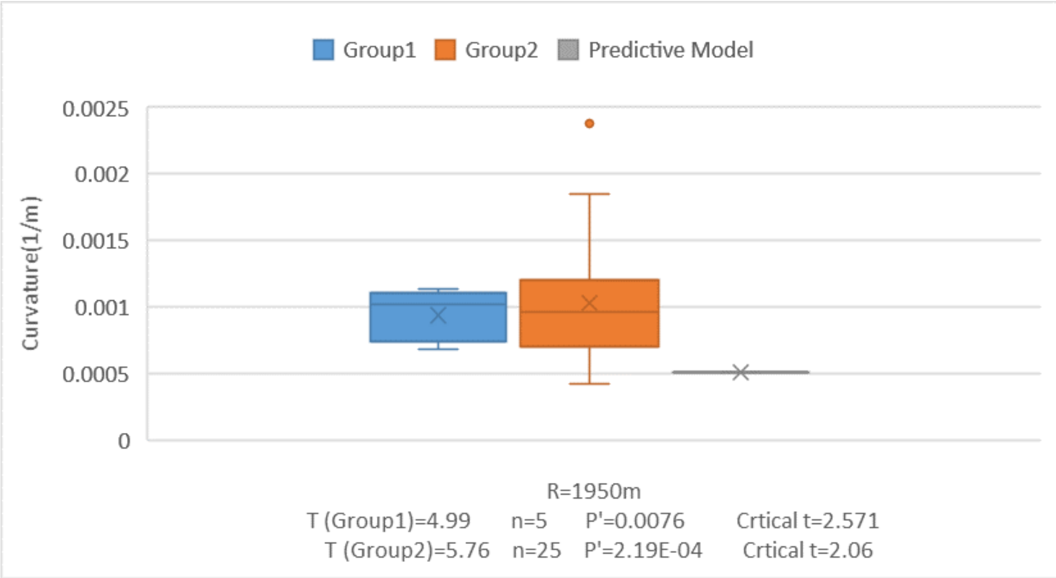

Group1 Group2 Predictive Model
Distance(m)
80
70
60
50
40
30
20
10
0
R=143m
T (Group1)=0.29 n=6 P'=0.95 Crtical t=2.37
T (Group2)=1.41 n=29 P'=0.14 Crtical t=2.04

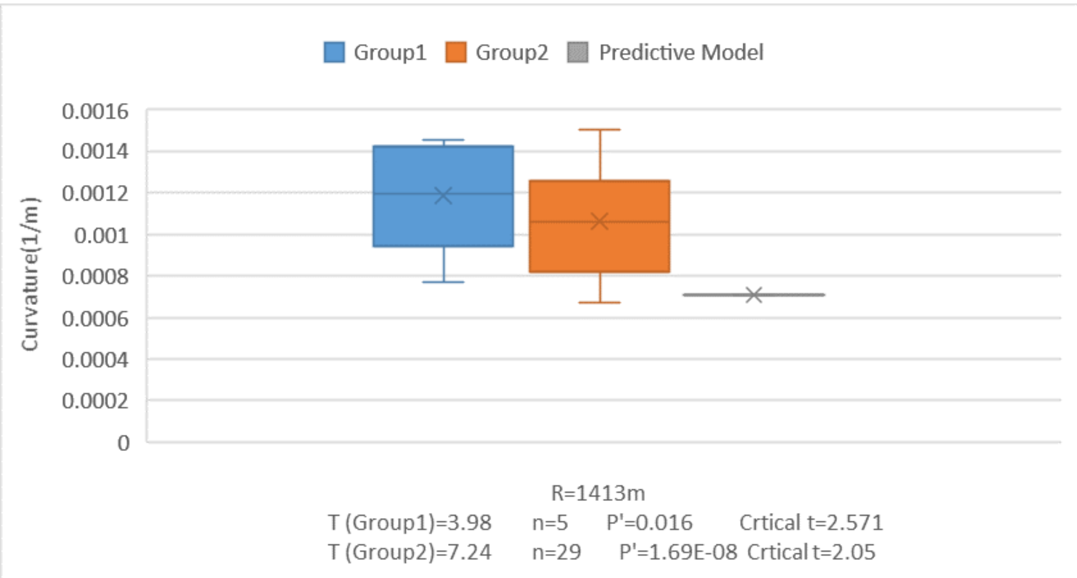

Group1 Group2 Predictive Model
Distance(m)
60
50
40
30
20
10
0
R=112m
T (Group1)=2.83 n=6 P'=0.037 Crtical t=2.37
T (Group2)=4.35 n=30 P'=0.00021 Crtical t=2.05

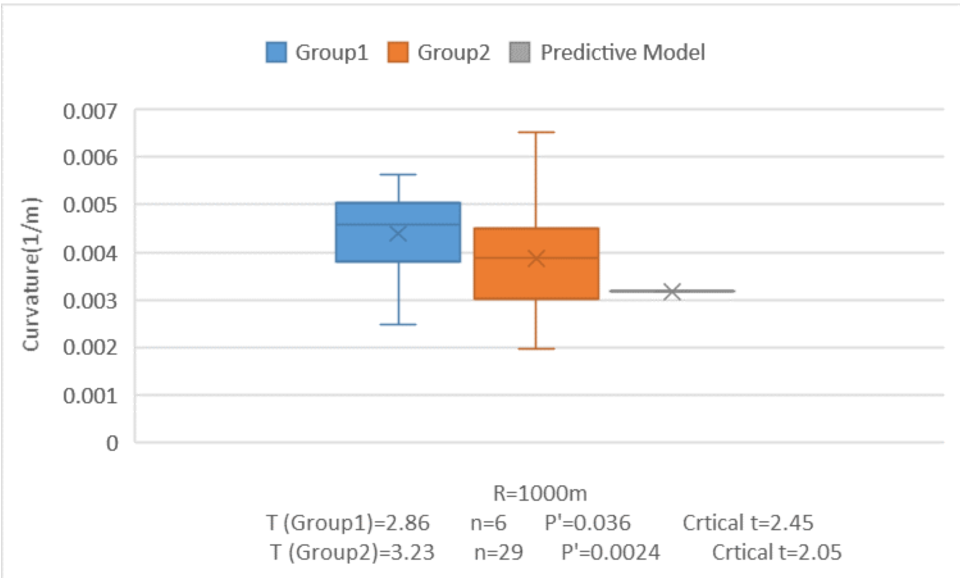

Group1
Group2
Predictive Model
Distance(m)
45
40
35
30
25
20
15
10
5
0
R=94m
T (Group1)=3.29 n=6 P'=0.022 Crtical t=2.45
T (Group2)=12.79 n=29 P'=7.26E-13 Crtical t=2.04

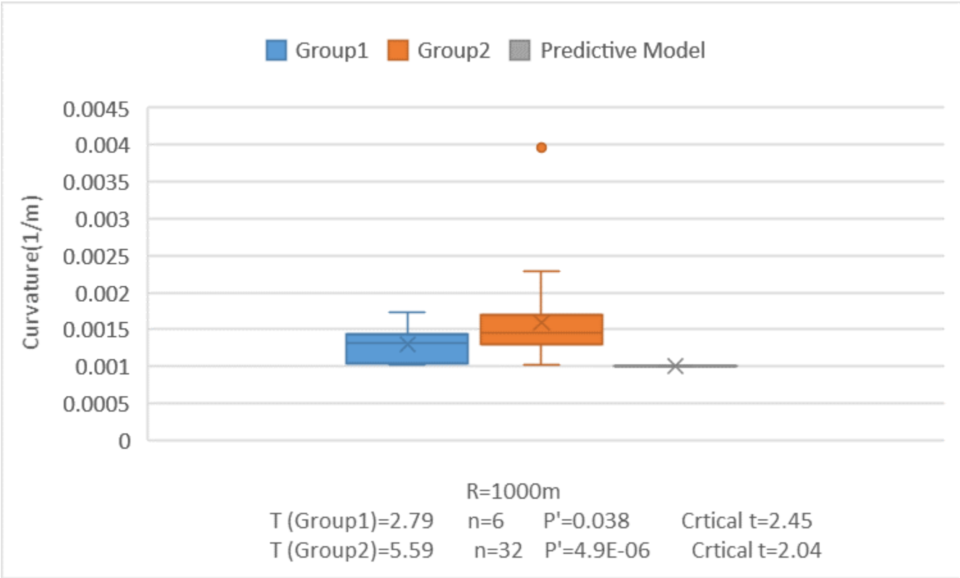

Group1
Group2
Predictive Model
Distance(m)
60
50
40
30
20
10
0
R=98m
T (Group1)=5.11 n=7 P'=0.0022 Crtical t=2.37
T (Group2)=9.92 n=28 P'=4.22E-10 Crtical t=2.05

