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A New Lean Model: Improving Race Team Performance through Team-Driver Communication Efficacy

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To the Graduate Council:

I am submitting herewith a dissertation written by Joseph Ruric Stainback IV entitled "A New Lean Model: Improving Race Team Performance through Team-Driver Communication Efficacy." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Industrial Engineering.

Rapinder S. Sawhney, Major Professor

We have read this dissertation and recommend its acceptance:

Xueping Li, Charles H. Aikens, Joseph H. Wilck, IV, David K. Irick

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Carolyn R. Hodges
Vice Provost and Dean
of the Graduate School

(Original Signatures are on file with official student records)

A New Lean Model: Improving Race Team Performance through Team-Driver Communication Efficacy

A Dissertation Presented for
the Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Joseph Ruric Stainback, IV
May 2010

DEDICATION

This dissertation is dedicated to my dearly loved Amber, who entered my life at the beginning of this dissertation journey and provided relentless support, empathy, and love during this entire process.

Finally, to my wonderful and dearly loved children, Lauran Rae Stainback and Joseph Ruric Stainback, V, who have tolerated my technical inquisitiveness all their lives and for whom I hope to have set an example that learning in any subject or discipline only stops when the human mind is at its final rest.

To quote Albert Einstein:

"I have no special talents. I am only passionately curious …. the important thing is not to stop questioning; curiosity has its own reason for existing. One cannot help but be in awe when contemplating the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of the mystery every day. The important thing is not to stop questioning; never lose a holy curiosity."

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I would like to provide my sincere gratitude to my major professor, Dr. Rapinder Sawhney, for his support, patience, and guidance toward my PhD endeavor, especially as an adult graduate student. A special thank you is merited for Dr. Charles Aikens who helped me understand my communications data and associated statistics. I would like to thank remaining members of my committee, namely, Dr. David K. Irick, Dr. Xueping Li, and Dr. Joseph H. Wilck, IV.

I would also thank the National Association for Stock Car Auto Racing Inc. (NASCAR), the NASCAR Camping World Truck Series (NCWTS), Racing Radios©, Wylerracing.com/SAFEAUTO (NCWTS Team), Toyota Racing Development (TRD), Stacy Compton (NCWTS Driver), and the entire 2009 Wylerracing.com/SAFEAUTO #60 NCWTS truck team.

Finally, I would like to thank Mr. Harishwaran Hariharan (Hari) for providing technical assistance with MATLAB® and the proof-of-concept speech recognition algorithms.

ABSTRACT

In some organizational settings and in the field of competitive automobile racing, certain situations and rules place an emphasis on and sometimes escalate the need for effective team communications. This dissertation hypothesizes that effective and dense communications contributes directly to team performance. Supported by organizational behavioral and lean six sigma theory, communications is declared a form of waste within the context of Industrial Engineering subject to data collection, measurements, and real-time, value-added metrics. Measuring and reporting trends in communications provides a basis for a new and unique model called a Communications Productivity Model (CPM) with an associated Communications Density Report (CDR). Industrial Engineering productivity, statistics, linguistic and text analysis tools were combined to develop a unique Dynamic Productivity Index (DPI) enhancing the CDR as a means to rapidly provide meaningful and value-added feedback on recent and future performance. Data was collected on actual automobile racing teams to validate the new communications model, report on the results using the CDR and introduce the DPI. Future research is also proposed in this dissertation to enhance the new communications model whereby speech recognition technologies are evaluated and tested.

PREFACE

As an adult PhD student with almost 26 years of industrial/manufacturing experience and as a lean practitioner, I am constantly thinking of ways to improve, modernize, and suggest change. When thinking about topics for a dissertation, however, I intentionally stayed away from my current industry and job assignment for fear that my dissertation research would have eventually felt as an extension to my current career assignment. I was concerned that my dissertation would become a "job" as opposed to a fun, positive, and memorable experience; thus I would have not been as motivated to complete this monumental task. With this in mind, I decided to pursue a dissertation within an area involving an endeavor I experienced beginning in 1996, whereby I worked for a NASCAR team as a pit crew member. Since 1996, I have participated and worked at various levels within NASCAR and have maintained contacts and connections with various race drivers, owners, and media representatives. My experience with NASCAR has provided a completely different "industrial" setting, considering their unique competitive/entertainment service and a customer base generated by sport fans and big corporate advertisements. Considering my continuous involvement in NASCAR and continuous productivity improvement acumen, the decision to use this field and find a unique and original productivity improvement niche was obvious. My dissertation journey in the NASCAR field has been a good one, and I hope my lean communications concept has merit for the future.

Lastly, in addition to the productivity improvement tool proposed in this dissertation, I have found NASCAR is rich in other productivity opportunities. Armed with advanced tools from the field of Industrial Engineering, I look forward to developing other productivity improvement solutions for this sport.

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ABBREVIATIONS AND SYMBOLS

ATC	Air Traffic Controller
CDR	Communications Density Report
CPM	Communications Productivity Model
DOE	Design of Experiment
DPI	Dynamic Productivity Index
d_x	Communications Density Measurements
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
HMM	Hidden Markov Model
IE	Industrial Engineer/Industrial Engineering
IRB	Institutional Review Board
LCM	Lean Communications Model
LSA	Latent Semantic Analysis
MATLAB®	MATrix LABoratory (programming software)
MHz	Mega-Hertz
MP3	Patented digital audio encoding format
MSC	Meaningful Speech Cluster
NASA	National Aeronautics and Space Administration
NASCAR	National Association for Stock Car Auto Racing
NCWTS	NASCAR Camping World Truck Series
NFL	National Football League
NNS	NASCAR Nationwide Series
NSCS	NASCAR Sprint Cup Series
OB	Organizational Behavior
OD	Overall (Communications) Density
PSRM	Passive Speech Recognition Model
RR	Racing Radios ©
SAS JMP®	SAS Institute trademarks (acronym definitions are obsolete)
SPC	Statistical Process Control
SR	Speech Recognition
SS	Super Sport
TAM	Text Analysis Methods
TPS	Toyota Production System
tur	Team Utterance Ratio
UAV	Unmanned Aerial Vehicles
US	United States
USB	Universal Serial Bus
WWW	World Wide Web

CHAPTER 1

INTRODUCTION

1.1 Background

The American automobile contributes to self identity and status is iconic and has contributed to the growth and globalization of the entire world [1,2]. More than a basic component of transportation, people have turned automobiles into a sport involving speed, danger, and excitement, over time giving way to the organizational emergence of competitive automobile racing worldwide with many classes and divisions. Automobile racing has emerged with unique cultural aspects driven by varied influential entities including region, media, rules (sanctioning organizations), team etiquette, language, sponsors, automobile manufacturers, and fans. Automobile racing teams and sanctioning organizations such as the National Association for Stock Car Auto Racing (NASCAR), the IZOD® Indycar Series®, and Formula 1 have significantly profited from the business and entertainment value of the sport [3]. In NASCAR, influential factors such as culture, profit, and fan base have spawned the racing phenomena and have sustained the phenomena for over 60 years. The sport has manifested into one of the most popular spectator sports and ranks with the top sports on television including the National Football League (NFL) [4]. Race car Racing, sanctioned by NASCAR, has a immense fan base exceeding 75 million people (one in three United States (US) adults), is the number two sport on television in the US, and is broadcast in over 150 countries in 20 languages, with over $2 billion in licensed product sales annually with more “Fortune 500 companies participating than any other sport” [4,5]. From the days of modifying cars to outrun law enforcement agencies to the human aspect for the “need-for-speed”, the sport has migrated from the true “stock” car (street designed automobiles with little or no modification for racing) to the aerodynamic and highly technological mechanical systems seen today. In short, exponential increases in technology have revolutionized and elevated the competitiveness of the sport, thus the sport has realized an exponential increase in popularity by fans, sponsors, and automobile manufactures over the past 60 years.

An increase in technology and changes in engine performance over time has moved race car racing away from the true “stock” car. The NASCAR racing cars today are not “stock” and do not possess any features seen on a car purchased from a local automobile dealership. A NASCAR race car exterior body does somewhat resemble the make and model design such as the Chevrolet Impala SS, Ford Fusion, or Toyota Camry; however, the designs are altered for aerodynamic purposes, and the make/model designation on the car is for advertising and sponsorship only. The engines in the race cars are also completely different from what would be purchased at a local dealership. A race car engine conforms to specific NASCAR specifications designed for speed and consistency while fabricated specifically for racing by state-of-the art engine builders. For the purposes of this dissertation, a “NASCAR race car” will be referred to as “race car and “race car driver” will be referred to as “driver”.

As with all of the other sanctioning bodies, NASCAR governs the rules and regulations to promote consistent competition among the race teams and sustain the safety on and around the race track. Over time, NASCAR has preserved one fundamental rule involving how information is relayed from the driver to the team (crew chief, car chief, spotter, engineers) during practice, qualifying or the actual race. This rule prohibits the transfer of electronic mechanical and/or race car performance commands by telemetry using off or onboard computers and/or within the race car ether actively or passively during races, qualifying events or practices. During any *race event* (defined from this point forward as practice, qualifying, and/or the actual race), the driver of the race car is the central communication link from the race car to the team. The driver is essentially the onboard computer relaying this information back to team members [6]. This rule places an important emphasis on the driver and team decision makers. Not only is the performance of the race team proportional to the racing skills of the driver, but the performance of the race team is also dependent on the cognitive ability of the driver to interpret and communicate effectively the response of the race car during high speed racing events. Successful performance is furthermore directly related to how well the driver and crew chief communicate, and this communication is vital to the performance of the entire team [6]. As with many other organizational entities, the human behavioral components of situational awareness, mental modeling, brevity, and communications are important aspects of success (and performance) in NASCAR racing, but are overlooked as analytical and measured aspects of the sport.

This dissertation will deal with aspects of performance as related to the abilities of the human to effectively communicate to other members of the organization. Members of the NASCAR racing sport often say that if the driver and crew chief communicated well, their performance would improve. As Industrial Engineers (IEs) concentrate on improving organizational processes, improving integrated systems involving people, and improving quality of the manufactured goods and services, they use the latest available tools to collect data, analyze, and recommend solutions to improve components and/or processes in any organizational context. The organizational context of NASCAR race teams, both in the shop and at a race event, fits well within the scope and associated tools used by IEs. IEs identify through formal and informal methodologies different types of waste and develop measures to streamline processes and/or eliminate waste outright. Current observations supported by literature and a survey prompted by this dissertation show that an abundance of waste in the way NASCAR teams communicate among racing events is predominant in the sport. These wasteful communications, especially miscommunications, result in poor performance for NASCAR race teams.

This dissertation will introduce an overview of relevant racing variables affecting performance to demonstrate the complexity of the race car and the racing event. A theoretical background in communications and some aspects of organizational behavior will be discussed relevant to high risk organizations. Finally, the context of the organizational behavior has served as a fundamental basis for the theoretical and quantitative research.

1.2 NASCAR Racing Basics

1.2.1 Mechanical and Team Relationships

Automobile racing's basic objective during a race event is to minimize lap times by maximizing speed. This objective is achieved by "sticking" the tires to the race track surface when the driver travels on both race track straight-aways and turns (or corners). Adjustments to the race car are made to achieve these objectives by taking a balance between tire/chassis parameters, speed, fuel performance, and mechanical equipment reliability. In addition to raw engine horsepower, the more tire grip a race car has, the faster the race car can go into the corners or around race track turns. Tire grip is made up of three factors: the amount of rubber that is in contact with the race track surface, the texture of the rubber at different temperatures, and the amount of weight the tire is carrying.

Within the aspects of tire/chassis parameters, the amount of rubber in contact with the race track surface ("sticking") is affected by the tire pressure, camber in the race car set-up (camber is the angle between the vertical centerline of the tires and the actual angle of the tires at rest), and the varying weight distributions during different race event track configurations. Tire pressure is affected by many variables including the temperature of the race track, race car weight, and tire design. The race track temperature is affected by the ambient temperatures of the weather (sunny/cloudy). During race events, temperatures on a tire are measured in three locations namely outside, middle, and inside. The differences in temperatures within these three locations indicate the degree of camber in the race car. The weight on the tire varies between the race track straight-aways and the race track corners or turns. Additionally, when camber in a race car is constantly changing in the race track corners, grip is optimized when the tire is adjusted to the optimized angle to compensate for the changes which is leaning slightly into the turn. Too much camber will slow the race car because the car becomes difficult to handle.

Two types of handling issues arise in race car racing. “Push” is where the rear end of the race car has more grip than the front and “loose” is when the opposite occurs. Other factors affecting the handling of the race car (tire grip) are aerodynamic effects on the weight distribution of the race car, race track conditions (fine debris and texture), sway bars, toe, caster, springs, shocks, and track bars. Optimal adjustments to these factors and variables improve the handling of the race car. For example, suspension springs are affected by race speed and angle of the race track ovals. The optimal adjustments to the suspension springs would produce the maximum overall speed and minimum lap times of the race car.

In effect, the race car, race track, and driver all take on a “personality” during a racing event. These personalities are changing constantly as environmental, psychological, and mechanical conditions change. Again, the bottom-line key objective in the sport is to optimize the race car mechanical components without jeopardizing the physical and mental conditions of the driver, jeopardizing mechanical features (wear), and jeopardizing fuel performance. In essence, the team is trying to build a relationship with the race track, the race car, and the driver in an optimum manner.

The crew chief is considered the “ring-leader” of a racing event and is chartered with molding the race car to the driver’s personality and race track conditions. A good driver will then find his “groove” in the race track during the actual race and if conditions are optimal, will outperform his competitors and have a chance to win a race.

1.2.2 Technology and Conveyance

Today, many scientific tools exist in NASCAR racing to analyze, process, and manipulate race car set-up data with the intent of reducing variation and making real-time adjustments based on the data acquired. Generally, though, race car adjustments during a race event are based on past testing data, past race track experience, and cognitive interpretation by the driver. Teams are allowed to use any mechanical and/or electronic means of collecting data *outside* of a race event, such as testing and in-shop research and development; however, this data can only be used for initial race car set-up prior to (and independent of) a race event. In addition, high-tech electronics can be used to set-up the race car during a race event; however, the electronics are required to be “external” to the race car and performed when the race car is at rest (static). An example of this would be electronic scales weighing the race car in between practice events. Again, NASCAR explicitly prohibits transfer of data either by telemetry and/or onboard computers within the race car ether actively or passively, respectively during a race event. On-board electronics (such as for data collection and monitoring) are also prohibited during the race events.

Without real-time electronic data, the responsibility for gathering such information falls to the driver. Automobile racing is highly dynamic and dangerous for both the driver and the team members. Race cars can exceed 200 mph during high speed races, and to be competitive, pit-stops are completed within seconds. Competition also drives quick and decisive decisions to change the variables on a race car; thus, accurate and concise communications are important to the driver and the team. The race track, garage area, pit area and inside of the race car are all noisy environments and there are many distractions increasing the chance for miscommunication and error. Because of the fast paced environment, psychologists have determined drivers make as many as fifty (50) decisions in one lap [7]. The driver is the communication link between the race car and the team; thus, the success of a team is dependent on a driver to understand the race car’s response on the race track, to understand the mechanical systems and to properly communicate the issues to the team.

1.2.3 Race Event Process

During a race event (termed by the media as a “race weekend”), a routine series of events occur in order to prepare the race car and compete (Figure 1). Race teams will initially set-up the race car at the race shop based on prior experience from previous races and testing data. Previous experience is usually a culmination of experienced driver and crew chief collaborations, including the use of written historical notes. The race car is then transported to the race track, off-loaded, and rechecked (initial adjustments). Generally, two practices are allowed by each race team during the same time frame (some race events allow only one practice and others allow up to three). Intermittent adjustments are made during the practices and the final race.

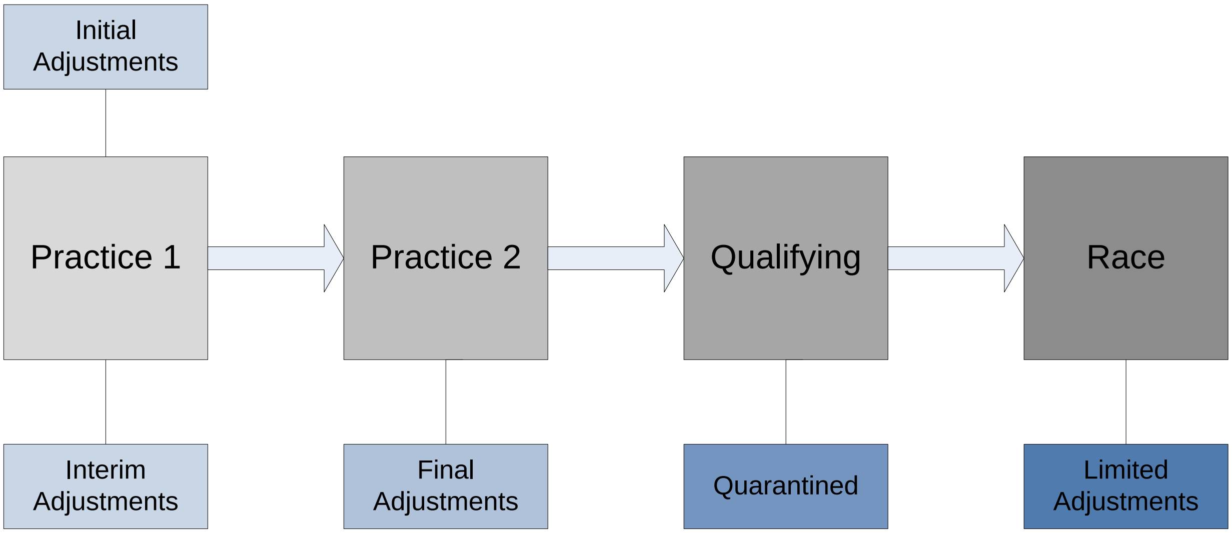

Figure 1 – Race Event Practice Process

Generally, before a practice begins, the race car passes through a NASCAR series of checks to assure that the race car meets all of the rules for the class and model of the race car. After the initial set-up and NASCAR inspections, the typical procedure for adjusting the race car prior to qualifying generally follows the process defined in Figure 1. During the practices, the race car is adjusted intermittently with the intent of optimizing the race car parameters for the current race track conditions. As stated, “balancing” (process of checking and rechecking the race the car) to the optimal set of parameters is performed using linear, pneumatic, and mass measurements when the race car is at rest. The intermittent adjustments (Figure 2) during a practice timeframe will vary by team depending on the success of the adjustments and the race track time comparisons to the other drivers. To maintain an equal “playing field” among the teams during a race event, NASCAR specifically defines the time and duration for all practices, qualifying, and race.

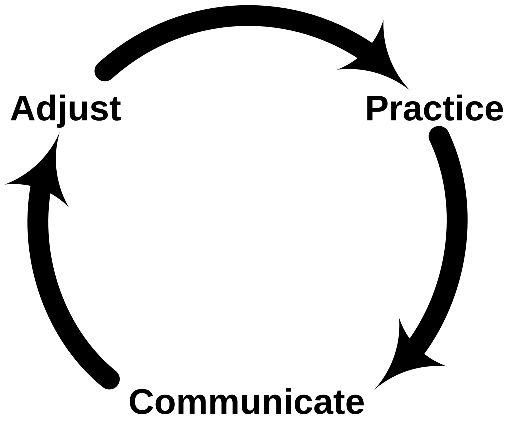

Figure 2 – Race Event Practice

Once the crew and driver are satisfied with the race car parameters (or run out of time), the race car is re-inspected by NASCAR officials and quarantined before and after the qualifying run. As with practice times, inspection and qualifying times are explicit.

Qualifying (or time trials) is usually two full laps, and the best (minimum) lap time achieved from both of the laps determines race position order. Since there are only a certain number of positions for a given race, a driver can “fail-to-qualify” if the driver does not achieve the minimum lap times and/or the competitor time qualifying results were better; thus, eliminating the team. To fail-to-qualify from the competition field results from lap times slower than the fixed number of competitors for the actual race. Achieving the minimum lap times is very competitive, placing emphasis on good equipment, experienced people and team chemistry, including communications.

1.3 Research Objectives

This dissertation hypothesizes that effective (and dense) communications play a role in race team performance and that increasing communications density improves the performance during certain race events. Communications density is simply the amount of meaningful words divided by the number of words spoken [8]. Meaningful words in the context of this dissertation are technical words used to describe the race car. For example, a physician may ask a patient what hurts and how much an injury or condition hurt from a scale from 1 to 10. The response may indicate a limb with a numeric response of five (5). This may signify to the physician a location with a medium pain tolerance level, allowing a prescription of the appropriate medication or treatment for the condition. In this case, the communication density is high between the physician and the patient as location and level of pain is (clearly) signified. If the patient responded with a specific anatomic organ, muscle, or bone, then the communication density would be higher still. Improving communications can result in higher levels of team decision quality, decision speed, and decision satisfaction within race organizations [9]. The fundamental premise of this research is that race teams with successful outcomes produce on average more semantically coherent communications of their race car attributes than poorly performing teams. As part of the data collection for the hypothesis and model validation of this dissertation, a case study with six (6) teams within the NASCAR Camping World Truck Series (NCWTS) was performed. The results of the data collection and performance parameters are presented in this dissertation with supporting statistical analysis.

In addition to confirming the hypothesis, a model for collecting, processing, and reporting NCWTS communications data is presented. The model and data is then transformed into an important feedback tool for the drivers and the team. The model starts with data collection, data processing, and continuous feedback using a simple and meaningful one page dashboard metric for a NASCAR race team. This one page dashboard metric provides different measures of communications density within a race event in relationship to performance.

The concept of improving communications within this dissertation resembles the Toyota Production System (TPS), referred to as lean and six-sigma concepts within IE; thus it is anticipated that this concept of understanding how we can improve and make our communications lean by eliminating wasteful communications can be accepted as a tool for productivity improvements in automobile racing and other industries as well. By developing a model and process for analyzing and reporting communications, this "lean communications" concept can be added to one of the eight (8) lean/waste minimization resources within the TPS.

Standardization and training are proposed as potential solutions to increasing communications density when important exchanges between the driver and the crew chief are relayed. Standardization and training can also increase the communications content and reduce the chance for error and miscommunication. The benefits of this standardization are important not only to improve the accuracy of information but also to improve the "sensemaking" and "sensegiving" process by providing a cognitive quantitative component during the communications process [10,11]. In other words, establishing standardization in communications between the driver and the team is theorized to improve the *cognitive* ability of the driver to articulate the different mechanical responses of the race car effectively during critical race events.

Finally, this dissertation establishes a model for a proposed automated method for collecting, processing, and reporting communications utilizing existing speech recognition technologies and algorithms.

In summary, this dissertation attempts to question the paradigm associated with NASCAR racing whereby performance is based solely on experienced drivers/teams and good equipment and targets the value of current communications phraseology during race events. A significant amount of valuable resources are invested in NASCAR, far exceeding many industry categories and there is a clear need in this industry beyond the mechanical aspects to introduce productivity improvements. The research proposed within this dissertation challenges this “closed” sport in order to improve communications (or eliminate communications waste) as another “competitive edge” over rival teams.

1.4 Research Scope

The focal point of this dissertation is providing an innovative approach (model) to handling communications involving human cognition related to mechanical systems. One important aspect of this dissertation and the associated analysis is the integration of several disciplines, namely Communications, Organizational Behavior (OB), Organizational Psychology, Ergonomics (in particular Organizational Ergonomics), and Industrial Engineering. This dissertation undertakes an IE approach to this integration through data collection, process modeling, and continuous feedback. Attempts to change human behaviors, communications abilities (ability to articulate), and/or human psychology in respect to relationships is beyond the scope of this dissertation. The TPS and lean concepts have proven, however, that waste can be found in many venues and by reducing waste, productivity improvements can be achieved. Communications as a form of waste need to be questioned thus deemed to be no different than any other form of waste found in manufacturing. Although, the understanding of good communications from a psychological and behavioral perspective should be well understood in order to make change, communications and associated communications “waste” is primarily obvious throughout industry. IEs and lean practitioners review processes and look for waste in order to transform organizations, practices, and procedures stuck in their own paradigm and in the case of NASCAR, this waste is driven by organizational emergence and culture.

In addition to the IE approach to productivity improvements related to communications, some research in OB is important to point out from a productivity improvement point of view. OB perspectives help to explain the theoretical reasons for human interactions. These research areas are explained in later chapters and contrasted to NASCAR, human interactions, and communications effectiveness.

1.5 Organization of Dissertation

The research is presented in seven (7) chapters organized as follows:

Chapter 1 – INTRODUCTION: Introduces the research background, objectives, and overall scope of the dissertation.

