NEW APPROACH FOR MINIMIZING HUMAN ERRORS IN HOSPITAL OPERATING ROOMS BY USING RFID ALERTING SYSTEMS

by

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ABSTRACT

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Patient safety is an increasing concern in health care due to the fact the increasing number of medical errors. Most fatal medical errors happen in hospital operating rooms. This research proposes a unique approach that decreases medical errors in hospital operating rooms using an RFID-based technology to alert doctors and nurses when the wrong tool enters to the operating area, via text message.

Radio frequency identification (RFID) is a portion of a new growth in the information era where items equipped with chips that can process data automatically will progressively become an essential part of everyday life. RFID permeates through many fields such as healthcare, warehouses, toll way systems, retailers, post services, security systems, tracking, supply chain management, library management, automobile industry and so on and so forth (Ayoade, 2007). This research focuses on healthcare systems, specifically operation rooms at the hospitals and provides an approach to increase the reliability of patients by using an RFID alerting system. By applying Design For Six Sigma (DFSSR) methodology this research proposes a unique approach that decreases medical errors in hospital operating rooms using an RFID-based technology to alert doctors and nurses when the wrong tool enters to the operating area.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure Page

LIST OF TABLES

CHAPTER 1

INTRODUCTION

According to institute of medicine (Kohn L. T., 2000) statistics about 44,000 to 98,000 people lost their lives from medical errors each year in United States. These medical errors charge United States to spend up to 17 to 29 billion dollars. Each year the number of deaths caused by medical errors makes it fall among the top ten reasons of death, which is higher than traffic accident, Human immunodeficiency virus (HIV), breast cancer or traffic accidents. Among all of these medical errors, surgery errors after drug related errors, is one of the most common errors that causes deaths. By enhancing the operating room (OR) environment through improved management, employee communication, medical process check and data transmission can raise the patient care (Po-Jen Chen, 2009).

This research proposes a new approach to decrease medical errors in order to prevent mistakes and build a reliable environment for patients in hospital operating rooms. The innovation of this research is using automatic technology that could directly communicate with the charge nurse who is responsible for all equipment that is needed for surgery to alert him/her about the wrong tools that enter the operating room. Design For Six Sigma Research (DFSSR) methodology is used for this research. This methodology has three main phases, which are Plan, Predict and Perform (3 P’s).

This research follows the given format: Chapter 1 presents the introduction, Chapter 2 provides relative definitions, background and literature review with respect to the research, Chapter 3 presents the approach and data collection technique, Chapter 4 presents data and results concerning the functionality of the approach and Chapter 5 discusses the conclusions.

The research question for this study is: Can text messaging be automated for hospital operations reliably and effectively? The overall objective of this research is: Can Radio Frequency Identification (RFID) and alerting technologies reduce the amount of fatal errors in the operating room? The goal is to evaluate a methodology that measures parameters, which determine reliability and effectiveness of automated texting technologies.

The first Specific Aim for this research is to evaluate the reliability and effectiveness of manual texting in hospital operations. The second Specific Aim is to evaluate the performance of the automated texting with RFID based technology. The third Specific Aim is to evaluate the manual texting versus auto texting technology.

CHAPTER 2

BACKGROUND

2.1 RFID and Patient Safety in Healthcare

This subsection develops background literature of using RFID in hospitals and also describes some existing alert systems that inform doctors and nurses in critical situations.

The first step in literature review is to look for pros and cons of implementing RFID-based technology in hospitals. Chiara Borea, Giovanni Miragliotta, Pala, Perego and Tumino (2011) propose a generic model that intends to increase the overall information regarding the possible profits that RFID technologies produce if implemented in a healthcare setting. Then they deliver managers working in healthcare services with effective equipment for the analysis and evaluation of investments in RFID technologies.

While most of the existing studies focus on demonstrating how RFID can benefit the healthcare industry, S. L. Ting, S. K. Kwok, Albert, Tsang and Lee (2009) focus on management problems associated with building an RFID scheme in medical associations. By employing a case study approach, they provide a practical structure to implement RFID-based technology in hospitals. As a result they propose 11-step development methodology for adopting an RFID system in a medical association, which are: information gathering, hardware selection, new system introduction, system design, system demo testing, security and permission setup, implementation, document policies and procedure setting, staff training, system monitoring and finally celebration.

After implementing RFID-based technology in hospitals, it is necessary to employ a reliable alert system both for equipment and patients. Min Chen, Sergio Gonzalez, Leung, Zhang and Li (2010) propose a second-generation RFID-Sys-based e-healthcare system that could alert the hospital in critical situations about the patient physiological signals. In this system the medical situations of a patient can be checked as recognized by the corresponding healthcare system, and afterward updated in the database by a Wi-Fi connection, a cellular phone, or something alike depending on the patient's position. For instance, a Zigbee-enabled (also recognized as IEEE 802.15.4) WBAN can easily send the patient's physiological signals to a cellular phone, which can in turn send this with GPS report to trace the patient in an emergency condition as required.

While the previous example was about alerting hospital for critical situation of patient, Paul Nagy, Ivan George, Bernstein, Caban (2006) propose an RFID-based system that more focuses on assets and equipment in hospitals. They develop five categories of equipment that should be tagged in operating rooms, which are: two intravenous poles, infusion pumps, operating table accessories, specialty patient monitoring cables and all most expensive and mission-critical possessions such as endoscopes, various retractor sets, crash/resuscitation carts, C-arms, bronchoscopes, transthoracic, transesophageal echo machines and so on and so forth. They also classify patient safety concerns in the preoperative settings into three parts, which are: right patient wrong treatment, right patient no treatment and unknown patient undetermined resource. In first classification, which is right patient wrong treatment, they point to the system that could look for dangerous co-location problems and make appropriate alerts.

Since our research is based on RFID technology we focused more on researches that employed RFID but there are some other alerting systems that are not based on RFID, for example David Alan Heck, Kathryn Rapala and Canada (2006) invented an alerting system for hospitals in order to enhance the patients' safety. This patent includes an output device, which incudes a computer monitor and bunch of indicators. Each indicator is presenting one of a plurality of indicator states, a red octagon, a yellow triangle and a green circle. This system could be linked to one or more other systems and receive data required for numerous status lists from those other systems. Because all of the indicators for an environment are exhibited on a single monitor, the operator can easily access the patient status regarding to the environment. This patent acts more like an active checklist that could partially avoid human errors.

One of the practical studies that considers most aspects of implementing RFID-based technology in operating rooms is proposed by Po-Jen Chen, Yung-Fu Chai and Huang (2009). The structure of their proposed system is based on an Ethernet communication framework with a sub-network allocated to the operating room to link individual workstations. This system is called “operation room management” (ORM), and it will scan it’s environment to identify if any non-allowed staffs have entered or if any prohibited medical supplies and drugs have been located in the OR. The system will alert or warn if any unexpected events have happened. This system has five steps as follow: 1.) Gathering all essential information from the patient. 2.) Entering an account and password to confirm the pre-surgery process has been completed. 3.) Checking patient identification, in this step, as soon as the patient arrives at the operating room the system will detect the patient and at the specific amount of time if the surgeon has not yet arrived the OR, the system will notice him/her by sending a text message to his/her cellular phone. 4.) The anesthesiologists have to confirm whether the surgical agreement has been signed before anesthesia. If the surgeons have not yet arrived into the operating room, a text message will be sent to notify that the anesthesia has been completed. 5.) If the patient has to be observed or examined in the recovery room, the system can automatically identify the patient with the entering time and departure time being recorded.

While most studies focus on one type of RFID technology either passive or active, Michael Kranzfelder, Dorit Zywitza, Jell and Schneider (2012) propose a model that applied both technologies. They employed passive tags to track surgical sponges and active tags to monitor surgeons. Their main objective was to develop a model to avoid retaining surgical sponges inside of the patients' body. There is an alerting interface that monitors the passive tags and shows the number of missing sponges. Results indicate that by using a flat antenna, the chance of retaining surgical sponges inside of a patients' body will significantly decrease.

2.2 Texting in Healthcare Environment

The next subject that needs to be described in the background review is about using cellphones in operating rooms by doctors. Many people think that doctors do not use their cellphones during the operation or even in a hospital environment but a questionnaire based survey of doctors from all specialties (A G Kidd, 2004) shows that 66% of doctors admitted to using it in the hospital and 64% admitted to leaving their cellphones on in 'high risk' areas such as operating rooms.

Based on Healthcare Internet Conference in Las Vegas, some novel projects being executed by several hospitals. One of these projects owned by Owen DeWitt of Las Colinas Medical Center in Irving, Texas. He is director of marketing for this hospital, and he desired to be able to deliver text message updates to family members waiting for news about a loved one having surgery. In this project a nurse in the operating room sends a text message to the family of the patients in order to aware them about the status of their patients. (AASE, 2009).

One other research about using text message in healthcare system evaluates the effect of a short messaging system for following up between surgeons and patients after surgery. This study considers the following factors for the research: telephone calls, number of clinic visits and days to surgical drain removal. Retrospective review identified 102 procedure-matched patients who underwent breast reconstruction for an oncologic diagnosis. They compare two groups of patient with the same conditions as follow: age group, gender, procedure, weight and complication of the procedure. Results show that clinic follow up for the clinic that used texting was one third less than the other clinic. The perspective of this study was not on cost analysis but it is necessary to mention that clinic follow up visits patients are free for three month. The clinic visits were limited to wound issues or complications, which was 20% for both groups (Rao R, 2012).

Good Samaritan Hospital and Regional Medical Center of San Jose in northern California are the first ones that equipped their emergency room wait times accessible to the public through text message. Users just text “ER” to specific number from a cell phone and reply with their position (zip code) to receive up-to-date wait times. This technology links computer systems in the ER with the texting abilities of cell phones and lets the users aware about the exact time that the last patient have waited to be visited by a doctor or associated provider. The wait time shown includes the elapsed time from patient entrance in the ER to being visited by an ER staff in the last four hours, and wait times are updated every 30 minutes (Farmer, 2010).

In another study researchers implemented a system to improve completing the clinical documentation and evaluate the results over time. They used custom software to constantly look for missing clinical documentation during anesthesia. They used patient allergies as a test case, regarding to a distinctive requirement in their system that allergies must be manually input into the electronic record. If no allergy data was input within 15 min of the “start of anesthesia care” event, a one-time prompt was sent via text to the individual, who is performing the anesthetic. They charted the daily portion of cases missing allergy data for the 6 months before implementing the alert system, and then they attained the same information for the following 9 months. They tested for systematic performance changes using statistical process control methodologies. Results indicate that before activating the alert system, the fraction of charts without an allergy comment was slightly more than 30%. This reduced to about 8% after beginning the alerts, and was significantly changed from baseline within 5 days (Warren S. Sandberg, 2008).

The last but not the least literature review about using text messages in healthcare systems is a research that proposed a methodology to measure the distance of the anesthesiologists' home from the hospital via sending a text message. They store this information in their anesthesia information management system (AIMS). Two unannounced simulated emergency recall maneuvers were conducted, with text messages sent requesting for the estimated time to return to the hospital. Replies to the simulated emergency alert were received from about 50% of staff, with 16 projecting that they would have been able to return to the hospital within 30 minutes on both dates. Of the non-responders to the alert, 48% declared that their cellphone was turned off or not with them, while 22% missed the message (Richard H. Epstein, 2010).

2.3 Previous Relevant Funded Researches

A research that is provided by Agency for Healthcare Research and Quality (1 U18 HS015846) develops, implements and evaluates a widespread team communication systems resulting in a toolkit that can be generalized to other settings of care. Regarding to the literature review of this study, analysis of 421 communication events in the operating room indicate communication failures in about 30 percent of team interactions; one-third of these risked patient safety by increasing pressure, disturbing routine, and increasing cognitive load in the OR setting. In this research communication problems have broken down into four classifications: (1) communications whose purposes were not achieved, (2) content that was not consistently complete and accurate, (3) failure to communicate with all the relevant individuals on the team and (4) communications that were too late to be effective (Catherine Dingley, 2008).

In another research that is funded by AHRQ (1 U18 HS016680) authors highly emphasize on the critical role of the team communication in operating room. Today, team communications in the OR are considered more by disruptive manners than by the smooth delivery of care. The noticeable differences in the background of the several disciplines lead to misinterpretations and misunderstandings. The consequence of the lack of role clarity and poor communication can prevent having effective teamwork (John T. Paige, 2008).

Another related research that is funded by U.S. Army Medical Research & Materiel Command (under contract DAMD-17-3-2-001) discusses the four pillars of a smart and safe operating room, which are: (1) Smart image (2) Ergonomics/human factors (3) Informatics and (4) Surgical simulation. In the informatics section, they believe that a manager of a well-run operating room should know the presence of physicians, nurses, anesthetists, patients and major pieces of equipment. They compare the commercial warehouses and supermarkets like Wal-Mart with healthcare environments in terms of tracking the inventory. A grocery like Wal-Mart tracks its items like a 99-cent paper towel but a charge nurse in a usual operating room suite might have to look for an ultrasound machine or C-arm. Redundancy, communication problems, Inefficiency, system failures and usage problems are among the concerns driving annual healthcare expenses to over a half-trillion dollars, or equivalent of 30 to 40 cents of each healthcare dollar. The challenge to the healthcare environment is to realize and improve procedures that lead to system failures and lower efficiencies, while concurrently jeopardies to patients (F. Jacob Seagull, 2008).

CHAPTER 3

METHODOLOGY

The proposed methodology and approach to minimize human errors in hospital operating rooms includes a framework that can be used by hospital managers, which would allow them to alert doctors when they are using a wrong tool.

3.1 DFSS-R Methodology

In this research we used DFSSR methodology to minimize errors by the following three phases, which are plan, predict and perform. Each phase has its own steps that will be explained in the current chapter.

3.1.1 Phase I: Plan

In this phase we need to investigate the problem and explain it in the define step. Then we need to identify the pathway of each experiment and describe it in the measure step.

3.1.1.1 Step 1 - Define

In this step the research question will be identified and the big picture of the problem statement will be addressed along with the reasons behind the selection of the topic. In other words this step is explaining the demands for the research and picturing the “big why”.

3.1.1.2 Step 2 - Measure

One of the important steps for DFSSR methodology is the measure step that includes defining metrics. The purpose of this step is to specify the metrics in order to measure the current procedure. This step is doable just by having records on the performance of the current process and it can create and improve the model (Peter B. Southard, 2012).

3.1.2 Phase II: Predict

The second phase of DFSSR methodology is predict. In this phase we focus on analyzing the expected outcomes of the experiment and try to identify the relevant technologies in order to design an alerting system that employs RFID technology. This phase has three steps, which are analyze, identify and design.