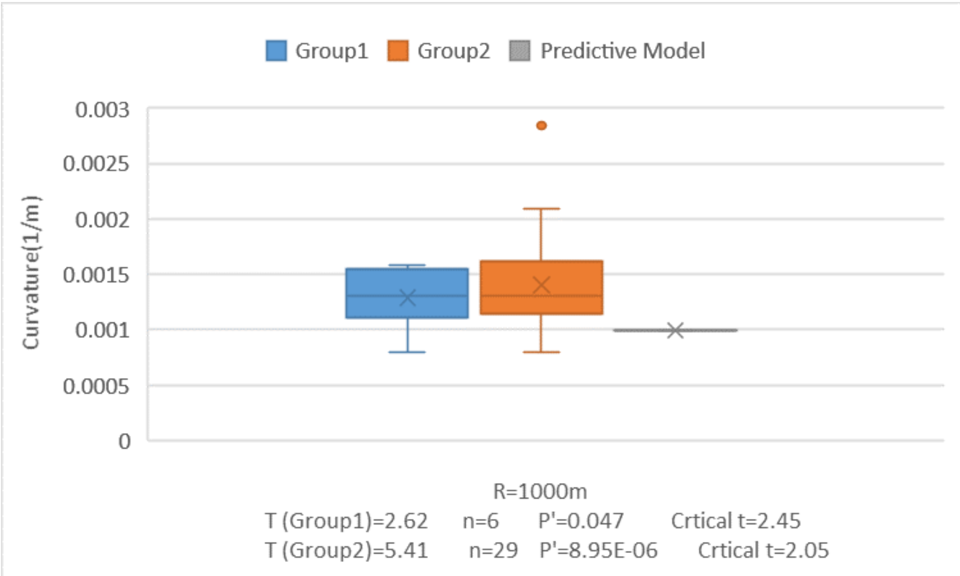
Attachment 11 Curvature

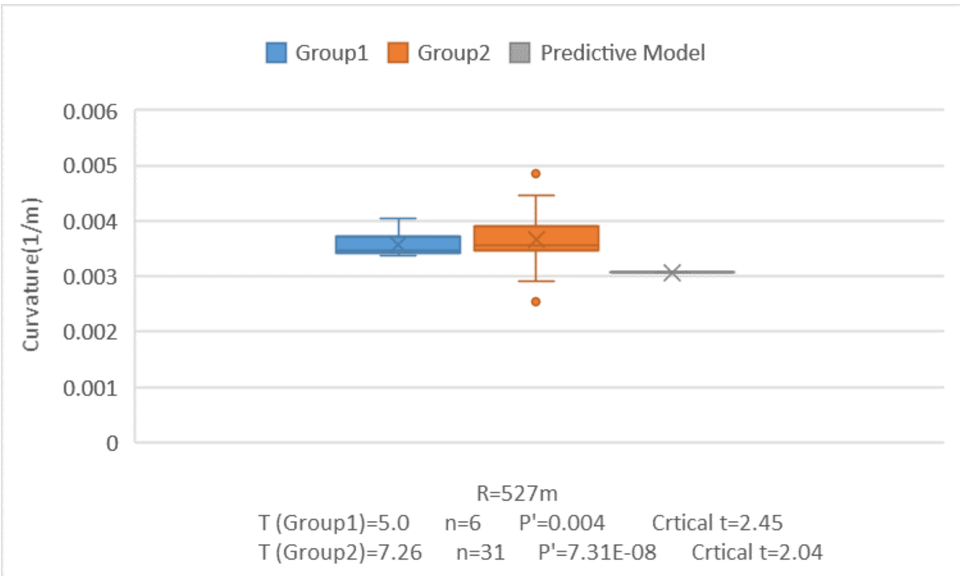


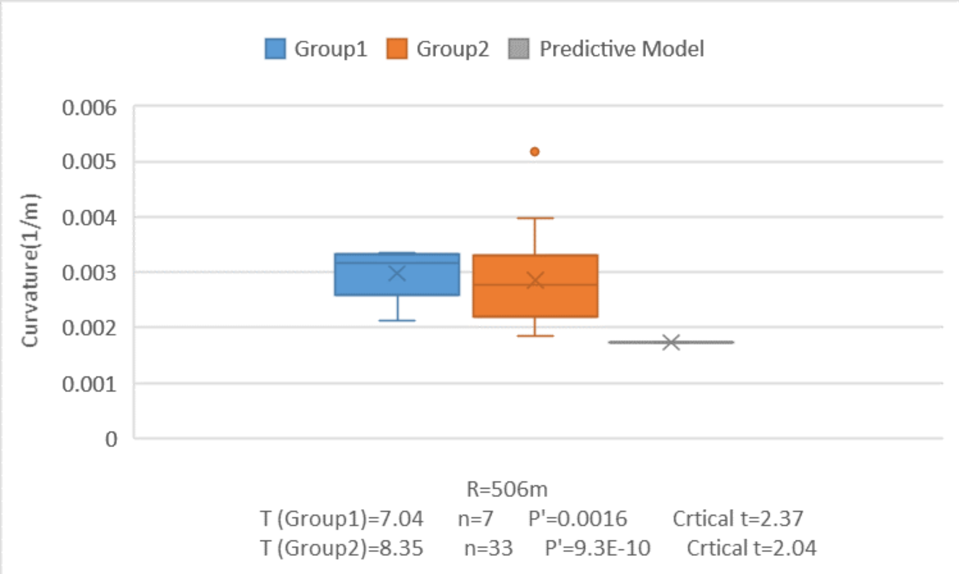


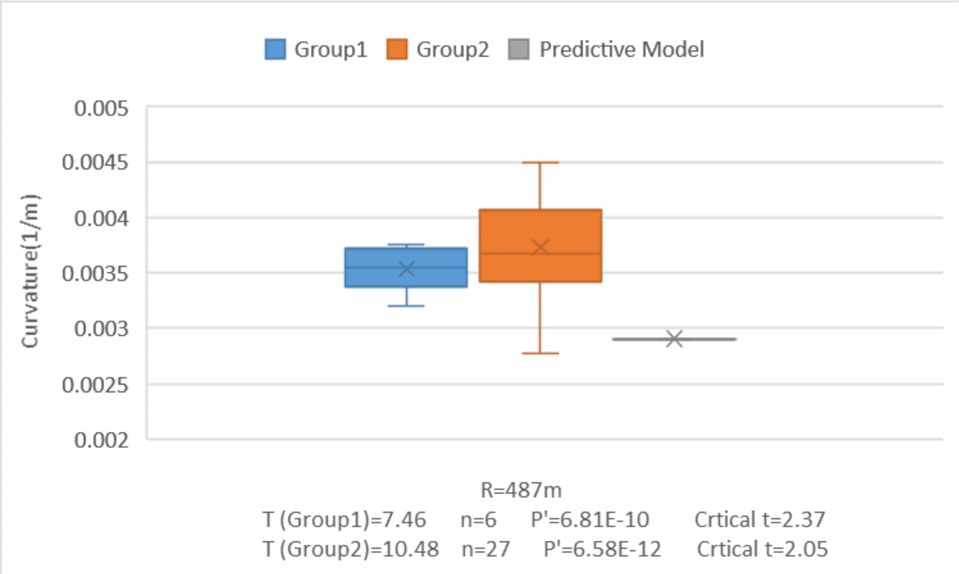


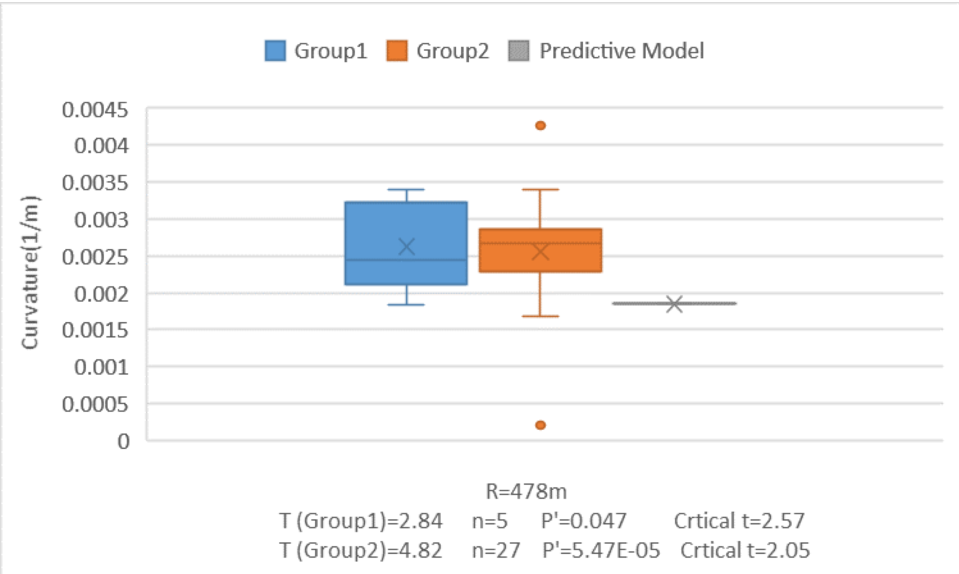

Group1 Group2 Predictive Model
Curvature(1/m)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
R=1000m
T (Group1)=2.79 n=6 P'=0.038 Crtical t=2.45
T (Group2)=5.59 n=32 P'=4.9E-06 Crtical t=2.04

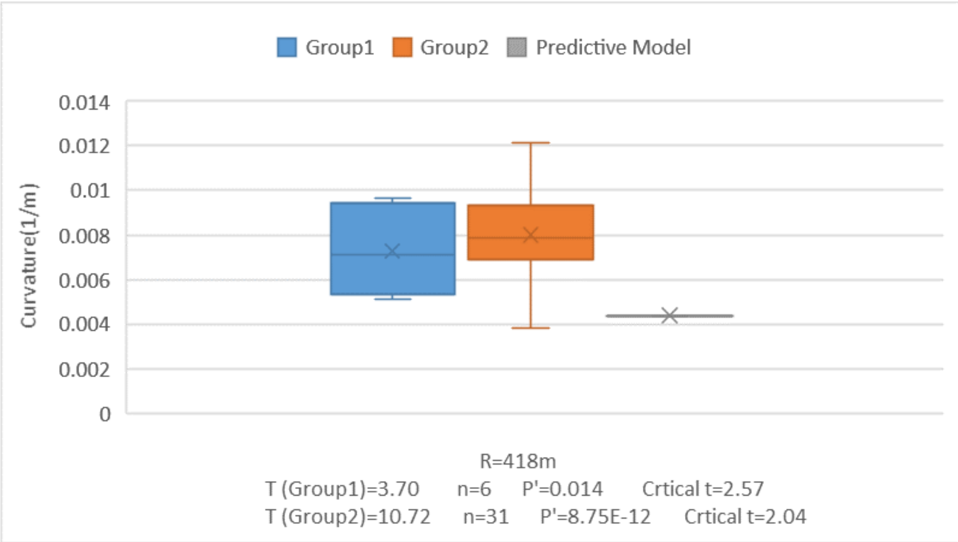

Group1 Group2 Predictive Model
Curvature(1/m)
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
R=1000m
T (Group1)=2.62 n=6 P'=0.047 Crtical t=2.45
T (Group2)=5.41 n=29 P'=8.95E-06 Crtical t=2.05

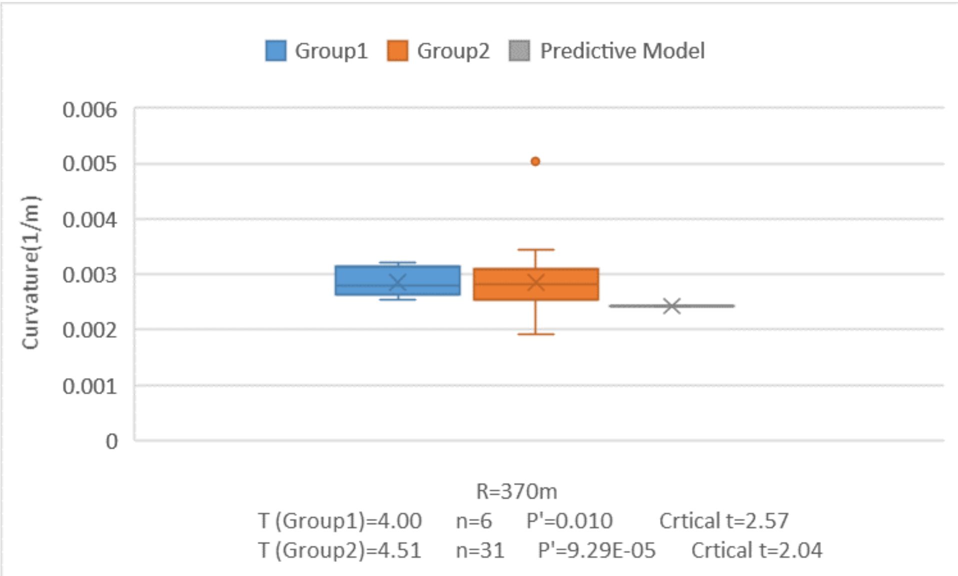

Group1 Group2 Predictive Model
Curvature(1/m)
0.006
0.005
0.004
0.003
0.002
0.001
0
R=527m
T (Group1)=5.0 n=6 P'=0.004 Crtical t=2.45
T (Group2)=7.26 n=31 P'=7.31E-08 Crtical t=2.04

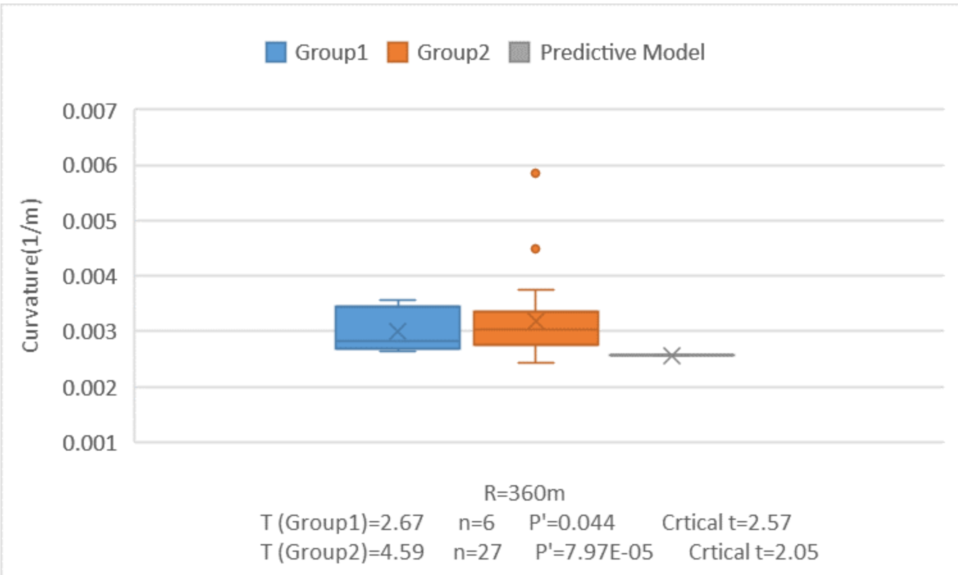

Group1
Group2
Predictive Model
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=506m
T (Group1)=7.04 n=7 P'=0.0016 Crtical t=2.37
T (Group2)=8.35 n=33 P'=9.3E-10 Crtical t=2.04

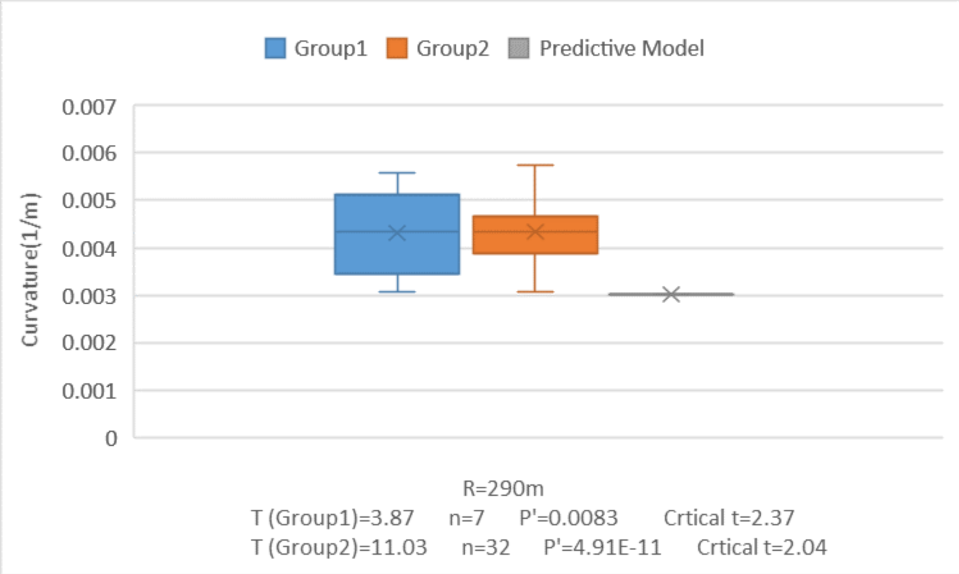

Group1
Group2
Predictive Model
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
Curvature(1/m)
R=487m
T (Group1)=7.46 n=6 P'=6.81E-10 Crtical t=2.37
T (Group2)=10.48 n=27 P'=6.58E-12 Crtical t=2.05

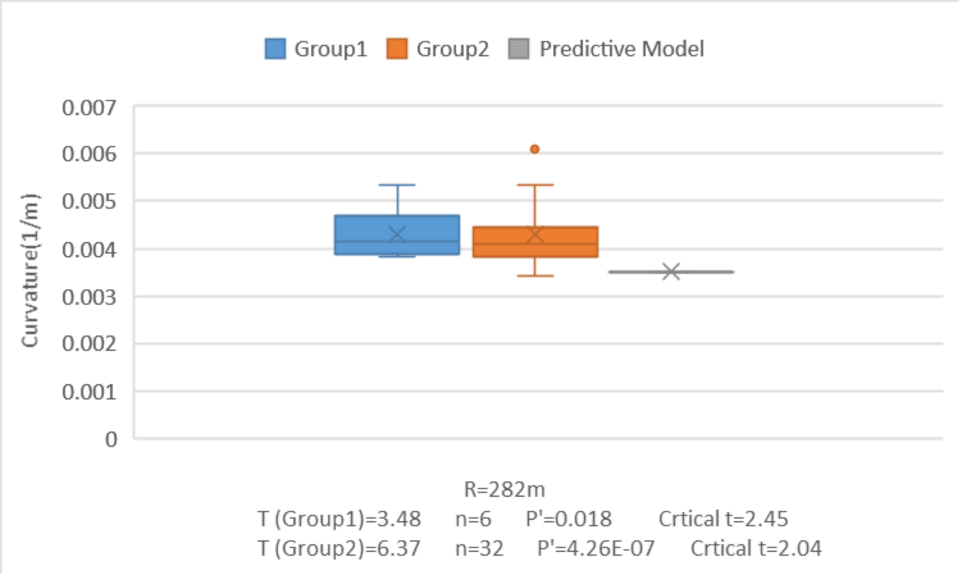

Group1
Group2
Predictive Model
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Curvature(1/m)
R=478m
T (Group1)=2.84 n=5 P'=0.047 Crtical t=2.57
T (Group2)=4.82 n=27 P'=5.47E-05 Crtical t=2.05