Chapter 2 – LITERATURE REVIEW: Reviews relevant sources in communications, conveyance, measurement methods, racing applicability, speech recognition (SR) technologies, and performance feedback.

Chapter 3 – MERGING COMMUNICATIONS IMPROVMENTS TO PRODUCTIVITY IMPROVMENTS: Contrasts Organizational Behavior (OB) aspects of communications to productivity, introduces the new concept of lean communications, and associates the new tool with current practices under the Toyota Production System (TPS). In addition, the effects of lean (wasteful) communications on racing performance are presented with an assessment (informal survey) among racing professionals and fans.

Chapter 4 – NASCAR CAMPING WORLD TRUCK SERIES (NCWTS) CASE STUDY: Presents communication data collection process involving, equipment, procedures, data summarization method, performance data, and transcribing. In addition, this chapter introduces data processing methodologies using MATLAB®. The case study established the methodology and process for the new lean model developed as part of this dissertation.

Chapter 5 – STATISTICAL DATA ANALYSIS AND MODEL: Discusses data from the NCWTS case study and associated statistics, confirms/validates the dissertation hypothesis, and introduces a unique Dynamic Productivity Index (DPI) and unique Team Communications Report (CDR).

Chapter 6 – AUTOMATED DATA COLLECTION: Introduces an automated method for collecting communications data using speech recognition (SR) algorithms and converting the algorithms to search for a unique concept called Meaningful Speech Clusters (MSCs). A proof-of-concept algorithm is discussed and then created; the results are presented.

Chapter 7 – APPLICATIONS AND RECOMMENDATAIONS: Discusses applications in industry along with the recommendations stemming from this dissertation.

CHAPTER 2

LITERATURE REVIEW

The literature search for this dissertation was intensive and included a wide scope of relevant academic areas. The lean model and value-added elements of reporting productivity associated with communications is a new concept driven by this dissertation; therefore, the available literature was limited in this focus area. On the other hand, the literature search for this dissertation capitalized on several elements of existing theory and technologies in various related disciplines. Additional critical thinking was applied to this theory culminating it into a new lean model for communications. The existing theory and technologies fell into the following major categories: NASCAR, Statistical/Scientific Models, Team Performance, Communications Performance, Communications Measurements, Text Analysis Tools, Productivity Tools (lean/six sigma), Ergonomics, Computational Tools, and Speech Recognition. Table 1 provides a summary of these categories as shown in the first column. Column 2 of Table 1 depicts the subcategory of literature acquired and reviewed. One or more sources of literature may have been acquired under each subcategory. The last column indicates the direct applicability of each subcategory to the theory, hypothesis and model.

A thorough search on literature associated with NASCAR team – driver dynamics was performed, including the review of subject matter books and periodicals and interviews performed with experts in relation to communications. Literature on communications modeling in this field was non-existent and was mainly limited to how communications and team chemistry affect performance. The literature associated with NASCAR team chemistry was used to justify the hypothesis (input). Most of the mechanical and racing variable knowledge was gleaned from personal experience; however, books and periodicals were acquired to compile a database of racing terms to support the model and computer algorithms.

Statistical models were evaluated through the literature search in order to determine the best value added metric for an automobile racing environment. This research paralleled computational tools (MATLAB®, SAS JMP®, and Excel), communications measurement, and text analysis tools to develop the interrelated computer programs and algorithms.

Communications theory was supported by studying literature on team performance and communications performance within high-risk organizations including other sporting venues where communications is extremely important to performance in a team setting. This literature search paralleled other dynamic and high risk organizations included the National Football League (NFL), National Aeronautics Space Administration (NASA), the United States military, and Air Traffic Controllers (ATCs).

The tools and techniques for measuring communications in a team setting were evaluated thoroughly and the resources were found to be extensive. Despite the vast resources, most of the techniques found were too complex or theoretical to fit the highly dynamic racing environment. On the other hand, some of these communications measurement techniques from literature were too general. For example, communication measurements that focused on organizational productivity in the office concentrated mainly on passive communications such as emails, memos, reports, and meetings were eliminated. The focused goal of this literature search was to determine a means of measuring the quality of what is being said in relation to the performance of acute situations or challenges, leading to the work at New Mexico State University (NMSU). Most of the bases of the theory and model development in this dissertation are derived from papers written by academia sponsored by NMSU and the associated Cognitive Engineering Research Institute (CERI). Although this research centered mostly on laboratory settings, the research was used to support the model and proof the hypothesis in this dissertation.

Finally, the introduction of a new lean communications model and tool for the TPS required a thorough search to determine if any other work in the TPS/lean/six sigma academics explored communications as a component to productivity improvements.

Table 1 – Literature Search Focus Areas

Category	**Research Areas**	**Applicability**
NASCAR	Team Chemistry	✓
	Success	✓
	Communications	✓
	Mechanical – Variables - Keywords	✓
	Automobiles – General	✓
	Quality Improvements in Racing	✓
	Experience – Statistical Analysis	✓
	Reward System – Statistical Analysis	
	Multicar Teams – Statistical Analysis	
	Sponsorships	
	Best Driver – Statistical Analysis	
Statistical / Scientific Models	Linear Regression Modeling	✓
	Golf Handicap Calculations – Statistics	✓
	Pool Handicap System	✓
	Markov Models	
	Fuzzy Logic	
	Monte Carlo Methods	
	Persuasive Communications	
	Instant Messaging	
	Simulation – Communications	
	Probability Models	
	Data Mining	
Team Performance	Team / Organizational Culture	✓
	Shared Mental Models	✓
	Situation Awareness	✓
	Sensegiving – Sensemaking	✓
	Group Think	✓
	Transactive Memory	✓
	Team Sports Models	✓
	Knowledge Representation	
	Team Cognition Measurements	
	Macrocognition	
	Decision Making	
	Mental Models	
	Distribution Cognition	
	Mental Workload Modeling	
	Natural Language Processing	
Communications and Performance	Interviewer – Applicant	✓
	Clarity of Communications	✓
	Accidents - Miscommunication	✓
	Training	✓

Table 1 – Literature Search Focus Areas (continued)

Category	**Research Areas**	**Applicability**
Communications and Performance	Phraseology	✓
	Information Flow	
	Communications Flow	
	Communications – Linguistics in Organizations	
Communications Measurements	Latent Semantic Analysis	✓
	FAUCET	✓
	Simple Observations	✓
	Video – Audio – Coding	✓
	FAA – Military – Actual Video/Audio	✓
	Coherence	✓
	Team Cognition	✓
	Communications Flow Analysis	✓
	NFL	
Text Analysis Tools	Gunning Fog Index	✓
	Stop Words	✓
	Content Analysis	✓
	Linguistics – Phonetics	✓
	Readability Index	✓
	Lexical Density	✓
Productivity Tools	Toyota Production System / Lean	✓
	Six Sigma	✓
	Confidence Intervals	✓
	Control Charts	✓
Ergonomics	Human Factors	✓
	Human Reliability Metrics	
Computational Tools	MATLAB®	✓
	SAS JMP®	✓
	Microsoft Excel and Word	✓
Speech Recognition (SR)	Correlation Coefficients	✓
	Audio Signal Basics	✓
	Dynamic Time Warping	✓
	Mel Frequency Scale Ceptral Coefficients (MFCC)	✓
	Cosine Transformations	✓
	Fourier Transformations	✓
	Matrix Vector Classifiers	✓
	Neural Networks	
	MATLAB® - Hamming	
	Computer SR Wake-up Concepts	
	Auditory Models	
	Digital Signal Processing / Spectral Analysis	

CHAPTER 3

MERGING COMMUNICATIONS IMPROVEMENTS TO PRODUCTIVITY

3.1 Organizational Behavior

NASCAR racing is not immune to organizational dynamics and should be included in Industrial Engineering (IE), Systems Engineering, and Organizational Behavior (OB) research to explain human interactions. This research includes tools and theoretical concepts in basic business management principles, OB theories, psychology, and the tools used to improve processes in IE and Systems Engineering. From observations in the field of NASCAR racing (and other organizations as well), good relationships among team members, including efficient communications, and accurate mental modeling definitely lead to effective (good) performance. In a sport geared toward the complexities of the mechanical components (race car) and the experience of the driver/team, the success of the NASCAR organization, as with other organizations, still comes down to the *human component*. The most advanced technological computer systems, high capital, and revenues, expertise, and best equipment cannot substitute for the effective use of humans to connect, to establish relationships, and to be able to articulate to each other the what, the how, and the when within the context of complex systems namely machines or automobiles. As shown in the Venn diagram in Figure 3, NASCAR has evolved over time from a sport concentrating only on the equipment aspects (fast “stock” car) where “for decades, the sport was dominated by mechanics and crew chiefs whose primary qualification was the grease under their fingernails” to promoting expertise in people (good teams and drivers) and developing a solid process over the past 60 years [14].

The intent of this dissertation is to transform another important racing variable into a measured performance attribute and to determine the effects of these aspects on performance. Currently, NASCAR organizations place significant emphasis on equipment (especially engines, suspensions, aerodynamics and associated tools);

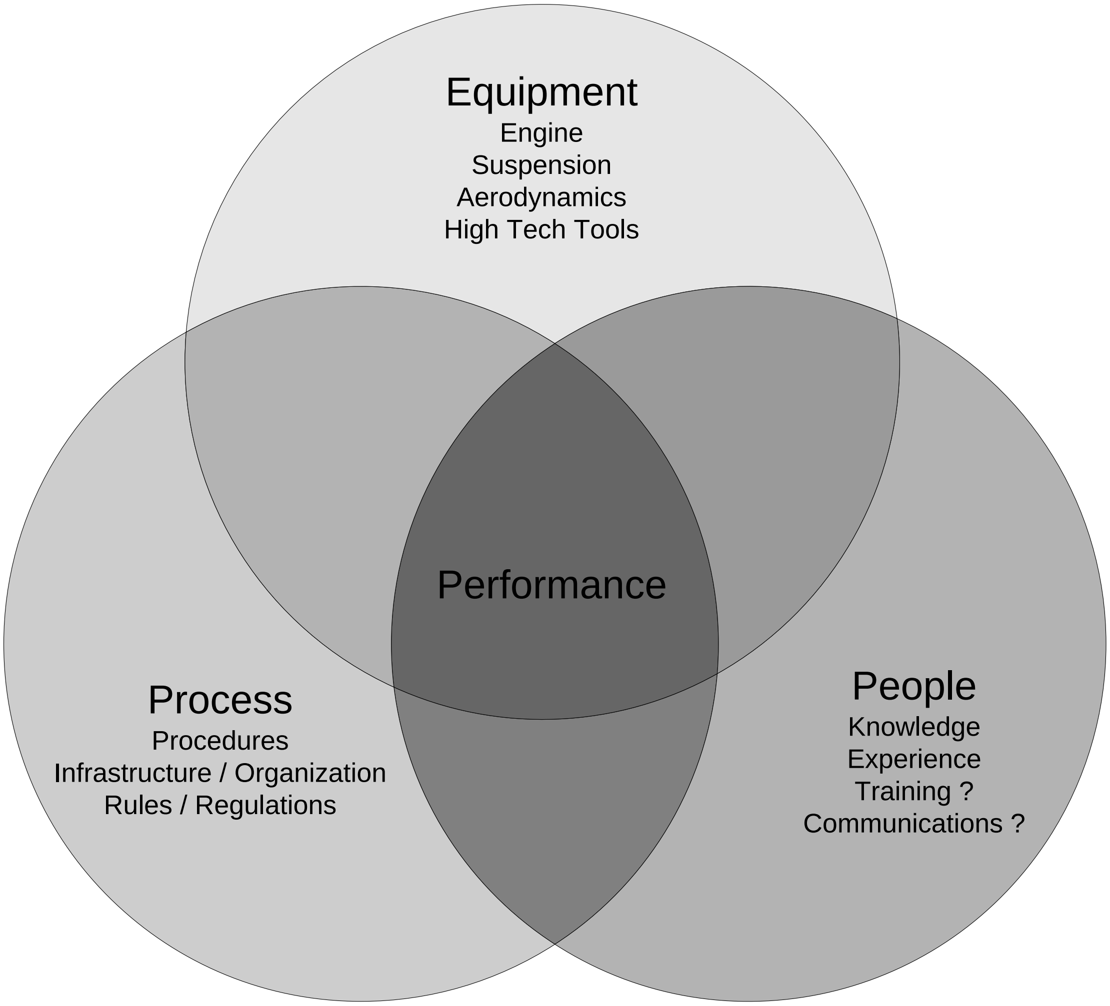

Figure 3 – Performance Venn Diagram

however, when it comes to "people," their Stock Car Racing emphasis is only on the knowledge and experience of the team rather than their communications abilities. An example of emphasis placed on communications within an organizational context in other complex organizations can be found within NASA, where life and the expense of complicated equipment are at stake (performance measures). The space shuttle is most complicated mechanical system known to mankind; however, this complicated system still needs human intervention and effective communications in order for it to function properly. NASA has perfected team communications especially during critical operations such as operating the space shuttle. Adaptation of the rigor and formality seen within NASA is hypothesized to improve NASCAR team performance where the communication protocols are similar. Finally, miscommunications have caused team inefficiencies and mistakes during race events directly affecting the performance of a race team. These observations and OB concepts coupled with other organizational practices are the basis for the research questions and the new communications model for this dissertation.

Understanding the organizational context of NASCAR provides a foundation for corrective measures to determine the need for change and improve communications. NASCAR can be characterized as an intersection of two distinct organizational contexts namely a generic organizational model and a high risk organization. Sports organizations fall within the context of a generic organizational model as sports models take on basic organizational parts including teamwork, competition, divergence, entrepreneurship, and diversity [15]. High risk organizations on the other hand, involve three primary characteristics: the potential to create a catastrophe including loss of life, large numbers of highly interdependent subsystems with many possible combinations which are non-linear and poorly understood, and subsystems that are transmitted rapidly with little attenuation [16]. NASCAR racing is high risk in that drivers risk their lives by driving speeds up to 200 mph and simultaneously with up to 43 other drivers. Although many safety features have been put into place, dangers to the drivers, pit crews, and sometimes fans remain.

"Catastrophic" events in NASCAR racing are rarer because the current organizational and business models are driven by its inherent culture, spawned from southern roots and the strict guiding principles of the original family creating the NASCAR sanctioning body. This culture allows for the centralization of the sport whereby "… strong organizational cultures provide a centralized and focused cognitive system within which delegated and loosely coupled systems can function effectively ...” [10]. Centralization, via culture is precipitated on the values of self prescribed cohesion and close relationships among its members. In essence, the reliability of the subsystems within NASCAR depends on the effective close relationships and more importantly the trust of its members to prevent problems. Additionally, NASCAR’s culture has evolved its own language, phraseologies, methods, rules, and protocols [13,17].

This theory of culture implicitly encompasses a closed loop system of learning and relationship building over time and repetition. As with normal high-risk systems, little time is devoted to learning by experimentation and induced failure because NASCAR limits the amount of time on the race track intentionally [16]. Learning and relationship building within high risk organizations are normally performed by practice (simulation), training, and historical recall of actual events (lessons learned/experience). The intense repetitive nature of these venues provides the opportunity for its members to build successful relationships among its members. As the industry grows over time, however, the culture tends to break down, requiring regimented organizational approaches to compensate for the increased diversity and involvement by other organizations and entities. Similarly, high risk organizations such as the NFL and military have adopted intense practice and training among their members before a formal football season or combat deployment, respectively. The growth within these “organizations” replace team “chemistry” with regiment, procedure, training, and formal communication protocols and systems to carry out their missions.

From OB literature, though, the interaction between people shapes “form and intent” therefore emphasizes the importance of how team objectives are successfully completed [18]. Connecting fundamental OB theory in respect to cognitive intent establishes a basis for why communications are important during dynamic racing events since the objective of a race team is to provide the driver with a mechanically well-balanced race car for a particular race track by making the appropriate adjustments to the race car based on the driver’s input. Communication serves as the vehicle and means for a series of “sensemaking,” “sensegiving,” transactive memory (two or more people can share the task of remembering by using each other as memory storage components), brevity, and/or mental models among the team members, including the driver, crew chief, and all of the support personnel during a race event to make the correct changes to the race car [10,11,19, 20]. Drivers should share a mental model or universal understanding of the race car with the other team members during race events in order for proper adjustments to be made to compensate for ever changing variables. Thus, these OB theories further support the importance of communications among with the elements of mechanical engineering and aerodynamics, especially considering the extremely competitive and highly dynamic environment.

Given that history has provided evidence of effective performance from training and associated communication protocols in high risk organizations such as Air Traffic Controllers (ATCs), the NFL, and the military, NASCAR needs to adopt these changes to transform to another competitive level. Regimented training and formal team building among NASCAR team members is emerging; however, productivity improvements could languish by sustaining the current variable language and informal phraseologies, therefore the current language and informal phraseologies is hypothesized as an opportunity for improvement and this improvement is theorized to translate into an increase in performance.

While, this dissertation does overlap with the communications discipline in respect to the cognitive and relationship components of communication in addition to OB aspects, other factors which influence communications such as conflict, persuasion, self-disclosure, and the social component are not addressed.

3.2 Toyota Production System and Lean

Lean for IEs is a philosophy spawned by the Toyota Production System (TPS) to provide the best automobiles through superior quality, low cost, and shortest lead time by concentrating on the elimination of waste. Scholars and engineers have defined and redefined lean to adapt it to the manufacturing of goods and services with the intent of increasing productivity while concentrating on equipment and people with a sustained process improvement program (the "four-pillars" of lean). Lean should not be viewed as a tool but rather a habit, a philosophy built around its broad definition of economy and centered on people's everyday lives; thus, anyone can be and should be a "lean practitioner." As a lean practitioner, one should constantly think about and consider eliminating waste and improving processes and systems, thereby changing to meet customer demands. In work environments, waste can be detected in many forms, centering on the eight defined types of waste: Waiting, Overproduction, Rework, Motion, Processing, Inventory, Intellect, and Transportation [5]. For example, non-value added overproduction can involve printing extra copies of reports, producing components that are not needed, working ahead of deadlines, stockpiling inventories, and/or developing excessive or redundant systems. The success of lean is rooted in what is good for the customer, good for the organization, and good for the lean practitioner and the people who do the hands-on work. Lean thinking challenges people's habits by changing the way they think about waste, and, in fact, communications can be thought of as a form of waste. Commensurate with the example of non-value added elements of overproduction, waste in communications can be found with over communication, under communication, communication of information not needed, and developing communication dialogues unnecessary to the task at hand. In addition, effective communications is way companies and business entities can improve productivity and save costs. Since the primary goal of lean is to eliminate waste, the proof of the effectiveness of Communications within this dissertation justifies adding communications as the ninth form of waste for the TPS.

The TPS has defined three broad categories of waste (in Japanese terms): muda (no value or unproductive), muri (excessiveness/unorganized), and mura (inconsistency). Since muda's premise is no value or unproductive, and terminology under the TPS is driven by Japanese terms, the term "mudabanashi" is adopted to provide an "identity" to wasteful communications commensurate with the TPS.

3.3 Communications and Effects on Racing Performance

Over the course of a race season, depending on the success (or failure) of the race outcomes, the public and news media will often refer to successful performance and communication between the driver and crew chief as "good chemistry." Good chemistry is generally defined by the media as a team (mainly driver and crew chief) that has achieved a high number of driver points (usually within the top 10) for a race season. A racing journal, however, defines team chemistry as "how people function and interact" and further explains that "[team chemistry] is a crucial and elusive element to the overall success of every [NASCAR] Sprint Cup organization, but can be tricky to manage [6]." Furthermore, team chemistry may be defined by its absence, as Brian Vickers, a popular NASCAR driver, states/describes a lack of team chemistry as "anything from a disagreement, and argument, a lack of communication, passive aggressiveness, or a fistfight [6]." Team chemistry, communications, relationships, and experience are all thought to be very important in NASCAR because unlike many other sporting events, auto racing is coalescence between humans and machines. However, in actuality, in NASCAR racing, the goal is effective communication between driver and crew chief; therefore, the use of "chemistry" in respect to communications is a misnomer. The objective is to impart accurate and meaningful information between the sender (driver) and the receiver (crew chief or team members).

Academic study in NASCAR is in its infancy, especially considering communications as a productivity component [21]. Over the years, NASCAR teams and drivers have adopted slang and terminology for their sport (Table 2). The driver and crew chief (or team members) use this terminology and/or dialectic expression to communicate what changes are necessary for the race car when the race car is driven around the race track. The hypothesis in this dissertation contends that communications using non-specific and qualitative statements can be viewed as inefficient. Many of the discussions between the driver and the crew chief (or team members) are intended to communicate the “feel” of the race car; however, adjectives describing the different aspects of how the race car feels are interpretative and non-specific. These types of communications should be translated into specific quantitative and measurable racing attributes in order for the team to make specific mechanical adjustments to the race car.

Precise mechanical cognition and its translation into effective articulation of the car performance by the driver to the team members during any race events should increase the chance for proper car adjustments. In addition to the increases in engine and aerodynamic technologies, ongoing race car set-up research continues to explain, enhance, and troubleshoot race car set-ups and is reported though many race car technical journals. At the race shop, in between race events, technical discussions do transpire between the engineers, mechanics, and the various team members responsible for race event set-ups at the race track. The effectiveness of these discussions, however, appear to break down at the race track when the time durations are shorter, when sudden race track/environmental conditions change and when pressures to make the critical adjustments are highly dynamic.

Although success still comes down to good equipment and experienced teams, communications is argued to be an important component of a successful racing team. In order to substantiate the hypothesis in this dissertation, data was collected from an organized survey among team owners, drivers, team members, fans, NASCAR officials, and the media (Section 3.7).

Table 2 – Driver to Crew Chief Communication Examples

Driver	Crew Chief	Discussion
"..that turned better, I don't know where the speed's at … I mean that's … we need to … you know … obviously we need to make some big changes somewhere … um .. that turned, definitely turned better … we need more of the same … um .. we just need more the same .. you know .. if ah …. that was probably on a from a scale from 1 to 10 that was a 4 better … we'll probably need about that same amount again… "	Ok … lets change both upper slope on the left and lets pull the rear end back about 1/8th or so on the right… I don't know if want to put it up on all 4 for a minute or however you guys want to do it … get measurements first .. then we'll go ahead and do that	The driver reacts to the first adjustment to the race car after a few laps: the first adjustment improved the car's performance, but the driver is trying to explain to the crew chief to make a similar adjustment but more of it. Notice that the driver used a scale to explain the first adjustment improvement.
"When I need to unwind, I need to crank wheel, crank wheel, crank wheel"	None.	The driver recounts the race car behavior exiting the corner and when the driver emphasizes "crank wheel" three times, he is trying to communicate the degree in which he is trying to control the car and maximize speed.
"When you get next to the wall, you have so much wheel in it, you get loose"	Ok, let adjust the right camber in the left front to make it dig in more right there in that part of the corner	In this dialogue, the driver is explaining the reaction of the race car from his effort to correct it from hitting the wall.
" … turned better … um … didn't turn quite as good on entry … um … turned better through the center … better off…"	" .. did that [change] help that swingin' out .. on exit .. late exit?	The tweaking of the race car is performed when the terminology of the communications start to change from "exit" to "late exit" as an example.

Driver and Crew Chief recorded conversations from Wylerracing.com Race Truck Number 60 racing in the Camping World Truck Series in Martinsville, Virginia 2009 [22,23].

3.4 Measurement of Communications and Effectiveness

Measurements in communication and content analysis are common in social sciences in the study of linguistics within books, websites, recorded human communications, and other printed media. These studies primarily center on making inferences about various characteristics and effect of communication in different contexts. Characteristics can include inferences on writing style, readability of written communications, patterns, communications content, individual traits, dialect (cultural), intelligence, techniques of persuasion, and the overall generalized flow of communications. These communication's measurements and categorizations appear to measure characteristics within the context of what is communicated as opposed to the effectiveness of what is being said or conveyed in relation to an act of accomplishing something. Measurement variables in typical content analysis involve sentence structure, word length, keyword frequencies, space measurements, measuring the number of lines in text etc. [5]. Examples of quantitative measurements of text are the Gunning Fog Index, the Readability Test Tool, Lexical Density, Passive Index, and Flesch-Kincaid Index.

The field of content analysis is expanding and can involve any kind of communications content analysis. Many companies on the World Wide Web (WWW), for example, are interested in the effectiveness of websites, measuring website content, and searchability using text analysis tools and algorithms. Although these tools are useful for their applications, none of the tools sufficiently measure text, linguistics in relation to the subject measured, and performance simultaneously.