3.1.2.1 Step 3 - Analyze

The analyze step emphases on the origins of variation and mistakes. It afterwards tries to specify the origin reason of those errors. This step analyses the process by providing knowledge to answer questions like, what the process is, what it presently does, what it should do, what its capabilities are, and how the procedures should be directed (Peter B. Southard, 2012).

3.1.2.2 Step 4 - Identify

The second step of the predict phase is identify. This step basically guarantees that the organization realizes the measures for success (Antony, 2002).

3.1.2.3 Step 5 - Design

The final step of the predict phase is design. Once the organization realizes the metrics of the plan, these metrics should be transformed into definite and effective design (Antony, 2002).

3.1.3 Phase III: Perform

The last but not the least phase for this methodology is perform. The whole concept of this phase is to prove the feasibility of our design by using design of experiment. This phase includes two steps, which are optimize and verify that are explained in the following.

3.1.3.1 Step 6 - Optimize

This step includes the additional consideration of plan to guarantee applicable "makeability" – subsequently the organization is assured that the outcome can be produced in the recognized design metrics and satisfied the planed budget (Antony, 2002).

3.1.3.2 Step 7 - Verify

In the second step of perform phase, we are going to verify the new design of the proposed approach, to prove the presence of improvements according to a hypothesis statement and to efficiently minimize the human errors in hospital operating rooms (M. Sokovic, 2010).

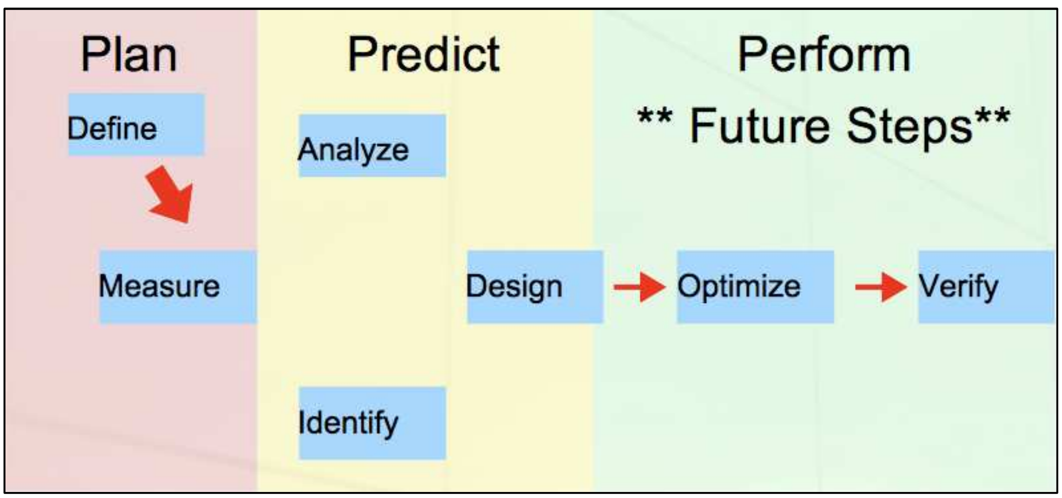

Figure 3.1 DFSS-R Methodology

3.2 Approach

As we stated before, our overall methodology is DFSS-R and the approach is set based on this methodology. The methods and approach envisioned for this research include system reliability calculations to determine the performance of auto-system versus manual system in the hospital operating room. We use a population of UTA students to test existing equipment of traditional fixed and handheld readers with existing software located in the Radio Frequency and Auto Identificaiton (RAID) Labs to collect data.

3.2.1 List of Equipment

The equipment that is used for this experiment are listed below:

3.2.1.1 ATID Handheld RFID Reader

AT570 is a slim rugged industrial PDA for reading RFID or scanning Barcodes. It is a mobile computer that is designed to read RFID tag data within a 13.56MHz access range and simultaneosly perform a real-time transfering activity to the host computer. It can also be connected to other devices to execute applications provided by ATID.

The specifications for this device are: WI-FI: 802.11 B/G WEP/WPA, GSM/GPRS: EGSN900, GSM1800, GSM1900 (SIM CARD SUPPLIED BY ENDUSER), GPS: SIRF3, FREQUENCY: 860 MHz ~ 960MHz, CAMERA: 1.3 MEGAPIXEL, ACCESS RANGE: 13.56 MHz, READING RANGE: 0M ~ 7M, WRITING RANGE: 0M ~ 3M and RF OUTPUT: 1W EIRP.

Figure 3.2 ATID Handheld RFID Reader

3.2.1.2 ALIEN RFID Reader

The ALR-9900+ is a Radio Frequency Identification system that operates at a frequency of 902 ~ 928 MHz. This reader enables users to deploy best in class electronic product code (EPC GEN2) RFID solutions for supply chain, manufacturing and asset management applications. This reader has automated mode, multiple platforms and flexible general purpose Input/Output (GPIO) system.

The specifications for this device are: Supported RFID tag products: EPS GEN2: ISSO 1800-6c, Reader protocols: Alien Reader Protocol. Firmware upgradable, Transmission channels: 50, Power: Robust universal AC-DC power; 100 ~240 VAC, 50 ~ 60 Hz.

Figure 3.3 ALIEN RFID Reader

3.2.1.3 Motorola Andrew RFID-900-SC Antenna

Designed specifically for long-range and large area Radio Frequency Identification (RFID) tag reading, Motorola's High-Performance Area RFID Antennas offer a new level of operational efficiency in areas previously too large to accommodate RFID technology. The AN400 antenna offers a new level of operational efficiency in areas previously too large to accommodate RFID technology. Its wide read field and high-speed RF signal conversion allows fast and accurate communication of EPC-compliant passive tag data. The high-performance area antennas are easy to mount on ceilings and walls to create superior read zones around shelves, doorways and dock doors – anywhere boxes and pallets are moving into and out of a facility. The specification for this device is: Frequency: 902 ~ 928 MHz.

Figure 3.4 Motorola Andrew RFID-900-SC Antenna

3.2.1.4 Mannequins and Beds

In order to simulate the real operating room it is required to use mannequins and hospital beds. The RFID lab is equipped with mannequins and hospital beds, which are shown in figure 3.5. The beds are exactly the same as the beds that are using in high-tech hospitals. The mannequins in this research play the patient role and the environment around the patient is tried to emulate the real settings in hospital operating room.

Figure 3.5 Mannequins and Hospital beds

3.3 Specific Aims

After an interview with one of the surgeons of University of Texas Southwestern about the average number of tools that are used in operating room for each operation, he declares that for 12 hours operations they use approximately 40 to 50 instruments and for 2 hours operations they use approximately 25 to 30 instruments. Regarding to this interview, we assume our experiment is for 2 hours operations, therefore 30 items are tagged plus 3 extra tools, in other words 30 items are placed on the table that are supposed to be on the table which are necessary for the operation but 3 extra tools are also placed on the table, which are the wrong tools that experimenters should recognize and write the tag ID down.

Different tag brands are used for this experiment because in the real world equipment is not tagged with the same tag brands. Different objects with different shapes are tagged to make the environment more similar to the actual operating room, for instance we use objects with different materials, like plastic, metal, wood and so on and so forth. Figure 3.6 shows the items that are tagged and placed on the table.

Figure 3.6 Items are tagged and placed on a table

3.3.1 Specific Aim #1

The first Specific Aim for this research is to evaluate the reliability and effectiveness of manual texting in hospital operations. To address this aim the following experiment is designed.

A reasonable amount of equipment (33 items) is tagged and placed on a table, 24 identifiers with a list of equipment that is supposed to be on the table are asked to manually check all of the equipment via a handheld RFID reader and also check if there is any wrong tool on the table. If they detect any wrong tool they write it down and then send a text message containing the extra tag IDs to another experimenter who is playing the role of charge nurse and alert him/her about the wrong tool. We assume that the list of equipment that is provided for experimenters is 100% accurate.

It is also assumed that in different times there are different numbers of human error, so the experiment is run in different time slots. We define four time slots for this experiment, which are shown in table 3.1. Each time slot has a label followed by the start and end time, which means if the experimenter runs the experiment for instance between 8:40am to 9:20am, it is considered as time slot A or if s/he runs it from 3:30pm to 4:00pm it is considered as time slot D.

Table 3.1 Time Slots of the experiment

Row	Time Slot Label	From:	To:
1	A	8:00am	10:00am
2	B	10:01am	12:00pm
3	C	1:00pm	3:00pm
4	D	3:01pm	5:00pm

In order to avoid correlation, each identifier ran the experiment just once and with 24 identifiers and four time slots, we have 6 students in each time slot, which means 6 different students in each time slot. More than half of the identifiers have no background knowledge of RFID and the purpose of selecting these inexperienced people is that in the real hospital environment they may hire a person who has no background information about RFID, therefore it is more close to the real world when we select inexperienced identifiers. A training session is held for both inexperienced and experienced identifiers to show them how they can work with the equipment and also how to fill the experiment sheets.

Table 3.2 shows the 30 items and the tag IDs associated to these items. Experimenters for Specific Aim #1 check the existence of these tag IDs with a handheld RFID reader and if it is read, they put the check mark in the Existence column and if not, they cross it.

Table 3.2 Experiment sheet for scenario I part a.

ROW	TAG ID		Existence
1	E200 9051 3205 0207	0590 D83B	
2	E200 9051 3205 0207	0700 CDB2	
3	E200 9051 3205 0207	0760 CA04	
4	E200 9051 3205 0207	0940 B686	
5	E200 9051 3205 0207	0820 C26A	
6	E200 9051 3205 0207	1000 B274	
7	E200 9051 3205 0207	0880 BE84	
8	E200 9051 3205 0207	0890 BA89	
9	E200 9051 3205 0207	1010 AE55	
10	E200 9051 3205 0207	1130 A1B9	
11	E200 9051 3205 0207	0950 B687	
12	E200 9051 3205 0207	1120 A5F8	
13	E200 9051 3205 0207	1060 AA2A	
14	E200 9051 3205 0207	0650 D149	
15	E200 9051 3205 0207	0710 CDB3	
16	E200 9051 3205 0207	0640 D4D0	
17	E200 9051 3205 0207	1310 9083	
18	E200 9051 3205 0207	1250 94D9	
19	E200 9051 3205 0207	1430 836B	
20	E200 9059 6218 0044	2310 2897	
21	E200 9037 9110 0096	1000 B0B8	
22	E200 9037 9110 0096	1060 A86E	
23	E200 9037 9110 0096	1080 A870	
24	E200 9037 9110 0096	1040 AC9C	
25	E200 9037 9110 0096	1020 AC9A	
26	E200 9037 9110 0096	1010 AC99	
27	E200 2996 9618 0128	2820 022E	
28	E200 2996 9618 0128	2540 135E	
29	E200 2996 9618 0128	2630 0DB7	
30	1000 0000 0000 0000	0000 0002	

Table 3.3 shows a blank table, which is for the experimenters if they find any tag ID that does not exist in table 3.2. In this experiment, all of the tag IDs that are listed in table 3.2 exist on the table plus three other tags that the experimenters should recognize and write it down in table 3.3 as extra tag IDs. The experiment sheet includes table 3.2 and table 3.3 and a place for the name of the experimenter, the time slot that the s/he runs the experiment and start and end times.

Table 3.3 Experiment sheet for scenario I part b.

Row	Extras (TAG ID)
1	
2	
.	
.	
.	
20	

The start time is the time that the experimenter begins the experiment, which is reading the tags with the handheld and the end time is the time that the text message is delivered to the person who is playing the role of the charge nurse.

Figure 3.7: An experimenter is reading the tags by RFID handheld

The expected outcomes for this aim were to simulate performance of operating room personnel who were using texting as a means to track and identify inventory. We hypothesize there would be a large amount of human error based on the operating time periods.

3.3.2 Specific Aim #2

The second Specific Aim is to evaluate the performance of the automated texting with RFID based technology. To address this aim the following experiment is designed.

A reasonable amount of equipment (33 items) is tagged and placed on a table. Then, this table is placed between portal antennas and the RFID reader starts reading the tags and if it detects any wrong tool, it highlights it on a computer and the operator gets alerted about the wrong tool and texts the charge nurse. Because we do not have a reader that can generate a text message we have to make some assumptions to complete the experiment. Since the existing equipment cannot generate text messages, we assume that the RFID reader sends all of the text messages that it is supposed to send.

This experiment is run for six times in 4 different time slots. Although it is proved that the performance of electrical devices does not depend on different time of the day, but in order to have the same condition for this experiment and the experiment that is explained for Specific Aim #1 we run it in different time slot. The Alien RFID reader reads the tags, which are in it's reading area in few seconds and by the picture that is associated to each tag, the operator quickly recognizes the wrong tools.

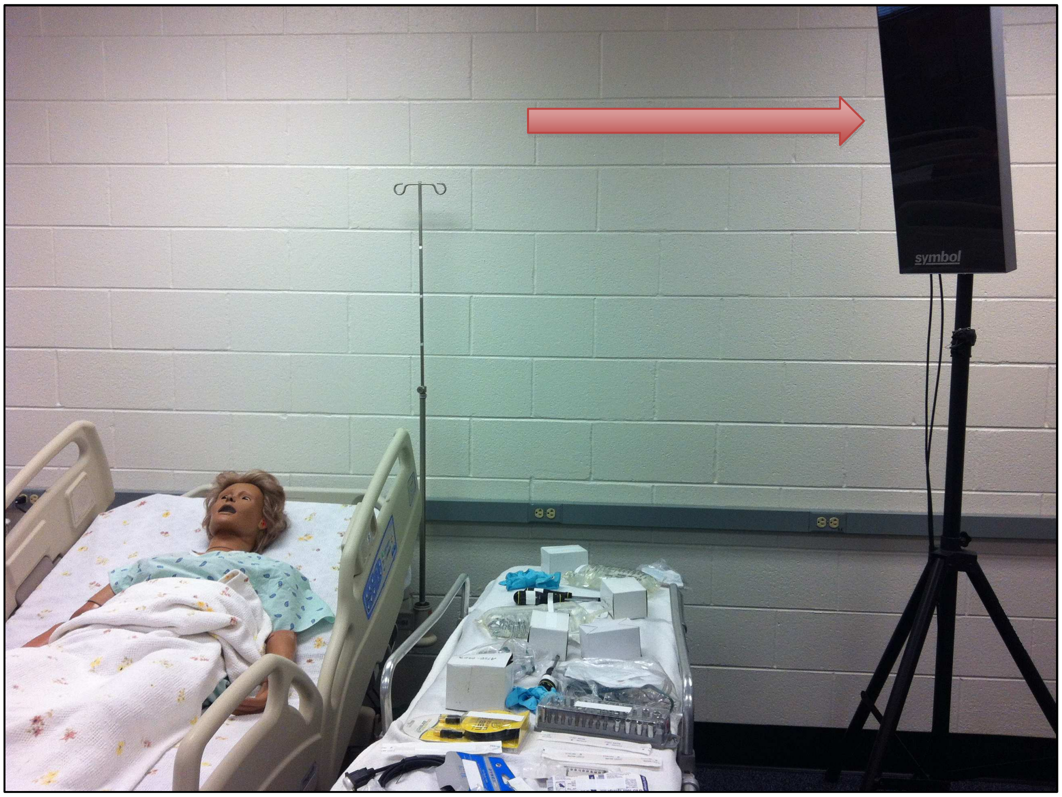

Figure 3.8: The portal antenna is reading tag IDs

The expected outcomes were to benchmark the performance of simulated enhanced RFID system with texting capabilities. We hypothesize that this system can be described that can incorporate the texting and RFID into a system that can automate alerts.