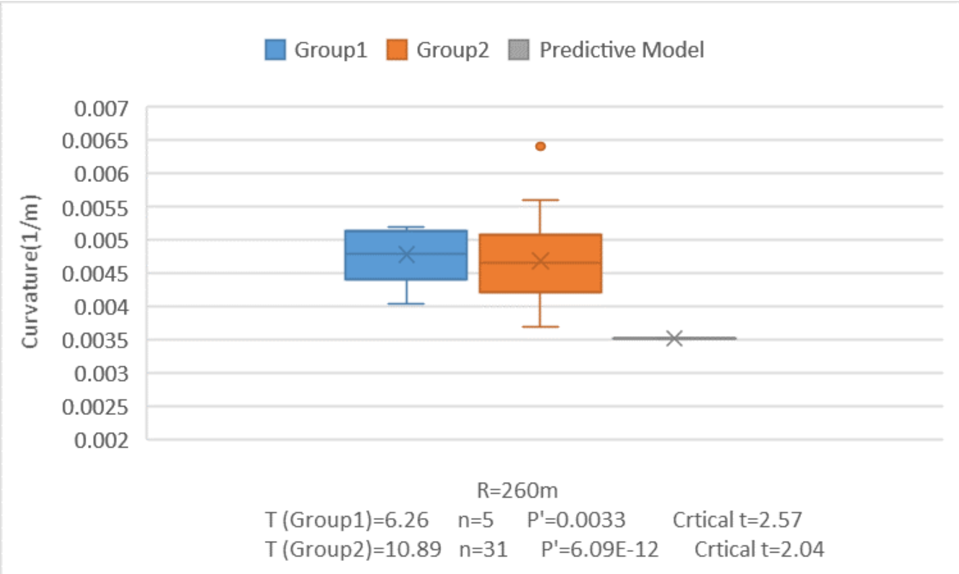

Group1
Group2
Predictive Model
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Curvature(1/m)
R=418m
T (Group1)=3.70 n=6 P'=0.014 Crtical t=2.57
T (Group2)=10.72 n=31 P'=8.75E-12 Crtical t=2.04

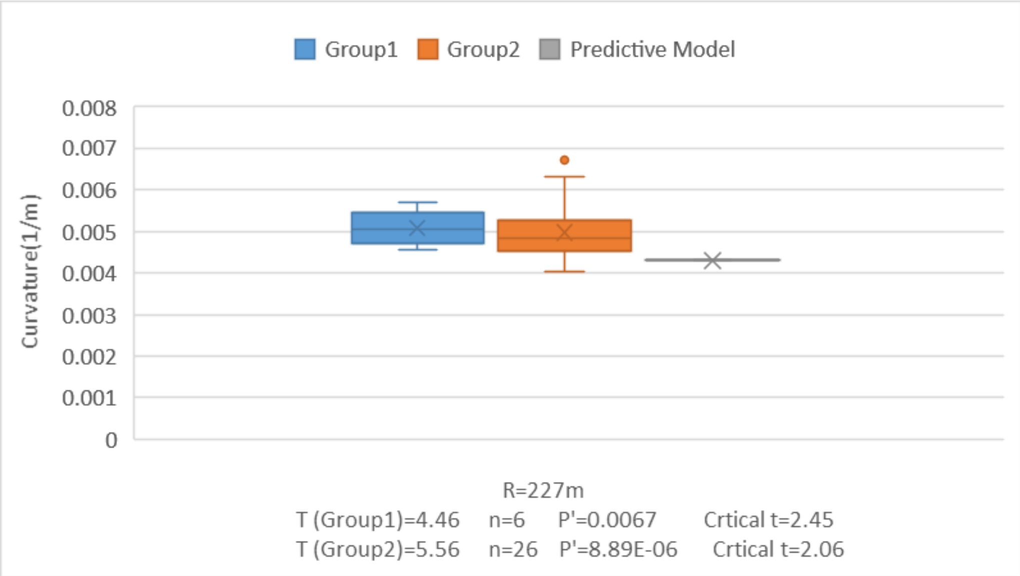

Group1
Group2
Predictive Model
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=370m
T (Group1)=4.00 n=6 P'=0.010 Crtical t=2.57
T (Group2)=4.51 n=31 P'=9.29E-05 Crtical t=2.04

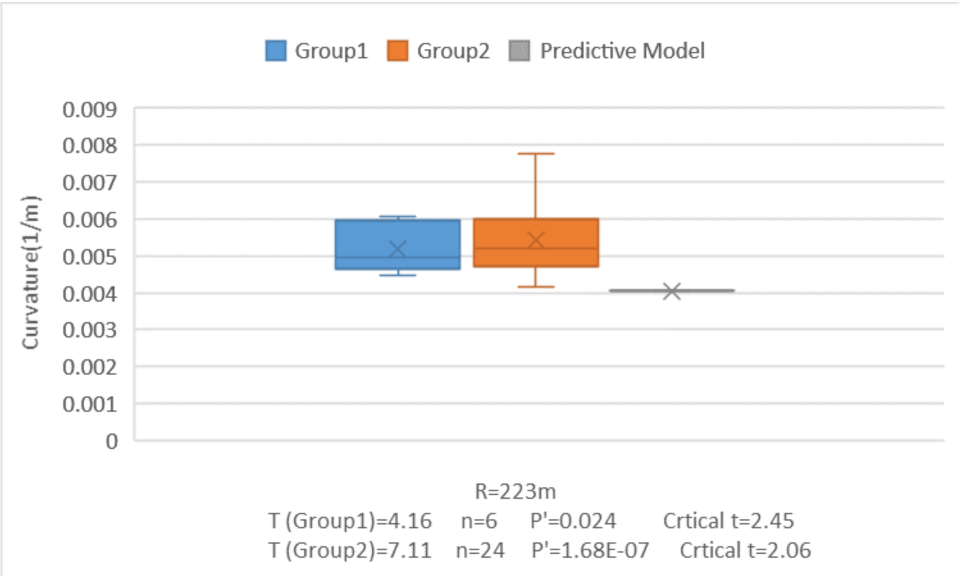

Group1
Group2
Predictive Model
0.007
0.006
0.005
0.004
0.003
0.002
0.001
Curvature(1/m)
R=360m
T (Group1)=2.67 n=6 P'=0.044 Crtical t=2.57
T (Group2)=4.59 n=27 P'=7.97E-05 Crtical t=2.05

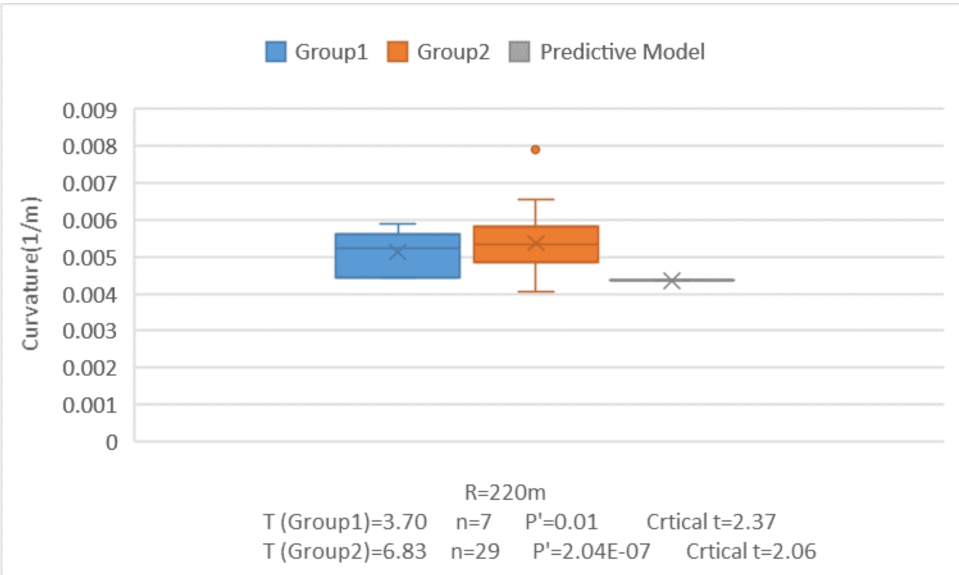

Group1
Group2
Predictive Model
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=290m
T (Group1)=3.87 n=7 P'=0.0083 Crtical t=2.37
T (Group2)=11.03 n=32 P'=4.91E-11 Crtical t=2.04

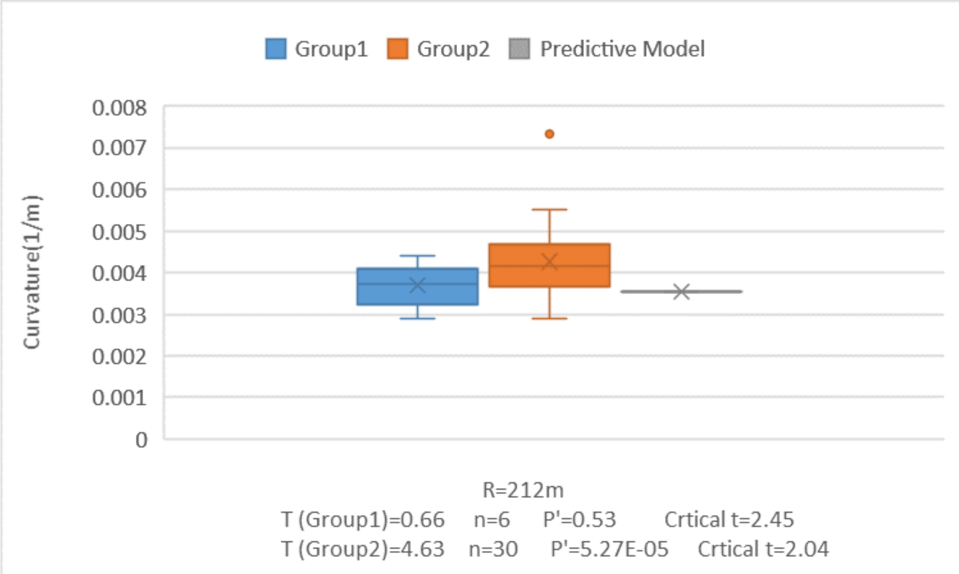

Group1
Group2
Predictive Model
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=282m
T (Group1)=3.48 n=6 P'=0.018 Crtical t=2.45
T (Group2)=6.37 n=32 P'=4.26E-07 Crtical t=2.04

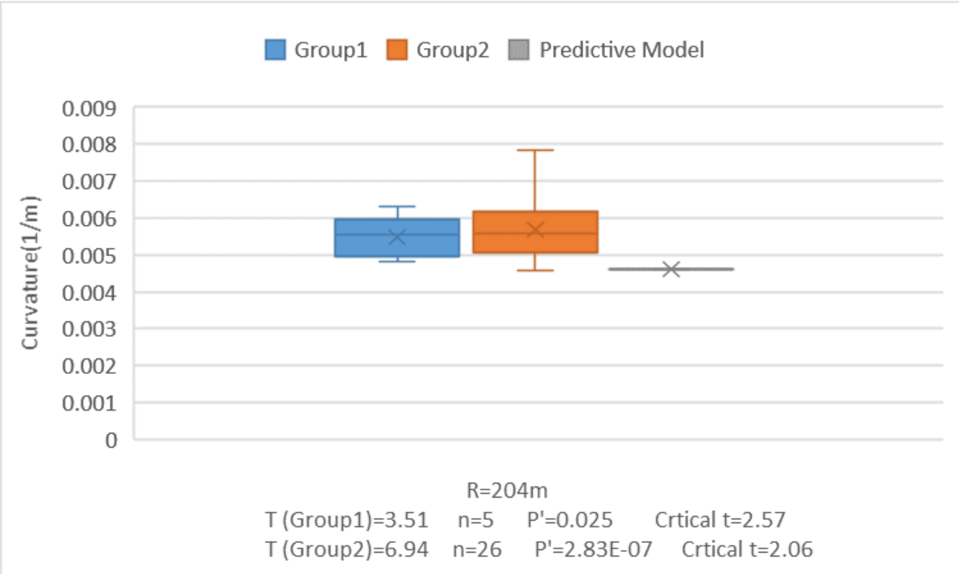

Group1
Group2
Predictive Model
0.007
0.0065
0.006
0.0055
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
Curvature(1/m)
R=260m
T (Group1)=6.26 n=5 P'=0.0033 Crtical t=2.57
T (Group2)=10.89 n=31 P'=6.09E-12 Crtical t=2.04

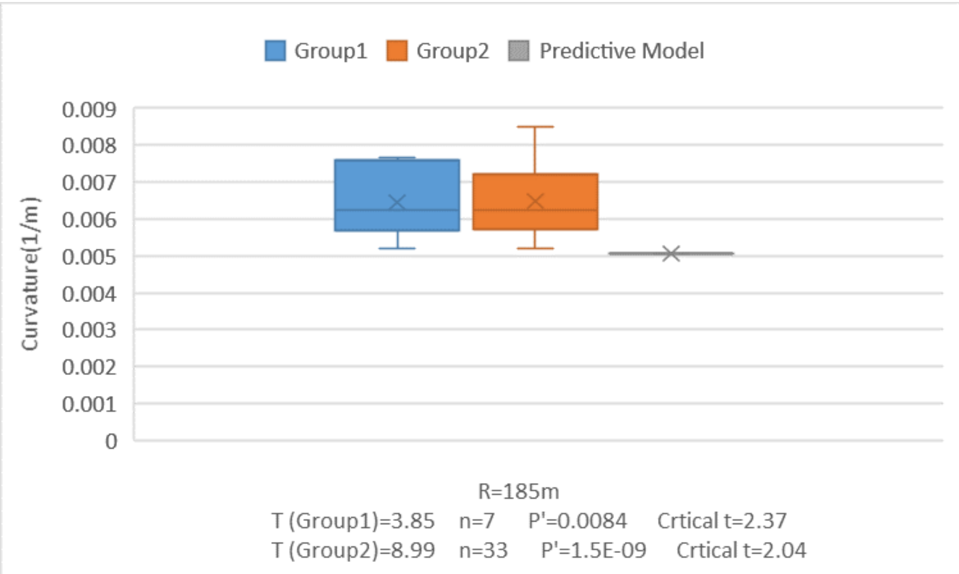

Group1
Group2
Predictive Model
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=227m
T (Group1)=4.46 n=6 P'=0.0067 Crtical t=2.45
T (Group2)=5.56 n=26 P'=8.89E-06 Crtical t=2.06