Over the past few decades, communications, training, and human cognition has emerged in research to understand the effectiveness of communications [24]. Other forms of communications measurements have materialized as a mechanism to quantify the effectiveness of teams. While, the Cognitive Engineering Research Institute (CERI) measures real-time team performance and team processes, their research is limited to structured environments such as UAV command and control in the military, emergency response teams, and homeland security response teams [25]. Although the CERI's research is focused on trained subjects and structured processes, yet some of the work and modeling performed at the CERI is used as a basis for the model proposed in this dissertation. One particular note from these measurement techniques and results is that studies have shown that the use of standard phraseologies is better (improves performance) however, more communications are not always related to better performance [24].

Considering the momentum and generalized findings of other research in communications in relation to performance, the proposed model in this dissertation is needed as a *practical* tool to measure the performance of specialized organizations. The proposed model and productivity tool presented in this dissertation is a culmination of research performed in basic linguistics, content analysis, and research performed on formal and structured organizations with the intent to provide a useful and value-added instrument for practical productivity improvement feedback.

3.5 Communication Performance Measures in NASCAR Racing

During a typical race season an enormous amount of driver and team performance data is produced within the various race car divisions and in particular the three major divisions of NASCAR, namely the NASCAR Sprint Cup Series (NSCS), NASCAR Nationwide Series (NNS) and NASCAR Camping World Truck Series (NCWTS). Within a race team, highly advanced and sophisticated systems process and collect mechanical and aerodynamic data before race events and during testing. NASCAR as a sanctioning body collects official driver and team data by their statisticians to determine the eligibility and criteria for monetary winnings, rankings commensurate with adherence to the rules, cumulative race statistics, and overall team points determined by formulation. The overall team point formulation takes into consideration wins and overall race position throughout the year. As discussed in Chapter 1, data collection by electronic means during a race event is non-existent, and this data is collected statically when the race car is at rest.

Team performance during a race event is measured by race track times during the various race event laps, position compared to the field of competitors, number of laps completed in the actual race, number of passes a driver makes during a race, time spent during a pit stop, number of laps lead in a race, and outperformance of all of the competitors during the actual race. Overall positive performance, especially winning races by the team and the driver, precipitate high monetary winnings from NASCAR and additional revenue through corporate sponsorships. NASCAR revenues are mostly collected from membership fees, a percentage of race event ticket sales from the fans, official NASCAR merchandise sales, TV (media) sponsorships, and corporate sponsorships.

Restricted increments of the race events limit the ability to create mechanisms for immediate feedback on team performance beyond the standard performance measures such as position and lap times. Data collection to measure *within* team performance, while critical race events occur, is essentially nonexistent. Some teams, however, video record pit-stops and replay for critiquing purposes. In essence, feedback during and after race events is essentially expressed verbally by the team members to each other either immediately after the race event or when they return to the race shop.

3.6 Major Variables Impacting Performance in Racing

One of the interesting aspects of NASCAR is the many variables that could affect the outcome of a race event at each level of organizational structure. At the individual level, drivers have experiences and personalities that motivate their aggressiveness and in turn affect their performance in either a positive or negative way. The combined effort of the individuals and the organization itself is expressed as teamwork, and the net effect of teamwork can influence a team's organizational stability and team cohesiveness. Weak teams and associated teamwork can contribute to the ability to sustain continuity, communications, and logistics. Moreover, corporate sponsorship establishes the financial strength of a team. This financial strength is typically proportional to having good equipment (race cars) thus defining performance. Many other subtle factors affecting team performance exist as well, including changes in the environment (weather and race track conditions), mechanical failure, and human error.

In addition to human and organizational variables, race car mechanical variables are numerous and unquestionably impact the performance of a race team. Many of the mechanical variables were discussed in Chapter 1 of this dissertation. In evaluating all of these variables as a whole, a generalized categorization of these variables can fall into three major categories:

- Experience
- Equipment
- Communications (Team Chemistry)
- Other Minor Influences

The major categories of racing variables are supported by the opinions of team owners, media, and team members including nationally recognized drivers. As indicated, communications appear in the list of influential factors as a component to team chemistry. The inclusion of communications can be justified through academic research in other OB contexts and the literature search on NASCAR team performance factors. In addition, a simple survey was performed during the case study for this dissertation, the results which are discussed in the next section, supported the addition.

3.7 Communications Impact to Performance (Survey Results)

To access the contribution of communications to race team performance, a survey was conducted among team owners, drivers, fans, media, NASCAR officials, and team members. Given the dynamics of the sport, the dependability of receiving responses from a controlled group of subjects was uncertain. In lieu of a controlled group, individuals were selected at random during a race event depending on their availability and time to answer the questions. Attempts were made to contact recipients via email (over 20 emails were sent out): however, the best approach was to hand deliver the survey and explain the objectives one-on-one to each person.

The format of the survey is straightforward. The respondents were asked two questions and their reply was in the form of numeric percentages. All of the percentages entered for each question added up to one-hundred percent (100%). The first question asked the following:

> "Successful performance (winning) in NASCAR racing depends upon many different factors. These factors include, are not limited to, good equipment, and experienced people, including drivers and crew chiefs. What percentage do you think communications (i.e. chemistry) play into the success of a NASCAR team in percentage "%" numbers?"

The eligible categories to populate the percentages for question one were Equipment – Engine, Chassis, Car Manufacturer Support, Experienced People (Team), Communications (Chemistry), and Other (if applicable). The second question consisted of the following:

> "If your answer for Communications above is greater than 0, what percentage would you rate the importance of communications having the following characteristics between the Driver and Crew Chief?"

The eligible categories to populate the percentages for question two were Acquaintance Time (amount of time they have known each other), Cognitive Ability (ability to explain mechanically), Years of Experience, and Relationships (how well the crew chief and driver get along). The second question of the survey was designed for additional information to access team chemistry in relation to other factors. The addition of these interesting contributors based on some of the OB research, were not, however intended to support the hypothesis in this dissertation, but rather to explain the motivation behind good communications. The format and layout of the survey is in Appendix A. Approval to use human subjects was secured via the University of Tennessee's Research

Institutional Review Board (IRB). The reporting of this survey within this dissertation is anonymous under the provisions of the IRB.

All of the surveys were collected and the percentage data was compiled. Twenty-two subjects were interviewed to complete the survey. The results of the survey were compiled into a Microsoft Excel spreadsheet, and cumulative results were tallied [26]. Figure 4 presents the results of the survey. The purpose of the survey was to strengthen the assertion that communications plays a significant role in performance directly using the latest opinions and information from the various respondents. As shown, the average contribution to success result was approximately 33.2% with a 95% confidence interval between 39.7% and 26.6%. The resulting statistics may be found in Appendix B.

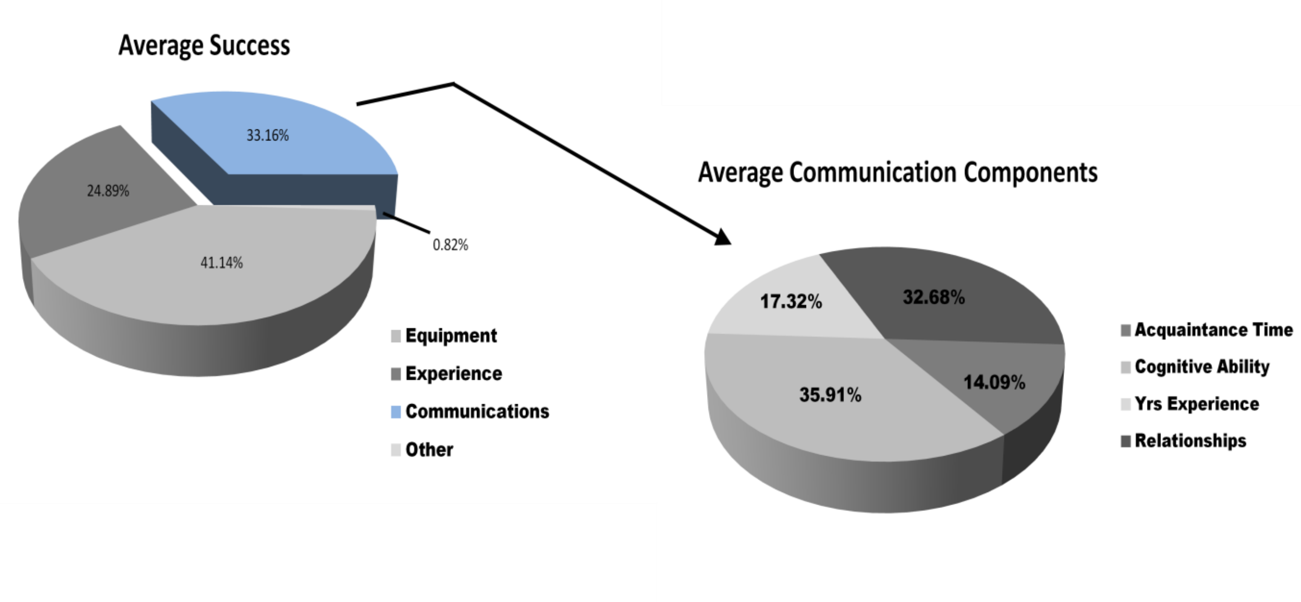

Figure 4 – Overall Communications Survey Results

CHAPTER 4

NCWTS CASE STUDY

4.1 NCWTS Licensing, Data Collection and Team Involvement

The NASCAR Camping World Truck Series (NCWTS) was selected as the case study to collect data, test the hypothesis of this dissertation, test/validate the proposed communications model, and implement a lean communication tool. The first challenge for completing this process was to enter the sport by joining a race team as an engineering intern. Previous experience in NASCAR and knowing a driver provided the opportunity to join a team for the NCWTS 2009 season. The Wylerracing.com/ SAFEAUTO Number 60 Toyota Truck team driven by Stacy Compton was the sponsoring team [22,23]. As the owner and driver of this team, Mr. Compton allowed data collection for this dissertation and encouraged other productivity feedback for his race team.

A NCWTS license was required to work, participate, and enter the NASCAR garage and pit areas. NASCAR has very strict gated compounds where the race cars are offloaded and serviced in the garage area, pit areas, and race track. While primarily for safety, the controls also protect the integrity of the rules by protecting against unauthorized adjustments to the race cars and tampering with other team’s equipment, race track, fuel storage areas, and tire storage compounds. Ten (10) NCWTS races were attended with the intent to collect an array of communications and performance data. Appendix D lists the 2009 NCWTS races attended for the data collection within this dissertation. The green box outlining the race date in Appendix D signifies the race attended. The data collection from these ten (10) races predefined the sample size of the statistical analysis discussed in Chapter 5. Of the ten (10) races, valuable data was collected from six racing venues namely, Kentucky, Nashville, Bristol, Martinsville2 (second 2009 Martinsville race), Talladega and Phoenix. These race venues provided an excellent sampling cross section of short, medium and long tracks for the statistical analsysis.

Productivity feedback reports were also provided to the Number 60 team business manager/driver but were beyond the scope of this dissertation thus are not be provided or discussed; however, these productivity feedback areas have precipitated other opportunities for subsequent improvement at a later time.

Of the ten (10) NCWTS races attended, consistent and auditable communications data was collected from six (6) race events with a total of eleven (11) practices (one race event only had one (1) practice session). In addition to collecting data from the Number 60 race truck, five (5) other teams were selected for communications data collection, consistent with the recommendations from this dissertation's committee recommendations during the proposal stage. The criteria for selecting the team-driver combination were the following:

- two (2) senior drivers (drivers with greater than 10 years experience in NCWTS)
- two (2) mid-level drivers (drivers with greater than five years and less than 10 years of experience in NCWTS)
- two (2) rookie drivers in the NCWTS.

Driver to team communications are broadcast publically over two-way radios on Federal Communication Commission (FCC) regulated frequencies in the 800-900 Mega-Hertz (MHz) range. The FCC channels are managed by commercial radio companies who sell radios and accessories to NASCAR race teams and fans. Teams use the radio equipment to communicate to each other during the noisy race events. The radios used are robust, durable, and of high broadcasting quality, thus clarity of the communications on the radio transmissions is generally clear. To assure compliance with human subject research and any other research ethics criteria for recording communications data, a University of Tennessee IRB review and disposition was requested. The IRB approved the communications data collection of the teams using radio receivers and recording equipment on the basis that the communications occur over open airwaves and the information is accessible by the general public. The only stipulation placed on data collection by the IRB was that the teams not be identified in the dissertation by the NCWTS Truck number or by the driver name (except for the team sponsoring the case study). Each team was therefore identified in the various datasets as single numeric 1 through 6. A second number 1 or 2 was used to identify the practice number. Therefore, race event/team "Martinsville2 2-2" would be driver 2, practice number 2 for the second Martinsville race event in the 2009 NCWTS season.

Communications data collection from the first four (4) races was unsuccessful, primarily due to equipment logistics. In the first race event attended, Atlanta (March 2009), time was spent getting oriented with the team and its procedures and protocols as well as explaining the hypothesis to the driver, team, and crew chief and why it would be necessary to collect communications data by recording. In addition, an attempt was made to record radio transmissions in digital audio from all six (6) drivers using only two (2) Bearcat® scanners, a laptop computer, and one MP3 recorder. Consequently, no valuable data was collected during the Atlanta race event. Similarly unsuccessful, in the second race event attended, Martinsville1 (March 2009), an additional attempt was made to collect communications data using the same equipment as in the first race, but this race was rained out, and postponed until the following Monday. Therefore, no practice data was acquired during this race event. In order to compensate for the lack of adequate equipment, at the third race event attended, Charlotte (May 2009), a set of five (5) radios were rented from Racing Radios (RR) and six simple voice recorders were purchased in an attempt to adequately record the transmissions [27]. After setting-up the rented radios and voice recorders, the data collected remained inadequate, primarily because the radios were hard to handle, presented unanticipated distortions, frequently changed channel settings by handling (thus losing the intended driver transmissions), and the rental costs for five (5) radios protracted over seven (7) additional races exceed the budgetary considerations of this dissertation. While the distortion was likely a result of poor connections between the radio and the voice recorder as well as other unknown factors with the voice recorders, inadvertent changing of the channels was operator error. Overall, the receiving qualities of the radios were adequate; however, alternate means were necessary due to the expense of renting.

In an attempt to improve reception and ease of radio receiver set-up, five (5) Solo II's ® (Figure 5) were purchased from RR, in the fourth race attended Memphis (June 2009) [27]. Solo II's are pager-like receivers designed specifically for fans to listen to team communications during NASCAR race events. The cost of these devices were well within budget, were easy to program, had clear reception, and convenient in size. During the Memphis practice events, the transmissions were received using the Solo II's tethered to digital voice recorders by 3.5mm double–male audio jacks. However, recorded practice sessions from the Memphis race were later determined inadequate. For unknown reasons, the digital voice recorders did not turn off the microphone when the 3.5mm tethers were inserted into the microphone jack causing the recordings to receive background racing noise and preventing the voices on the recordings from being discernable. Some data was obtained from these recorders, however, the digital voice recorders were not equipped with a Universal Serial Bus (USB) connection thus, the only way recording could be transferred to a computer was to replay the recordings and record the recording using Microsoft's Sound Recorder® ultimately very time consuming and inefficient [26]. The magnitude of the time required to replay these recordings digitally back to a computer was an oversight; the digital voice recorders were abandoned and discarded.

Finally, for the fifth (5th) though tenth (10th) race, five (5) RCA® MP3 recorders with USB connections were purchased as a replacement to the voice recorders (Figures 6, 7, and 8). A routine procedure was established for the remaining six (6) races by gleaning the experiences from the first four (4). Each Solo II was numbered from 1 to 5 using a Sharpie® marker and programmed to a particular driver's radio frequency. Additionally, each new MP3 recorder was labeled from 1 to 5, thus pairing each Solo II / MP3 recorder by number (1 with 1, 2 with 2, etc – Figure 7) for each race practice event. Simplifying the procedure prevented these errors during the noisy and distraction filled race events. To accurately track the recordings, each driver was labeled 1 through 5 in sequential order of their race truck number. Since drivers are not be identified in this dissertation, a "key" associating the driver and truck number to the recorder/Solo II is not be provided; however, such information has been archived by the author. A Bearcat Sportcat® scanner was used and programmed to a sixth (6th) driver sponsoring this dissertation. The scanner was used with an equivalent, different brand (Olympus®) MP3 recorder thus numbering was not required. The scanner and Olympus® MP3

Figure 5 – RR Solo II Receiving Equipment / Instructions

Figure 6 – RCA MP3 Recorders

Figure 7 – Typical Recording Set-Up

Figure 8 – RCA MP3 Recording Equipment

equipment was already owned by the author of this dissertation and there was no concern over the equivalency of the digital recordings between the Olympus® or RCA® units. The team number to recorder/Solo II combination remained the same throughout the data set to prevent digital recorder or digital file to driver transposition errors while transferring the files to a computer. The typical equipment set-up during race event practices is shown in Figures 9 and 10.

In addition to programming the scanner and Solo IIs, the scanner was fully charged and the batteries were replaced in the receivers / MP3 recorders prior to each race event (16 total batteries). Battery depletion was noticeable in the equipment during the long practice runs.

As stated in Chapter 1, race event practices are scheduled during race events thus all drivers start and stop at the same time. NASCAR's regimented scheduling all of the

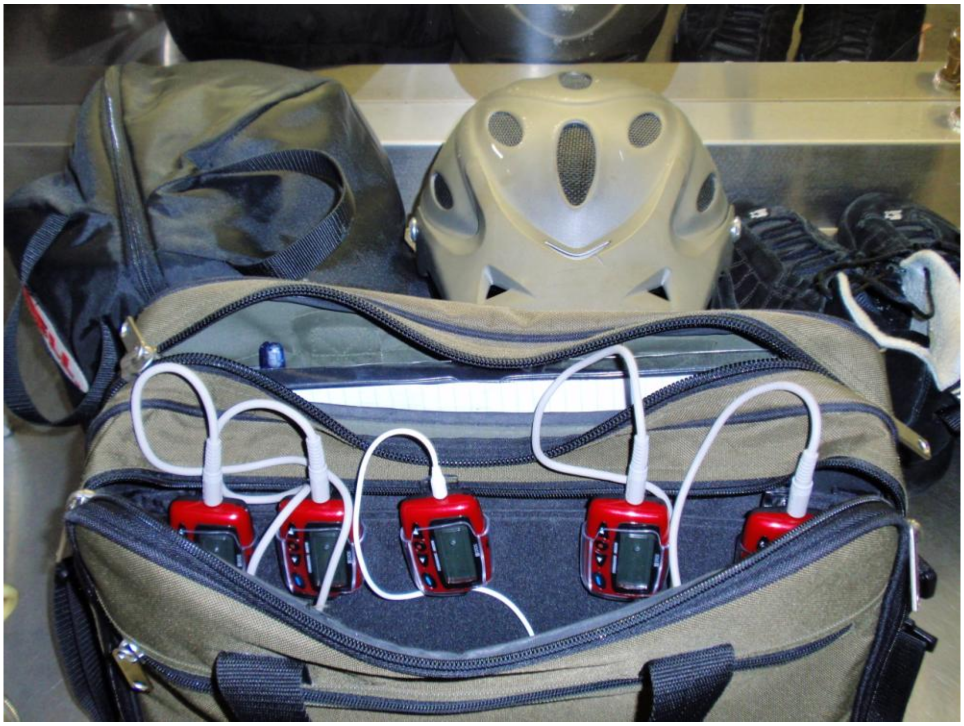

Figure 9 – Recording Equipment Set-Up at Race Event

Figure 10 – Recording Equipment Set-Up at Race

drivers for a race event practice was convenient for the data collection and consistency in the data. Once recording started, each driver was monitored to assure that the equipment was functioning properly and to assure a team did not change frequencies. Occasionally, a team will change frequencies due to local interference on their designated frequency channel. Teams might start out on their assigned channel one (1) and switch over to their alternate channel two (2) if this occurs. In addition to the primary frequency (channel 1), alternate channels (channel 2) are published publically for each driver. Since each Solo II was equipped with a spare 3.5mm jack, alternating between receivers using a set of standard earphones enabled the monitoring of all recordings without interruption. Driver six (6) was the Number 60 truck and was monitored using the Bearcat scanner [28]. In this case, a 3.5mm splitter allowed listening in on this conversation while tethered to the Olympus MP3 recorder (Figure 11).

Maintaining a robust and routine procedure for preparing and recording the race event practices allowed for consistent recording of all six (6) drivers during six (6) races, equating to 61 recorded sessions. All of the 61 recorded MP3 files were transferred and stored on a computer to prevent loss. Each MP3 file was named using the race venue driver number and practice number scheme described earlier. Commensurate performance data, such as race track position number, were collected for each driver in each practice in preparation for the statistical analysis. As a paid / licensed NASCAR team member, access to the official race data was authorized.

4.2 Transcribing using Sony Sound Forge ®

To assess each team's communications data, it was necessary to transcribe each recording to a text/Microsoft Word file [26]. Because the listening/transcribing process was so tedious, it required the use of audio processing software but still took several months to complete. Sony Sound Forge® was selected to assist in the transcribing based on reputation and potential use in advanced Speech Recognition (SR) (Chapter 6) [29].

Figure 11 – Radio Receiving Equipment and Headphones

Sony Sound Forge® features such as cropping silent areas, slowing down the audio, removing noise, and crackle, expediting the retrieval of the audio and placing markers at each point an utterance relative to driver – team to mechanical cognition transpired (Figure 12). In the areas of SR, Sony Sound Forge® can automate the preparation of the audio signals using add-ins to the software to reduce the volume of data vectors.

During transcribing, a standard Microsoft Word template was used for each recording and each file was saved using the race venue driver number and practice number scheme described earlier [26]. The template contained a consistent header with the race event name, driver name, and practice number for later processing. The procedure for transcribing the audio included capturing all dialogues relative to driver to team or team to driver in regard to mechanical and/or truck setups. Facts (e.g. discrete tire temperatures, engine parameters, lap times, etc.), safety comments, and casual conversations not relative to the race event practice cycle were ignored. Using these rules as a standardized procedure for transcription, all utterances relative to interpreting the race truck performance, set-up, and adjustments were captured in a consistent manner for all six teams. Sixty-one (61) Microsoft Word files for each transcript were created and saved for later processing.

4.3 MATLAB® Programming and Algorithms

After transcribing all of the audio files in Microsoft Word, saving the files to a text file was necessary for further processing. In addition, certain terms and nomenclature used by drivers needed adjustment before saving to the final text file. A Microsoft Word macro was created with converted strings of racing phrases to a condensed text set without spaces. The Microsoft Word macro was written to automate this process in order

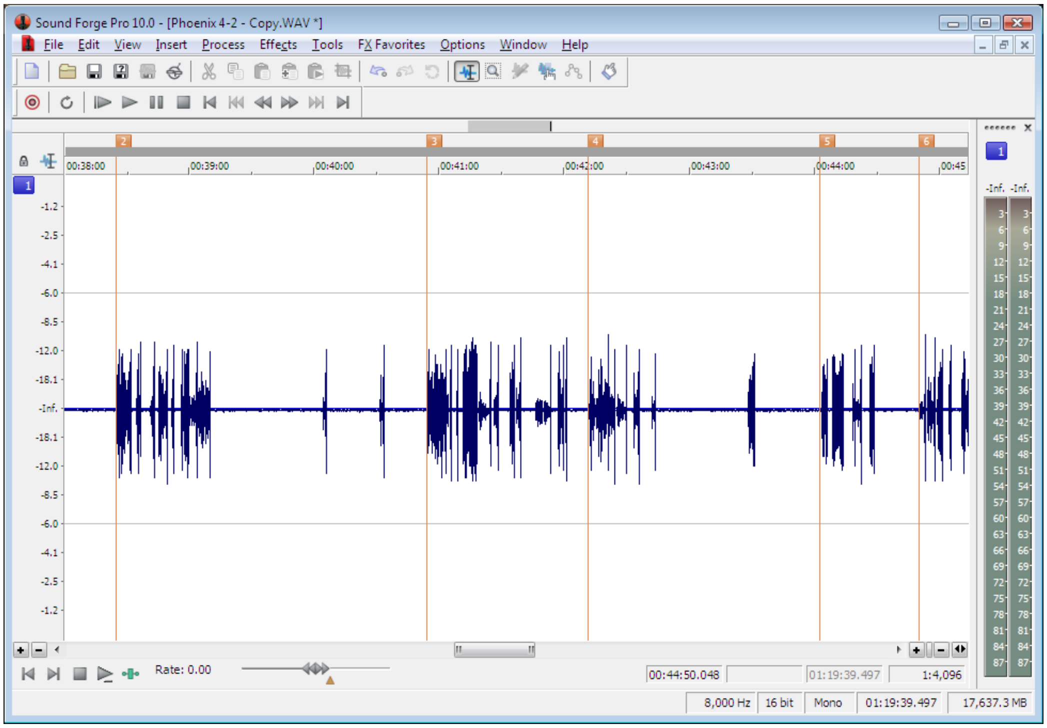

Figure 12 – Sony Sound Forge ®

to further develop consistency in text file processing and convert the file to a text file.