3.3.3 Specific Aim #3

The third Specific Aim is to evaluate the manual texting versus auto texting technology. To address this aim, all of the data that is gathered in previous aims are going to be compared. This aim is also has two parts, the first part is to compare the means of errors between two systems and the second part is to compare the time that it takes for each experiment to be completed for each system. By running experiments from first two specific aims we will have 8 categories of data that each of them includes 6 observations.

The expected outcomes were to identify key differences between the manual texting process and the simulated automated texting system with RFID tagged inventory. We hypothesize though texting is a semi-automated process the automated system would perform better based on time of day. We expect similar performance during earlier times of day but as the day is extended performance will be impacted.

3.4 Data Analysis Tools

Different data analysis tools are employed for this research and these tools are used for each Specific Aim. Here are the explanations for each tool:

3.4.1 ANOVA

Analysis of variance prototypes are purposed for applications where the results of the predictor variables on the response variable are desired. Analysis of variance prototypes are beneficial for records for both experimental and observational researches. Analysis of variance prototypes are basically used to analyze the outcome of the explanatory variable(s) under analysis on the response variable. Table 3.4 shows ANOVA elements that should be calculated for this study (John Neter, 1996).

Table 3.4 ANOVA table elements (John Neter, 1996)

Source of Variation	SS	df	MS	$E\{MS\}$
Between treatments	$SSTR = \Sigma n_i (\bar{Y}_{i.} - \bar{Y}..)^2$	$r - 1$	$MSTR = \frac{STTR}{r-1}$	$\sigma^2 + \frac{\Sigma n_i (\mu_i - \mu.)^2}{r-1}$
Error (Within Treatments)	$SSE = \Sigma\Sigma (Y_{ij} - \bar{Y}_{i.})^2$	$n_T - r$	$MSE = \frac{SSE}{n_T - 1}$	σ^2
Total	$SSTO = \Sigma\Sigma (Y_{ij} - \bar{Y}_{..})^2$	$n_T - 1$		

3.4.2 F-Test

It is usual to start the analysis of a single factor study by defining whether the factor level means (μ_1) are equal or not. $H_0: \mu_1 = \mu_2 = \cdots = \mu_r$, $H_a: not\ all\ \mu_i\ are\ equal$

$$F^* = \frac{MSTR}{MSE}$$

Since F^* is distributed as $F\ (r - 1, n_T - 1)$ while H_0 holds and that great values of F^* reach to the conclusion H_a the proper decision rule to control the level of significance at α is: If $F^* \leq F\ (1-\alpha; r-1, n_T - r)$ conclude H_0 and If $F^* > F\ (1-\alpha; r-1, n_T - r)$ conclude H_a (John Neter, 1996).

3.4.3 Normal Probability Plot

When each residual is plotted against its expected value under normality, it is called a Normal Probability plot. A plot that is nearly linear suggests agreement with normality, where as a plot that departs substantially from linearity suggests that the error distribution is not normal.

3.4.4 Box Plot

Exploratory data analysis includes the use of statistical tools to determinate patterns that may not be revealed in a collection of records. One specific tool is the "box plot," which is applied to visually synopsize and compare collections of records. This tool uses the median, the estimated quartiles, the minimum and the maximum points to convey the level, range, and symmetry of a distribution of records. It considerably easily to recognize outliers and can be easily created manually (Williamson DF, 1989).

3.4.5 Tukey's Multiple Comparison Procedure

Tukey's range test compares all of the possible pairs of means and this test is concreted on studentized range distribution. The studentized distribution is similar to the t-test. Tukey's test applies while the family of interest is the set of all pairwise comparisons of factor level means: In other words, the family contains of approximations of all pairs $D = \mu_i - \mu_{i'}$ or of all tests with the form: $H_0: \mu_i - \mu_{i'} = 0, H_0: \mu_i - \mu_{i'} \neq 0$. The family confidence coefficient for the Tukey's method is exactly $1 - \alpha$ when all sample sizes are equivalent, and the family significance level is precisely α. The family confidence coefficient is greater than $1 - \alpha$ when the sample sizes are not equal and the family significance level is less than α. In other words, the Tukey's method is conservative when the sample sizes are not equivalent (John Neter, 1996).

3.4.6 Residual Plot

Residual plots are beneficial for analysis of variance prototypes, which are included: (1) normal probability plots (2) dot plots (3) time plots or other sequence plots (4) plot against the fitted values. Residual plots can be useful in identifying the following statements from ANOVA model: outliers, non-constancy of error variance, non-normality of error terms, omission of important explanatory variables and non-independence of error terms (John Neter, 1996).

3.5 Hypothesis Tests

Hypothesis tests for this research are dedicated to each aim, in other word each Specific Aim has it's own hypothesis that are explained in the following subsections. We chose $P - Value = 0.1$ for all hypothesis for two main reasons, first of all: knowing an error could cause a huge disaster in hospital operations, it is not realistic to choose an α more that 0.1 and secondly: in order to get some significance levels for results for this research we did not select the small α.

3.5.1 Hypothesis for Specific Aim #1

3.5.1.1 Hypothesis Test for the Number of Errors in Manual System

One of important factors that this research has focused on is human error. First hypothesis test is formed based on the results of the data analysis tools that were explained in the last section. The statement for this hypothesis is: We hypothesized that there is a significant difference between the means of human error for each time slot, which are time slot A, B, C and D. We reject the null hypothesis if the mean number of errors for all time slots is equal.

$H_0: \mu_{ME1} = \mu_{ME2} = \mu_{ME3} = \mu_{ME4}$, $H_a: not\ all\ \mu_{MEi}\ are\ equal$

3.5.1.2 Hypothesis Test for the Times of Completion in Manual System

The other factor that needs to be considered for hypothesis test is the time that it takes for each identifier to complete the experiment and it includes recognition of the wrong tool(s) and sending a text message. We hypothesized that there is a significant difference between the means of mean times of completion for each time slot. We reject the null hypothesis if the mean times of completion for all time slots are equal.

$H_0: \mu_{MS1} = \mu_{MS2} = \mu_{MS3} = \mu_{MS4}$, $H_a: not\ all\ \mu_{MSi}\ are\ equal$

3.5.2 Hypothesis for Specific Aim #2

3.5.2.1 Hypothesis Test for the Number of Errors in Auto System

The same hypothesis from aim #1 is also applied for auto system, which is aim #2 and this hypothesis test is formed based on the results of the data analysis tools that are explained in last section. The statement for this hypothesis is: We hypothesized that there is a significant difference between the means of the auto system error for each time slot, which are time slot A, B, C and D. We reject the null hypothesis if the mean numbers of errors for all time slots are equal.

$H_0: \mu_{AE1} = \mu_{AE2} = \mu_{AE3} = \mu_{AE4}$, $H_a: not\ all\ \mu_{AEi}\ are\ equal$

3.5.2.2 Hypothesis Test for the Times of Completion in Auto System

The other aspect that needs to be considered for hypothesis test is the time that it takes for the auto system to complete the experiment and it includes recognition of the wrong tool(s) and sending a text message. We hypothesized that there is a significant difference between the mean times of completion for each time slot. We reject the null hypothesis if the mean times of completion for all time slots are equal.

$H_0: \mu_{AS1} = \mu_{AS2} = \mu_{AS3} = \mu_{AS4}$, $H_a: not\ all\ \mu_{ASi}\ are\ equal$

3.5.3 Hypothesis for Specific Aim #3

3.5.3.1 Hypothesis Test for the Number of Errors in Manual and Auto System

This Specific Aim is designed to evaluate the reliability and effectiveness of manual texting comparing to the auto-texting. The first hypothesis test examines the reliability of these two systems. We hypothesized that there is a significant difference between the means of errors from manual texting and auto-texting. We reject the null hypothesis if the mean number of errors for manual and automatic system are equal.

$H_0: \mu_{ME} = \mu_{AE}$, $H_a: not\ all\ \mu\ are\ equal$

3.5.3.2 Hypothesis Test for the Times of Completion in Manual and Auto System

The other hypothesis is for evaluating the effectiveness of manual and auto texting systems. This hypothesis focuses on the mean times of completion parameter and compares two systems. We hypothesized that there is a significant difference between the mean times of completion for each system. We reject the null hypothesis if the mean times of completion for both systems are equal.

$H_0: \mu_{AS} = \mu_{MS}$, $H_a: not\ all\ \mu\ are\ equal$

CHAPTER 4

RESULTS

The result chapter follows the same steps from the approach section of the methodology chapter and the results for each step are shown in the same order. This chapter includes raw data that is gained by the experiments, analysis of the raw data and the results of the hypothesis tests. All statistical calculations are calculated by SAS software.

4.1. Results for Specific Aim #1

4.1.1 Number of Errors for Manual System

All 24 experiments for the first experiment are run during one week in different time slots, the results of human errors are shown in table 4.1. Each cell of this table represents the number of errors of each individual experimenter. For instance the first observation from time slot A shows that the first identifier had 3 errors for recognizing tags and sending the text message. These errors include mistyping the tag ID and not recognizing the wrong tag.

Table 4.1 24 Observations from 24 different identifiers

Time Slots	Observations					
A	3	1	2	1	2	1
B	2	1	1	2	1	1
C	0	0	0	1	1	0
D	1	0	1	1	1	3

4.1.1.1 ANOVA Table and F-Test

The ANOVA table for the errors of manual system is calculated by SAS and shown in Table 4.2. The P-Value that is calculated in this table is much smaller than the p-value that is considered for the F-Test. There are two ways to check our hypothesis, first using F* and second using the P-Value, here we use the p-value to check the hypothesis, and because it is smaller than 0.1, we reject the null hypothesis, the explanation of this hypothesis will be explained in the hypothesis section.

Table 4.2: ANOVA table for number of errors in manual texting system

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	5.79166667	1.93055556	3.56	0.0325
Error	20	10.83333333	0.54166667		
Corrected Total	23	16.625			

4.1.1.2 Normal Probability Plot

The normal probability plot of the number of manual errors is shown in figure 4.1. By analyzing this plot, it could be inferred that it has a slightly longer tail on the left, therefor the normality is not satisfied and it is violated but this is not a required assumption.

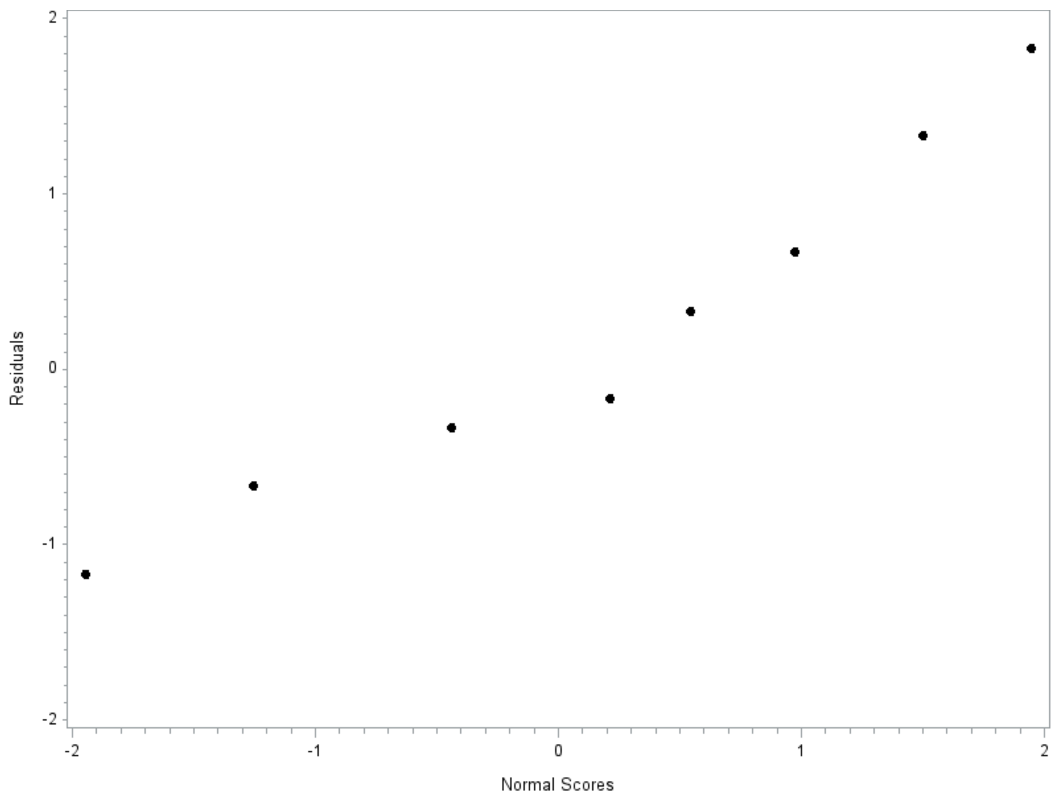

Figure 4.1: Normal Probability Plot for number of errors in the manual system

If normality was one of the required assumptions, it would be necessary to have some transformation in our data but for this experiment it is not required.

4.1.1.3 Box Plot

The box plot for the number of errors for the manual system is shown in figure 4.2. From this plot, it could be easily recognized by the following characteristics of data: The smallest observation, lower quartile (Q1), median (Q2), upper quartile (Q3), mean and the largest observation.