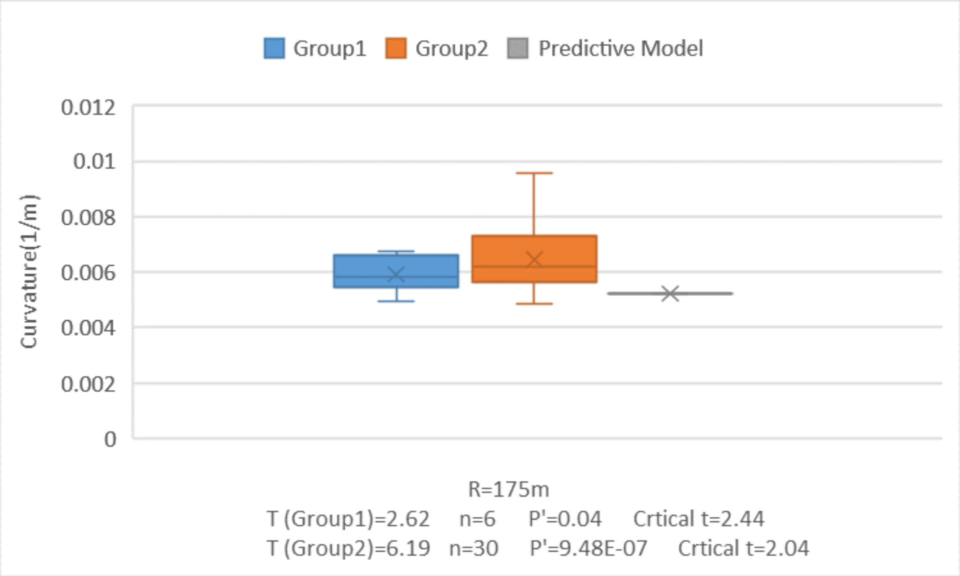

Group1
Group2
Predictive Model
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=223m
T (Group1)=4.16 n=6 P'=0.024 Crtical t=2.45
T (Group2)=7.11 n=24 P'=1.68E-07 Crtical t=2.06

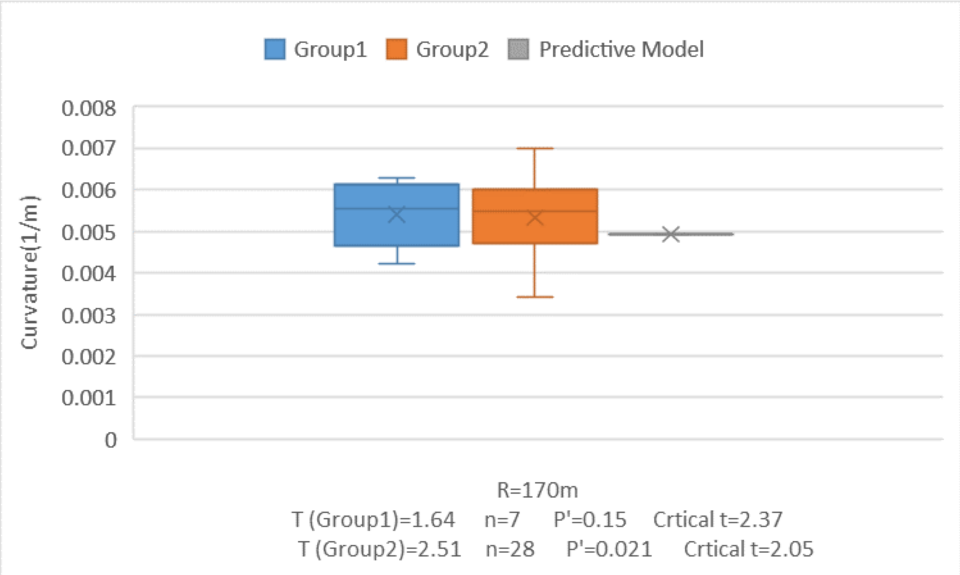

Group1
Group2
Predictive Model
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
Curvature(1/m)
R=220m
T (Group1)=3.70 n=7 P'=0.01 Crtical t=2.37
T (Group2)=6.83 n=29 P'=2.04E-07 Crtical t=2.06

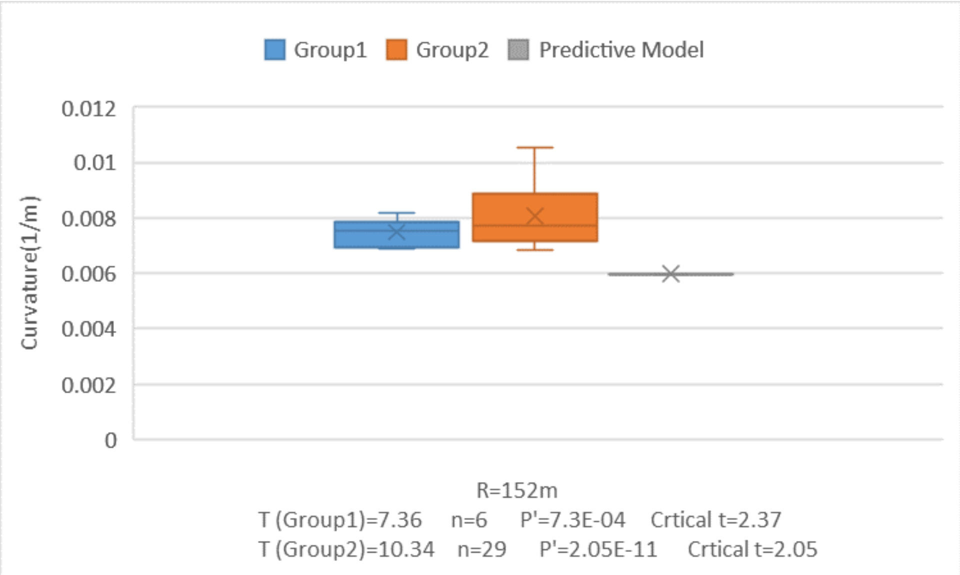

Group1
Group2
Predictive Model
Curvature(1/m)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
R=212m
T (Group1)=0.66 n=6 P'=0.53 Crtical t=2.45
T (Group2)=4.63 n=30 P'=5.27E-05 Crtical t=2.04

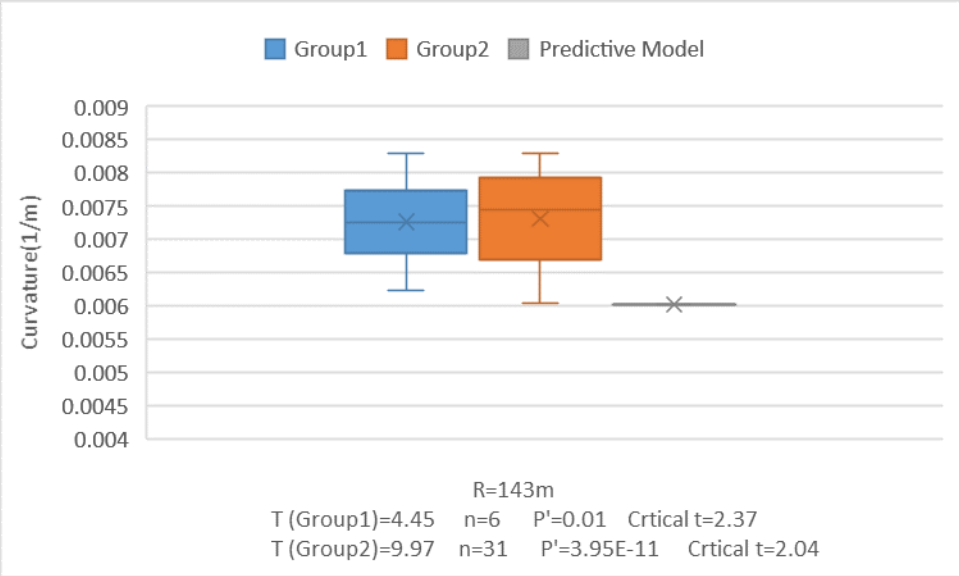

Group1
Group2
Predictive Model
Curvature(1/m)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
R=204m
T (Group1)=3.51 n=5 P'=0.025 Crtical t=2.57
T (Group2)=6.94 n=26 P'=2.83E-07 Crtical t=2.06

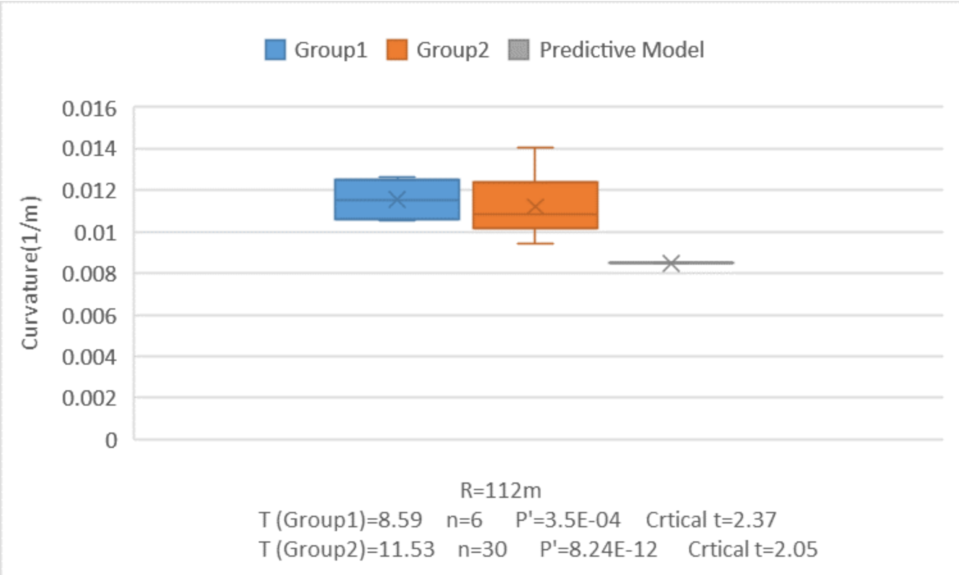

Group1
Group2
Predictive Model
Curvature(1/m)
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
R=185m
T (Group1)=3.85 n=7 P'=0.0084 Crtical t=2.37
T (Group2)=8.99 n=33 P'=1.5E-09 Crtical t=2.04

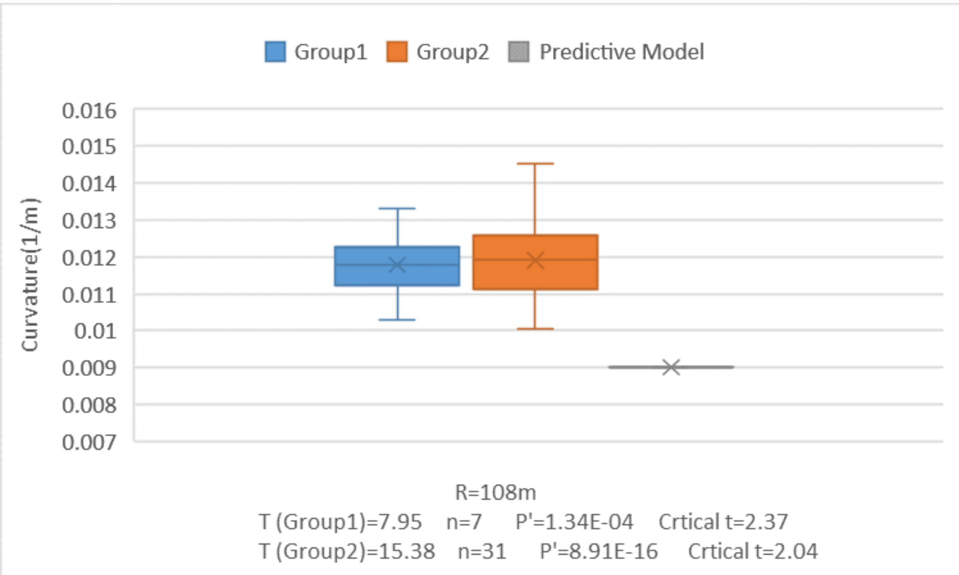

Group1
Group2
Predictive Model
Curvature(1/m)
0.012
0.01
0.008
0.006
0.004
0.002
0
R=175m
T (Group1)=2.62 n=6 P'=0.04 Crtical t=2.44
T (Group2)=6.19 n=30 P'=9.48E-07 Crtical t=2.04

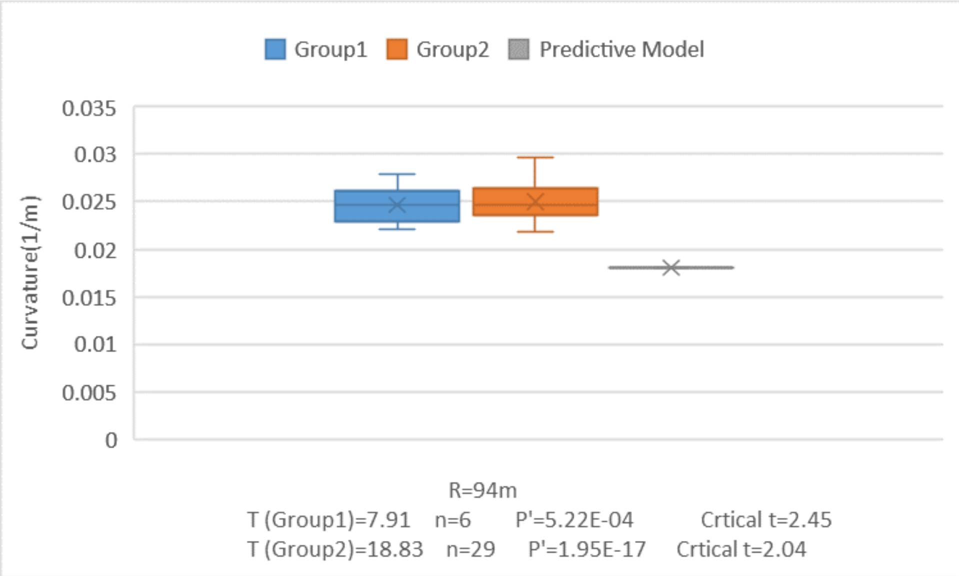

Group1
Group2
Predictive Model
Curvature(1/m)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
R=170m
T (Group1)=1.64 n=7 P'=0.15 Crtical t=2.37
T (Group2)=2.51 n=28 P'=0.021 Crtical t=2.05