A Mathworks MATrix LABoratory (MATLAB®) program was created to process text files [30,31,32]. The MATLAB® program automated the execution of the Microsoft Word files, read, and processed the text files, stored calculated data to a Microsoft Excel file, performed statistics, and generated a summary report [26]. The resulting report shown in Appendix E is discussed further in Chapter 5.

All of the data fields stored into the Microsoft Excel file were stored into a worksheet consistent for each venue / driver / practice sequence [26]. When all of the text files were run, sixty-one (61) rows containing twenty three (23) fields were stored. Race event practice performance data from NASCAR.com® were added to this worksheet. The table was then uploaded to SAS JMP® for statistical processing [33].

The case study and model validation performed for this dissertation was extremely successful resulting in the following outcomes:

- Collected communications and performance data in a consistent manner.
- Confirmed the contribution of communications through an organized survey among racing experts (as discussed in Chapter 3).
- Confirmed and validated the use of a process model proposed in Chapter 5 for the collection, processing, and reporting of commutations data in a meaningful way.
- Confirmed and validated the use of an algorithm that produces a unique index and a unique concise report to provide meaningful feedback to a NASCAR race team and driver.
- Confirmed the basic hypothesis proposed in this dissertation that performance is influenced by communications (a statistically significant relationship).

- Created additional productivity improvement opportunities in NASCAR
- Facilitated the lean communications model proof-of-concept thus the applicability to other fast-paced working environments.
- Created opportunities for further research in ‘reverse’ speech recognition to potentially automate communications data processing (Chapter 6).

CHAPTER 5

STATISTICAL DATA ANALYSIS AND MODEL

5.1 Discussion

Data and associated statistics collected in the NCWTS case study confirm the hypothesis presented in this dissertation. This confirmation applies to the six (6) drivers studied, including the individual driver of the team sponsoring the case study. Confirmation of the hypothesis establishes the basis for providing a value-added tool to the racing industry, a tool resulting from the other communications models coupled with statistical models designed to characterize and organize the system of collecting, processing, and reporting the data with the ultimate goal of providing meaningful feedback to a fast-paced organizational system. The delivery and effectiveness of communications in a fast-paced environment (working under stress and involving critical decision making) is a challenge as practice and theory suggests. Providing an added layer of productivity feedback in relationship to communications by the use of IE tools speaks to this challenge. To overcome these challenges, a straightforward proposed process model, associated computational mathematics (statistics) and delivery component (dashboard metrics), is proposed.

5.2 Communications Productivity Model

The unique Communications Productivity Model (CPM) developed for this dissertation, as depicted in Figure 14, parallels the survey discussed in Chapter 3 and the process proposed the dissertation proposal. The survey detailed in Chapter 3 focused on three major factors affecting the performance of a race team, namely People (Team – Experience), Equipment, and Communications. As the survey showed, each of these attributes contributes to a certain percentage to the performance of a race team as determined by the number of wins and according to the overall team standings in the NASCAR sanctioned point system. The survey, albeit notional, served only to justify the dissertation hypothesis, not to prove it. Proof of the hypothesis and model validate is determined by the data collected and analyzed in the NCWTS case study.

In order to support the hypothesis that communications is a significant factor contributing to winning races, an investigation into the various communication models used for organizations was launched to evaluate applicability to NASCAR teams. As discussed in Chapter 2, the study of communications is not novel, the literature search determined that while measurements in communications occur in various aspects of industry in a passive sense, most of the models and studies fall short in measuring the quality of what is being said in relation to the performance of acute situations or challenges coupled with providing immediate feedback. This dissertation combines several models in a balance specifically designed for NASCAR teams with the intent of producing a value-added model for the sport. This model is intended to provide meaningful feedback as a means to reduce and eliminate wasteful communications. Meaningful feedback, in turn, provides an incentive to increasing the density of what is being said during critical and important race events. By increasing the density of communications, increases in driver cognition in the interpretation of race car performance can occur, with improved race car set-up accuracy and a significant elimination of errors postulated.

The communications model proposed in this dissertation is a culmination of several models used to study communications (Figure 13). Latent Semantic Analysis (LSA), a method undertaken by New Mexico State University, measures team cognition through communications density (amount of meaningfulness of information per the number of words spoken), lag coherence (measurement of relative information – on topic, repeating information), and automatic tagging (sorting and categorization of information according to a set of codes for the purpose of characterizations) [8]. The model proposed in this dissertation uses the element of communications density for the data analysis.

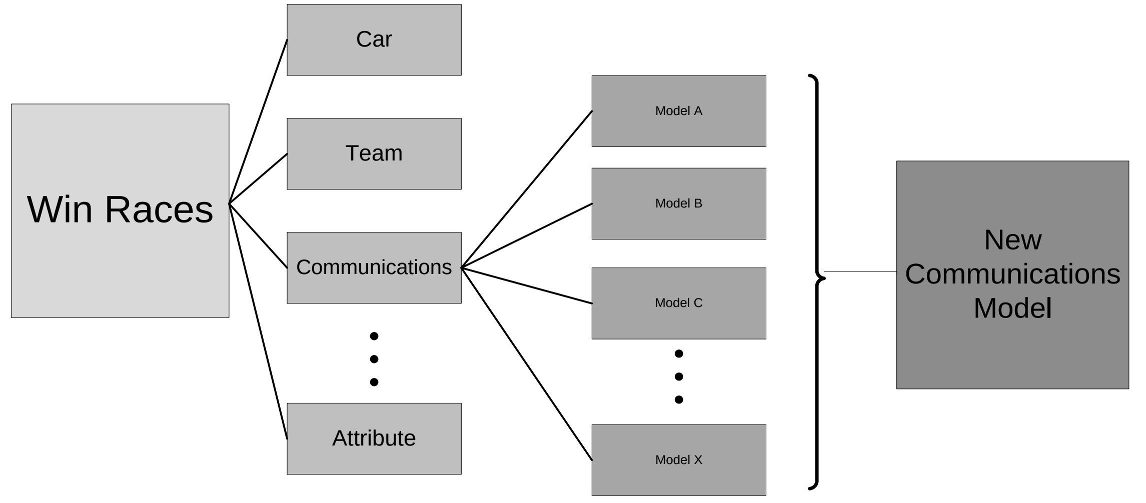

Figure 13 – Communications Contribution to Racing

Communications density is analogous to average velocity where average velocity is calculated as [8]:

$$\boldsymbol{Rate = \frac{Distance}{Time}}$$

thus; communications density is calculated as:

$$\boldsymbol{Density = \frac{Meaningfulness}{Words\ Spoken}}\ .$$

LSA focuses on communications content and flow, but for the model proposed in this dissertation, the latter (flow) is not considered [8]. For the short critical durations of the race events, communications flow is likely not a significant contributor, a postulation which could be considered in future research. LSA methods have been useful in laboratory settings such as studying military reconnaissance missions using team scenarios in the military specifically Predator Unmanned Aerial Vehicles (UAVs). These LSA methods in the military settings generally parallel fast-paced racing settings for measuring communications and have been proven to show the effectiveness of teams and team cognition, justifying the usefulness for this dissertation [8].

Elements of Content Analysis (evaluation of communications content via recorded human communications, keyword frequencies, and determining what is communicated) are utilized in this dissertation model [5]. The lean communications model capitalizes on text analysis tools used in linguistics and World Wide Web (WWW) website effectiveness. In particular, stop words, words with no meaning (notation of "stop words" and "no meaning words" are the same and are used interchangeably in this dissertation), are eliminated to equalize and add density data sensitivity to the each team member's utterance values. A mathematical equation or computational linguistics calculation for gleaning the effectiveness of the communications is created and developed similar to text analysis tools used for gauging text understandability (Automated Readability Index) and readability (Gunning Fog Index) [5,34,35,36].

Merging the elements of the models and theoretical concepts above, the lean communications model variables for racing can be established. These variables are identified below:

- Racing Communications Density = d_x (x is the type of density)
- Key Words = Racing Words (from literature) = rw (Appendix F)
- Stop Words (from literature) = sw (Appendix G)
- Qualitative Words = qw (Appendix H)
- Total Words Uttered = t

The communications density equation in conjunction with the other theoretical text analysis models yields the following fundamental equations as measures of communications for racing:

$$\boldsymbol{d_1} = \frac{\sum \boldsymbol{t} - \sum \boldsymbol{sw} - \sum \boldsymbol{qw}}{\sum \boldsymbol{t}} \boldsymbol{X}\ \mathbf{100}$$

$$\boldsymbol{d_2} = \frac{\sum \boldsymbol{rw}}{\sum \boldsymbol{t}} \boldsymbol{X}\ \mathbf{100}$$

$$\boldsymbol{d_3} = \frac{\sum \boldsymbol{rw}}{\sum \boldsymbol{t} - \sum \boldsymbol{sw}} \boldsymbol{X}\ \mathbf{100}$$

$$\boldsymbol{d_4} = \frac{\sum \boldsymbol{qw}}{\sum \boldsymbol{t}} \boldsymbol{X}\ \mathbf{100}$$

$$\boldsymbol{d_5} = \frac{\sum \boldsymbol{rw}}{\sum \boldsymbol{t} - \sum \boldsymbol{sw}} \boldsymbol{X}\ \mathbf{100}$$

$\boldsymbol{d_1}$ = Overall Density
$\boldsymbol{d_2}$ = Racing Word Density (aggregate)
$\boldsymbol{d_3}$ = Racing Word Density (without stop words)
$\boldsymbol{d_4}$ = Qualitative Word Density (aggregate)
$\boldsymbol{d_5}$ = Qualitative Word Density (without stop words)

Other variations of $\boldsymbol{dx}$ evaluated in the model include reducing the aggregate number of racing and qualitative words to the number of unique words to the total number of words and total number for both $\sum \boldsymbol{t}$ and $\sum \boldsymbol{t} - \sum \boldsymbol{sw}$, respectively.

Team performance (as a dependant variable - $\boldsymbol{p}$) can be measured in a variety of ways. Measuring team performance using the live races during the race event would not be appropriate since the actual race is cluttered with uncertainties resulting from accidents, mechanical breakdowns, and competition thus not an effective reflection of race car set-up performance. Data collected during the actual race would introduce statistical noise and unexplained variation. As discussed in earlier chapters, race car set-up performance is based on initial and practice set-up iterations. Practices as indicated by practice running order value ($\boldsymbol{p}$), are therefore presented as the dependent variable of this research.

Other variables established in the communications analysis model include:

- Driver Utterances = $\boldsymbol{du}$
- Team Utterances = $\boldsymbol{tu}$

From these variables, measures of team-driver imbalances can be evaluated by evaluating the ratio:

$$\boldsymbol{tur = \frac{du}{tu}\ X\ 100\ .}$$

Team utterance ratio ($\boldsymbol{tur}$) provides an indication if the team or the driver is communicating more or less in relation to each other. In theory, since the driver is cognitively interpreting the performance of the race car, the *tur* should be around 1 or more.

Unlike some of the other communications models where data is codified, it was not necessary to codify the transcripts for the mathematical algorithms in the model presented in this dissertation. MATLAB® has features built in to manipulate the transcript text files, thus programming the variables and ratios ($\boldsymbol{t, d_x, rw, qw, sw}$ and $\boldsymbol{tur}$) was efficient, consistent, and accurate. Table 3 describes the numerator and denominator variables computed from the text files using MATLAB®. Ratios (density calculations) of the variables were computed across both total number words **(*TNW*)** and total words without no-meaning words **(*TWwoNM*)**. Once all of the variables and ratios were complied, linear and multiple linear regression models were used to confirm the dissertation's hypothesis.

Table 3 – Parameter Variables Computed from Transcripts

No.	Variable Nomenclature	Definition
1	***TNW***	Total Number of Words (Σt)
2	***TUW***	Total Unique Words (Σtu)
3	***TWwoNM***	Total Words without No Meaning Words ($\sum t-\sum sw$)
4	***RW***	Racing Words (Σrw)
5	***URW***	Unique Racing Words (Σurw)
6	***Dvr***	Driver Number
7	***TeamM***	Team Utterances
8	***Drivers***	Driver Utterances
9	***UQW***	Unique Qualitative Words (Σuqw)
10	***QW***	Qualitative Words (Σqw)

As discussed in Chapter 4, the case study in this dissertation centered on a model to collect, analyze, and report communications data in a value-added means for a NASCAR team. The proposed and validated process model follows the process map shown in Figure 14. Six (6) of the races from the case study followed this process, producing consistent data, processing and reporting. Given the current feedback from the sponsoring team members, the process model and associated report has proven to be robust and sufficient for future communications for a 'dashboard' productivity feedback tool within the racing environment. Race event, data collection, and compiling have been explained in Chapter 4, and the MATLAB® analysis functions of the model are explained in this chapter. The declared name of the "lean" process model in this dissertation is the Communications Productivity Model (CPM).

Subsequent to the development and validation of the CPM, the new model is compared with other communications/team models. Appendix C is a summary of this comparison and as shown, the CPM favors other models evaluated in this dissertation especially measuring real-time data of actual events, rapid feedback, intelligence gathering, displaying an overall statistical index, producing a practical output, and proceduralizing the equipment/process.

5.3 Composite Data Analysis (All Teams)

The sixty-one (61) records (rows) of communications data was collected from six (6) drivers and six (6) race events in the case study. The variables in Table 3, associated ratios, and density calculations were determined, corresponding into twenty-three (23) columns of data for each of the sixty one (61) records. The sixty-one (61) rows by twenty-three (23) columns of data were stored in a MATLAB® matrix. The MATLAB® matrix was transferred to a SAS JMP® statistics package table for further analysis. In addition, each driver's official performance $(\boldsymbol{p})$ ranking for each practice was added to the SAS JMP® file with the performance data obtained from an official NASCAR database.

Given the many variables influencing NASCAR racing, a means of determining the statistical significance of communications relative to performance across all drivers as a composite dataset would be unreasonable and is therefore not be used. The composite data is used as an indication (trend) if communications is influencing performance across all drivers. Driver Number 6, of the team sponsoring the case study, is used to validate the final model since communications is a within team dynamic and influenced by other factors (equipment and people) and these factors could be removed. Holistic measurements across all teams should average out the variably effects of the correlations since each team may have unique "within team" equipment or experience issues. Interpreting multiple drivers' equipment and/or people issues from the audio recordings would be impossible. These factors clearly support developing a communications model for a single team whereby influential factors can be discarded when necessary and the assumption that minor equipment issues would be accounted for thought the variability measurements of the correlated values.

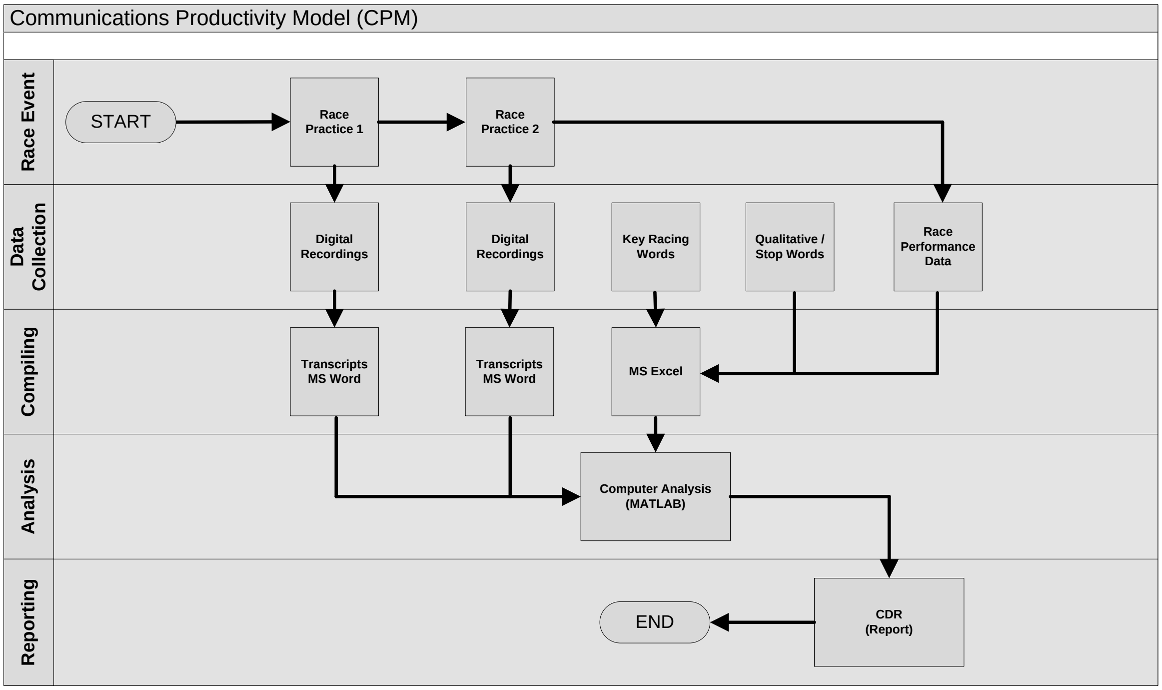

Figure 14 –Communications Productivity Model (CPM)

The holistic view of all six (6) drivers, however, did indicate (broadly) that communications does influence performance in most of the drivers. Regression was used as the statistical basis for the data analyses. Before the final regression model across all of the drivers was developed, diagnostic evaluations were performed to determine outliers and unusual data. The normal plot of p validates the supposition as discussed earlier that the density values of each driver are different and do not follow a normal distribution. While, SAS JMP® provides several means to perform diagnostics and screening to derive at a final model, this analysis was only seeking a trend as an indicator. The variable d_2 (*TWD*) was therefore regressed against p. Normal plots of p and d_2 (*TWD*) were accessed as shown in Appendix I. The normal plot of d_2 (*TWD*) indicated three outliers, and these data were removed from the analysis, thus $n = 58$. The regression model for this data is explained by the following normal error regression model:

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 X_i + \varepsilon_i$$

β_0, β_1, and β_2, represent regression parameters
Y_i is the response variable (p)
X_i are known constants (d_2 and dvr)
ε_i are independent $N(0, \sigma^2)$

Regressing d_2 (*TWD*) and dvr verses p, the results showed a clear negative slope for each driver when evaluating the whole model indicating that for every incremental increase in density there is a commensurate decrease in the value of race position. A driver's race position during practice is best when it approaches 1 or 1st position. The dependent variable (p) is coded in SAS JMP® as ordinal based on "assuming that the effect of the independents is the same for each level of the dependent" as with the case of race track position (p) and (technical racing word) communications density (d_2) [37].

The r^2 for this regression model is ***0.5235*** and the parameter estimates indicate a statistically significant intercept for four (4) out of the six (6) drivers, a statistical significance on the respective parameters are significant at the *95%* confidence level. Two (2) of the drivers parameters were in the positive direction, thus other factors may be influencing performance.

Plotting the residuals verses predicted values (Appendix I) indicates a slope of zero and adequate randomness thus proving linearity of the regression function and consistency of the error variances. Although d_2 (*RW2TWwoNM*) is not significant ($prob > |t| = 0.2219$), other indicators such as the negative regression slope on all six (6) drivers in the whole model, r^2, significance on the intercept, statistical significance on four drivers, and the normality of the residual plots provide sufficient justification that the composite analysis across all drivers support a trend toward communications density as positive contributor to racing performance. Additional analysis to remove “problematic” drivers such as experience and unusually high densities (Driver 3 and 4) did not improve the composite model. In addition, various SAS JMP® non-linear models were tested against the composite data with no improvements in correlations found. Further analysis on the sponsoring team for the case study was performed to confirm significance and the statistical model.

5.4 Data Analysis of the Team Sponsoring the Case Study

A regression model of communications density verses practice performance on Driver Number 6 (team sponsoring the case study) confirms the hypothesis in this dissertation. Before the regression model was developed, a portion of the data was excluded from the regression analysis based on actual knowledge of the sponsoring race team issues. Participating and analyzing the sponsoring team, a clear understanding of unique and abnormal mechanical issues encountered during each practice across the six race event practices were known. At times, mechanical issues can outweigh all other factors during a practice session. When this occurs, it was observed that no level of communications can compensate for an inherent mechanical issue. This can be justified by the survey discussed in Chapter 4 (41.14% of success is influenced by equipment). Driver number 6 had a mechanical issue during the Bristol practice and this data was excluded from the regression analysis. Excluding the Bristol practice reduced $\boldsymbol{n}$ from eleven (11) to nine (9). Reducing the sample size from 11 to 9 did not affect the significance of the test (see below).

After the Bristol data was excluded from SAS JMP®, diagnostic evaluations were performed to determine outliers and unusual data and normal plots of $\boldsymbol{p}$ and $\boldsymbol{d_2}$ and $\boldsymbol{d_3}$ (*TWD* and *RW2TwoNM*) were accessed as shown in Appendix J. The normal plots of $\boldsymbol{d_2}$ and $\boldsymbol{d_3}$ (*TWD* and *RW2TwoNM*) indicate that the Shapiro-Wilk W Test is not significant (*Prob<W*), thus the null hypothesis is accepted where the distribution of the data is

normal. The normal plot for $\boldsymbol{p}$ appears to have some unusual features; however, $\boldsymbol{p}$ is expected to vary with $\boldsymbol{d_2}$ and $\boldsymbol{d_3}$**.** SAS JMPs® screening tool was used to evaluate data and associated effects to assist with which variables to put into the model (Appendix J). As another screening measure, SAS JMP® multivariate analysis of $\boldsymbol{p}$ and $\boldsymbol{d_2}$ (*TWD*) shows that the correlation coefficient (how well the data clusters around the model's regression line) is ***-0.7892***. The closer the correlation coefficient is to one (1), the greater the linearity of the data.

Similar to the regression model for all of the drivers, the regression model for this data is explained by the following:

$$\boldsymbol{Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i}$$

$\boldsymbol{\beta_0}$ and $\boldsymbol{\beta_1}$ represent regression parameters
$\boldsymbol{Y_i}$ is the response variable $(\boldsymbol{p})$
$\boldsymbol{X_i}$ is a known constant $(\boldsymbol{d_2})$
$\boldsymbol{\varepsilon_i}$ are independent $\boldsymbol{N(0, \sigma^2)}$

Regressing $\boldsymbol{d_2}$ (*TWD*) verses $\boldsymbol{p}$, the results showed a clear negative slope and a $\boldsymbol{r^2}$ (coefficient of determination) of ***0.6229***. *P-values* for both the intercept and $\boldsymbol{d_2}$ (TWD) are statistically significant. The *p-value* for $\boldsymbol{d_2}$ (*TWD*) is ***0.0114*** rejecting the null hypothesis at an alpha of *0.05* (*95%* confidence) thus accepting the alternative hypothesis $\boldsymbol{(H_\alpha: \beta \neq 0)}$ that there is a linear relationship between $\boldsymbol{p}$ and $\boldsymbol{d_2}$ (*TWD*). As with the whole model, a negative slope indicates for every incremental increase in density there is a commensurate decrease in the value of race position. The strength of this relationship is very good (robust model) as indicated by the coefficient of determination and coefficient of correlation values. Plotting the residuals verses predicted values (Appendix J) indicate a slope of zero and adequate randomness, thus proving the linearity of the regression function and consistency of the error variances. In addition, the parameter power estimates in Appendix J shows an LSN (Least Significant Number) of **5.9999** whereby this would be the sample size needed to sustain the significance of the parameter estimate at the 0.05 level. In essence, the sample size is sufficient at the current 'slope' and confidence level.

The screening test also indicated constant $\boldsymbol{d_3}$ (*RW2TwoNM*) showed significance with $\boldsymbol{p}$. This model is also included in Appendix J and the $\boldsymbol{r^2}$ for this regression model is ***0.5653***, the parameter estimates indicating a statistically significant intercept. Interpreting the difference between the technical (racing) word density (*TWD*) and racing word to stop words $\boldsymbol{d_3}$ (*RW2TwoNM*) the density values are the percentage of racing words to the total words uttered verses total meaningful words. For any given driver, the amount of no meaning words are a constant proportion of the total utterances, thus $\boldsymbol{d_2}$ (*TWD*) and $\boldsymbol{d_3}$ (*RW2TwoNM*) are linearly correlated. SAS JMP® analysis does show a linear correlation at $\boldsymbol{r^2}$ of ***0.9323***. Since a regression model of $\boldsymbol{p}$ verses $\boldsymbol{d_3}$ (*RW2TwoNM*) is essentially redundant, therefore this model is ignored.