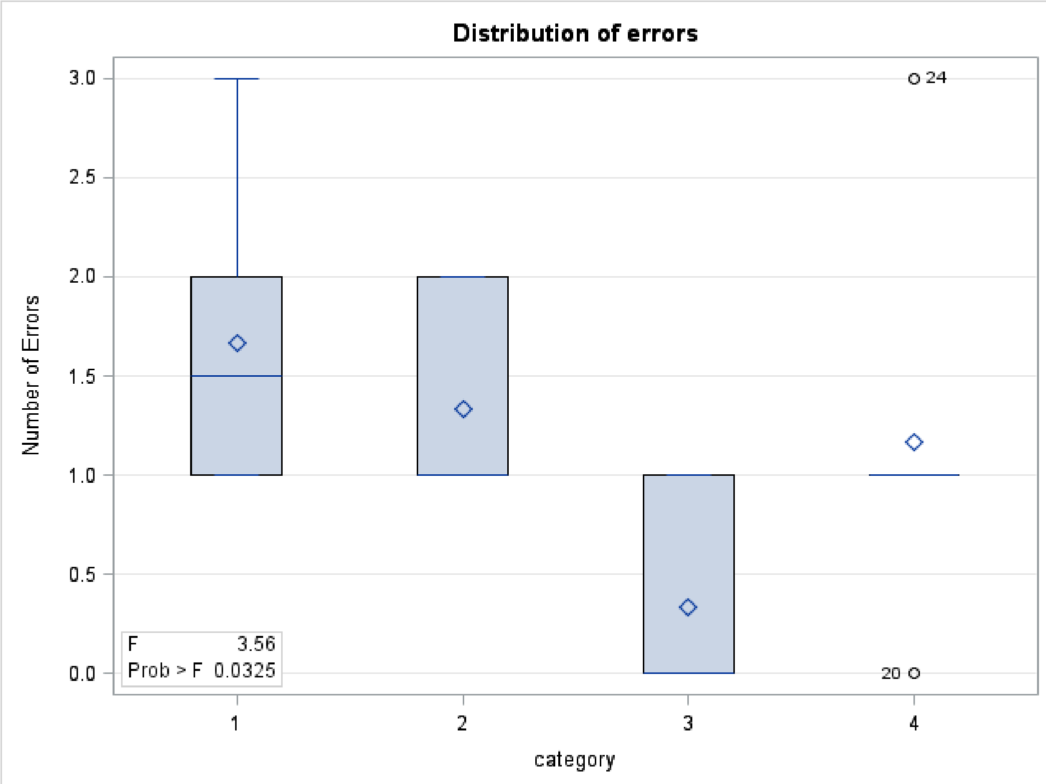

Figure 4.2: Box Plot of the number of errors for manual system

By the analyzing this plot, it could be visually inferred that there is a considerable difference between the means of category 1 and category 3 but in order to confirm this difference, further analysis is required, which is done with Tukey's test.

4.1.1.4 Tukey's Test

The results of Tukey's test are shown in table 4.3. As it was mentioned before, Tukey's is a comparison test to recognize if there is any difference between the means of each category for a specified significant level. Comparisons significant at the 0.1 levels are indicated by ***. This test controls the Type I experimentwise error rate.

Table 4.3 Tukey's Test for the number of errors for manual system

Alpha	0.1
Error Degrees of Freedom	20
Error Mean Square	0.541667
Critical Value of Studentized Range	3.46154
Minimum Significant Difference	1.0401

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
1-2	0.3333	-0.7067	1.3734	
1-4	0.5000	-0.5401	1.5401	
1-3	1.3333	0.2933	2.3734	***
2-1	-0.3333	-1.3734	0.7067	
2-4	0.1667	-0.8734	1.2067	
2-3	1.0000	-0.0401	2.0401	
4-1	-0.5000	-1.5401	0.5401	
4-2	-0.1667	-1.2067	0.8734	
4-3	0.8333	-0.2067	1.8734	
3-1	-1.3333	-2.3734	-0.2933	***
3-2	-1.0000	-2.0401	0.0401	
3-4	-0.8333	-1.8734	0.2067	

From the analysis of this table, it can be inferred that the minimum significance difference for these categories is 1.0401; if a difference between the means of each category fall beyond this number, it shows that two categories have significant difference between their means. Table 4.2 shows that at 0.1 significant level, category 1 and category 3 have significant a difference between their means.

4.1.1.5 Residual Plot

The other important plot that should be considered is the residual plot to be sure that we have a constant variance for the data. The residual plot for the number of errors in the manual system is shown in figure 4.3.

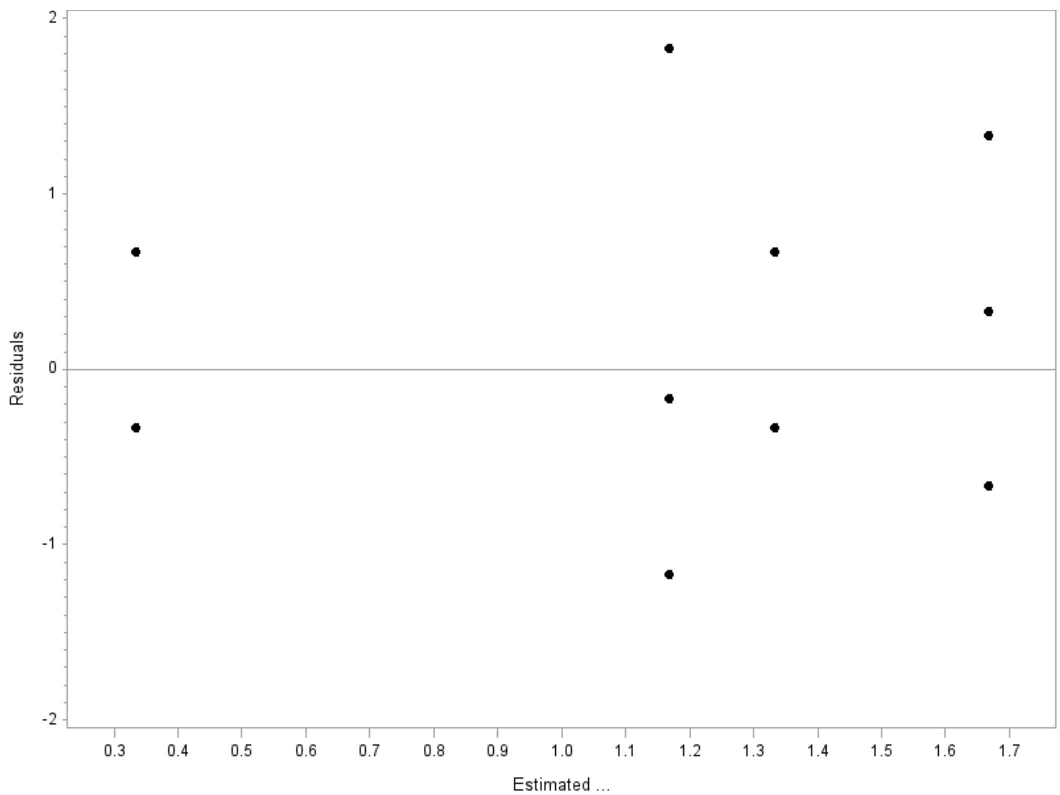

Figure 4.3 Residual Plot for the number of errors in manual system

As it appears in figure 4.3, there is no funnel shape for the data and there is no curvature to be considered, therefore by the analysis of this plot it could be inferred that constant variance is satisfied and no need for transformation.

4.1.1.6 Dot Plot

The last but not least analysis for this data is the dot plot, which shows the scattering of data on each category. There is not much information could be inferred from this plot but it is important to have it in order to check for outliers and gaps among the data. The dot plot for the number of errors in the manual system is shown in figure 4.4. For the following plot, it could be inferred there is no outlier and no gap among the data.

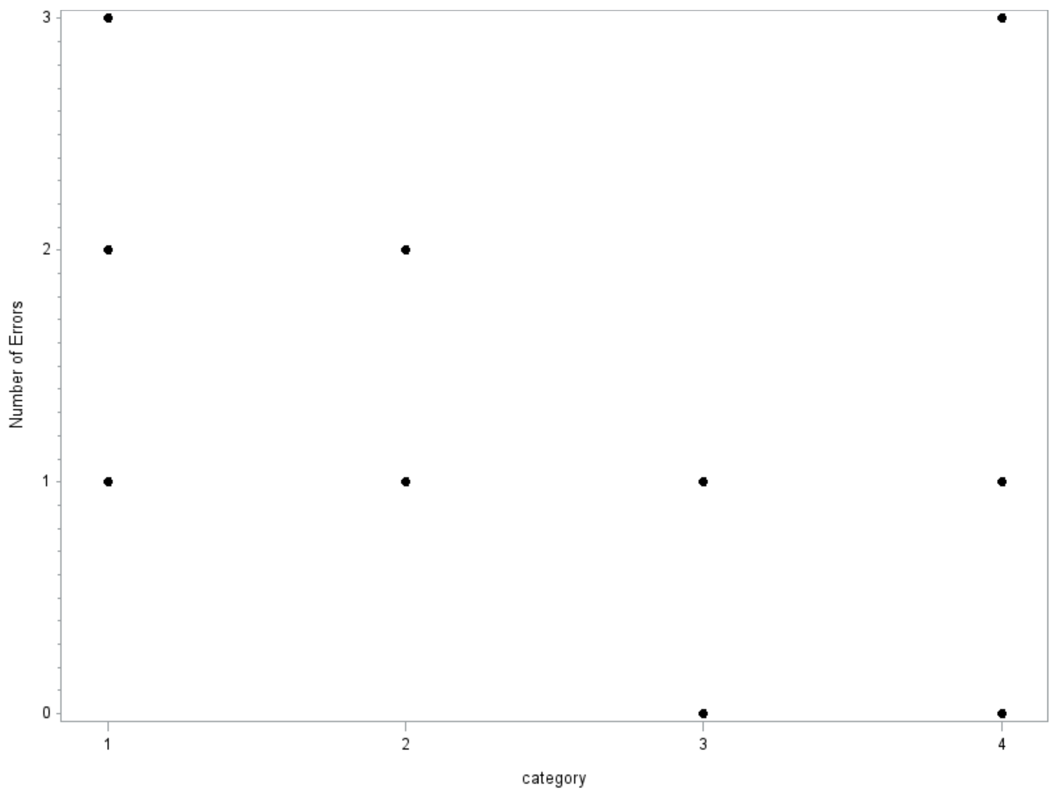

Figure 4.4: Dot Plot for the number of errors in manual system

4.1.2 Times of Completion For Manual System

The time that it takes for each observation to be completed is measured and includes reading time, checking the tags and sending an appropriate message. Table 4.4 shows these times in the minute unit.

Table 4.4: Time that it takes for each observation for manual system to be completed (minutes)

Row	Categories	Observations (Minutes)					
1	Time Slot A	8	22	18	22	13	18
2	Time Slot B	18	21	10	27	11	17
3	Time Slot C	21	14	26	25	30	22
4	Time Slot D	17	13	17	8	18	13

4.1.2.1 ANOVA Table and F-Test

The ANOVA table for the mean times of completion for the manual system is calculated by SAS and shown in Table 4.5. The P-Value that is calculated in this table is much smaller than the p-value that is considered for F-Test. There are two ways to check our hypothesis, first using F* and second using the P-Value. Here we use p-value to check the hypothesis and because it is smaller than 0.1, we reject the null hypothesis, and the explanation of this hypothesis will be explained in hypothesis section.

Table 4.5: ANOVA table for the mean times of completion for manual texting system

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	868050	289350	2.82	0.065
Error	20	2050200	102510		
Corrected Total	23	2918250			

4.1.2.2 Normal Probability Plot

The normal probability plot of the time that it takes for the experiments to be completed for the manual system is shown in figure 4.5. By analyzing this plot, it could be inferred that it has a slightly shorter tail on the left, therefore the normality is not satisfied and it is violated, but this is not a required assumption.

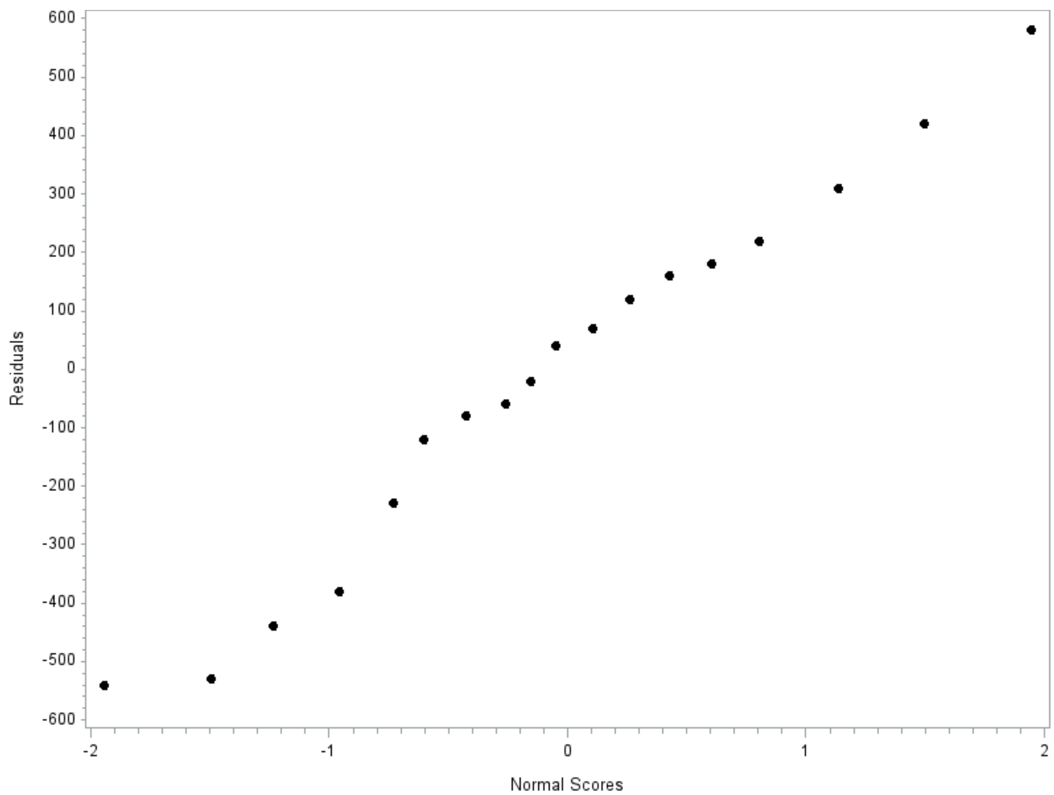

Figure 4.5: Normal Probability Plot for the mean times of completion in manual system

4.1.2.3 Box Plot

The box plot for the number of errors in the manual system is shown in figure 4.6. By the analysis of this plot, it could be visually inferred that there is a considerable difference between the means of category 4 and category 3, but in order to confirm this difference, further analysis is required, which is done with Tukey's test.