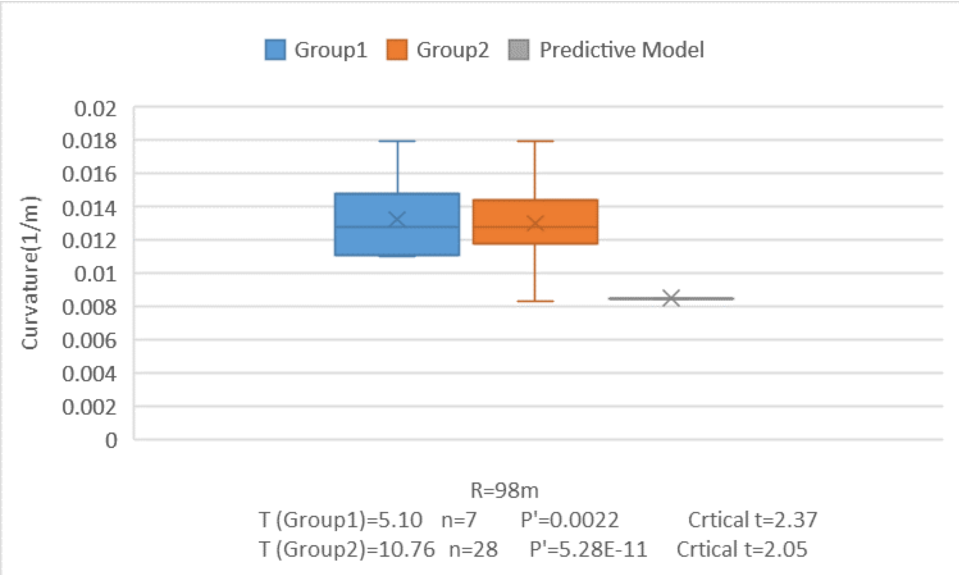

Group1
Group2
Predictive Model
Curvature(1/m)
0.012
0.01
0.008
0.006
0.004
0.002
0
R=152m
T (Group1)=7.36 n=6 P'=7.3E-04 Crtical t=2.37
T (Group2)=10.34 n=29 P'=2.05E-11 Crtical t=2.05


Group1 Group2 Predictive Model
Curvature(1/m)
0.009
0.0085
0.008
0.0075
0.007
0.0065
0.006
0.0055
0.005
0.0045
0.004
R=143m
T (Group1)=4.45 n=6 P'=0.01 Crtical t=2.37
T (Group2)=9.97 n=31 P'=3.95E-11 Crtical t=2.04

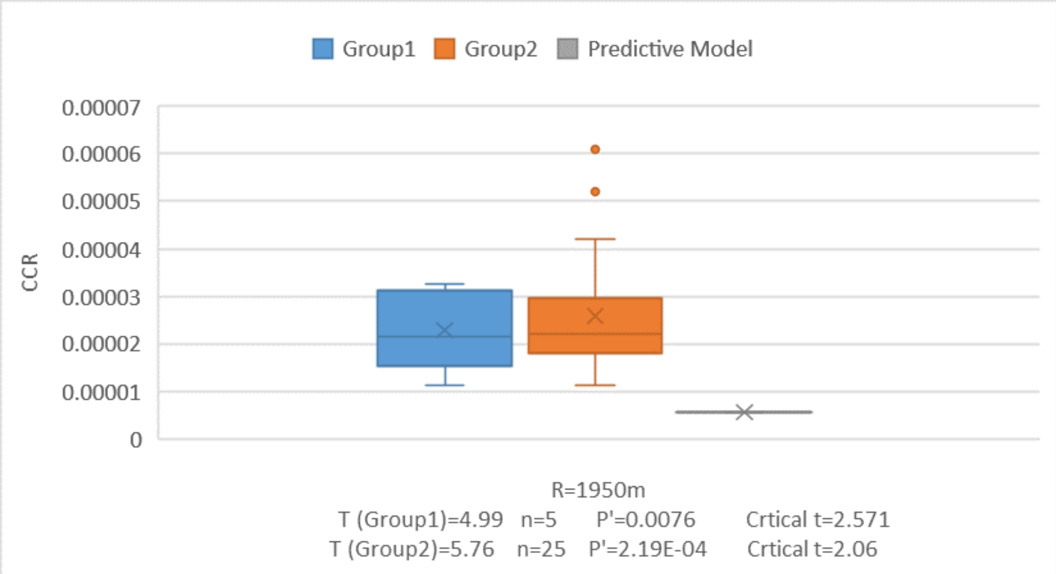

Group1 Group2 Predictive Model
Curvature(1/m)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
R=112m
T (Group1)=8.59 n=6 P'=3.5E-04 Crtical t=2.37
T (Group2)=11.53 n=30 P'=8.24E-12 Crtical t=2.05

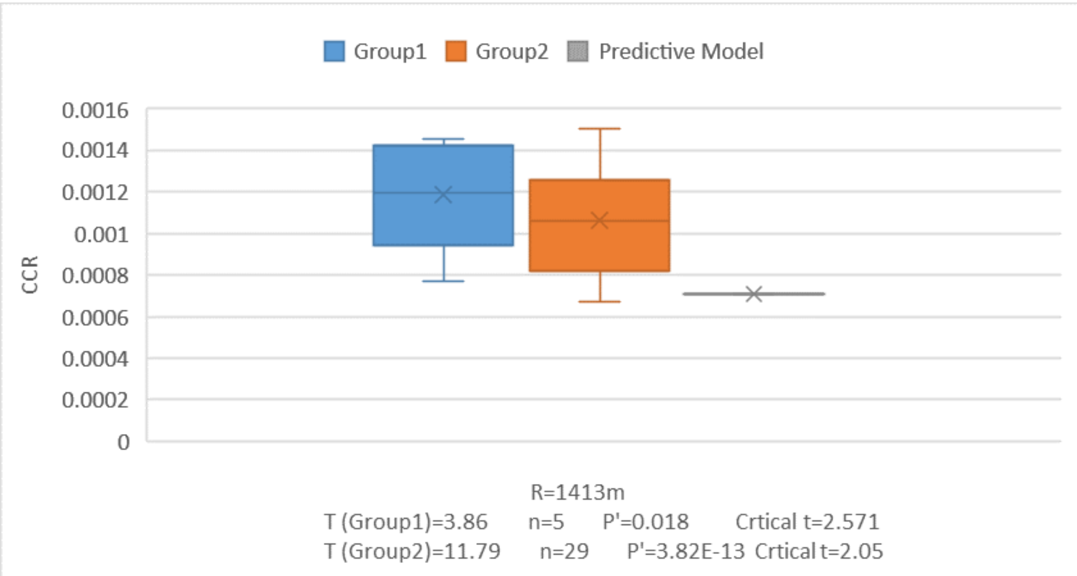

Group1 Group2 Predictive Model
Curvature(1/m)
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
R=108m
T (Group1)=7.95 n=7 P'=1.34E-04 Crtical t=2.37
T (Group2)=15.38 n=31 P'=8.91E-16 Crtical t=2.04

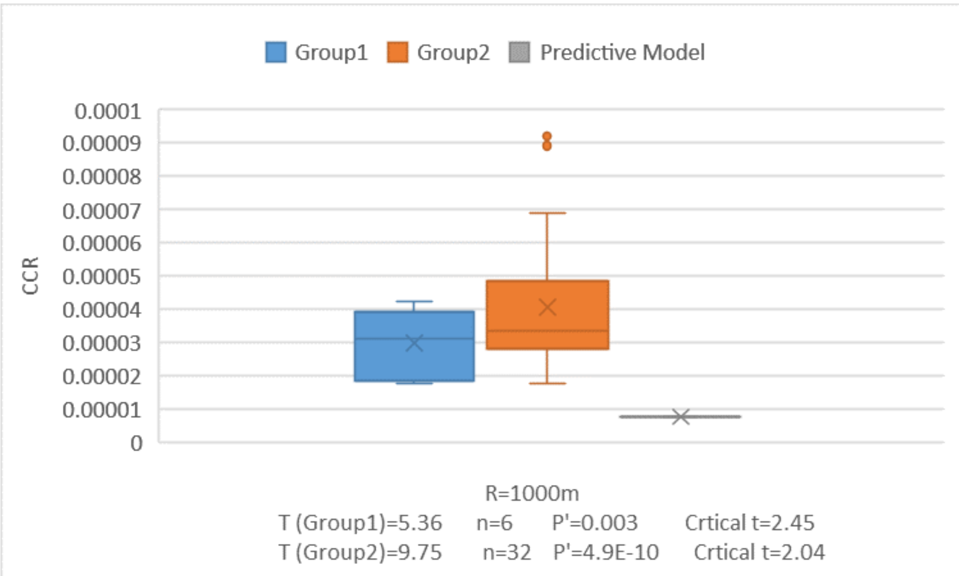

Group1
Group2
Predictive Model
Curvature(1/m)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
R=94m
T (Group1)=7.91 n=6 P'=5.22E-04 Crtical t=2.45
T (Group2)=18.83 n=29 P'=1.95E-17 Crtical t=2.04

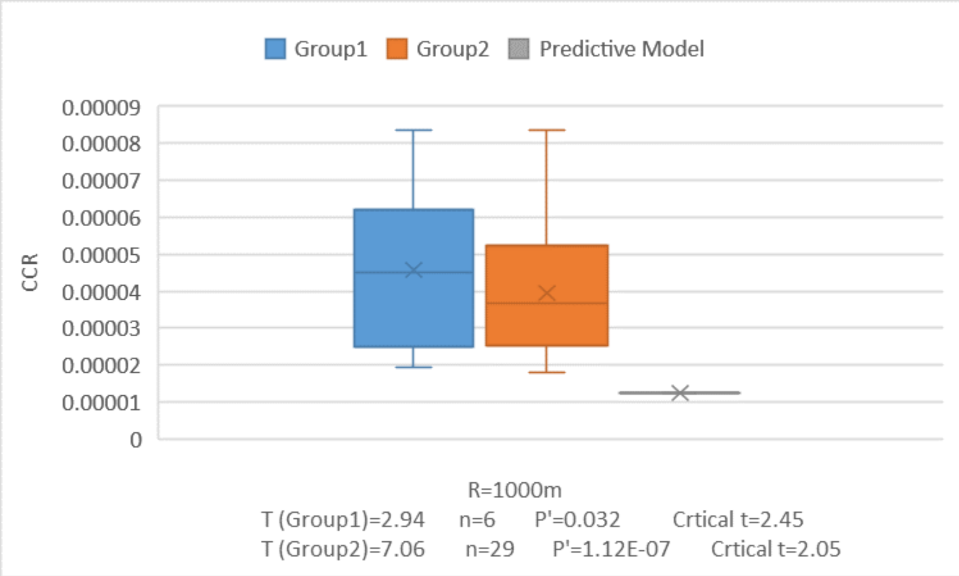

Group1
Group2
Predictive Model
Curvature(1/m)
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
R=98m
T (Group1)=5.10 n=7 P'=0.0022 Crtical t=2.37
T (Group2)=10.76 n=28 P'=5.28E-11 Crtical t=2.05

Attachment 12 Curvature Change Rate

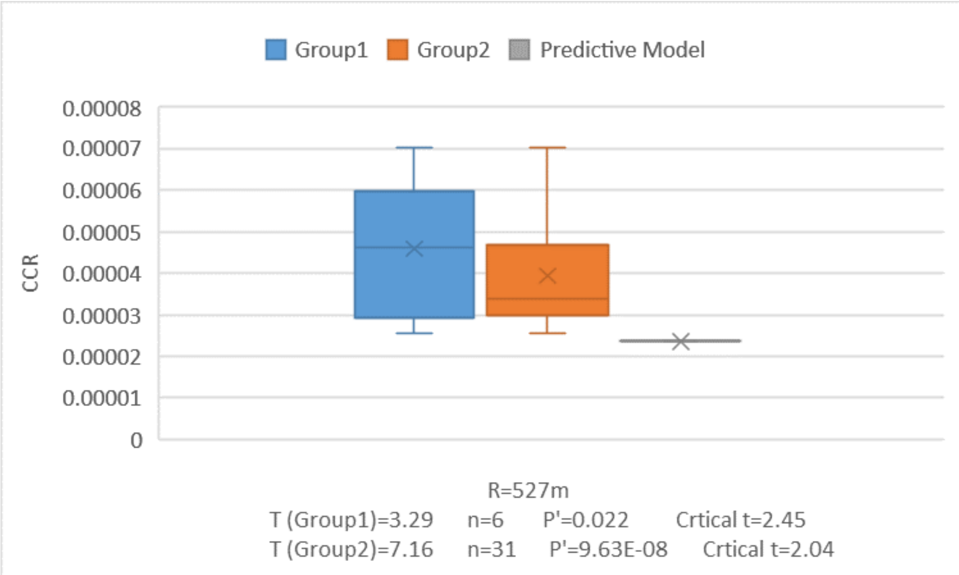




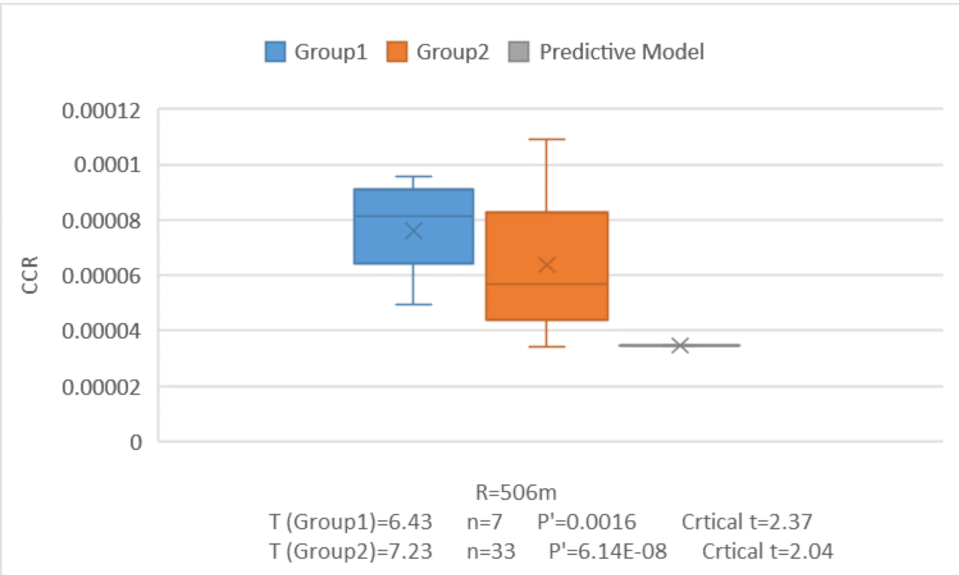




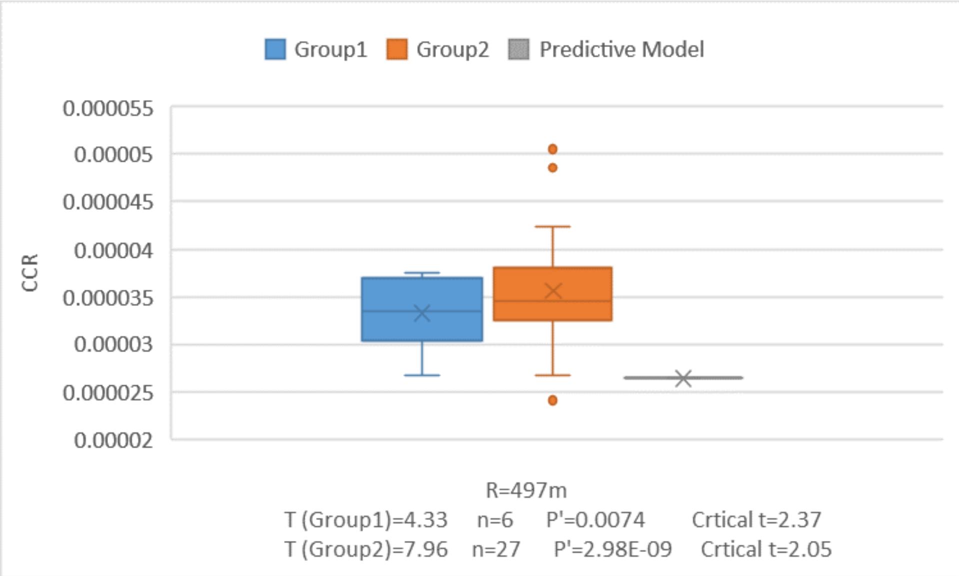
Group1
Group2
Predictive Model
CCR
0.00009
0.00008
0.00007
0.00006
0.00005
0.00004
0.00003
0.00002
0.00001
0
R=1000m
T (Group1)=2.94 n=6 P'=0.032 Crtical t=2.45
T (Group2)=7.06 n=29 P'=1.12E-07 Crtical t=2.05