An expected regression model for communications density would be to demonstrate a relationship between $\boldsymbol{p}$ to both (technical) $\boldsymbol{d_2}$ (*TWD*) and (qualitative) $\boldsymbol{d_4}$ (*QWD*). The screening analysis in Appendix J, however did not indicate any significance of $\boldsymbol{d_4}$ (*QWD*) as an independent variable with $\boldsymbol{p}$ or significance when paired with $\boldsymbol{d_2}$ (*TWD*) in a multiple linear regression equation (no interactions applied). Although qualitative utterances should be independent of technical (racing) word utterances, the regression models yielded mixed results. Regressing $\boldsymbol{p}$ verses $\boldsymbol{d_4}$ (*QWD*), the resulting $\boldsymbol{r^2}$ is ***0.3651*** with no significance on the response variable and regressing $\boldsymbol{p}$ verses both $\boldsymbol{d_2}$ (*TWD*) and $\boldsymbol{d_4}$ (*QWD*) as a multiple linear regression model yielded a $\boldsymbol{r^2}$ of ***0.6802***, again with no significance on the response variables. The whole model and leverage plots did indicate an outlier, Phoenix practice number 1. Removing the data for $\boldsymbol{p}$, $\boldsymbol{d_2}$ (*TWD*), and

d_4 (*QWD*), the correlation of determination, r^2 improved with a value of ***0.9346***. The variable d_2 (*TWD*) is significant with a *p-value* of ***0.0018*** and d_4 (*QWD*) that is not significant at ***0.0659***. Although under normal circumstances, d_2 (*TWD*) and d_4 (*QWD*) should be independent as discussed earlier, when d_2 (*TWD*) is correlated with d_4 (*QWD*) some relation exists (not significant) between the two. This may be explained by the finite time allotted to a practice session, thus constraining the total amount of utterances (e.g. if d_2 (*TWD*) must reduce, d_4 (*QWD*), and vice versa). For now, since n is small ($n = 8$), more data may be needed to reaffirm this model.

The robustness of this model is improved by the interaction effects of *TWD* and *QWD*. The effects of predictor variables *TWD* and *QWD* are not additive and can be considered dependent on each other (e.g. as *TWD* goes up, *QWD* should go down during a specific and constrained time frame such as the NASCAR practice session). These qualities justify interacting both TWD and *QWD* in the regression model. When this is performed using $n = 8$ (outlier removed), the model improves to an $r^2 = 0.9682$ and both *TWD* and *QWD* are significant. The significance of these parameter estimates further confirms the hypothesis in this dissertation. See Appendix J.

5.5 Dynamic Productivity Index (DPI)

The results of the regression models confirming a strong correlation between p and d_2 (*TWD*), establish the basis for a productivity feedback component to assist the driver and team. The fast paced NASCAR environment and confined time constraints on practices are not suitable for traditional productivity feedback tools such as control charts and other Statistical Process Control (SPC) measurements to monitor a process. SPC methods are primarily useful in manufacturing environments for process improvement, process parameter estimation, and process capability determinations [5]. In NASCAR racing, productivity feedback requires immediate, meaningful, and rapid feedback or else the data becomes instantly obsolete and/or lost in the fray. Considering these factors, a unique Dynamic Productivity Index (DPI) has been developed to report a measure of performance goal based on recent data and associated variations in past data. Appendix L contains the $\boldsymbol{p}$ verses $\boldsymbol{d_2}$ (*TWD*) regression model in a graphical form. Actual data points are plotted with 95% confidence intervals. The linear equation is shown at the top of the graph. The red line represents the maximum performance achieved in a practice, a position of one (1). Substituting one (1) into the linear equation results in a density value of ***9.114***, thus in theory if Driver 6 has a communications density value of ***9.114***, the driver could achieve a performance of one (1). The variation in the data around the regression line defines the band of the *95%* confidence interval therefore taking into consideration the spread in density values it would be unreasonable to expect a driver to achieve a performance of one (1) at the regressed value of ***9.114***. Considering the supposition that the next practice achieves a $\boldsymbol{p = 5}$ and $\boldsymbol{d_2}$ *(TWD)* = ***10.0***, a density value of ***10.0*** is above the ***9.114***; however, $\boldsymbol{p}$ is not one (1) or less. A $\boldsymbol{d_2}$ *(TWD)* of ***10.0*** appears to be within the *95%* confidence interval.

The dynamics of a racing event does not lend itself to allow the team and drivers to study data and graphics before and between practices. To this end, a meaningful index is derived as a simple measure of current performance and with an “incentive” for future performance. The DPI is intended to provide a meaningful value in terms of words for the team to achieve beyond the last race practice. The DPI uses a combination of regression, averaging, and a productivity improvement factor as an incentive for improved performance. The basis of the DPI is the average of occasions where the density regression line crosses one (1) (perfect performance) of the communications before and after a race event and applying a 20% productivity factor. The density is converted from a percent to a decimal and multiplied by the last practice’s total number of words. This gives a nominal density goal and by subtracting it from the last number of racing words provides a difference in the number or increase to be achieved over the last practice. The DPI is calculated by the following equation:

$$DPI_i = \left(\left(\frac{\left(\left(\frac{\left(\frac{1+\beta 0_{i-1}}{\beta 1_{i-1}}\right)+\left(\frac{1+\beta 0_i}{\beta 1_i}\right)}{2}\right)\right)*1.20}{100}\right)*TW_i\right)-RW_i \quad \text{where } i = \text{last practice.}$$

Given the example above where ***p=5, d*₂** (*TWD*) = ***10.0***, *RW* = ***120*** and *TW* = ***1200***, the DPI is calculated to be

$$DPI_i = \left(\left(\frac{\left(\frac{\frac{(45.84-1)}{4.87}+\frac{(38.89-1)}{3.87}}{2}\right)*1.20}{100}\right)*1200\right)-120 = 16.78 = {\sim}17 \text{ (words)}$$

In this example, ***120*** racing words (*RW*) were spoken out of ***1200*** total words (*TW*) in the last practice. The DPI is calculated to be ***17*** (words) for the next practice. The team can quickly glean the density goal for the next practice. This goal in additional number of words is not necessarily to achieve a number one (1) racing position since there are many other variables to contend with but rather a productivity goal of increasing the communications density based on their past performance. The graphical representation of the regression equations and the intersection of the average are shown in Figure 15. The DPI is reported in the Team Communications Density Report (CDR) (Appendix E) introduced in the next section.

5.6 Team Communications Density Report

Based on practical experience and Organizational Behavior (OB) research related to high risk organizations, implementation of productivity improvement metrics in a NASCAR racing environment during a race would be difficult. A Team Communications Density Report (CDR) (Appendix E) is created to proactively provide the team with a brief and concise measured goal based on the recent communications data and associated

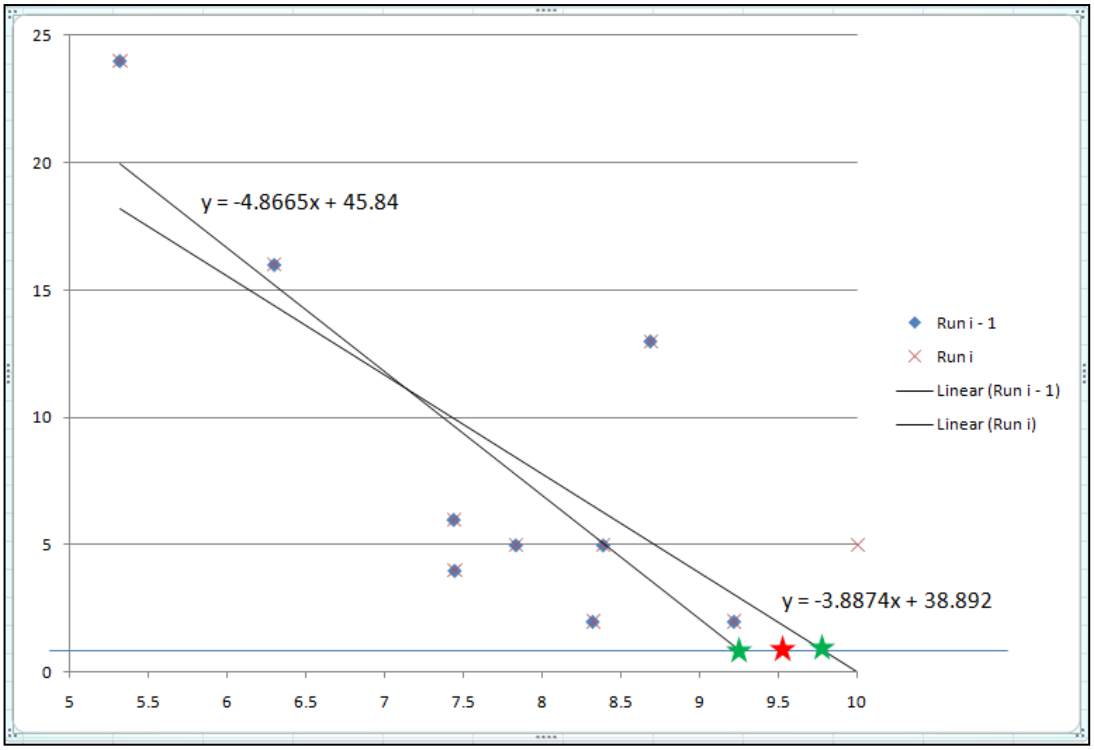

Figure 15 –DPI Graphic

variability. Drivers and team members are constantly reacting to dynamics related to mechanical elements of the race car, race track variations, environmental variations, team personalities, fans, media, sponsors, and team owners. The dynamics during a race event prevent drivers and teams from any active productivity improvement ideas, concepts or metrics. Ironically, team members and drivers, are actually already utilizing elaborate 'mechanical' and 'performance' metrics throughout each race event: metrics inherent to the sport itself which have evolved from necessity and the increasing mechanical technologies associated with the race car (shock compression data, engine performance data, etc.). Although the current metrics are important, they are mostly passive and focus on elements that can be controlled directly.

Given the dynamics and fast-paced environment, proactive and dynamic productivity feedback on productivity elements outside of the mechanical elements of a race team presents enormous opportunities. As discussed earlier, productivity feedback during a race event should be immediate, meaningful, and rapid. Considering this criteria, the final delivery component of the lean communications model is a one page CDR as shown in Appendix E. Details of the graphics in Appendix E can be found in Appendices K and L. The CDR has nine (9) parts or sections as described below:

- Part 1 – Header section stating the race track, driver, and practice number.
- Part 2 – Communications density results (stated in percentages).
- Part 3 – Aggregate word utterances of the practice
- Part 4 – Driver/team communications statistics including the ***tur***
- Part 5 – Pareto analysis of the top five (5) racing and qualitative words
- Part 6 - Pareto analysis of the top ten (10) words overall
- Part 7 – Three-dimensional (mesh) graphic regressing $\boldsymbol{p}$ with $\boldsymbol{d_2}$ (*TWD*) and $\boldsymbol{d_3}$ (*QWD*)
- Part 8 – DPI
- Part 9 – Two-Dimensional graphic regressing $\boldsymbol{p}$ with $\boldsymbol{d_2}$ (*TWD*) with confidence intervals and boundary conditions.

The CDR is important for the various reasons discussed throughout this dissertation. Specifically, the information provided in the sections provides the following insight. The Pareto analysis is relatively self explanatory by providing the type and frequency of the racing and qualitative terms for immediate and historical productivity feedback purposes. In evaluating the top five (5) racing words closely, another important feature is noted. Intelligence can be gleaned on other drivers (if communications density measurements are obtained on other drivers) to determine their race car issues and corrective measures.

The Three-Dimensional (mesh) graphic regressing $\boldsymbol{p}$ with $\mathbf{d_2}$ (*TWD*) and $\mathbf{d_3}$ (*QWD*) is an important metric whereby the assessment made as to how qualitative and racing word densities would optimize performance in visual in nature. In addition to the DPI discussed in Section 5.4, the final two-dimensional graphic also provides the regression model with a visual representation of the confidence intervals, regression line and boundary conditions. The red square around the blue data point signifies the current *TWD*.

As an example, evaluating the attached report, the productivity feedback for the driver is that there are no unusual imbalances between the team and driver utterances ($\boldsymbol{tur > 1}$), the team improved from the last practice (up arrow in the DPI box), communications density is making a contribution to performance (current *TWD* is near regression line), qualitative words should go down (slope of the line in the first graphic), and by increasing technical word density by seventeen (*17*) more words from the last practice could result in performance improvement up to the number one (*1*) position. Higher resolution three-dimensional and two-dimensional plots are provided in Appendices K and L. The CDR is a turn-key html printout from the MATLAB® program discussed in Chapter 4 and represents the final output of the CPM.

CHAPTER 6

AUTOMATED DATA COLLECTION

The pre-processing of audio data into transcripts associated with the case study involves a very labor intensive process. Manual playback of the audio recordings to extract the pertinent dialogue from each of the drivers and team members is time consuming and error prone. Attempts to preprocess the audio data between race event practices in order to provide immediate feedback to the team would be extremely challenging given the tight time constraints set by NASCAR. Although the Communications Productivity Model (CPM) discussed in Chapter 5 is effective, an automated approach would increase the speed of producing the team Communications Density Report (CDR) between race practices.

As discussed in Chapter 4, the audio data obtained during the race events where recorded and stored on standard MP3 recorders. The digital format and sound quality data of these files is described in Table 4. Further research has determined that the quality of these audio files is sufficient enough to analyze using speech processing tools.

Table 4 – Case Study Audio Data Format and Quality Values

Criteria	**Value**
Audio Sample Rate	8,000 kHz
Audio Bit Rate	64 and 128 kps
Audio Bit Depth	16 Bit
Channels	1 (Mono)

Speech processing is the study of speech signals and associated processing methods [5]. Various applications of speech processing exist including Speech Recognition (SR), Speaker Recognition, Speech Coding, Voice Analysis, Speech Synthesis, and Speech Enhancement [5]. Speech processing as a digital application has been in existence for almost 50 years, and many forms of SR applications appear in cell phones, automobiles, and computer applications. SR's general aim is to evaluate the unique linguistic signature of a voice (speech signal) across many frequencies and rates and to process it into a command or to recorded it as text representing the word(s) uttered.

Computer programs and algorithms use various models to process and recognize speech across a wide range of voice inputs. Different frequencies and rate distributions of speech are detected among different sound patterns of people. At times, the same person will have different voice pitch levels, thus complex computer models are needed to account for the variation. In order for computer models to detect speech signals, audio files are converted into mathematical vectors of a decibel spectrum over time (speech sounds at various frequencies) and using complex signal functions such as Fourier transforms, cepstral coefficients, Hamming, Mel Frequency scale Ceptral Coefficients (MFCC), and cosine transformations to decompose and/or normalize the audio data into mathematical functions across different speakers and associated recording environments. Additionally, statistical techniques such as Hidden Markov Models (HMM) are used to compliment the vector transformation/normalizations and compensate for the variation in speakers and associated recording environments. Dynamic Time Warping is another approach whereby a specified word vector is compared to various trained word vector templates [38]. Computer algorithms incrementally compare or align both the specified word and the trained word to find a match [5,38].

However, when aligning traditional SR mathematical models to the application in this dissertation, complex signal transformations may not be necessary. Drivers and team members who are speaking in the recorded audio files are known, thus voice patterns can be extracted directly from existing audio, spoken (trained) before a race event or spoken (trained) during the off-season. Simpler pattern recognition principles and techniques can be used mathematically to categorize input speech vectors and process them into identifiable classes by their features or attributes. Specific keywords and/or key phrases, by the race team members, referred to in this dissertation as Meaningful Speech Clusters (MSCs), which are relevant and of interest can be enrolled in a database as a digital prototype gallery. By means of learning or training, robust classifiers can be developed to detect and segregate the training gallery of MSCs, which can be considered as "word space" into "word areas" allowing computer algorithms to detect the word area of interest in a source speech vector. A computer algorithm (model) can account for the noisiness and direction of linear relationships statistically of the word areas using correlation coefficients. By setting a particular threshold to the correlated data, detection of the MSC to the source speech vector can be achieved. Correlation coefficients are defined by the following equation:

$$\boldsymbol{R}_{(\boldsymbol{i},\boldsymbol{j})}= \frac{\boldsymbol{C}_{(\boldsymbol{i},\boldsymbol{j})}}{\sqrt{\boldsymbol{C}(\boldsymbol{i},\boldsymbol{i})\boldsymbol{C}(\boldsymbol{j},\boldsymbol{j})}}\,.$$

In MATLAB®, the above equation is converted into the following equation and 'corrcoef' command for processing matrix vectors "where a matrix of *p-values* for testing the hypothesis of no correlation." :

$$[\boldsymbol{R},\boldsymbol{P}] = \boldsymbol{corrcoef}(\boldsymbol{x},\boldsymbol{y})\,,$$

"each *p-value* matrix is the probability of getting a correlation as large as the observed value by random chance, when the true correlation is zero [31].“ The *p-value* in this equation defines the threshed of correlation between the base speech vector and the MSC.

To test this theory, a proof-of-concept algorithm was written in MATLAB® against hypothetical base speech vector and four (4) word MSCs. The results of this proof-of-concept were extremely promising. The algorithms were able to detect the MSCs within a known source speech vector and a nominal threshold level. Trails were also made by corrupting the speech signals with white noise. Appendix M contains the outputs of the algorithm.

Automated detection of the MSCs within a source speech vector is equivalent to manually counting words, except some error would be introduced resulting from potential false positive and false negative detections of MSCs within the base speech vector. While for the purpose of productivity feedback, 100% accuracy is not necessary, experimentation to further confirm the proof-of-concept algorithm could involve a statistically controlled experiment to obtain the relevant data to assess the effect of recognition accuracy. Source speech vectors with variable lengths and noise levels would be introduced with the associated MSCs to produce the appropriate word / phase count. Manual counting appropriate word / phases would complement the experiments and determine the accuracy of the algorithms / model.

For the purpose of communication productivity improvements in relation to this dissertation, the new model is called an automated Passive Speech Recognition System (PSRS) as shown in Figure 16. As other organizations and working dynamics could benefit from the PSRS where communications have a moderate or significant role in productivity, the PSRS and proof-of-concept model described in this chapter will continue as future post-doctorial research through further experimentation and/or journal publications.

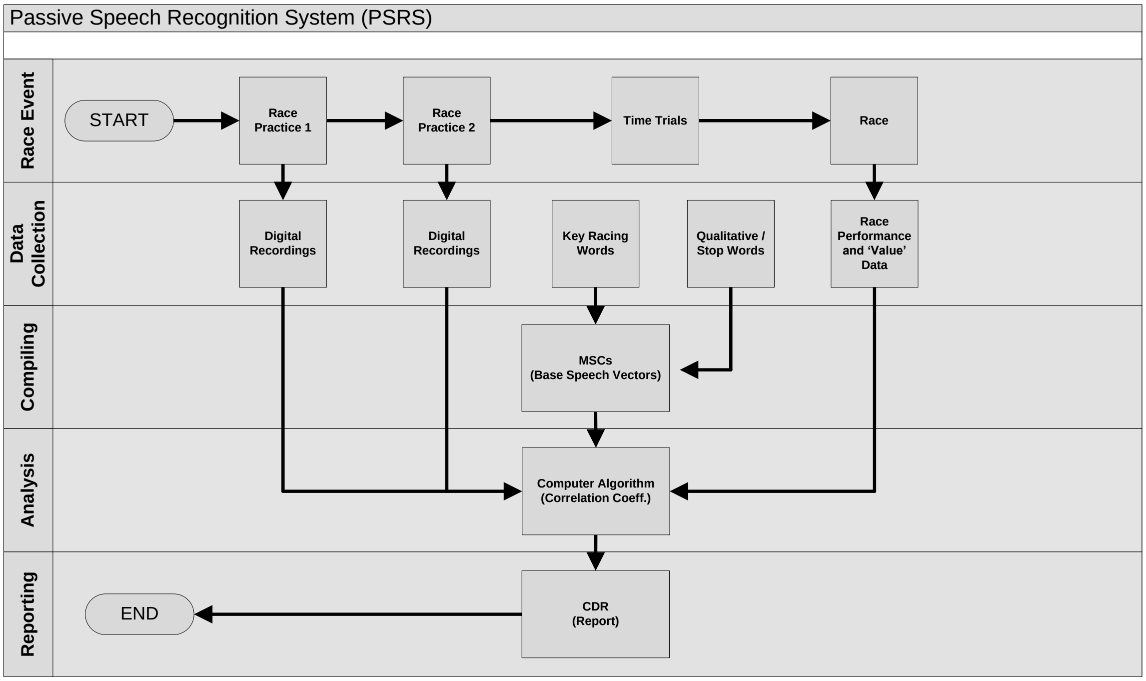

Figure 16 – Passive Speech Recognition System (PSRS)

CHAPTER 7

APPLICATIONS AND RECOMMENDATIONS

7.1 Applications

The Communications Productivity Model (CPM) in this dissertation has the potential to benefit other organizations whereby communications is an important contributor to the outcome. Research is ongoing in formal government and military applications; however, the CPM and associated Communications Density Report (CDR) is geared more toward the real-time commercialized applications of communications. These applications could include other sporting and commercialized venues, such as sail boat racing and the medical field, respectively. Establishing the Passive Speech Recognition System (PSRS) model would furthermore enhance marketability for other applications such as normal organizational meetings whereby communications could be evaluated as a means of evaluating productivity in office environments.

7.2 Recommendations

Studying, analyzing and measuring communications data as an element of waste was well received by NASCAR racing professionals, peers and by the academia supporting this dissertation. In addition to ongoing research to establish a robust PSRS, other actions will be taken as a result of the wide acceptance of “lean communications” coupled with the CPM and CDR. These actions should include (but are not limited to):

- Evaluate potential improvements in communications density as a result of the CDR and Dynamic Productivity Index (DPI) tools by collecting additional data on one NASCAR race team.
- Proceduralize and simplify the CPM and associated computer programs through documentation and compiling, respectively.

- Develop a regimented and documented training program for NASCAR racing as a continuous improvement component to the CPM by standardizing the communications phraseology. From the literature search, teams who use standard phraseology demonstrated improvements in communications, proving more communication is not better; however, "mismatches between expectations and actual communications may be reduced through the standardization of communication sequences [24]." Standardization in phraseology can be achieved through a documented program coupled with training and practice.
- Develop several journal articles from this research. In particular, establish communications as a ninth 9^{th} form of waste within the lean/six sigma academics. In addition, the proof-of-concept work on the Speech Recognition algorithms for the PSRS should be published.
- Evaluate the exclusive rights or potential patents resulting from the concepts pertinent to this dissertation.
- Evaluate other productivity improvement areas for research within the NASCAR racing environment especially during the racing events.