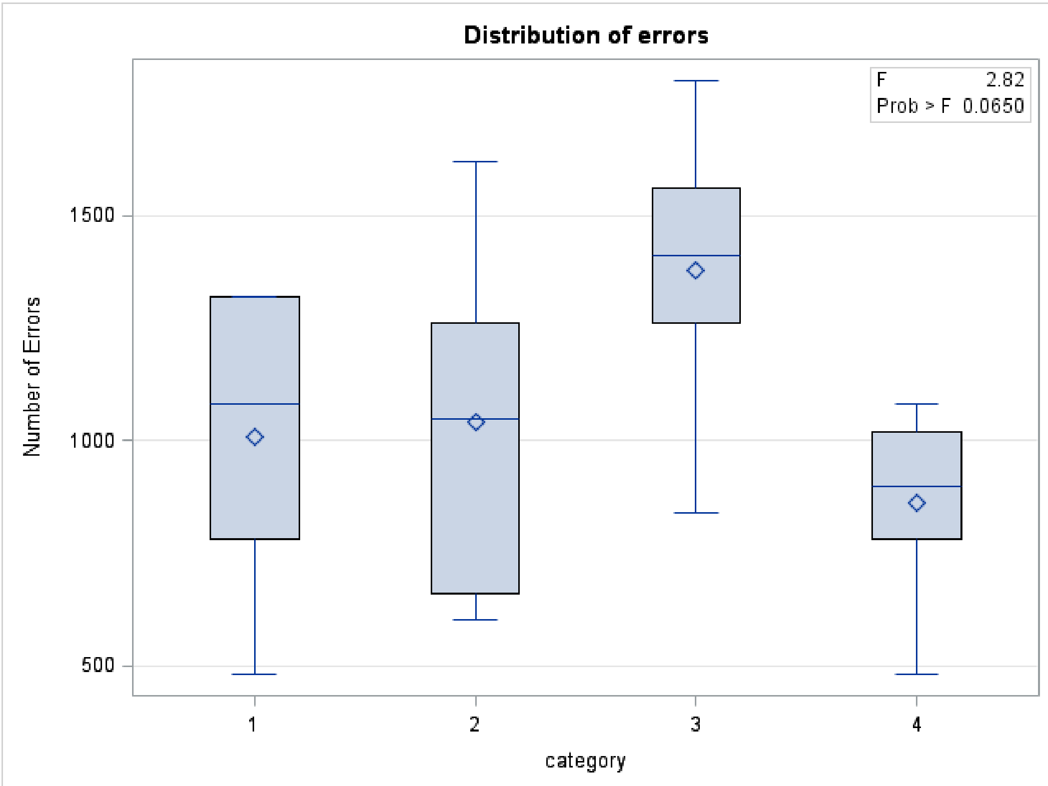

Figure 4.6: Box Plot of the peed for manual texting system

4.1.2.4 Tukey's Test

The results of Tukey's test are shown in table 4.6. As it was mentioned before, Tukey's is a comparison test to recognize if there is any difference between the means of each category for a specified significant level. Comparisons significant at the 0.1 levels are indicated by ***. This test controls the Type I experimentwise error rate.

Table 4.6: Tukey's Test for the mean times of completion for manual texting system

Alpha	0.1
Error Degrees of Freedom	20
Error Mean Square	102510
Critical Value of Studentized Range	3.46154
Minimum Significant Difference	452.46

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
1-2	340.0	-112.5	792.5	
1-4	370.0	-82.5	822.5	
1-3	520.0	67.5	972.5	***
2-1	-340.0	-792.5	112.5	
2-4	30.0	-422.5	482.5	
2-3	180.0	-272.5	632.5	
4-1	-370.0	-822.5	82.5	
4-2	-30.0	-482.5	422.5	
4-3	150.0	-302.5	602.5	
3-1	-520.0	-972.5	-67.5	***
3-2	-180.0	-632.5	272.5	
3-4	-150.0	-602.5	302.5	

From the analysis of this table, it can be inferred that the minimum significance difference for these categories is 452.46; therefore if a difference between the means of each category fall beyond this number, it shows that two categories have a significant difference between their means. Table 4.6 shows that at a 0.1 significant level, category 1 and category 3 have a significant difference between their means.

4.1.2.5 Residual Plot

The other important plot that should be considered is a residual plot to be sure that we have a constant variance for the data. The residual plot for the number of errors in the manual system is shown in figure 4.7.

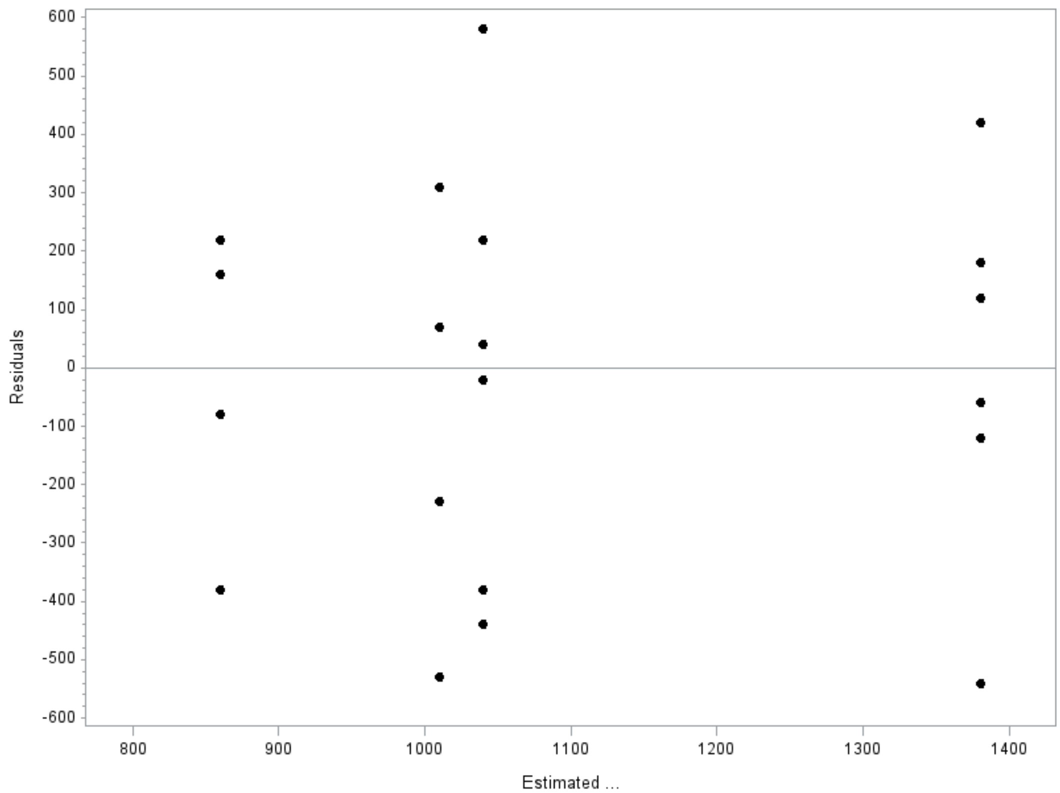

Figure 4.7: Residual Plot for the mean times of completion for manual texting system

As it appears in figure 4.7 there is no funnel shape for the data and also there is no curvature to be considered, therefore by the analysis of this plot, it could be inferred that constant variance is satisfied and no need for transformation.

4.1.2.6 Dot Plot

The last but not the least analysis for this data is a dot plot, which shows the scattering of data on each category. There is not much information could be inferred from this plot but it is important to have it in order to check for outliers and gaps among the data. The dot plot of the number of errors in the manual system is shown in figure 4.8. For the following plot, it could be inferred there is no outlier and no gap among the data.

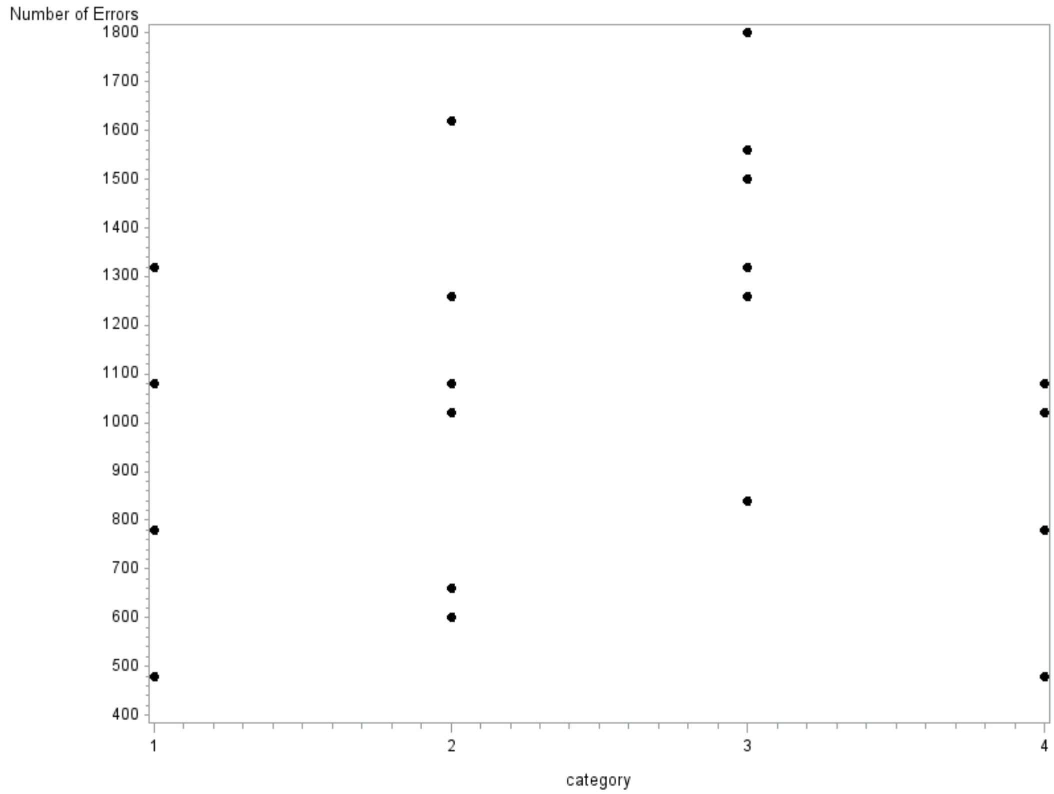

Figure 4.8: Dot Plot for the mean times of completion for manual texting system

4.2 Results for Specific Aim #2

4.2.1 Number of Errors for Auto System

The results of 24 observations from auto texting are shown in table 4.3. The errors of each time slot are shown in each individual cell.

Table 4.7: Number of errors for auto system in each time slot

Row	Categories	Observations					
1	Time Slot A	1	0	0	1	1	0
2	Time Slot B	0	0	0	1	0	1
3	Time Slot C	0	0	0	1	0	0
4	Time Slot D	1	0	0	1	1	2

4.2.1.1 ANOVA Table and F-Test:

The ANOVA table for the errors of the auto system is calculated by SAS and shown in Table 4.8. The P-Value that is calculated in this table is greater than the p-value that is considered for F-Test. There are two ways to check our hypothesis, first using F* and second using the P-Value. Here we use p-value to check the hypothesis and because it is greater than 0.1, we fail to reject the null hypothesis and we conclude H_0, and the explanation of this hypothesis will be explained in hypothesis section.

Table 4.8: ANOVA table for the number of error in auto texting system

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.45833333	0.48611111	1.5	0.2461
Error	20	6.5	0.325		
Corrected Total	23	7.95833333			

4.2.1.2 Normal Probability Plot

The normal probability plot for the number of manual errors is shown in figure 4.9. By analyzing this plot, it could be inferred that it is mostly straight, therefore the normality is satisfied and it is not violated.

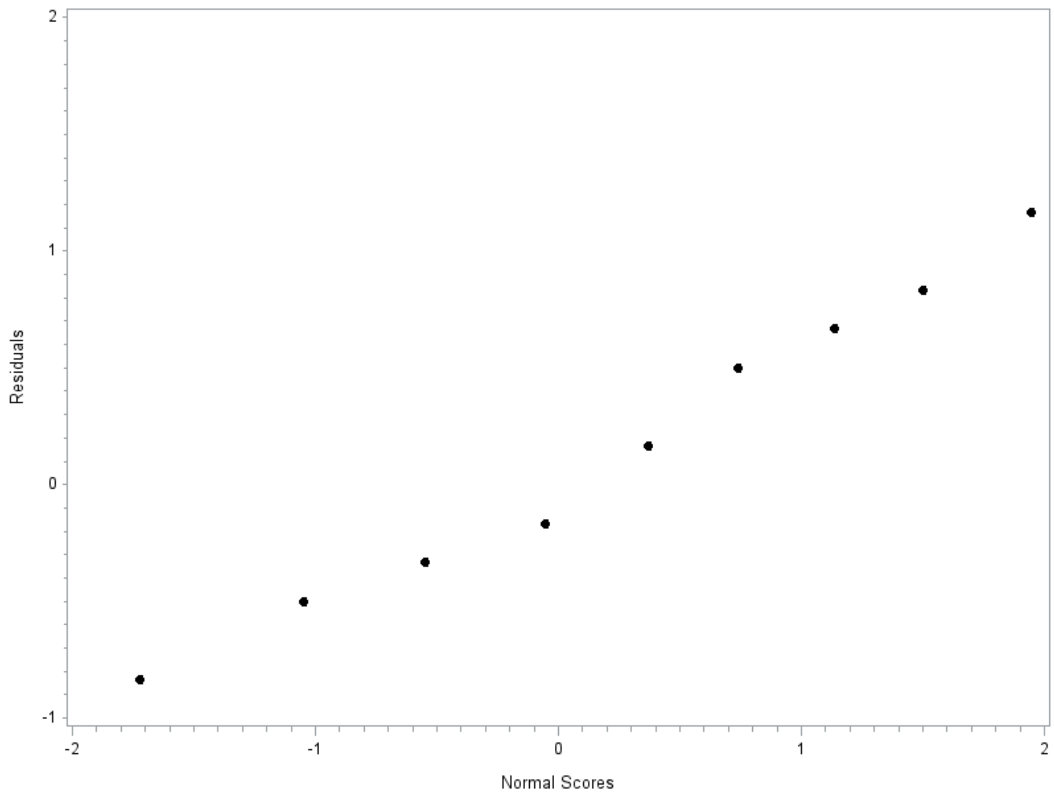

Figure 4.9: Normal Probability Plot for number of errors in auto system

4.2.1.3 Box Plot

The box plot for the number of errors for the auto system is shown in figure 4.10. By the analysis of this plot, it can be visually inferred that there is not a considerable difference among the means of categories, but in order to confirm this statement, further analysis is required, which is done by Tukey’s test.