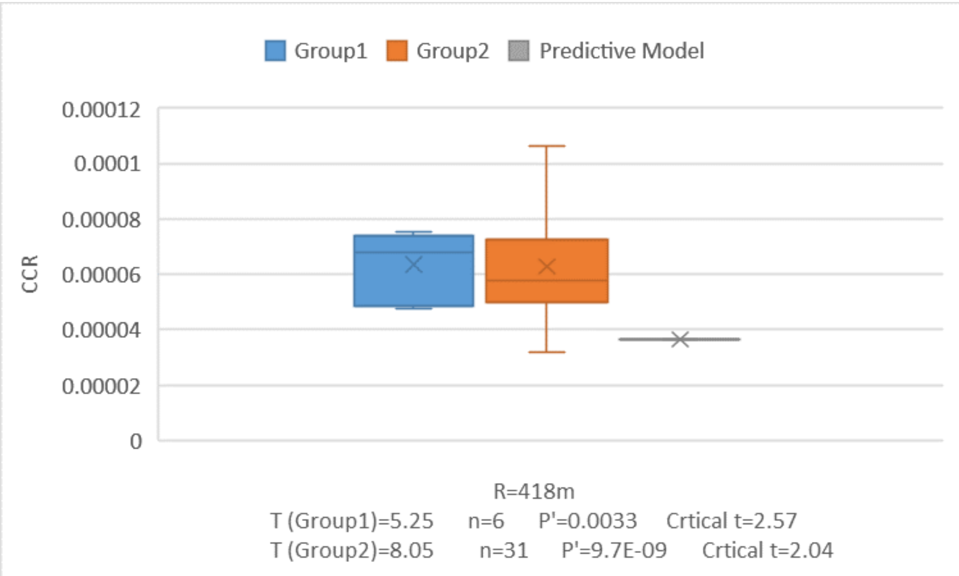


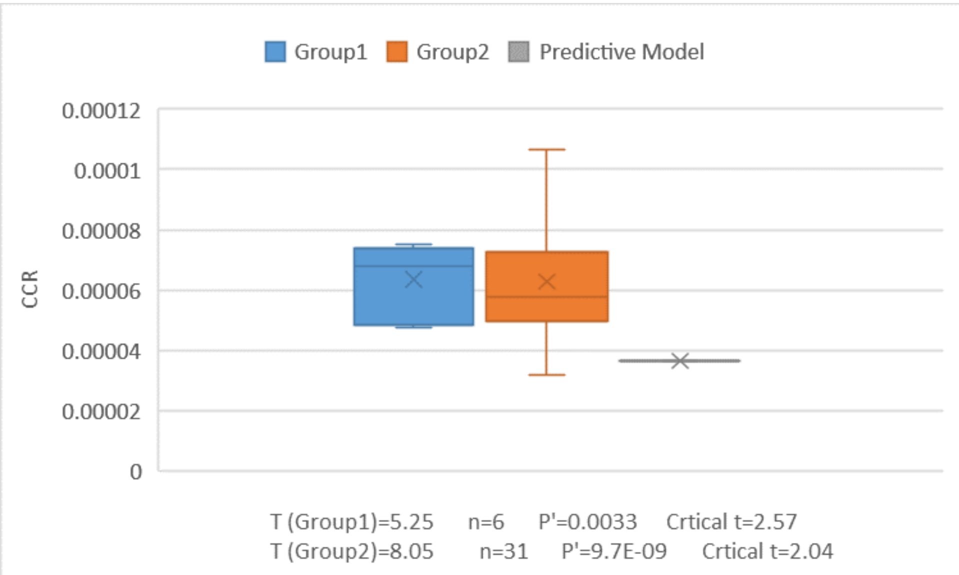
Group1
Group2
Predictive Model
CCR
0.00008
0.00007
0.00006
0.00005
0.00004
0.00003
0.00002
0.00001
0
R=527m
T (Group1)=3.29 n=6 P'=0.022 Crtical t=2.45
T (Group2)=7.16 n=31 P'=9.63E-08 Crtical t=2.04

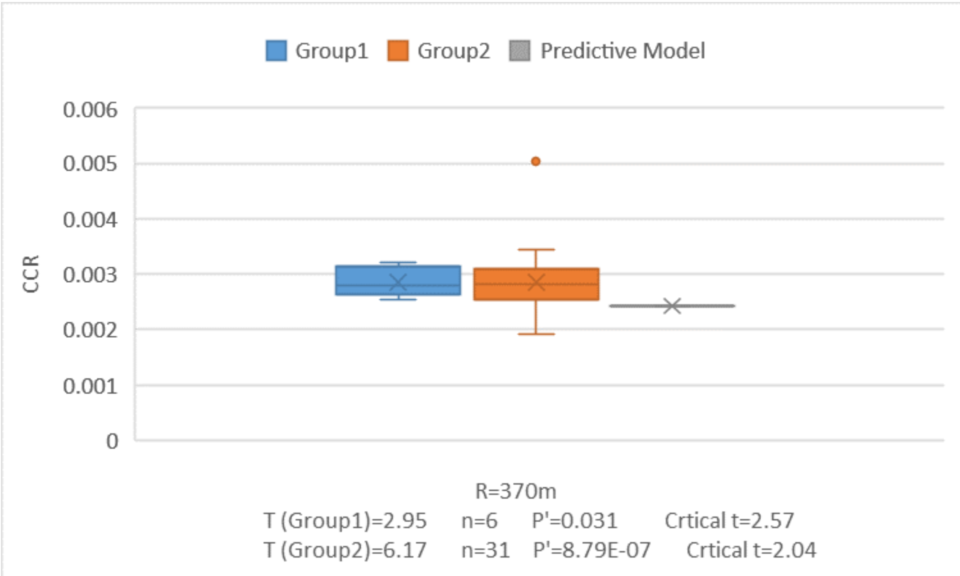


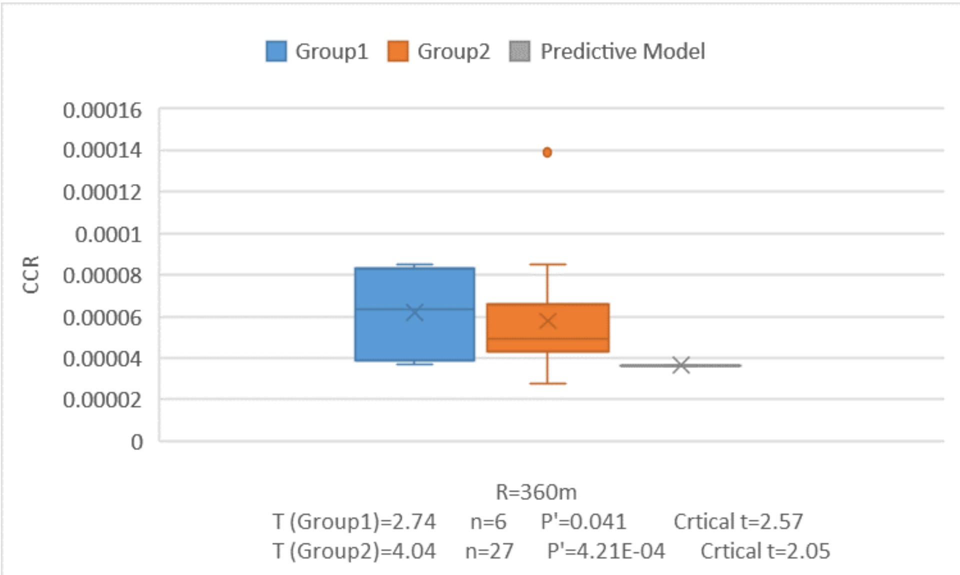
Group1
Group2
Predictive Model
CCR
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
R=506m
T (Group1)=6.43 n=7 P'=0.0016 Crtical t=2.37
T (Group2)=7.23 n=33 P'=6.14E-08 Crtical t=2.04

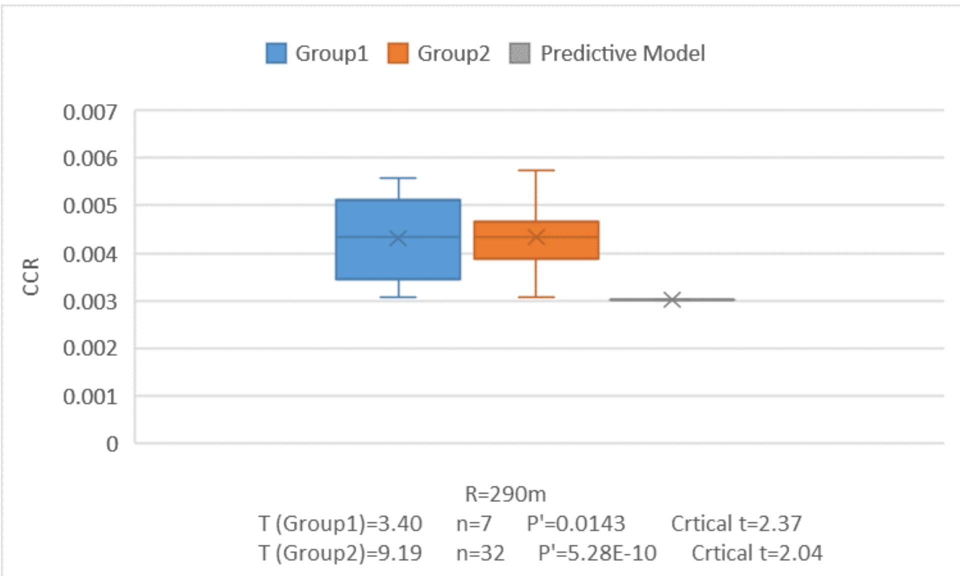

Group1 Group2 Predictive Model
0.000055
0.00005
0.000045
0.00004
0.000035
0.00003
0.000025
0.00002
CCR
R=497m
T (Group1)=4.33 n=6 P'=0.0074 Crtical t=2.37
T (Group2)=7.96 n=27 P'=2.98E-09 Crtical t=2.05

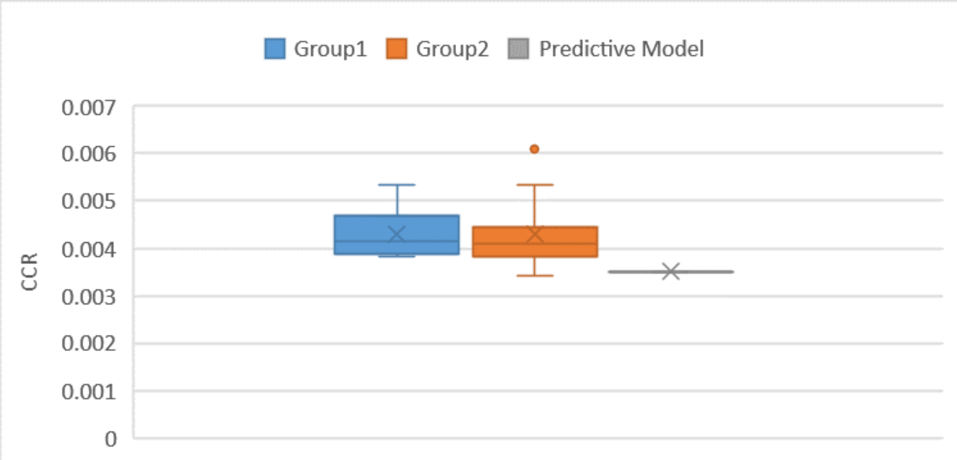

Group1 Group2 Predictive Model
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
CCR
R=418m
T (Group1)=5.25 n=6 P'=0.0033 Crtical t=2.57
T (Group2)=8.05 n=31 P'=9.7E-09 Crtical t=2.04


Group1 Group2 Predictive Model
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
CCR
T (Group1)=5.25 n=6 P'=0.0033 Crtical t=2.57
T (Group2)=8.05 n=31 P'=9.7E-09 Crtical t=2.04