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APPENDICES

Appendix A – Communications Questionnaire Form

Successful performance (winning) in NASCAR racing depends upon many different factors. These factors include, but limited to, good equipment, experienced people including drivers and crew chiefs. What percentage do you think communications (ie chemistry) play into the success of a NASCAR team by completing the following blanks (percentage '%' numbers):

______% Equipment – Engine, Chassis, Car Manufacturer Support

______% Experienced People (Team)

______% Communications (Chemistry)

______% Other (if applicable) ______________________________

100% 100% Total

If your answer for communications above is greater than 0, what percentage would you rate the importance of communications having the following characteristics between the Driver and Crew Chief:

______% Acquaintance Time (amount of time they have known each other)

______% Cognitive Ability (ability to explain mechanically)

______% Years of Experience

______% Relationships (how well the crew chief and driver get along)

100% 100% Total

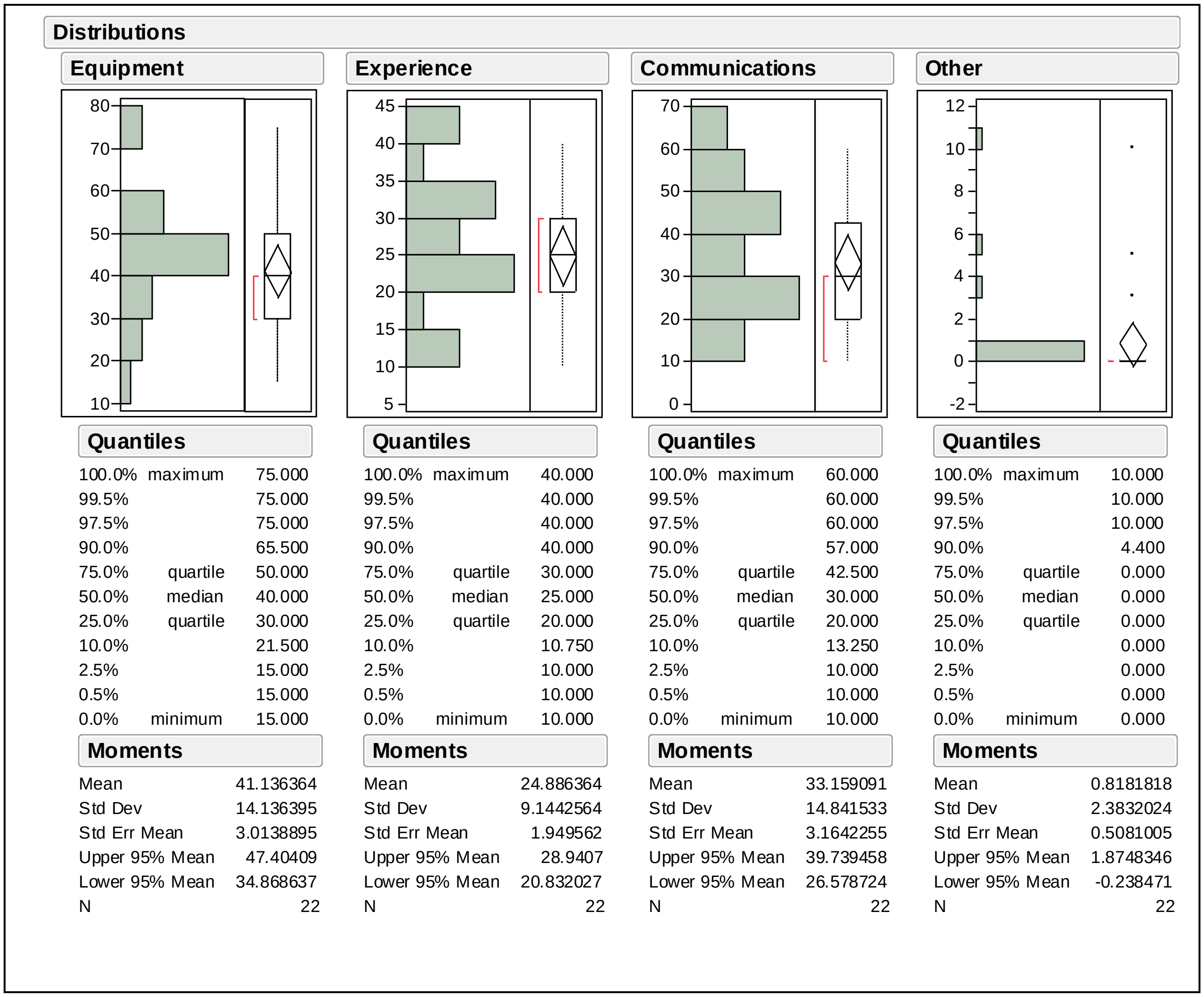
Revision 2, June 29, 2009

The results of this questionnaire will be used as part of a comprehensive doctorial dissertation on communications relative to NASCAR racing. Please return answers to this questionnaire to Joe Stainback:

jstainback@utk.edu
865-719-8923
http://web.utk.edu/~jstainba

Under the provisions of the University of Tennessee's Internal Review Board, respondents will not be identified within the compiled information and all responses to this questionnaire will be destroyed. This is a non-statistical survey to obtain a general indication of how communications contribute to success of a race team. Participants are selected based on their knowledge and experience in NASCAR and it is recognized this knowledge and experience will vary from individual to individual.

Appendix B – Statistical Results from the Communications Survey



Distributions

Equipment

Quantiles

```
100.0%  maximum     75.000
99.5%               75.000
97.5%               75.000
90.0%               65.500
75.0%    quartile   50.000
50.0%    median     40.000
25.0%    quartile   30.000
10.0%               21.500
2.5%                15.000
0.5%                15.000
0.0%     minimum    15.000
```

Moments

```
Mean              41.136364
Std Dev           14.136395
Std Err Mean      3.0138895
Upper 95% Mean     47.40409
Lower 95% Mean    34.868637
N                        22
```

Experience

Quantiles

```
100.0%  maximum     40.000
99.5%               40.000
97.5%               40.000
90.0%               40.000
75.0%    quartile   30.000
50.0%    median     25.000
25.0%    quartile   20.000
10.0%               10.750
2.5%                10.000
0.5%                10.000
0.0%     minimum    10.000
```

Moments

```
Mean              24.886364
Std Dev           9.1442564
Std Err Mean       1.949562
Upper 95% Mean      28.9407
Lower 95% Mean    20.832027
N                        22
```

Communications

Quantiles

```
100.0%  maximum     60.000
99.5%               60.000
97.5%               60.000
90.0%               57.000
75.0%    quartile   42.500
50.0%    median     30.000
25.0%    quartile   20.000
10.0%               13.250
2.5%                10.000
0.5%                10.000
0.0%     minimum    10.000
```

Moments

```
Mean              33.159091
Std Dev           14.841533
Std Err Mean      3.1642255
Upper 95% Mean    39.739458
Lower 95% Mean    26.578724
N                        22
```

Other

Quantiles

```
100.0%  maximum     10.000
99.5%               10.000
97.5%               10.000
90.0%                4.400
75.0%    quartile    0.000
50.0%    median      0.000
25.0%    quartile    0.000
10.0%                0.000
2.5%                 0.000
0.5%                 0.000
0.0%     minimum     0.000
```

Moments

```
Mean              0.8181818
Std Dev           2.3832024
Std Err Mean      0.5081005
Upper 95% Mean    1.8748346
Lower 95% Mean    -0.238471
N                        22
```

Appendix C – Communications Analysis Methods and Models

Method / Model	Performance Prediction	Meaningful Statistics	Qualitative Utterance Measurements	Dominance	Team Interactions	Transcript Density (Content)	Real-Time (Analysis of Actual Event)	Rapid Feedback Mechanism	Intelligence Gathering	Overall Statistical Index	Practical Output	Standardized Equipment / Process	Sequential Flow Analysis
LSA	✓	✓	✓	✓	✓	✓							
FAUCET	✓	✓	✓	✓	✓								✓
TAM		✓	✓					✓		✓			
Process Observations					✓		✓	✓	✓				
CPM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

FAUCET – Flow Analysis of Utterance Communications Events for Teams (Dominance Measurements, Flow Quantity, Flow Sequence (ProNet), stability (CHUMS), flow as a team surrogate)

LSA – Latent Semantic Analysis (Density Measurements, performance score, automatic tagging, lag coherence)

TAM – Text Analysis Methods (Gunning Fog Index, Readability Index, Lexical Density, Average Words per Sentence, Number of Sentences, Word Count, Unique Words)

CPM – Communications Productivity Model (CPM) using a Communications Density Report (CDR) with a Dynamic Productivity Index (DPI)

References [5, 8, 13, 17, 39, 40, 45]

Appendix D – NCWTS Schedule

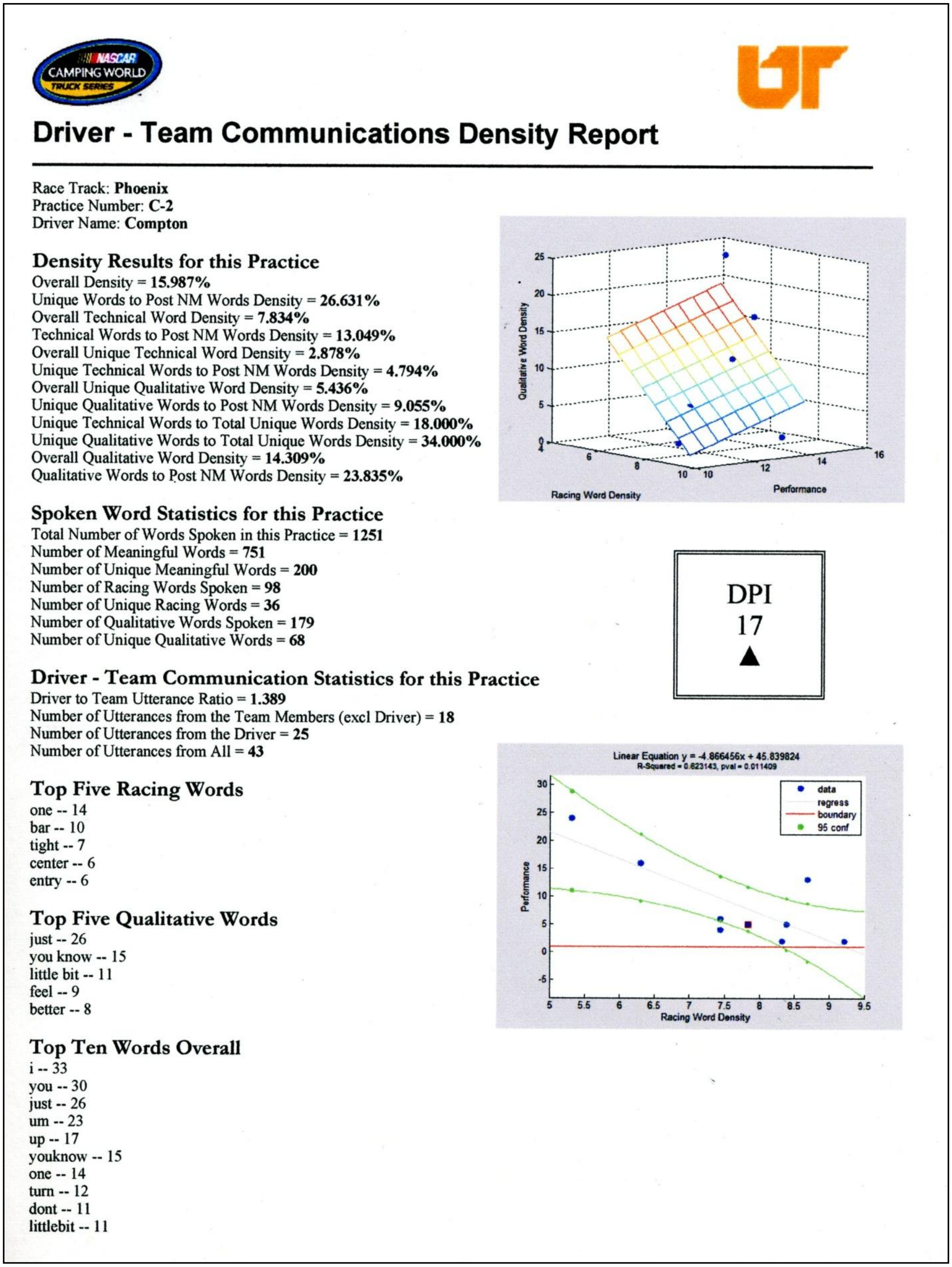
2009 NASCAR CAMPING WORLD TRUCK SERIES

SCHEDULE OF EVENTS

	DATE	RACE/FACIILITY	TV NETWORKS	TV START	RACE START
	Feb 13	***NEXTERA ENERGY RESOURCES 250*** Daytona Int'l Speedway, Daytona Beach, Fla.	SPEED	7:30 PM	8:00 PM
	Feb 21	***SAN BERNARDINO COUNTY 200***, Auto Club Speedway, Los Angeles, Calif.	FOX	3:00 PM	3:00 PM
1	Mar 7	***AMERICAN COMMERICAL LINES 200***, Atlanta Motor Speedway, Atlanta, Ga.	SPEED	1:30 PM	2:00 PM
2	Mar 28	***KROGER 250***, Martinsville Speedway, Martinsville, Va	FOX	2:00 PM	2:00 PM
	Apr 25	***O'REILLY AUTO PARTS 250***, Kansas Speedway, Kansas City, Kan.	SPEED	5:30 PM	6:00 PM
3	May 15	***NORTH CAROLINA EDUCATION LOTTERY 200*** Lowe's Motor Speedway, Charlotte, N.C.	SPEED	7:30 PM	8:00 PM
	May 29	***AAA INSURANCE 200***, Dover International Speedway, Dover, Del.	SPEED	8:00 PM	5:00 PM
	June 5	***WINSTAR WORLD CASINO 400***, Texas Motor Speedway, Ft. Worth, Texas	SPEED	8:30 PM	9:00 PM
	June 13	***MICHIGAN 200***, Michigan Int'l Speedway, Brooklyn, Mich.	SPEED	1:30 PM	2:00 PM
	June 19	***CAMPING WORLD RV SALES 200***, Milwaukee Mile, Milwaukee, Wis	SPEED	8:30 PM	9:00 PM
4	June 27	***NASCAR CAMPING WORLD TRUCK SERIES 200*** Memphis Motorsports Park, Memphis, Tenn	SPEED	5:30 PM	6:00 PM
5	July 18	***BUILT FORD TOUGH 225 presented by the Greater Cincinnati Ford Dealers*** Kentucky Speedway, Sparta, Ky.	SPEED	6:30 PM	7:00 PM
	July 24	***NASCAR CAMPING WORLD TRUCK SERIES 200*** O'Reilly Raceway Park, Indianapolis, Ind.	SPEED	7:30 PM	8:00 PM
6	Aug 1	***TOYOTA TUNDRA 200***, Nashville Superspeedway, Nashville, Tenn.	SPEED	TBD	TBD
7	Aug 19	***O'REILLY 200***, Bristol Motor Speedway, Bristol, Tenn.	SPEED	7:30 PM	8:00 PM
	Aug 28	***CHICAGOLAND 250***, Chicago, Ill	SPEED	8:30 PM	9:00 PM
	Sept 5	***TBA***, Iowa Speedway, Newton, Iowa	SPEED	TBD	TBD
	Sept 12	***CAMPING WORLD 200***, Gateway International Raceway, St Louis, Mo.	SPEED	2:00 PM	2:30 PM
	Sep 19	***NEW HAMPSHIRE 200***, New Hampshire Motor Speedway, Loudon, N.H.	SPEED	2:30 PM	3:00 PM
	Sep 26	***QUIK LINER LAS VEGAS 350***, Las Vegas Motor Speedway, Las Vegas, Nev	SPEED	9:00 PM	9:30 PM
8	Oct 24	***KROGER 200***, Martinsville Speedway, Martinsville, Va.	SPEED	12:30 PM	1:00 PM
9	Oct 31	***MOUTAIN DEW 250***, Talladega Superspeedway, Talladega, Ala	SPEED	3:30 PM	4:00 PM
	Nov 6	***LONE STAR 350k***, Texas Motor Speedway, Fort Worth, Texas	SPEED	8:30 PM	9:00 PM
10	Nov 13	***TBA 150***, Phoenix International Raceway, Phoenix, Ariz.	SPEED	7:30 PM	8:00 PM
	Nov 20	***FORD 200***, Homestead-Miami Speedway, Miami, FL	SPEED	7:30 PM	8:00 PM

All times are EASTERN. Times and date subject to change. Check local listings.

Appendix E – Team Communications Density Report



Driver - Team Communications Density Report

Race Track: **Phoenix**
Practice Number: **C-2**
Driver Name: **Compton**

Density Results for this Practice

Overall Density = **15.987%**
Unique Words to Post NM Words Density = **26.631%**
Overall Technical Word Density = **7.834%**
Technical Words to Post NM Words Density = **13.049%**
Overall Unique Technical Word Density = **2.878%**
Unique Technical Words to Post NM Words Density = **4.794%**
Overall Unique Qualitative Word Density = **5.436%**
Unique Qualitative Words to Post NM Words Density = **9.055%**
Unique Technical Words to Total Unique Words Density = **18.000%**
Unique Qualitative Words to Total Unique Words Density = **34.000%**
Overall Qualitative Word Density = **14.309%**
Qualitative Words to Post NM Words Density = **23.835%**

Spoken Word Statistics for this Practice

Total Number of Words Spoken in this Practice = **1251**
Number of Meaningful Words = **751**
Number of Unique Meaningful Words = **200**
Number of Racing Words Spoken = **98**
Number of Unique Racing Words = **36**
Number of Qualitative Words Spoken = **179**
Number of Unique Qualitative Words = **68**

DPI
17
▲

Driver - Team Communication Statistics for this Practice

Driver to Team Utterance Ratio = **1.389**
Number of Utterances from the Team Members (excl Driver) = **18**
Number of Utterances from the Driver = **25**
Number of Utterances from All = **43**

Top Five Racing Words

one -- 14
bar -- 10
tight -- 7
center -- 6
entry -- 6

Top Five Qualitative Words

just -- 26
you know -- 15
little bit -- 11
feel -- 9
better -- 8

Top Ten Words Overall

i -- 33
you -- 30
just -- 26
um -- 23
up -- 17
youknow -- 15
one -- 14
turn -- 12
dont -- 11
littlebit -- 11

Appendix F – Typical Racing Terms (Words) [41,42,43,44]

- a arms
- ackerman
- aero
- aerodynamic
- aerodynamics
- aeropush
- align
- alignment
- angle
- angle of attack
- antidrive
- antisquat
- apron
- arm angles
- attitude
- back to the gas
- back to the power
- back to the throttle
- balance
- balanced
- ballast
- ball joint
- bar
- bars
- baseline
- bleed
- braking
- brake
- brake bias
- bump steer
- caliper
- camber
- caster
- center in
- center to roll
- centripetal force
- center off
- center of gravity
- chassis
- chatters
- corner
- coil bind
- coil over
- control arm
- control arms
- cowl
- cross weight
- cut
- cutting
- cycle
- dampers
- darted
- dartiness
- darty
- degree
- degrees
- down force
- draft
- drag
- drive off
- entry
- exit
- fan
- fender
- force
- forward bite
- forward drive
- free
- freed
- freer
- friction
- front geometry
- Fronts
- gear
- geometry
- get into the throttle
- grip
- half a round
- halfway
- inch
- indicator
- lap times
- late exit
- lateral force
- lateral speed
- lead
- let off the gas
- let off the power
- let off the throttle
- lift
- line
- load
- load
- loose
- looser
- mass
- middle
- negative
- nose
- over rotating
- over steer
- pitch
- pivot
- plant
- planted
- platform
- points
- positive
- pound
- power
- pressure
- pull bar
- push
- pushes
- pushy
- rear caliper temperature
- rear geometry
- rebound
- roll ability
- roll angle
- roll center
- rolling the center
- roll the center
- rotate
- rotate the center
- round
- rubber
- rubber on the track
- rubbers
- sets
- shock
- shocks
- side bite
- slide the nose
- slip angle
- snap loose
- spinning out
- spinning the tires
- splitter
- spoiler
- spoilers
- spring
- springs
- stagger
- steer
- steering
- suck up
- sway bar
- swing arm
- tach
- technical
- temps
- tie down
- tight
- tighten
- tighter
- throttle
- tire
- tire pressure
- tires
- tire sheet
- tire temperature
- tire wear
- toe
- torque arm
- torsion
- torsion bar
- track conditions
- track setup
- transfer
- transfers
- trioval
- up in the middle
- up off
- valance
- velocity
- wear pins
- wedge
- weight
- wheel
- wheels
- yaw
- yawing

Appendix G – Stop Words [34]

a	able	across	after	all
almost	also	am	among	an
and	any	are	as	at
be	because	been	but	by
can	cannot	could	dear	did
do	does	either	else	ever
every	for	from	get	got
had	has	have	he	her
hers	him	his	how	however
if	in	into	is	it
its	least	let	like	likely
may	me	must	my	neither
no	nor	not	of	off
often	on	only	or	other
our	own	rather	said	say
says	she	should	since	so
some	than	that	the	their
them	then	there	these	they
this	tis	to	twas	us
wants	was	we	were	what
when	where	which	while	who
whom	why	will	with	would
yet	your			

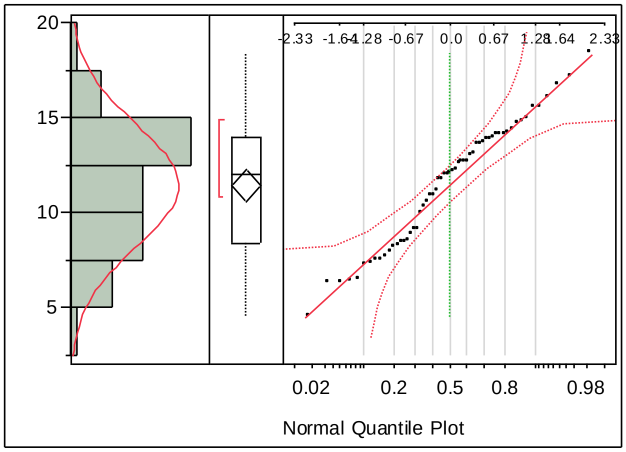
Appendix H – Qualitative Words

about	actually	all the way	a lot	awesome
awful	believe	better	big	bit
bitch	bunch	comfy	crap	damn
darn	decent	definitely	dicing	easy
feel	feels	felt	frickin	fuck
good	guess	gut feel	happy	hell
hurt	hurting	hurt me	I mean	just
killing me	kinda	little	little bit	lots
maybe	might	more	mostly	much
pretty	probably	quite a bit	real	screwed
screwing	seem	seems	shit	smidgen
snap	snaps	sorta	sort of	struggle
struggles	struggling	stuff	super	tendencies
tendency	tends	terrible	think	tick
tiny	ton	too	twitchy	ugly
way	way down	way up	weird	wiggled
wonderability	you know			

Appendix I – Composite Team Statistics

Distributions

RW2TWwoNM



Normal(11.4614,3.22264)

Quantiles

100.0%	maximum	18.390
99.5%		18.390
97.5%		17.806
90.0%		15.520
75.0%	quartile	13.968
50.0%	median	12.035
25.0%	quartile	8.438
10.0%		7.124
2.5%		5.364
0.5%		4.490
0.0%	minimum	4.490

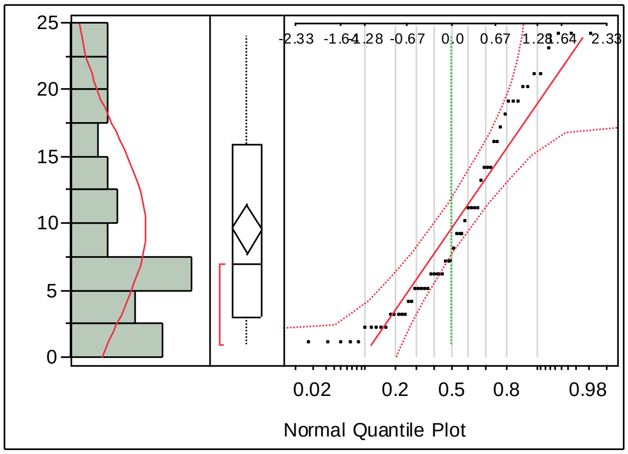
Moments

Mean	11.461379
Std Dev	3.2226356
Std Err Mean	0.4231528
Upper 95% Mean	12.308728
Lower 95% Mean	10.61403
N	58

Fitted Normal

Distributions

P



Normal(9.63793,7.20793)

Quantiles

100.0%	maximum	24.000
99.5%		24.000
97.5%		24.000
90.0%		21.000
75.0%	quartile	16.000
50.0%	median	7.000
25.0%	quartile	3.000
10.0%		1.900
2.5%		1.000
0.5%		1.000
0.0%	minimum	1.000

Moments

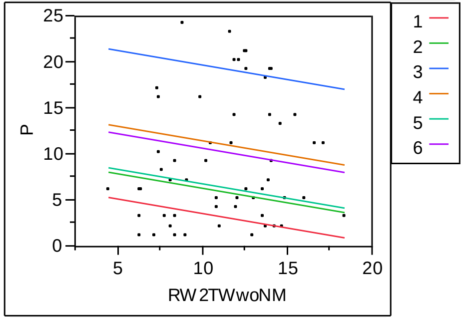
Mean	9.637931
Std Dev	7.2079349
Std Err Mean	0.9464482
Upper 95% Mean	11.533161
Lower 95% Mean	7.7427012
N	58

Fitted Normal

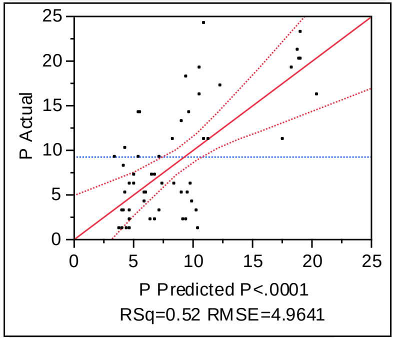
Appendix I – Composite Team Statistics

Whole Model

Regression Plot



Actual by Predicted Plot



Summary of Fit

RSquare	0.523522
RSquare Adj	0.465177
Root Mean Square Error	4.964067
Mean of Response	9.125
Observations (or Sum Wgts)	56