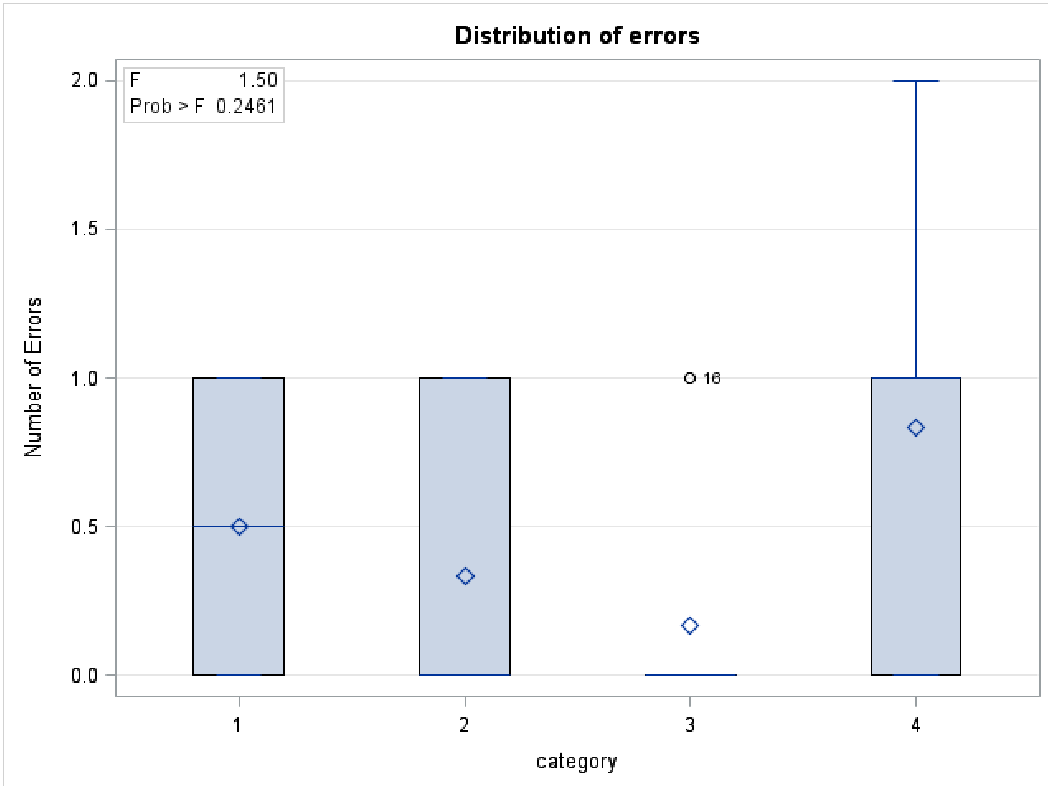

Figure 4.10: Box Plot of the number of errors for auto texting system

4.2.1.4 Tukey's Test

The results of Tukey's test are shown in table 4.9. As it was mentioned before, Tukey's is a comparison test to recognize if there is any difference between the means of each category for a specified significant level. Comparisons significant at the 0.1 levels are indicated by ***. This test controls the Type I experimentwise error rate.

Table 4.9: Tukey's Test for the number of errors for auto texting system

Alpha	0.1
Error Degrees of Freedom	20
Error Mean Square	0.325
Critical Value of Studentized Range	3.46154
Minimum Significant Difference	0.8056

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
4-1	0.3333	-0.4723	1.1390	
4-2	0.5000	-0.3056	1.3056	
4-3	0.6667	-0.1390	1.4723	
1-4	-0.3333	-1.1390	0.4723	
1-2	0.1667	-0.6390	0.9723	
1-3	0.3333	-0.4723	1.1390	
2-4	-0.5000	-1.3056	0.3056	
2-1	-0.1667	-0.9723	0.6390	
2-3	0.1667	-0.6390	0.9723	
3-4	-0.6667	-1.4723	0.1390	
3-1	-0.3333	-1.1390	0.4723	
3-2	-0.1667	-0.9723	0.6390	

From the analysis of this table, it can be inferred that the minimum significance difference for these categories is 0.8056; therefore if a difference between the means of each category fall beyond this number, it shows that two categories have significant difference between their means. Table 4.9 shows that at a 0.1 significant level, there is no category that have a major difference in means.

4.2.1.5 Residual Plot

The other important plot that should be considered is a residual plot to be sure that we have a constant variance for the data. The residual plot for the number of errors in the auto texting system is shown in figure 4.11.

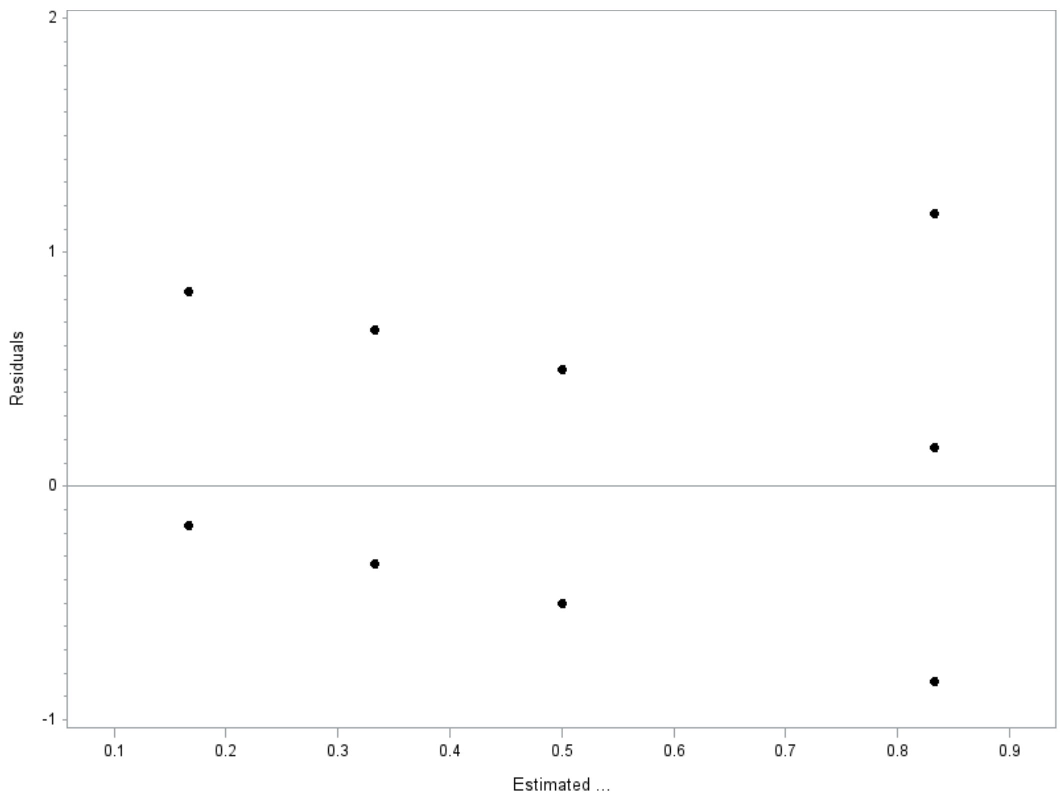

Figure 4.11: Dot Plot for the number of errors in auto texting system

As it appears in figure 4.11, there is no funnel shape for the data and also there is no curvature to be considered, therefore by the analysis of this plot, it could be inferred that constant variance is satisfied and no need for transformation.

4.2.1.6 Dot Plot

The last but not the least analysis for this data is a dot plot, which shows the scattering of data on each category. There is not much information to be inferred from this plot but it is important to have it in order to check for outliers and gaps among the data. The dot plot of the number of errors in the auto system is shown in figure 4.12. For the following plot, it could be inferred there is no outlier and no gap among the data.

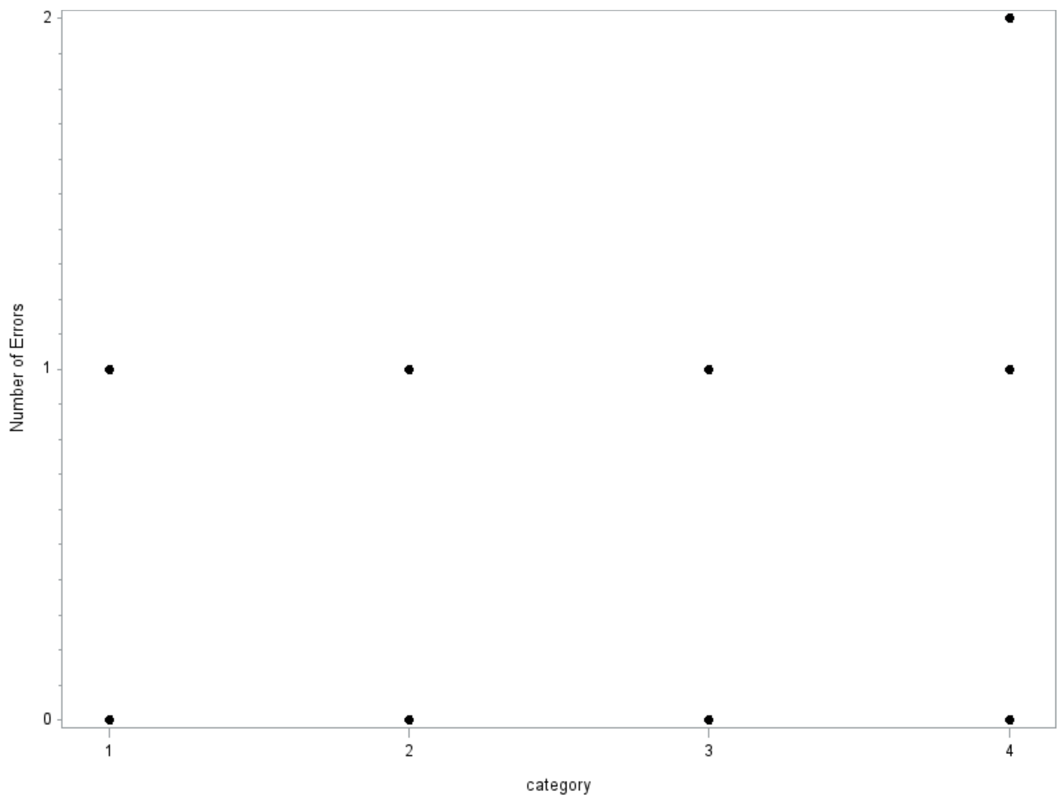

Figure 4.12: Dot Plot for the number of errors in auto texting system

4.2.2 Times of Completion For Auto System

The time that it takes for each observation to be completed by the auto-texting system is measured and includes reading time, checking the tags and sending an appropriate message. Table 4.10 shows these times in second unit.

Table 4.10: Time that it takes for each observation for auto-system to be completed (second)

Row	Categories	Observations (Seconds)					
1	Time Slot A	36	38	29	30	32	28
2	Time Slot B	37	27	28	31	32	27
3	Time Slot C	33	36	35	37	33	28
4	Time Slot D	28	30	34	38	32	27

4.2.2.1 ANOVA Table and F-Test:

The ANOVA table for the mean times of completion for auto system is calculated by SAS and shown in Table 4.11. The P-Value that is calculated in this table is greater than the p-value that is considered for F-Test. There are two ways to check our hypothesis, first using F* and second using P-Value. Here we use p-value to check the hypothesis, and because it is greater than 0.1, we fail to reject the null hypothesis and we conclude H_0, the explanation of this hypothesis will be explained in hypothesis section.

Table 4.11: ANOVA table for the mean times of completion for the manual texting system

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	34.8333333	11.6111111	0.8	0.5094
Error	20	291	14.55		
Corrected Total	23	325.8333333			

4.2.2.2 Normal Probability Plot

The normal probability plot of the time that it takes for the experiments to be completed for the auto system is shown in figure 4.13. By analyzing this plot, if we consider the first dot from the left is an outlier we can conclude that normal probability plot follows an S-shape, which means a shorter tail on both sides.

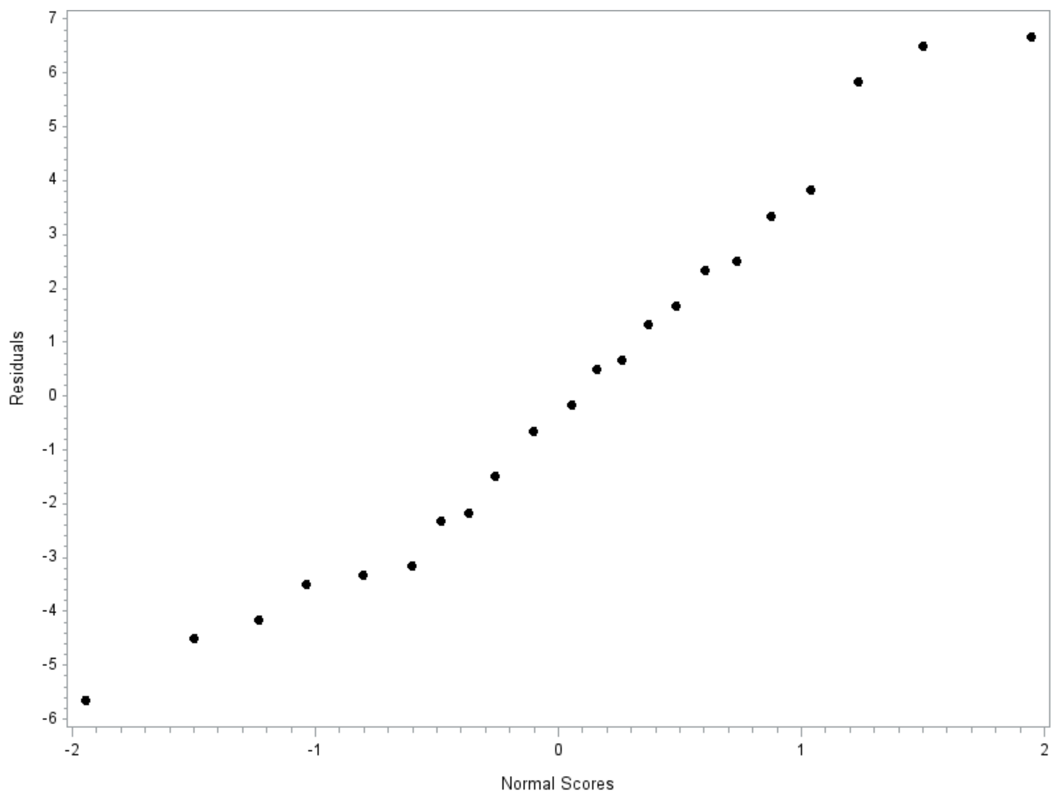

Figure 4.13: Normal Probability Plot for the mean times of completion in auto texting system

Even if the first dot from the left in figure 4.13 is not considered as an outlier, the normality is still violated and is not satisfied.