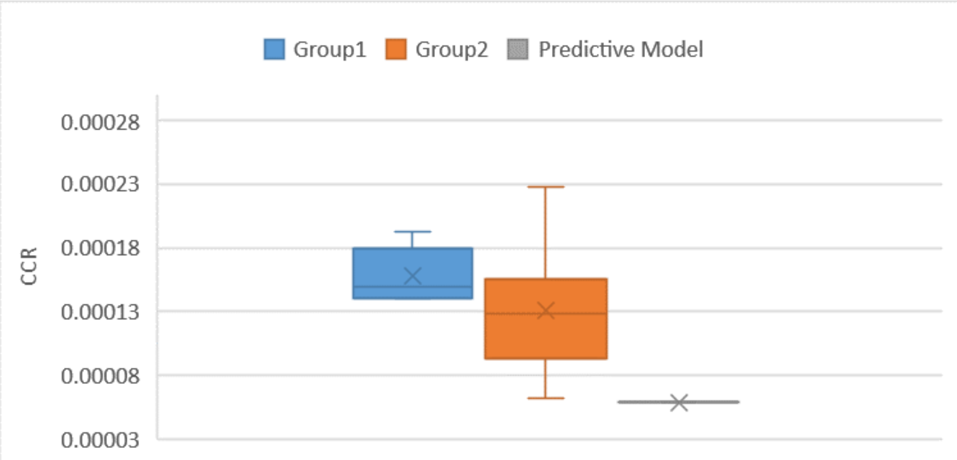

Group1 Group2 Predictive Model
0.006
0.005
0.004
0.003
0.002
0.001
0
CCR
R=370m
T (Group1)=2.95 n=6 P'=0.031 Crtical t=2.57
T (Group2)=6.17 n=31 P'=8.79E-07 Crtical t=2.04


Group1 Group2 Predictive Model
0.00016
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
CCR
R=360m
T (Group1)=2.74 n=6 P'=0.041 Crtical t=2.57
T (Group2)=4.04 n=27 P'=4.21E-04 Crtical t=2.05

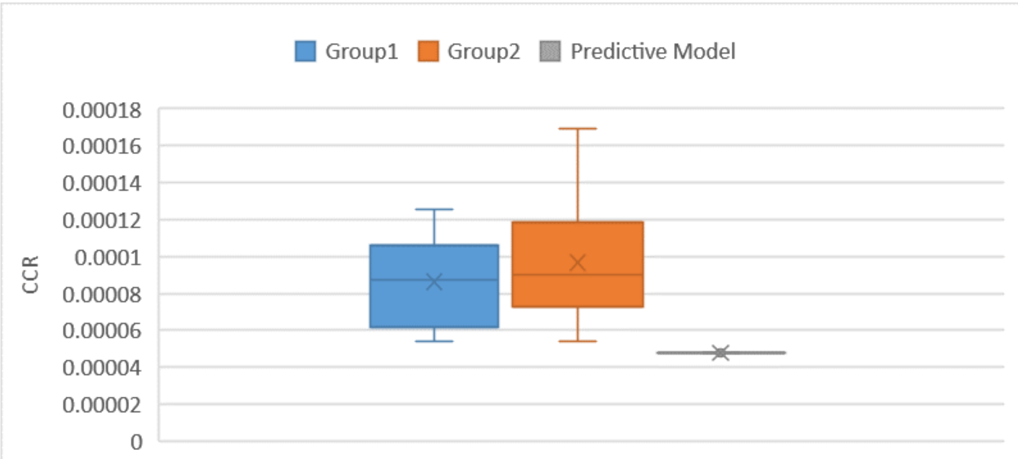

Group1 Group2 Predictive Model
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
CCR
R=290m
T (Group1)=3.40 n=7 P'=0.0143 Crtical t=2.37
T (Group2)=9.19 n=32 P'=5.28E-10 Crtical t=2.04



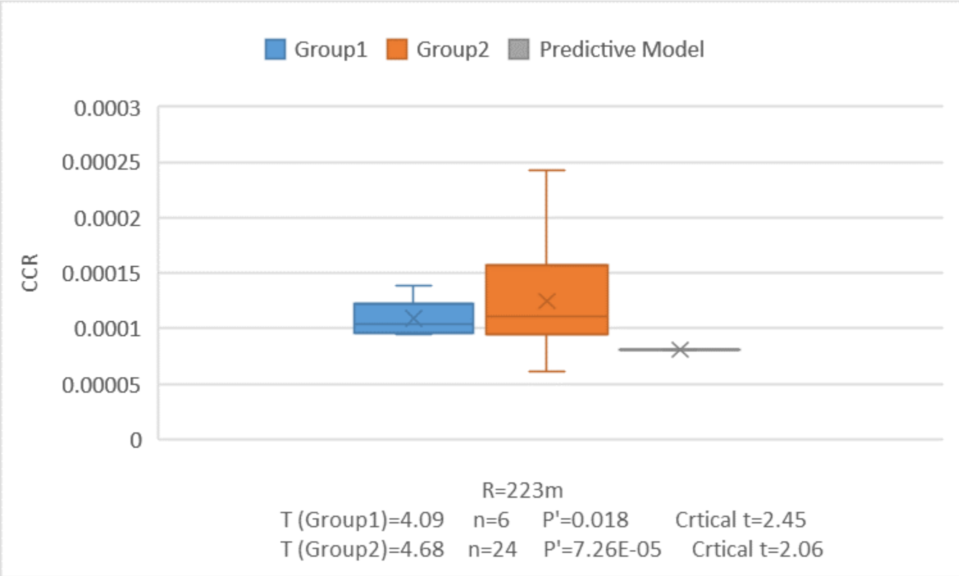
R=282m
T (Group1)=5.60 n=6 P'=0.0025 Crtical t=2.45
T (Group2)=7.47 n=32 P'=2.06E-08 Crtical t=2.04

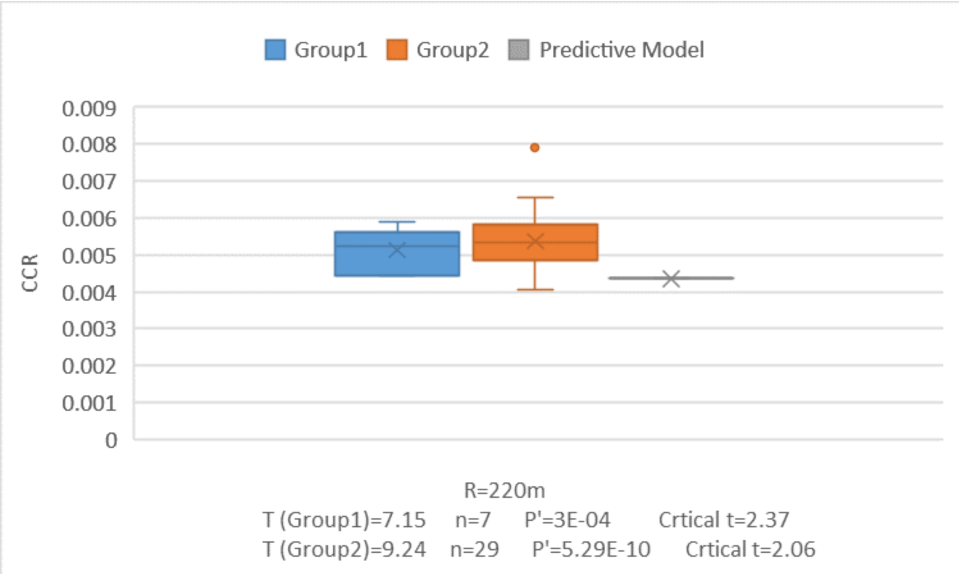


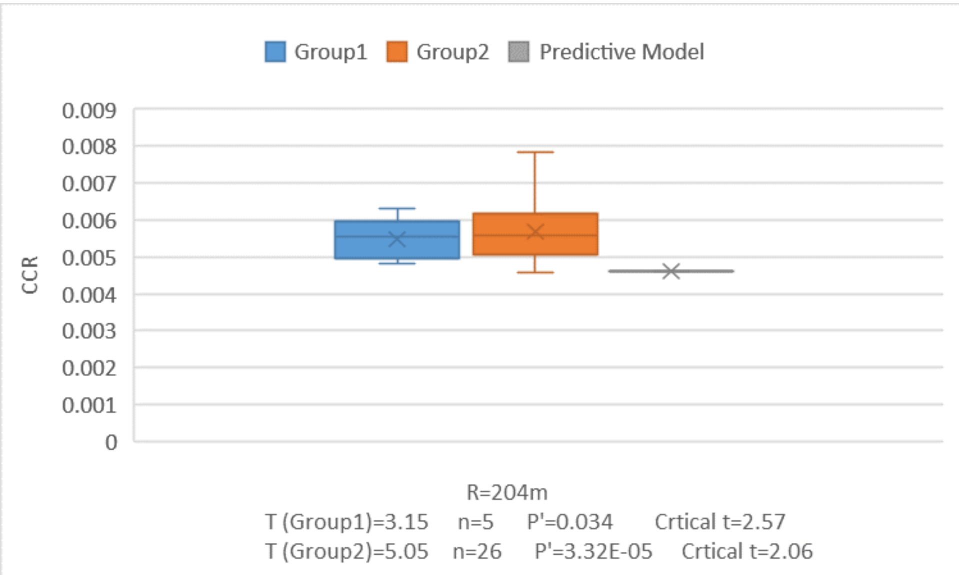
R=260m
T (Group1)=10.09 n=5 P'=5.43E-04 Crtical t=2.57
T (Group2)=8.67 n=31 P'=1.15E-09 Crtical t=2.04

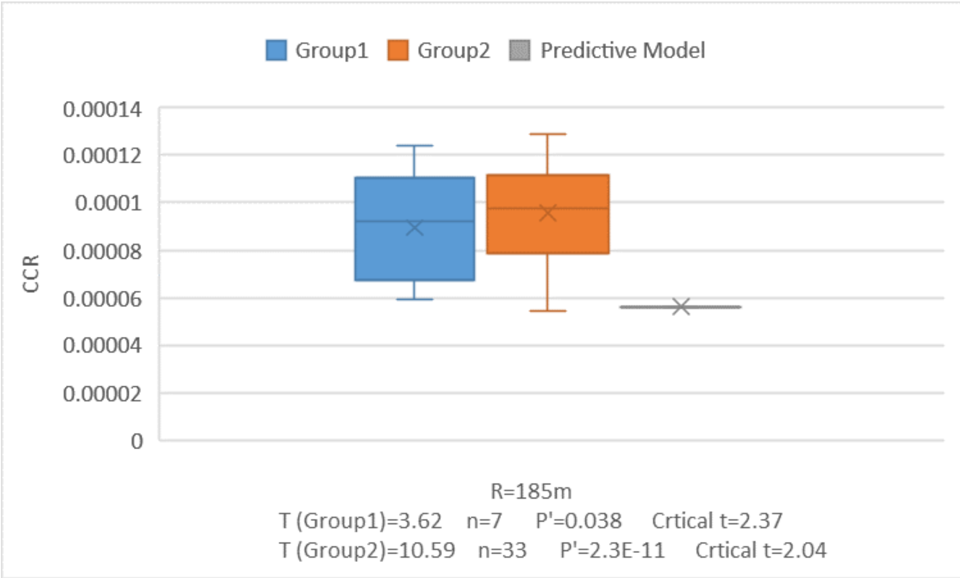


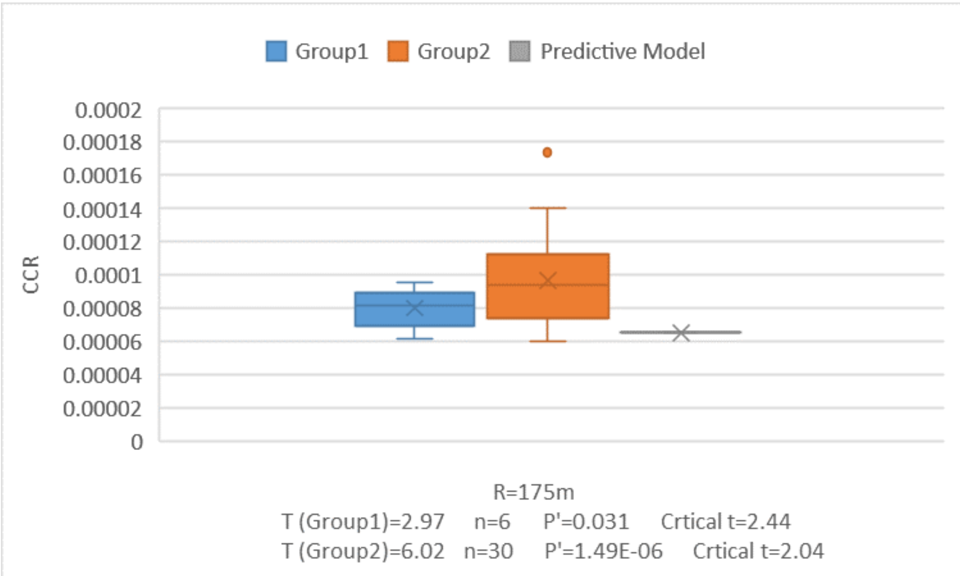
R=227m
T (Group1)=3.69 n=6 P'=0.014 Crtical t=2.45
T (Group2)=7.95 n=26 P'=4.95E-08 Crtical t=2.06

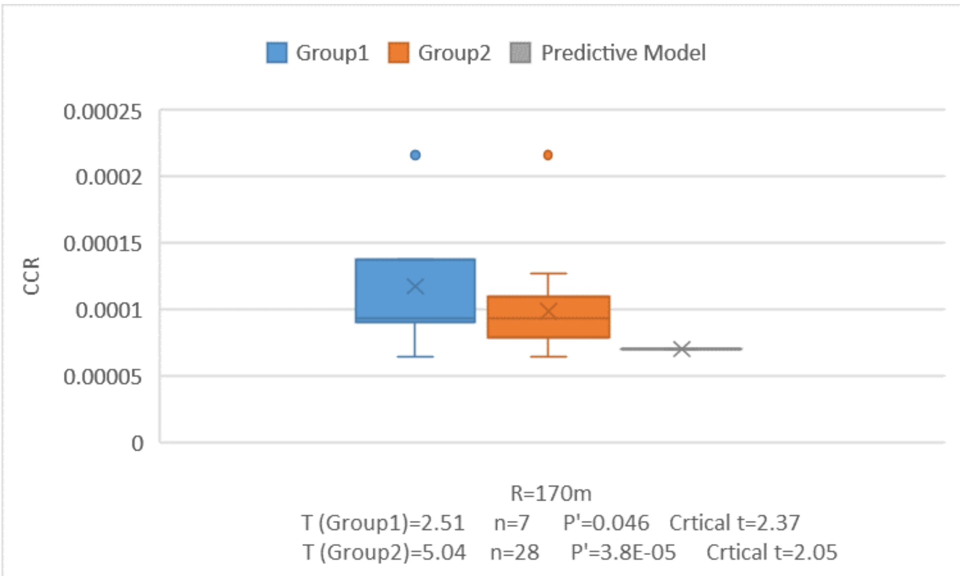

Group1
Group2
Predictive Model
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
CCR
R=223m
T (Group1)=4.09 n=6 P'=0.018 Crtical t=2.45
T (Group2)=4.68 n=24 P'=7.26E-05 Crtical t=2.06