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	6	1326.6691	221.112	8.9730
Error	49	1207.4559	24.642	**Prob > F**
C. Total	55	2534.1250		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
				0.1757
Lack Of Fit	48	1079.4559	22.489	**Prob > F**
Pure Error	1	128.0000	128.000	0.9790
Total Error	49	1207.4559		**Max RSq**
				0.9495

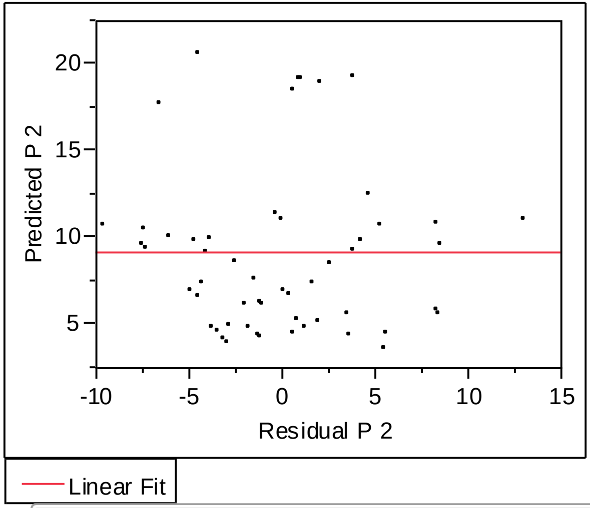
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.902588	2.966655	4.35	<.0001*
RW2TWwoNM	-0.314144	0.253911	-1.24	0.2219
Dvr[1]	-6.178028	1.720321	-3.59	0.0008*
Dvr[2]	-3.453671	1.395192	-2.48	0.0168*
Dvr[3]	9.9479996	1.541236	6.45	<.0001*
Dvr[4]	1.7453694	1.682151	1.04	0.3046
Dvr[5]	-2.945567	1.582984	-1.86	0.0688

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
RW2TWwoNM	1	1	37.7197	1.5307	0.2219
Dvr	5	5	1265.4141	10.2704	<.0001*

Bivariate Fit of Predicted P 2 By Residual P 2



Linear Fit

Predicted P 2 = 9.125 - 1.376e-16*Residual P 2

Summary of Fit

RSquare	0
RSquare Adj	-0.01852
Root Mean Square Error	4.956606
Mean of Response	9.125
Observations (or Sum Wgts)	56

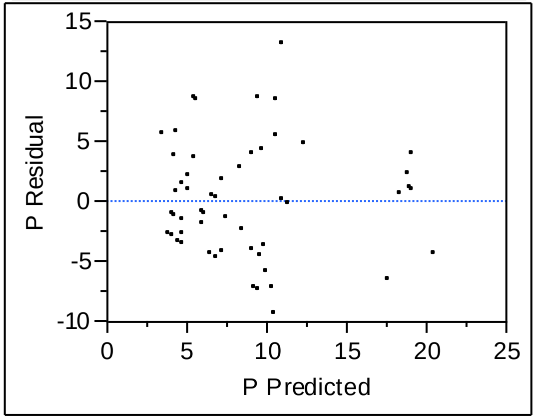
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.0000	0.0000	0.0000
Error	54	1326.6691	24.5679	**Prob > F**
C. Total	55	1326.6691		1.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.125	0.662354	13.78	<.0001*
Residual P 2	-1.38e-16	0.142642	-0.00	1.0000

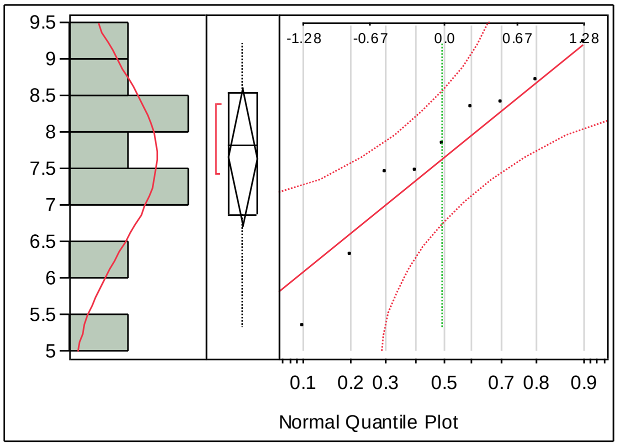
Residual by Predicted Plot



Appendix J – Driver 6 Statistics

Distributions

TWD



Normal(7.66222,1.22012)

Quantiles

100.0%	maximum	9.2200
99.5%		9.2200
97.5%		9.2200
90.0%		9.2200
75.0%	quartile	8.5400
50.0%	median	7.8300
25.0%	quartile	6.8700
10.0%		5.3200
2.5%		5.3200
0.5%		5.3200
0.0%	minimum	5.3200

Moments

Mean	7.6622222
Std Dev	1.2201207
Std Err Mean	0.4067069
Upper 95% Mean	8.60009
Lower 95% Mean	6.7243545
N	9

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	7.6622222	6.7243545	8.60009
Dispersion	s	1.2201207	0.8241391	2.3374716

-2log(Likelihood) = 28.1219893143788

Goodness-of-Fit Test

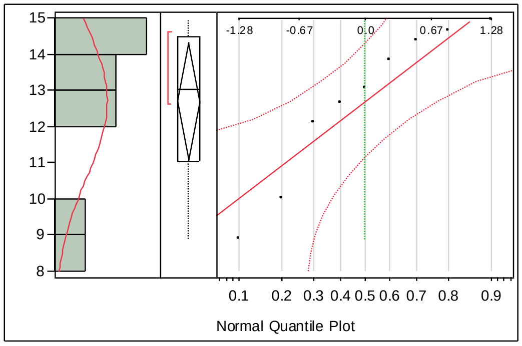
Shapiro-Wilk W Test

W	Prob<W
0.937723	0.5581

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Distributions

RW2TWwoNM



Normal(12.7067,2.09805)

Quantiles

100.0%	maximum	14.940
99.5%		14.940
97.5%		14.940
90.0%		14.940
75.0%	quartile	14.495
50.0%	median	13.050
25.0%	quartile	11.030
10.0%		8.880
2.5%		8.880
0.5%		8.880
0.0%	minimum	8.880

Moments

Mean	12.706667
Std Dev	2.0980527
Std Err Mean	0.6993509
Upper 95% Mean	14.319373
Lower 95% Mean	11.093961
N	9

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	12.706667	11.093961	14.319373
Dispersion	s	2.0980527	1.4171444	4.0193882

-2log(Likelihood) = 37.8790666465976

Goodness-of-Fit Test

Shapiro-Wilk W Test

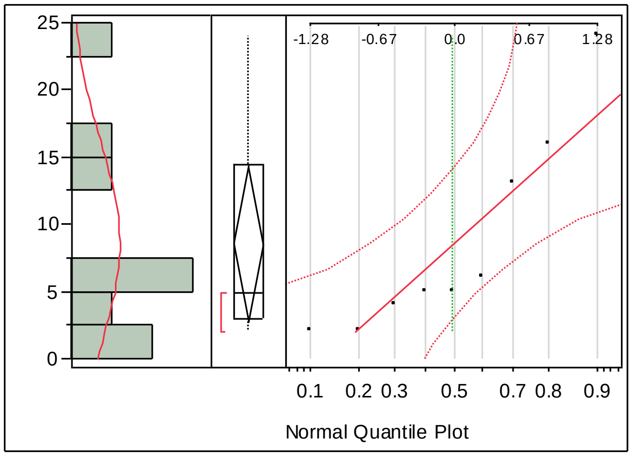
W	Prob<W
0.902868	0.2691

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Appendix J – Driver 6 Statistics

Distributions

P



Normal(8.55556,7.5185)

Quantiles

100.0%	maximum	24.000
99.5%		24.000
97.5%		24.000
90.0%		24.000
75.0%	quartile	14.500
50.0%	median	5.000
25.0%	quartile	3.000
10.0%		2.000
2.5%		2.000
0.5%		2.000
0.0%	minimum	2.000

Moments

Mean	8.5555556
Std Dev	7.5184957
Std Err Mean	2.5061652
Upper 95% Mean	14.334783
Lower 95% Mean	2.7763282
N	9

Fitted Normal

Parameter Estimates

Type	**Parameter**	**Estimate**	**Lower 95%**	**Upper 95%**
Location	μ	8.5555556	2.7763282	14.334783
Dispersion	s	7.5184957	5.0784208	14.403715

-2log(Likelihood) = 60.8534830324694

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	**Prob<W**
0.829600	0.0442*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Appendix J – Driver 6 Statistics

Multivariate

Correlations

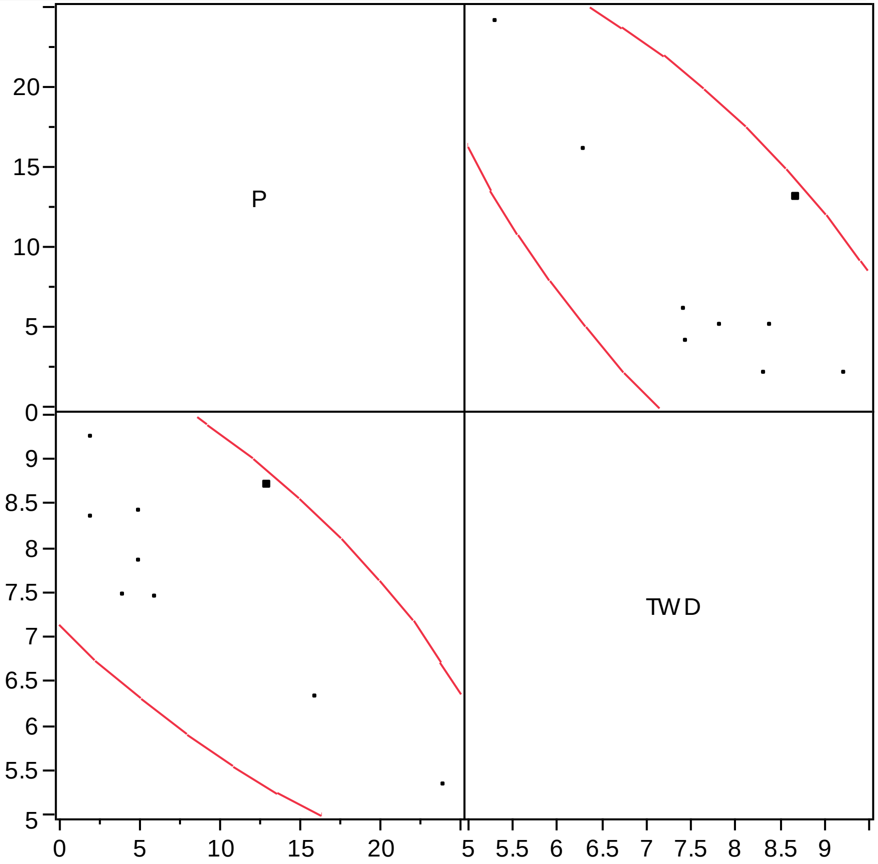
	P	TWD
P	1.0000	-0.7892
TWD	-0.7892	1.0000

The correlations are estimated by REML method.

CI of Correlation

Variable	by Variable	Correlation	Lower 95%	Upper 95%
TWD	P	-0.7892	-0.9600	-0.1906

Scatterplot Matrix

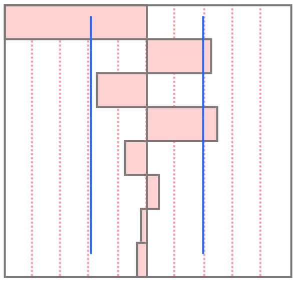


Appendix J – Driver 6 Statistics

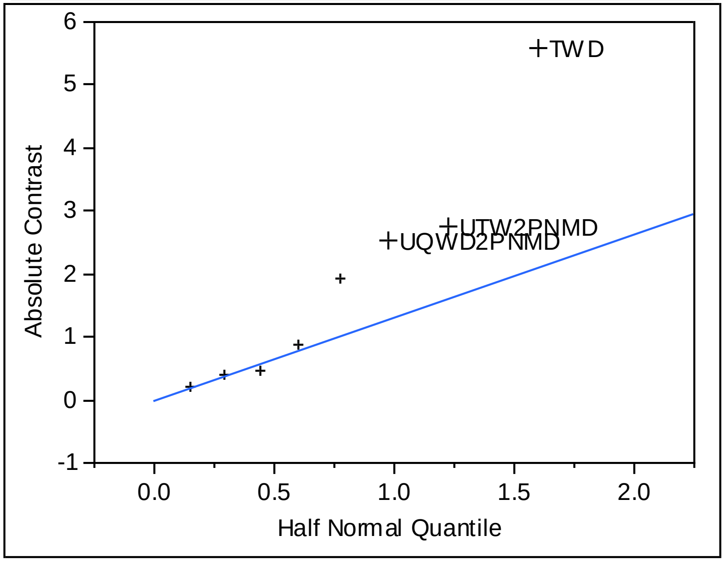
Screening for P

Contrasts

Term	Contrast	Lenth t-Ratio	Individual p-Value	Simultaneous p-Value
TWD	-5.59458	-4.27	0.0093*	0.0650
UQWD2PNMD	2.52414	1.93	0.0665	0.3583
UQWD	-1.92742	-1.47	0.1327	0.6368
UTW2PNMD	2.76980	2.11	0.0512	0.2825
UTWD	-0.87340	-0.67	0.5081	1.0000
QWD2TWwoNM	0.47557	0.36	0.7560	1.0000
OD	-0.20554	-0.16	0.8927	1.0000
RW2TWwoNM	-0.39784	-0.30	0.7936	1.0000



Half Normal Plot



Lenth PSE=1.3101

P-Values derived from a simulation of 10000 Lenth t ratios.

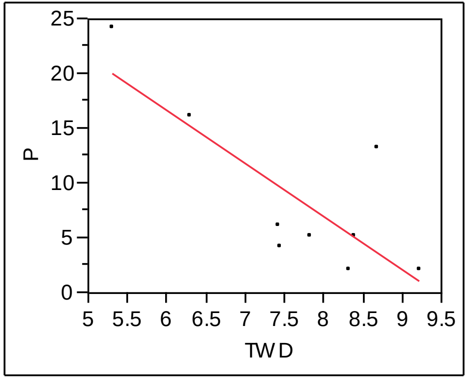
Supersaturated main effects--bias will make p-values too small.

Appendix J – Driver 6 Statistics

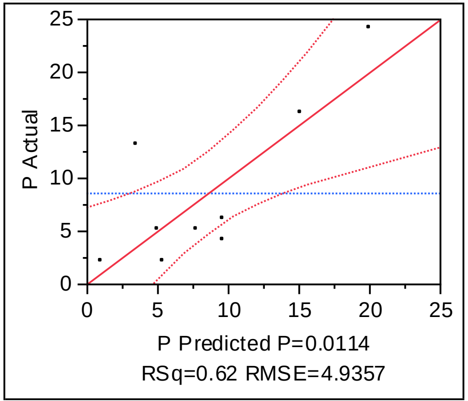
Response P

Whole Model

Regression Plot



Actual by Predicted Plot



Summary of Fit

RSquare	0.622911
RSquare Adj	0.569042
Root Mean Square Error	4.935698
Mean of Response	8.555556
Observations (or Sum Wgts)	9

Analysis of Variance

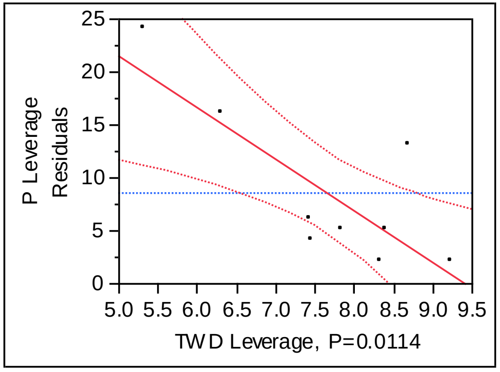
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	281.69440	281.694	11.5633
Error	7	170.52782	24.361	**Prob > F**
C. Total	8	452.22222		0.0114*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	45.820122	11.08142	4.13	0.0044*
TWD	-4.863415	1.430213	-3.40	0.0114*

TWD

Leverage Plot



Parameter Estimates

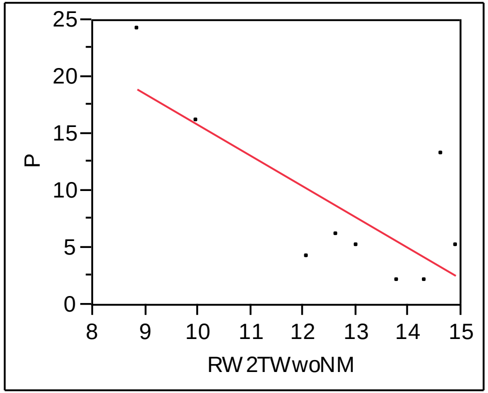
Term	Estimate	Std Error	t Ratio	Prob>|t|	LSV.05	LSN.05	AdjPower.05
Intercept	45.820122	11.08142	4.13	0.0044*	26.20341	5.1147	0.8180
TWD	-4.863415	1.430213	-3.40	0.0114*	3.381917	5.9999	0.6394

Appendix J – Driver 6 Statistics

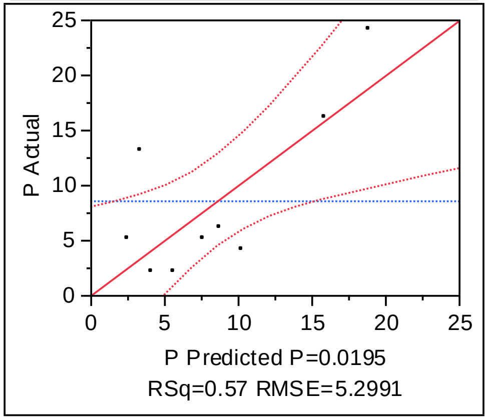
Response P

Whole Model

Regression Plot



Actual by Predicted Plot



Summary of Fit

RSquare	0.565334
RSquare Adj	0.503239
Root Mean Square Error	5.299132
Mean of Response	8.555556
Observations (or Sum Wgts)	9

Analysis of Variance

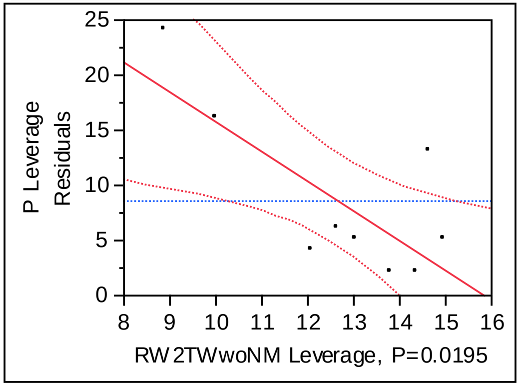
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	1	255.65666	255.657	9.1043
Error	7	196.56556	28.081	**Prob > F**
C. Total	8	452.22222		0.0195*

Parameter Estimates

Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	42.792801	11.4835	3.73	0.0074*
RW2TWwoNM	-2.694432	0.892983	-3.02	0.0195*

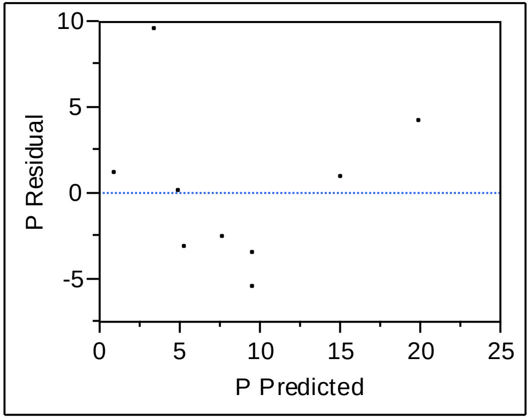
RW2TWwoNM

Leverage Plot

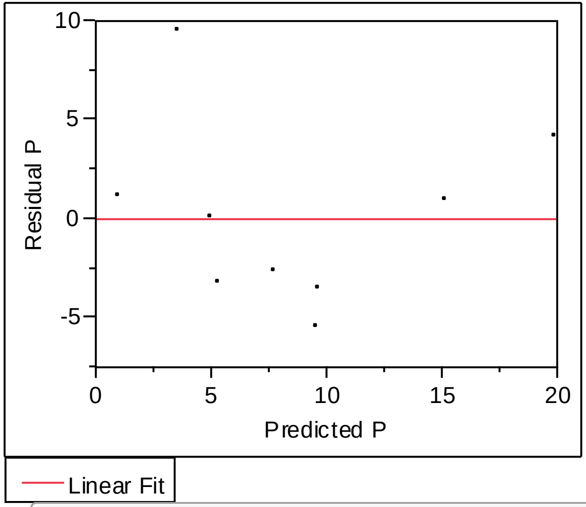


Appendix J – Driver 6 Statistics

Residual by Predicted Plot



Bivariate Fit of Residual P By Predicted P



Linear Fit

Residual P = 5.364e-15 - 2.578e-16*Predicted P

Summary of Fit

RSquare	0
RSquare Adj	-0.14286
Root Mean Square Error	4.935698
Mean of Response	3.16e-15
Observations (or Sum Wgts)	9

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	0.00000	0.0000	0.0000
Error	7	170.52782	24.3611	**Prob > F**
C. Total	8	170.52782		1.0000

Parameter Estimates

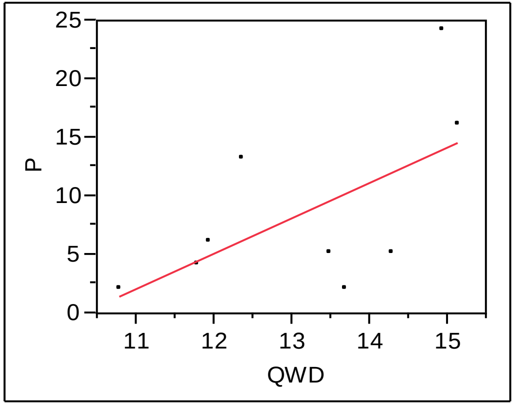
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.364e-15	3.006154	0.00	1.0000
Predicted P	-2.58e-16	0.294076	-0.00	1.0000

Appendix J– Driver 6 Statistics

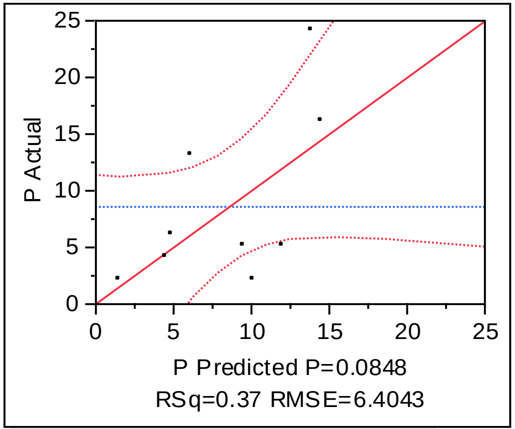
Response P

Whole Model

Regression Plot



Actual by Predicted Plot



Summary of Fit

RSquare	0.36513
RSquare Adj	0.274434
Root Mean Square Error	6.404265
Mean of Response	8.555556
Observations (or Sum Wgts)	9

Analysis of Variance

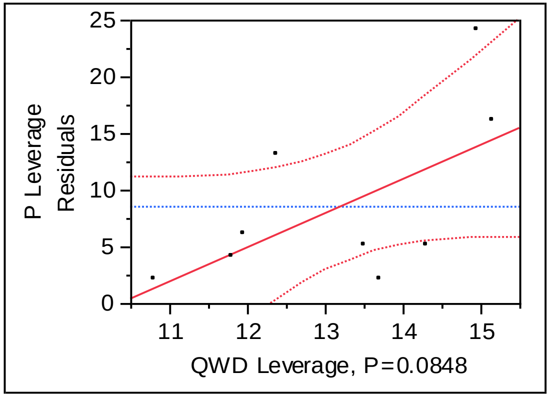
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	165.11995	165.120	4.0259
Error	7	287.10227	41.015	**Prob > F**
C. Total	8	452.22222		0.0848

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-30.89008	19.77488	-1.56	0.1622
QWD	2.9948602	1.492609	2.01	0.0848