4.2.2.3 Box Plot

The box plot of the mean times of completion for the auto texting system is shown in figure 4.14. By the analysis of this plot it can be visually inferred that there is not a considerable difference among the means of categories, but in order to confirm this statement, further analysis is required, which is Tukey's test.

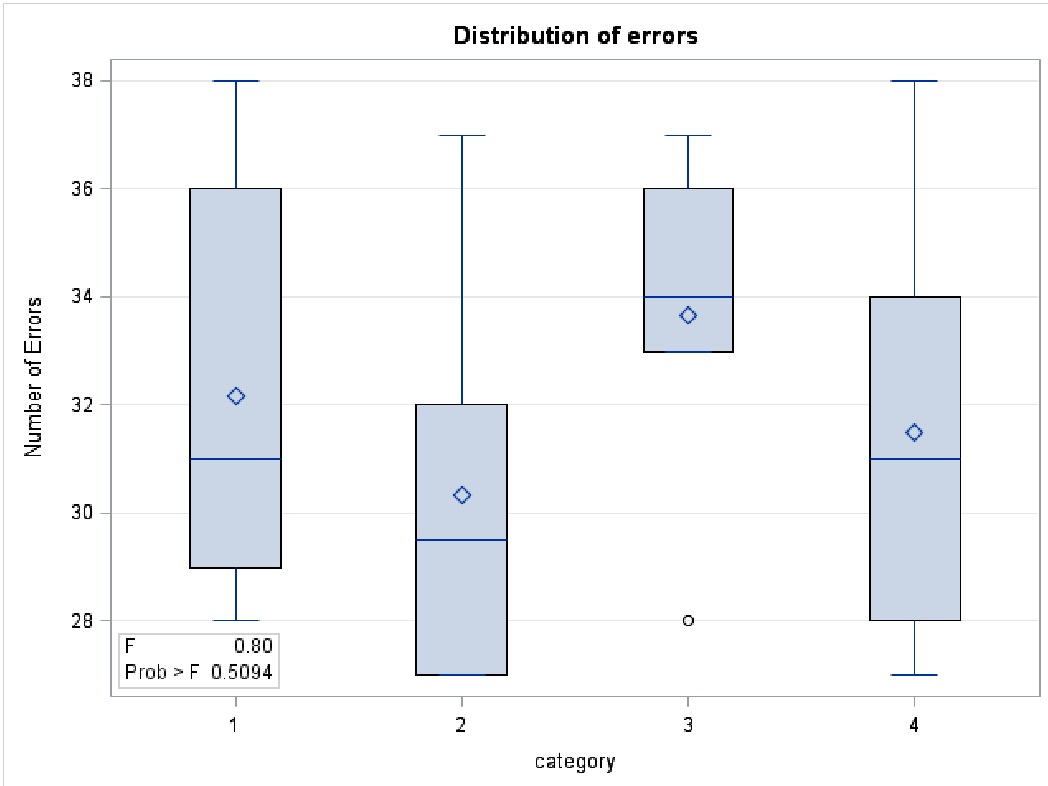

Figure 4.14: Box Plot of the mean times of completion for auto texting system

4.2.2.4 Tukey's Test

The results of Tukey's test are shown in table 4.12. As it was mentioned before, Tukey's is a comparison test to recognize if there is any difference between the means of each category for specified significant level. Comparisons significant at the 0.1 levels are indicated by ***. This test controls the Type I experimentwise error rate.

Table 4.12: Tukey's Test for the mean times of completion for auto texting system

Alpha	0.1
Error Degrees of Freedom	20
Error Mean Square	14.55
Critical Value of Studentized Range	3.46154
Minimum Significant Difference	5.3905

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
3-1	1.500	-3.890	6.890	
3-4	2.167	-3.224	7.557	
3-2	3.333	-2.057	8.724	
1-3	-1.500	-6.890	3.890	
1-4	0.667	-4.724	6.057	
1-2	1.833	-3.557	7.224	
4-3	-2.167	-7.557	3.224	
4-1	-0.667	-6.057	4.724	
4-2	1.167	-4.224	6.557	
2-3	-3.333	-8.724	2.057	
2-1	-1.833	-7.224	3.557	
2-4	-1.167	-6.557	4.224	

From the analysis of this table, it can be inferred that the minimum significance difference for these categories is 5.3905; therefore, if a difference between the means of each category fall beyond this number, it shows that two categories have a significant difference between their means. Table 4.12 shows that at 0.1 significant level, there is no category that has a major difference in means.

4.2.2.5 Residual Plot

The other important plot that should be considered is a residual plot to be sure that we have a constant variance for the data. The residual plot for the number of errors in the manual system is shown in figure 4.15.

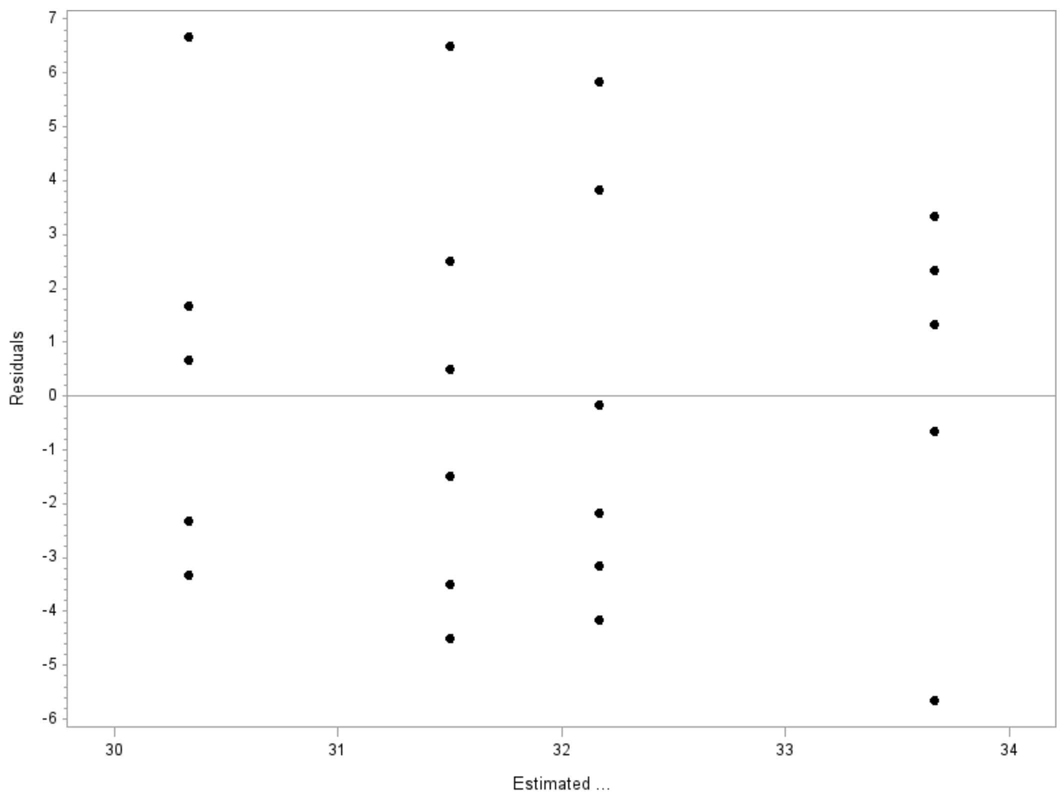

Figure 4.15: Residual Plot for the mean times of completion for auto texting system

As it appears in figure 4.15, there is no funnel shape for the data and also there is no curvature can be considered, therefore by the analysis of this plot, it could be inferred that constant variance is satisfied and no need for transformation.

4.2.2.6 Dot Plot

The last but not the least analysis for this data is a dot plot, which shows the scattering of data on each category. There is not much information to be inferred from this plot but it is important to have it in order to check for outliers and gaps among the data. The dot plot of the mean times of completion for the auto system is shown in figure 4.16. For the following plot, it could be inferred there is no outlier and no gap among the data.

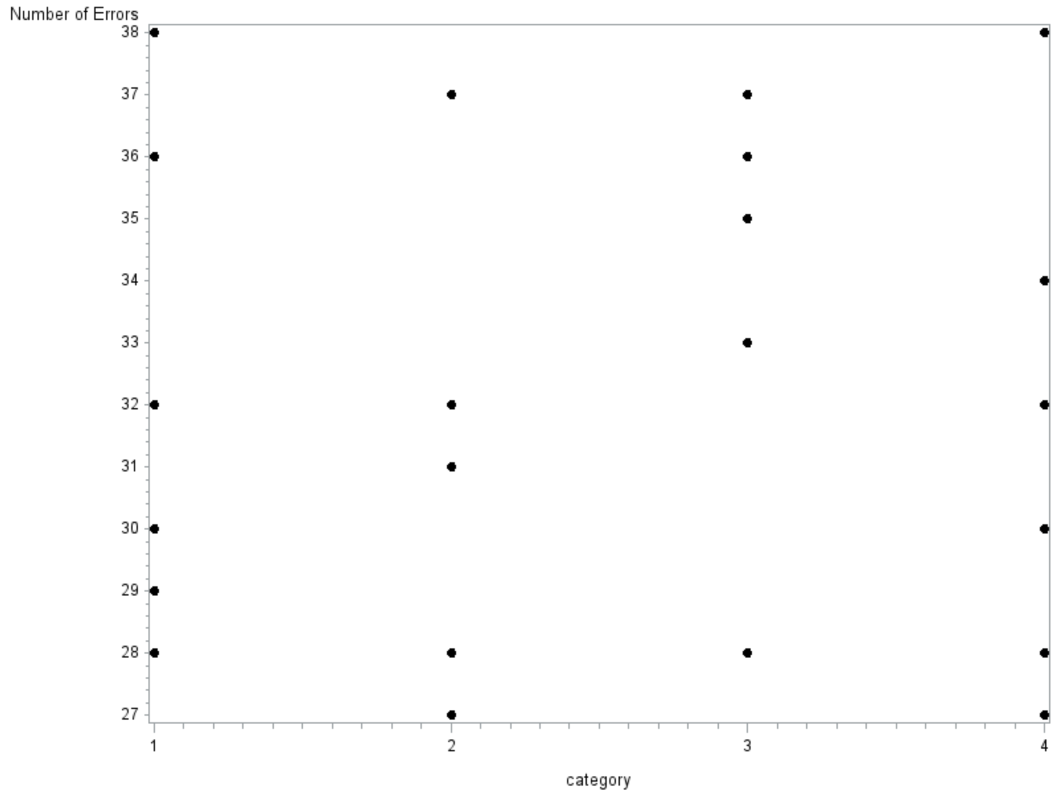

Figure 4.16: Dot Plot for the mean times of completion for auto texting system

4.3 Results for Specific Aim #3

4.3.1 Number of Errors for Manual and Auto System

The data for this aim is exactly the same as the one that is collected for previous aims. It is shown in a single table in order to analyze together and compare two technologies, which are manual texting and auto-texting. All of the errors from manual texting and auto texting are shown in table 4.13.

Table 4.13: Errors of Manual and Auto systems

Row		Categories	Observations					
1	Manual	Time Slot A	3	1	2	1	2	1
2		Time Slot B	2	1	1	2	1	1
3		Time Slot C	0	0	0	1	1	0
4		Time Slot D	1	0	1	1	1	3
5	Auto	Time Slot A	1	0	0	1	1	0
6		Time Slot B	0	0	0	1	0	1
7		Time Slot C	0	0	0	1	0	0
8		Time Slot D	1	0	0	1	1	2

4.3.1.1 ANOVA Table and F-Test:

The ANOVA table for Errors of Manual and Auto system is calculated by SAS and shown in Table 4.14. The P-Value that is calculated in this table is much smaller than the p-value that is considered for F-Test. There are two ways to check our hypothesis, first using F* and second using P-Value. Here we use p-value to check the hypothesis and, because it is less than 0.1, we reject the null hypothesis. The explanation of this hypothesis will be explained in hypothesis section.

Table 4.14: ANOVA table for Errors of Manual and Auto system

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	12.58333333	1.79761905	4.15	0.0016
Error	40	17.33333333	0.43333333		
Corrected Total	47	29.91666667			

4.3.1.2 Normal Probability Plot

The normal probability plot for the Errors of Manual and Auto system is shown in figure 4.17. By analyzing this plot, and the curvature that can be seen, it could be concluded that the normality is not satisfied and it is violated.