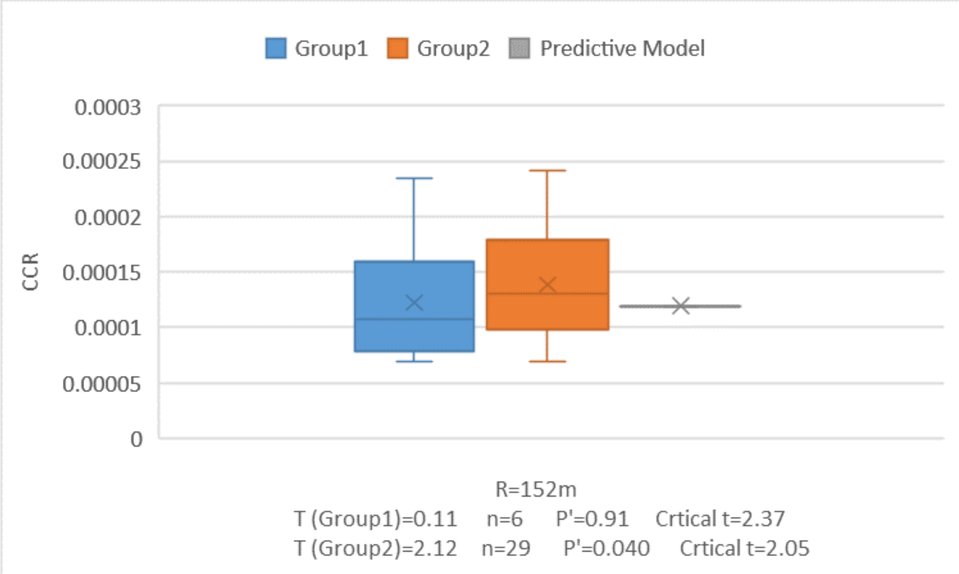

Group1
Group2
Predictive Model
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
CCR
R=220m
T (Group1)=7.15 n=7 P'=3E-04 Crtical t=2.37
T (Group2)=9.24 n=29 P'=5.29E-10 Crtical t=2.06


Group1
Group2
Predictive Model
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
CCR
R=204m
T (Group1)=3.15 n=5 P'=0.034 Crtical t=2.57
T (Group2)=5.05 n=26 P'=3.32E-05 Crtical t=2.06

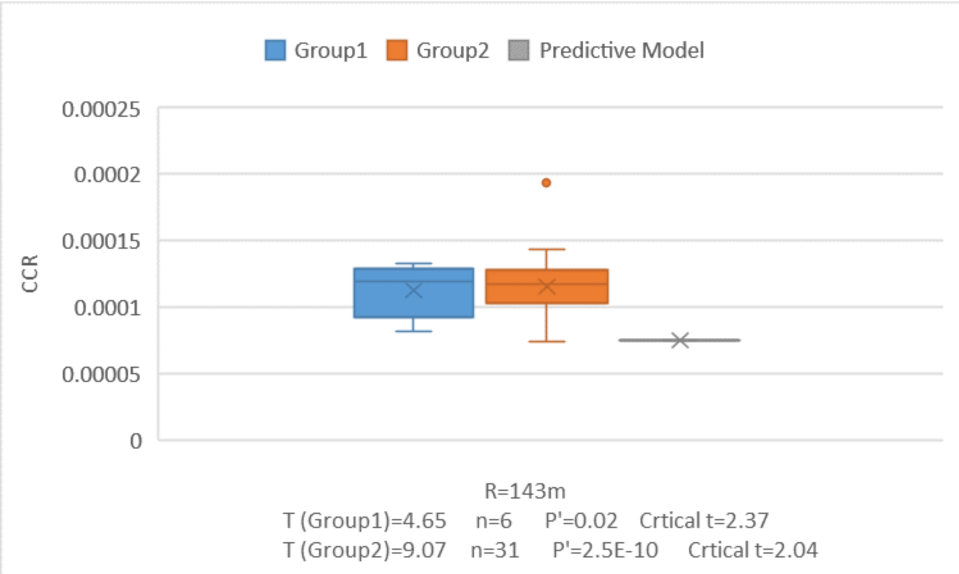

Group1
Group2
Predictive Model
CCR
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
R=185m
T (Group1)=3.62 n=7 P'=0.038 Crtical t=2.37
T (Group2)=10.59 n=33 P'=2.3E-11 Crtical t=2.04


Group1
Group2
Predictive Model
CCR
0.0002
0.00018
0.00016
0.00014
0.00012
0.0001
0.00008
0.00006
0.00004
0.00002
0
R=175m
T (Group1)=2.97 n=6 P'=0.031 Crtical t=2.44
T (Group2)=6.02 n=30 P'=1.49E-06 Crtical t=2.04

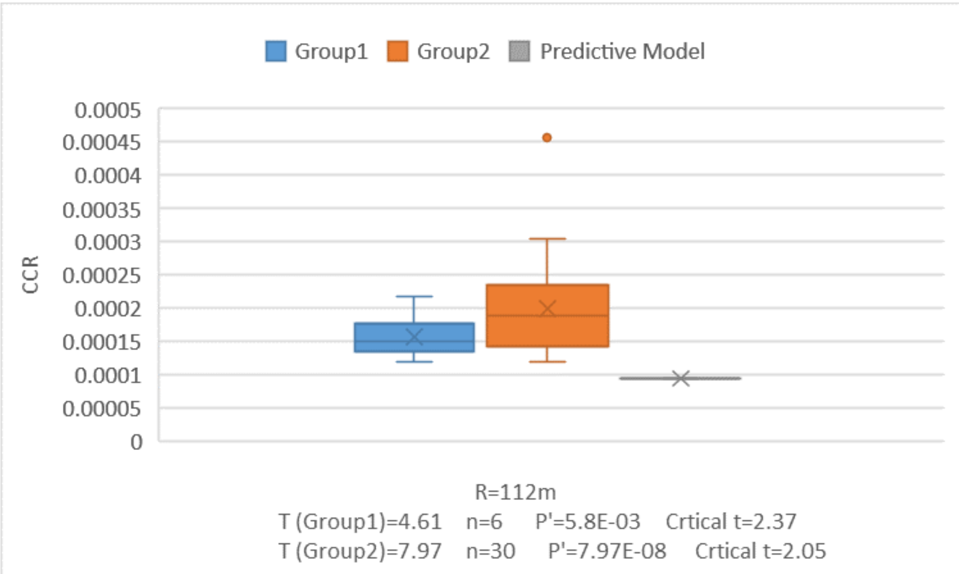

Group1
Group2
Predictive Model
CCR
0.00025
0.0002
0.00015
0.0001
0.00005
0
R=170m
T (Group1)=2.51 n=7 P'=0.046 Crtical t=2.37
T (Group2)=5.04 n=28 P'=3.8E-05 Crtical t=2.05



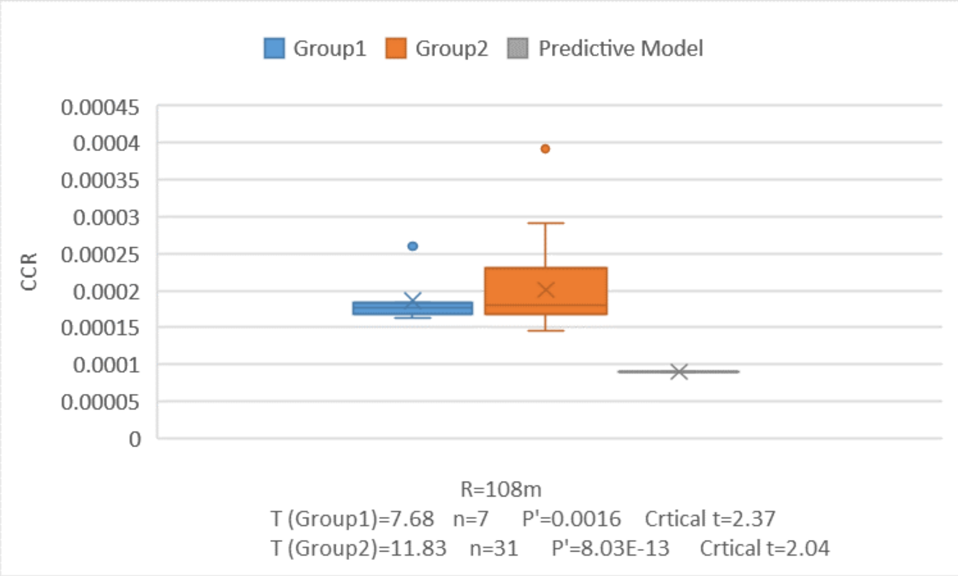
Group1
Group2
Predictive Model
CCR
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
R=152m
T (Group1)=0.11 n=6 P'=0.91 Crtical t=2.37
T (Group2)=2.12 n=29 P'=0.040 Crtical t=2.05

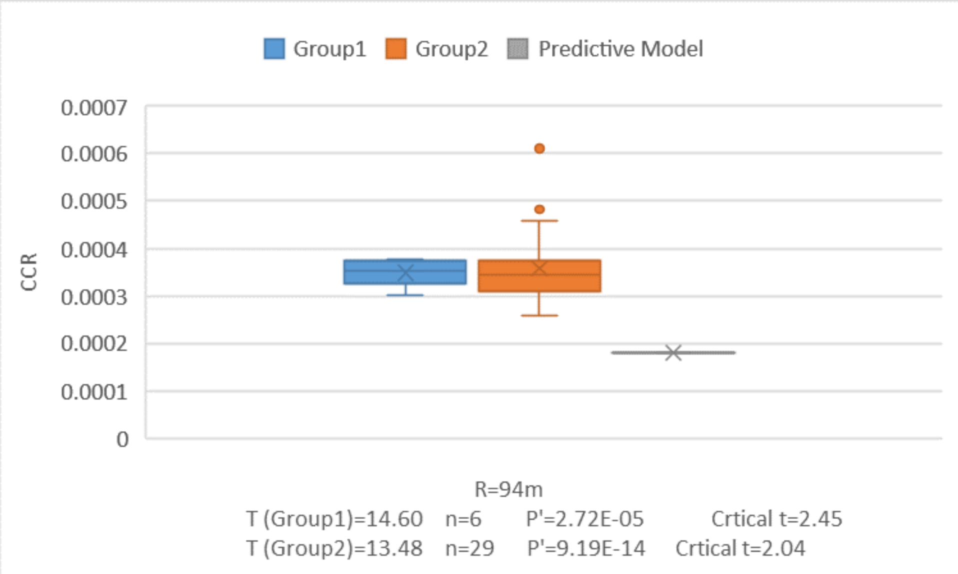


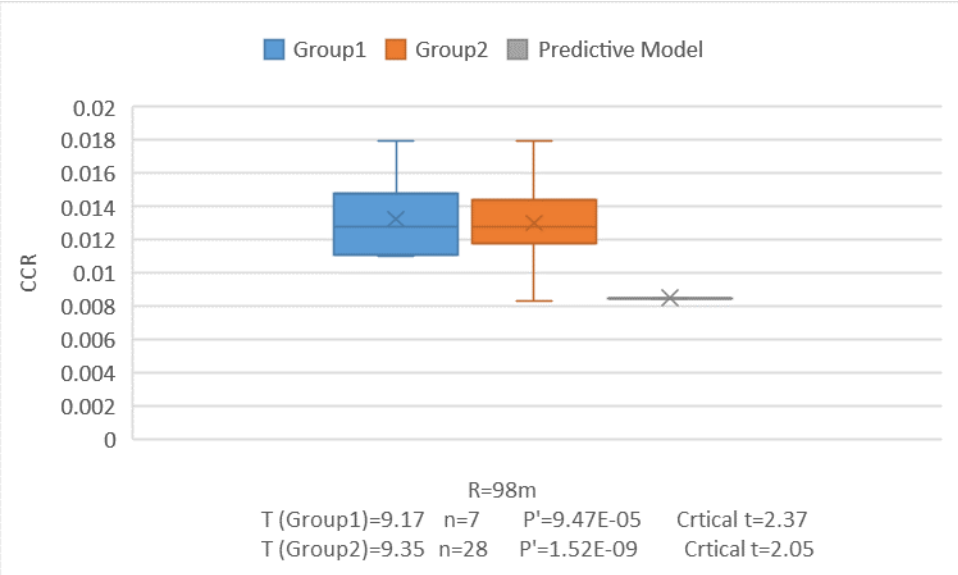
Group1
Group2
Predictive Model
CCR
0.00025
0.0002
0.00015
0.0001
0.00005
0
R=143m
T (Group1)=4.65 n=6 P'=0.02 Crtical t=2.37
T (Group2)=9.07 n=31 P'=2.5E-10 Crtical t=2.04



Group1
Group2
Predictive Model
CCR
0.0005
0.00045
0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
R=112m
T (Group1)=4.61 n=6 P'=5.8E-03 Crtical t=2.37
T (Group2)=7.97 n=30 P'=7.97E-08 Crtical t=2.05


Group1
Group2
Predictive Model
0.00045
0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
0.00005
0
CCR
R=108m
T (Group1)=7.68 n=7 P'=0.0016 Crtical t=2.37
T (Group2)=11.83 n=31 P'=8.03E-13 Crtical t=2.04


Group1
Group2
Predictive Model
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
CCR
R=94m
T (Group1)=14.60 n=6 P'=2.72E-05 Crtical t=2.45
T (Group2)=13.48 n=29 P'=9.19E-14 Crtical t=2.04


Group1
Group2
Predictive Model
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
CCR
R=98m
T (Group1)=9.17 n=7 P'=9.47E-05 Crtical t=2.37
T (Group2)=9.35 n=28 P'=1.52E-09 Crtical t=2.05

Acknowledgments

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