QWD

Leverage Plot

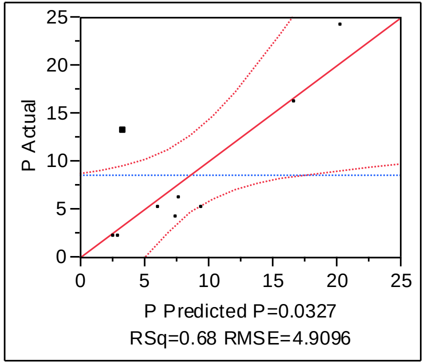


Appendix J – Driver 6 Statistics

Response P

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.680195
RSquare Adj	0.573594
Root Mean Square Error	4.909561
Mean of Response	8.555556
Observations (or Sum Wgts)	9

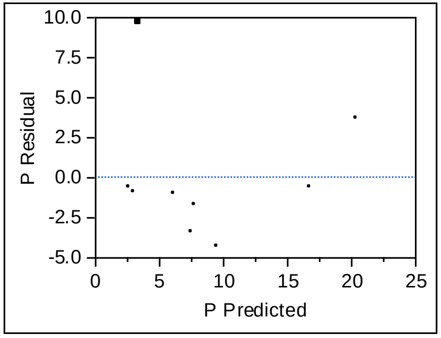
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	307.59948	153.800	6.3807
Error	6	144.62274	24.104	**Prob > F**
C. Total	8	452.22222		0.0327*

Parameter Estimates

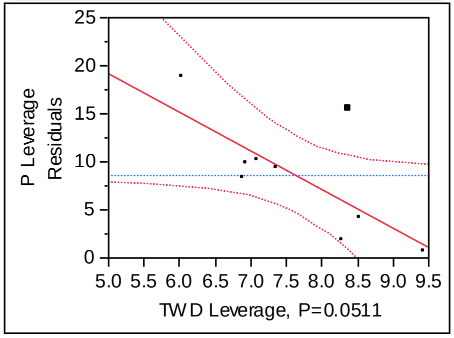
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	21.147355	26.22818	0.81	0.4508
TWD	-4.003643	1.646728	-2.43	0.0511
QWD	1.3730808	1.324483	1.04	0.3398

Residual by Predicted Plot



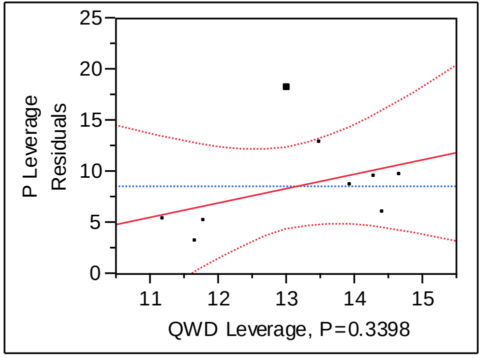
TWD

Leverage Plot



QWD

Leverage Plot

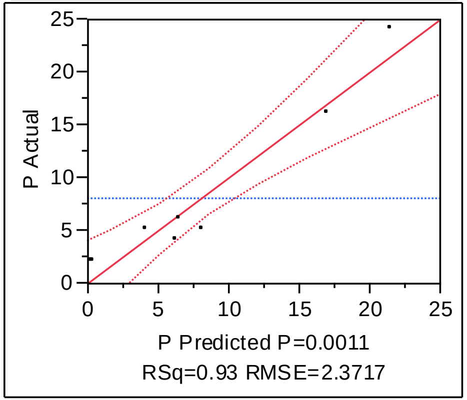


Appendix J – Driver 6 Statistics

Response P

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.934595
RSquare Adj	0.908433
Root Mean Square Error	2.37167
Mean of Response	8
Observations (or Sum Wgts)	8

Analysis of Variance

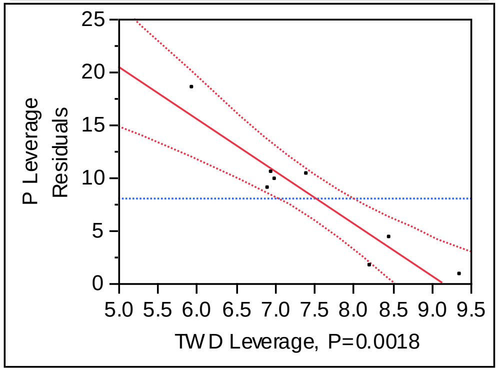
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	401.87590	200.938	35.7234
Error	5	28.12410	5.625	**Prob > F**
C. Total	7	430.00000		0.0011*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	25.461132	12.7055	2.00	0.1014
TWD	-4.964737	0.823043	-6.03	0.0018*
QWD	1.502785	0.640455	2.35	0.0659

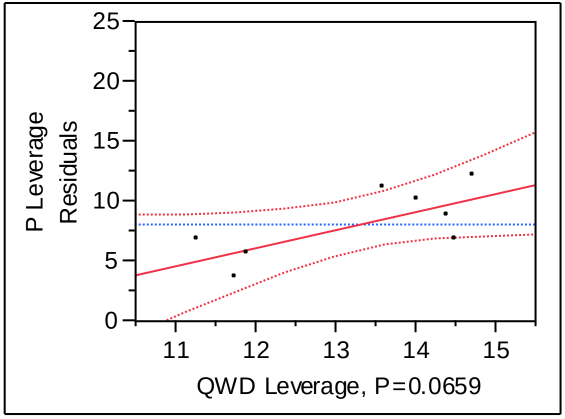
TWD

Leverage Plot



QWD

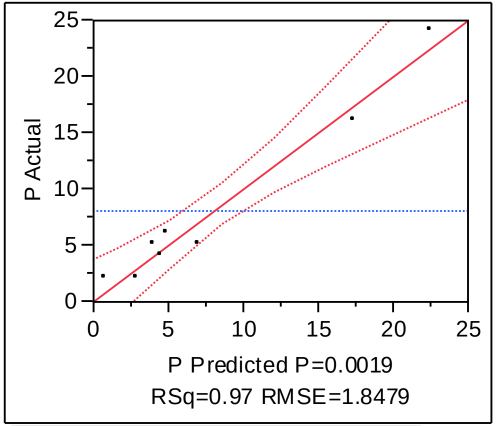
Leverage Plot



Appendix J – Driver 6 Statistics

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.968234
RSquare Adj	0.94441
Root Mean Square Error	1.847929
Mean of Response	8
Observations (or Sum Wgts)	8

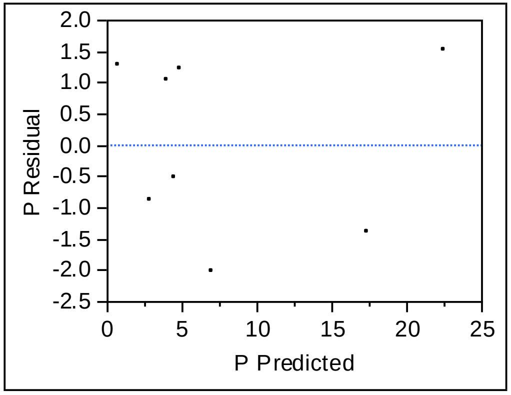
Analysis of Variance

		Sum of		
Source	**DF**	**Squares**	**Mean Square**	**F Ratio**
Model	3	416.34063	138.780	40.6403
Error	4	13.65937	3.415	**Prob > F**
C. Total	7	430.00000		0.0019*

Parameter Estimates

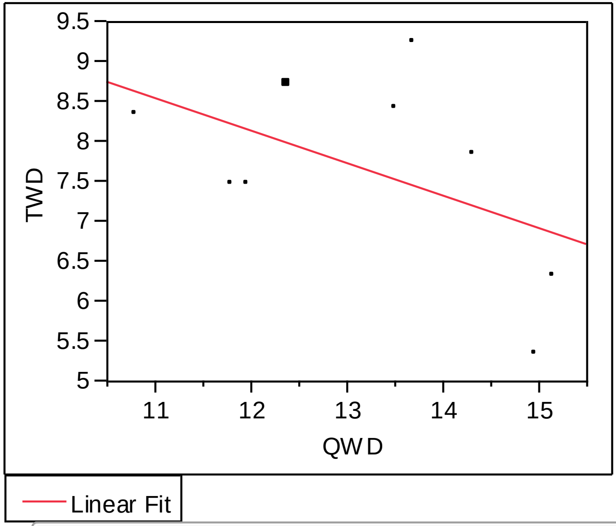
Term	**Estimate**	**Std Error**	**t Ratio**	**Prob>|t|**
Intercept	10.89809	12.16852	0.90	0.4211
TWD	-3.405377	0.992625	-3.43	0.0265*
QWD	1.6261863	0.502611	3.24	0.0318*
(QWD-13.27)*(TWD-7.53375)	-1.440012	0.699675	-2.06	0.1087

Residual by Predicted Plot



Appendix J – Driver 6 Statistics

Bivariate Fit of TWD By QWD



Linear Fit

TWD = 12.997523 - 0.405076* QWD

Summary of Fit

RSquare	0.253644
RSquare Adj	0.147021
Root Mean Square Error	1.126865
Mean of Response	7.662222
Observations (or Sum Wgts)	9

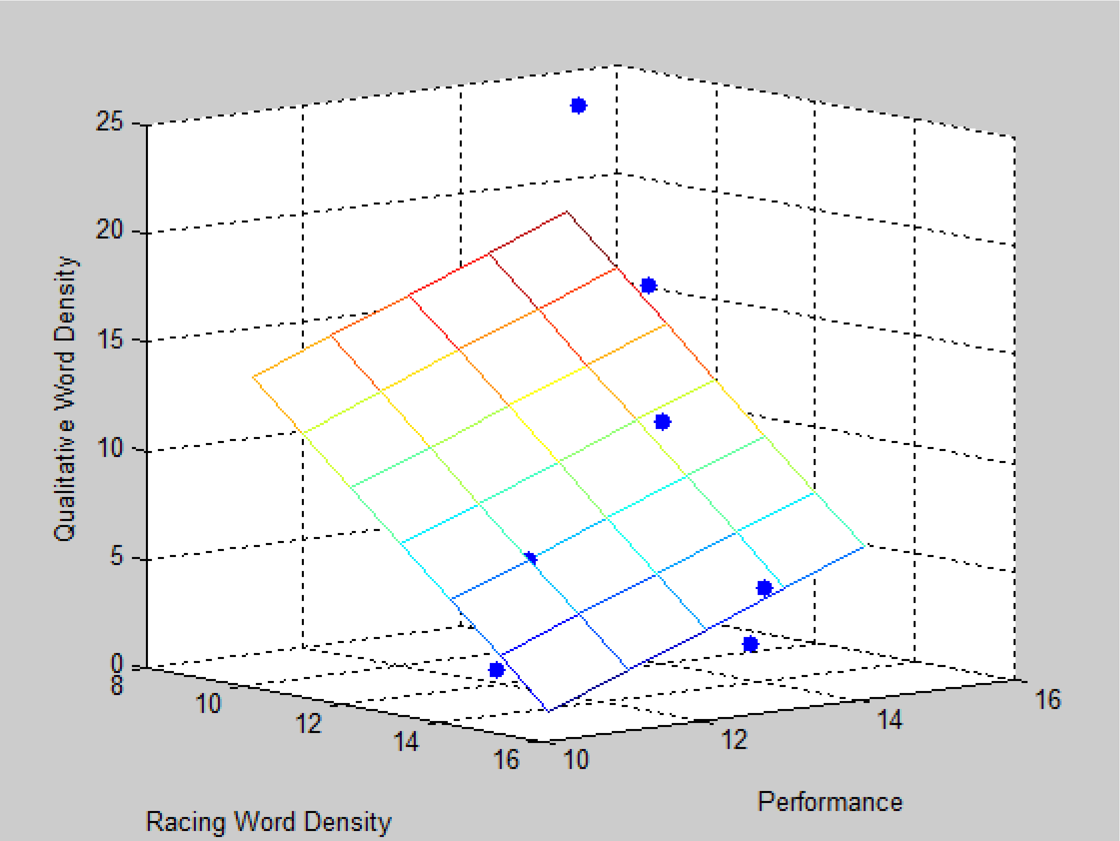
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3.020782	3.02078	2.3789
Error	7	8.888774	1.26982	**Prob > F**
C. Total	8	11.909556		0.1669

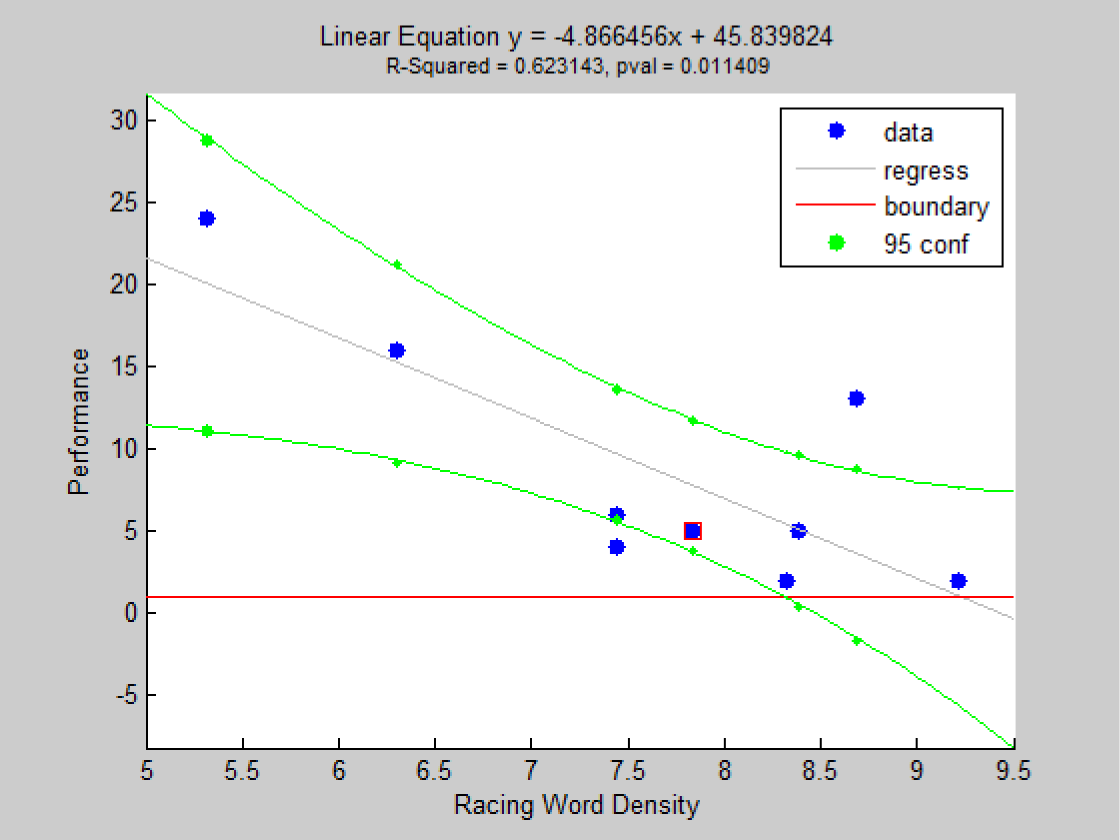
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.997523	3.479498	3.74	0.0073*
QWD	-0.405076	0.262633	-1.54	0.1669

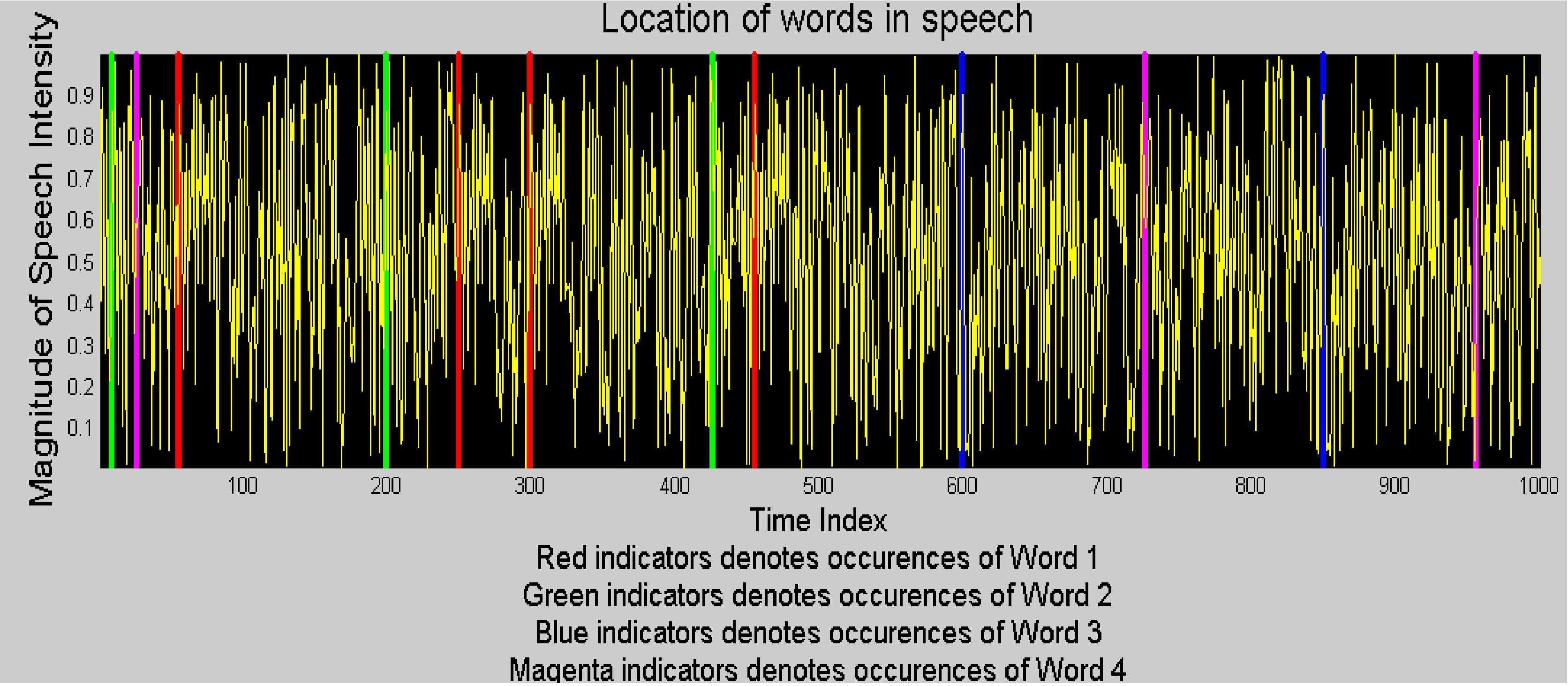
Appendix K – Three-Dimensional Graphic for the Team Communications Report



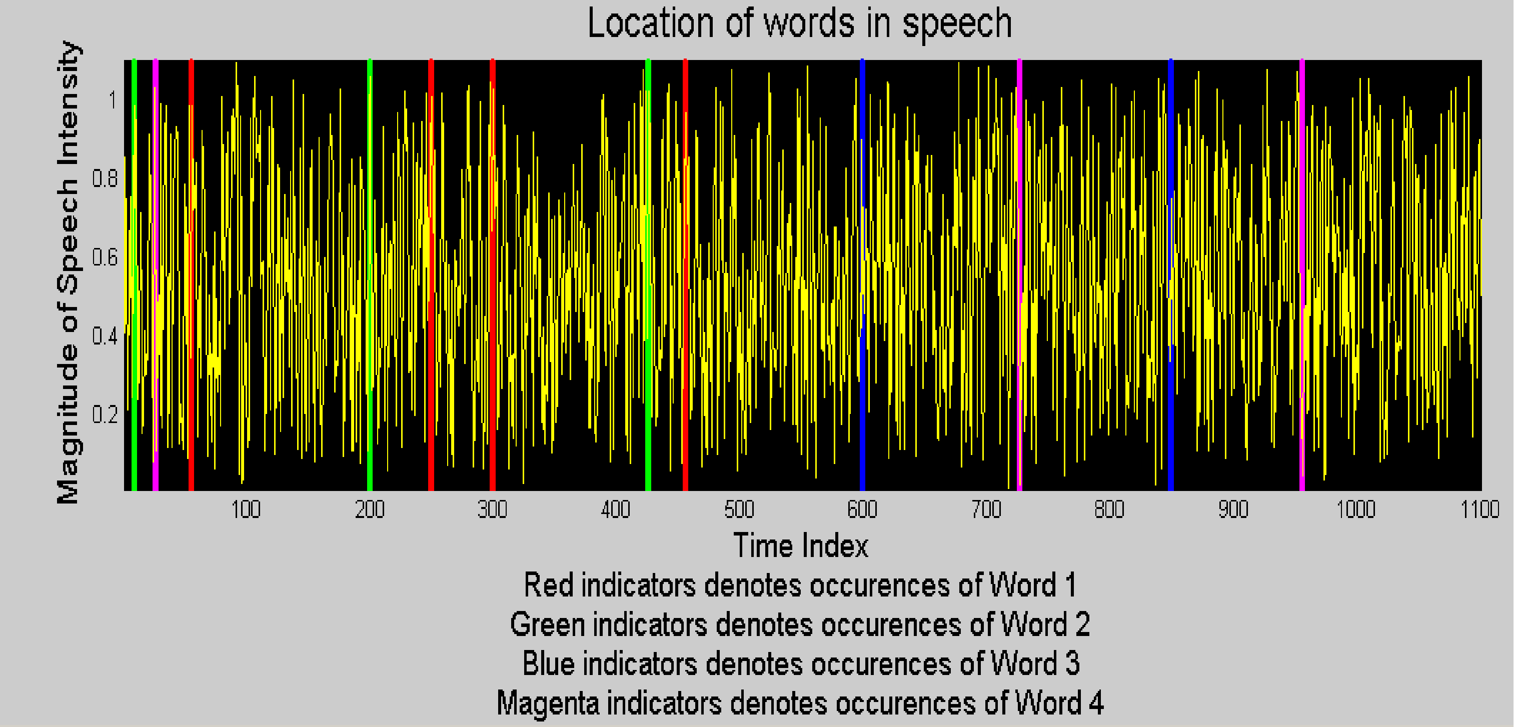
Appendix L – One-Dimensional Graphic for the Team Communications Report



Appendix M – Automated PSRS Data Output



Appendix M – Automated PSRS Data Output (with Artificially Induced Noise)



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JOSEPH RURIC STAINBACK, IV

Vita

Joe Stainback was born in Richmond, Virginia in 1961 and considers Richmond his hometown. Joe has two children, Lauran Rae Stainback and Joseph Ruric Stainback, V (Ruric). He enjoys Golf, NASCAR Racing, Astronomy, Writing, and Drawing.

Joe graduated from Manchester High School in Richmond, Virginia in 1980 and holds a Bachelor of Science Degree in Mechanical Engineering Technology from Old Dominion University, Norfolk, Virginia, awarded in 1984. After starting his career, Joe continued his education and earned a Masters degree in Engineering Administration from George Washington University, Washington, DC in 1987.

Joe is a member of the Institute of Industrial Engineers, Institute of Nuclear Materials Management, Navy League and several local community boards.

Joe's career began immediately following college in 1984 at the Babcock & Wilcox (B&W), Nuclear Operations Division in Lynchburg, Virginia. Joe worked 15 years within the Engineering Department of B&W holding various engineering and management positions supporting important United States Government programs. In the early 1990's, Joe had the opportunity to work on Space Reactor designs and the New Production Reactor (Particle Bed) for Tritium production. In 1996, Joe accepted an assignment within the Nuclear Materials Control Department within Safeguards and Security at B&W to implement the International Atomic Energy Agency (IAEA) inspections for the "Sapphire" Down-blending Project. Joe's unique and solid relationship with key US Government officials provided this opportunity to coordinate the implementation of the IAEA into a tightly controlled national defense facility. Under this assignment, Joe had the opportunity to be exposed to Nuclear Materials Accountability, Physical Security and new programs involving down-blending of Highly Enriched Uranium (HEU).

In 1998, Joe was asked to lead a Project to build large manufacturing facility and laboratory. Joe oversaw the conceptual design, design, construction and turnover of this $10 million dollar project into production. The project was constructed within cost and schedule while meeting strict Nuclear Regulatory Commission and Department of Energy requirements. Joe was asked to continue his project management role after 9/11 coordinating additional construction projects totaling $15 million dollars. Joe received personal accolades from the National Nuclear Security Administration (NNSA) for these achievements. Joe transferred to the Y-12 National Security Complex in 2004 and has held various Management positions and responsible for several significant transformation projects earning him four (4) NNSA Defense Program awards of Excellence.