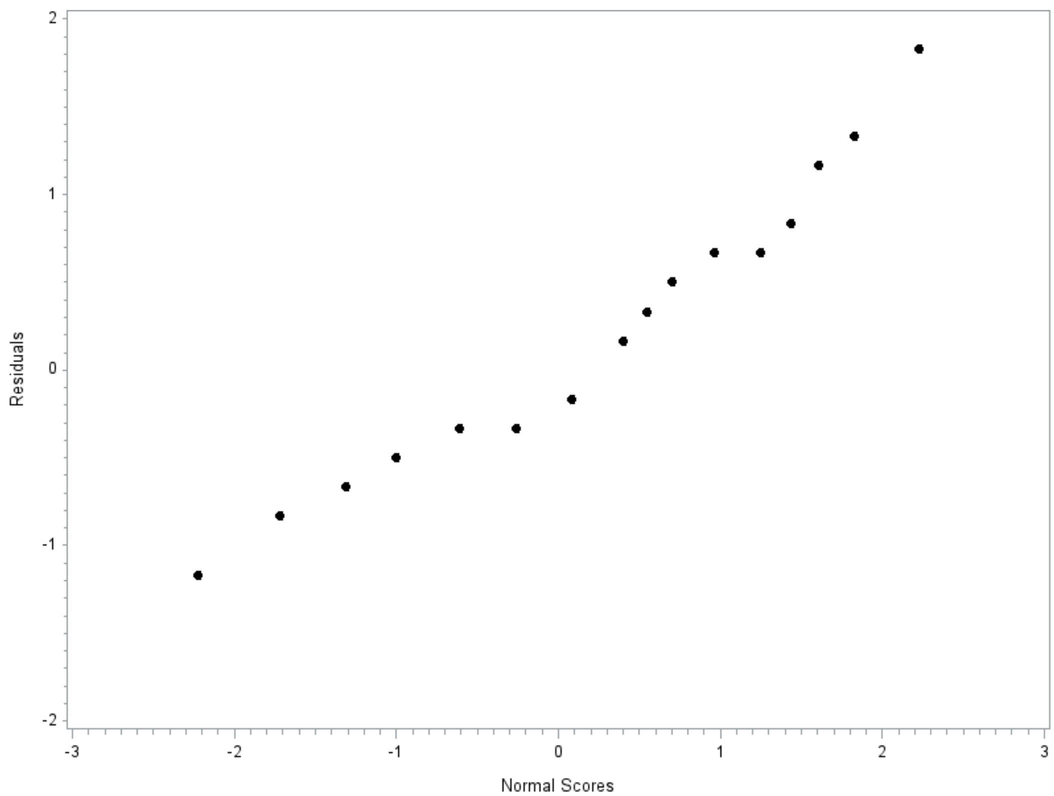

Figure 4.17: Normal Probability Plot for Errors of Manual and Auto system

4.3.1.3 Box Plot

The box plot for the number of errors of manual and auto system is shown in figure 4.18. By the analysis of this plot, it can be visually inferred that there is a considerable difference between the means of category 1 and category 7, category 2 and category 7, category 1 and category 5 and category 1 and category 6. Another analysis that could be explained is that most of the differences are between two systems, which are manual and auto texting, and it means that the difference between means from the four categories shows that the means of errors for two systems are considerable. These are just guesses by visual analysis, in order to confirm this statement, further analysis is required, which is Tukey's test.

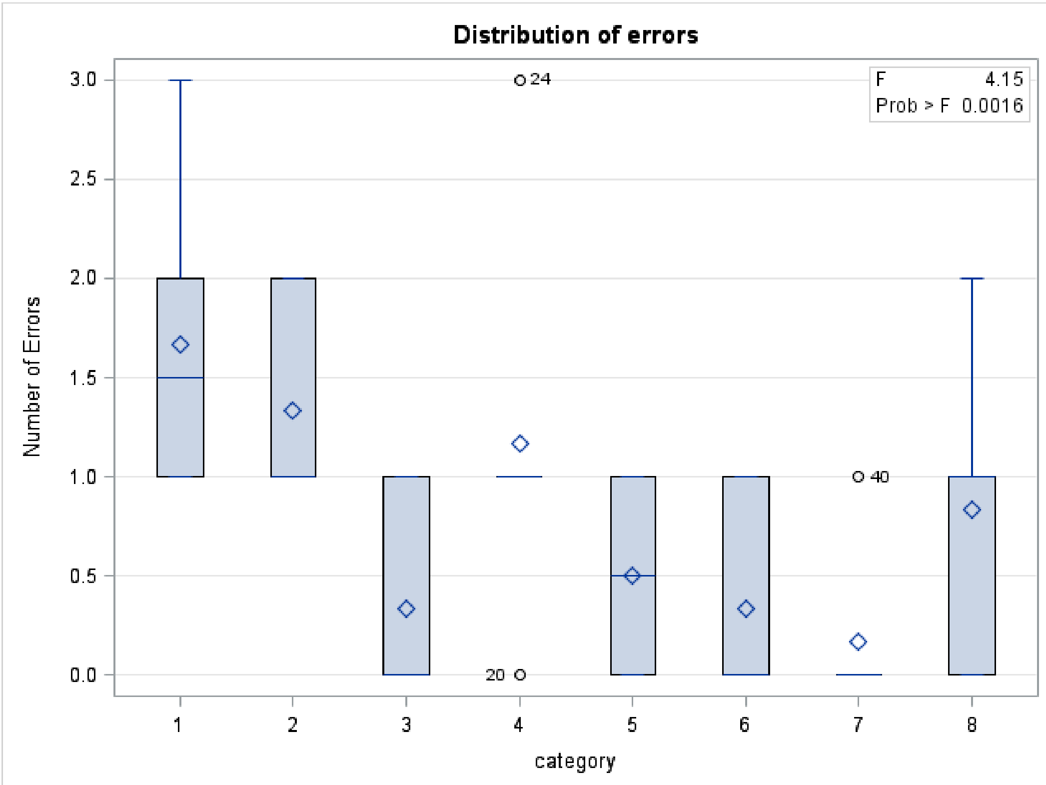

Figure 4.18: Box Plot of the number of errors of manual and auto system

4.3.1.4 Tukey's Test

The results of Tukey's test are shown in table 4.15. As it was mentioned before, Tukey's is a comparison test to recognize if there is any difference between the means of each category for a specified significant level. Comparisons significant at the 0.1 levels are indicated by ***. This test controls the Type I experimentwise error rate.

Table 4.15 shows only categories that have significance difference between their means and the complete table is attached to the appendixes.

Table 4.15: Tukey’s Test for the number of errors of manual and auto system

Alpha	0.1
Error Degrees of Freedom	40
Error Mean Square	0.433333
Critical Value of Studentized Range	4.09852
Minimum Significant Difference	1.1014

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
1-5	1.1667	0.0652	2.2681	***
1-3	1.3333	0.2319	2.4348	***
1-6	1.3333	0.2319	2.4348	***
1-7	1.5000	0.3986	2.6014	***
2-7	1.1667	0.0652	2.2681	***
5-1	-1.1667	-2.2681	-0.0652	***
3-1	-1.3333	-2.4348	-0.2319	***
6-1	-1.3333	-2.4348	-0.2319	***
7-1	-1.5000	-2.6014	-0.3986	***
7-2	-1.1667	-2.2681	-0.0652	***

From the analysis of this table, it can be inferred that the minimum significance difference for these categories is 1.1014; therefore, if a difference between the means of each category fall beyond this number it shows that two categories have significant difference between their means. Table 4.15 shows that at 0.1 significant level, there are multiple categories that have a major difference between their means. The majority of these differences are between two systems, which are manual and auto texting. From these results it can be inferred that there is a significant difference between the means of errors in the manual and auto systems.

4.3.1.5 Residual Plot

The other important plot that should be considered is a residual plot to be sure that we have a constant variance for the data. The residual plot for the number of errors in the manual system is shown in figure 4.19.

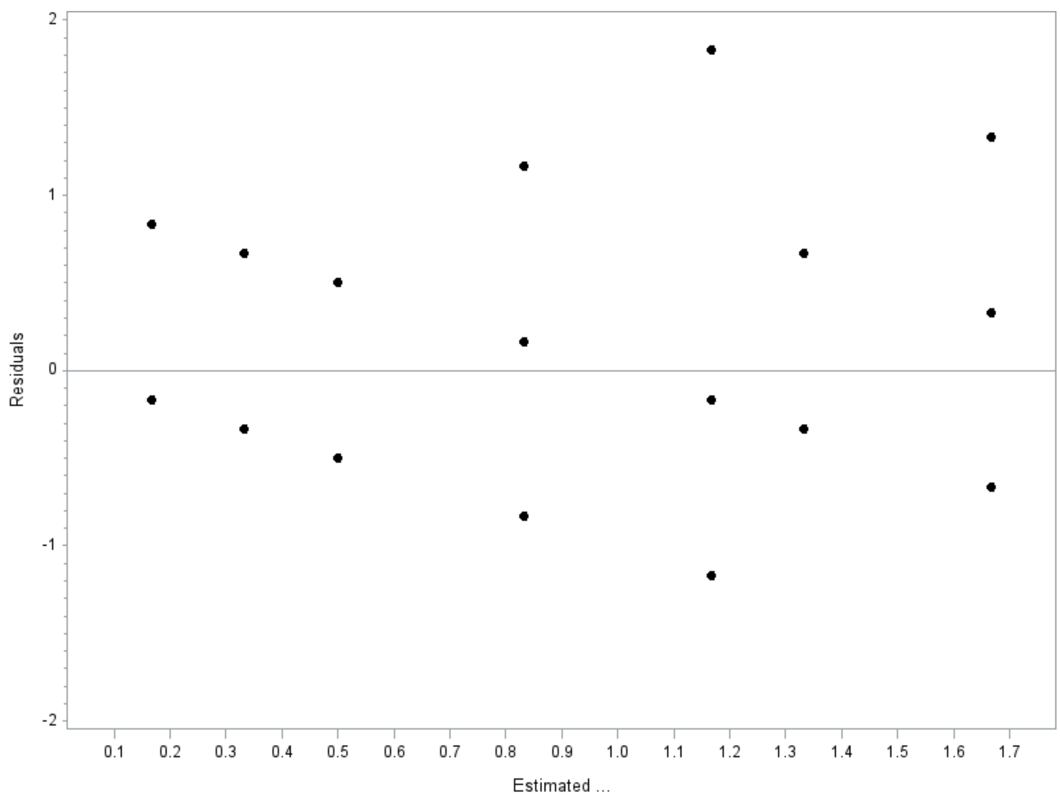

Figure 4.19: Residual Plot for the mean times of completion for manual and auto texting system

It seems that we have a funnel shape for the residual plot, in order to test the constant variance we use Modified-Leven test and the results are shown in table 4.16

4.3.1.6 Modified-Levene test

Modified-Levene test is used to check whether the variances of the samples increase or decrease. For conducting the “Modified-Levene” test, we should first divide the data in to groups of same population. In this research, the data are divided in two groups of 24, which are manual versus auto. The results are shown in table 4.16. Since $\alpha = 0.1$ and the p-value is 0.4771, which is greater than α Hence, it can be concluded that we are in an equal variance situation and should use equal variance t-test. The computed P-value for T-test is presented in Table 4.16, in which for equal t-test is p=0.6442. Since we fail to reject H_0. It means that we can say that our constant variance assumption is not violated or test fails to detect non-constant variance assumption.

Table 4.16: F-Test and T-Test for Modified-Levene test for the number of errors of manual and auto system

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	23	23	1.35	0.4771

group	N	Mean	Std Dev	Std Err	Minimum	Maximum
1	24	0.5784	0.5678	0.1159	0.0734	2.2202
2	24	0.5073	0.4887	0.0997	0.0734	2.0734
Diff (1-2)		0.0711	0.5297	0.1529		

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	46	0.46	0.6442
Satterthwaite	Unequal	45	0.46	0.6442

As it appears in figure 4.19, there is no curvature and also regarding to the Modified-Leven test constant variance is satisfied therefore it could be inferred that constant variance is satisfied and no need for transformation.

4.3.1.7 Dot Plot

The last but not least analysis for this data is a dot plot, which shows the scattering of data on each category. There is not much information to be inferred from this plot but it is important to have it in order to check for outliers and gaps among the data. The dot plot for the number of errors of the manual and auto systems is shown in figure 4.20. For the following plot, it could be inferred there is no outlier and no gap among the data.

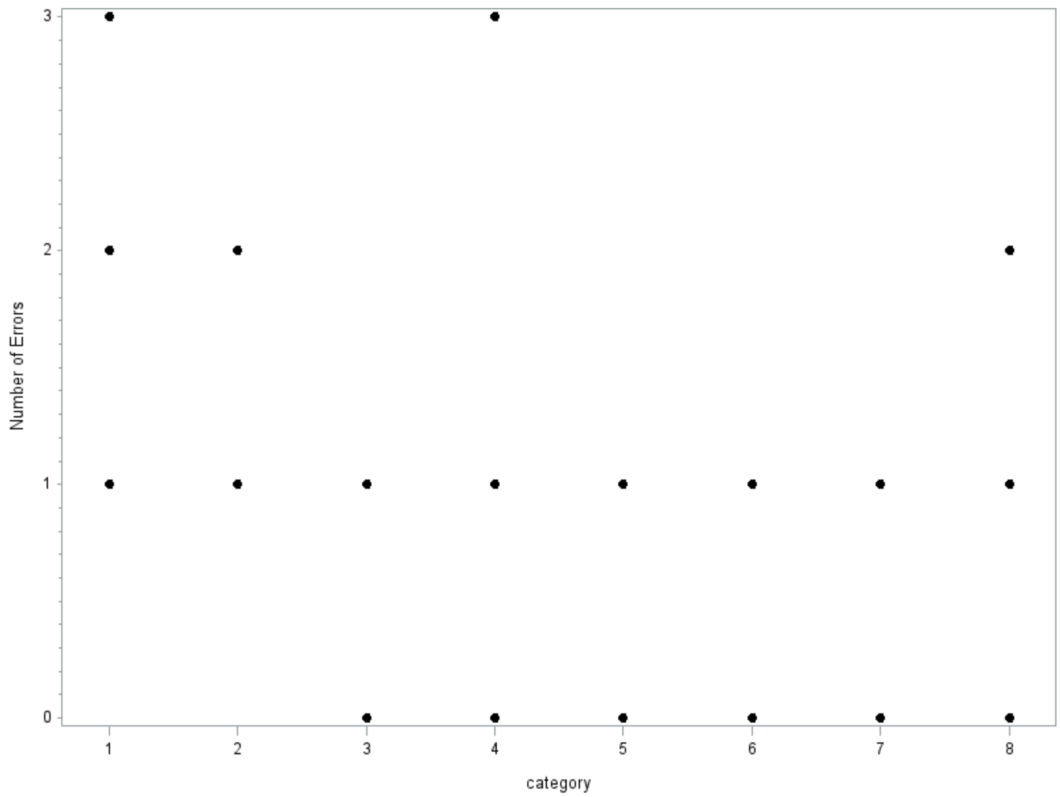

Figure 4.20: Dot Plot for the number of errors of manual and auto system

4.3.2 Times of Completion For Manual and Auto System

The time that it takes for each experiment to be completed for both manual and auto-texting is shown in table 4.17 and the units for this table is in seconds.

Table 4.17: Time of Manual and Auto system in seconds

Row	Categories		Observations (Seconds)					
1	Manual	Time Slot A	480	1320	1080	1320	780	1080
2		Time Slot B	1080	1260	600	1620	660	1020
3		Time Slot C	1260	840	1560	1500	1800	1320
4		Time Slot D	1020	780	1020	480	1080	780
5	Auto	Time Slot A	36	38	29	30	32	28
6		Time Slot B	37	27	28	31	32	27
7		Time Slot C	33	36	35	37	33	28
8		Time Slot D	28	30	34	38	32	27

4.3.2.1 ANOVA Table and F-Test:

The ANOVA table for the mean times of completion for the manual and auto systems is calculated by SAS and shown in Table 4.18. The P-Value that is calculated in this table is much smaller than the p-value that is considered for the F-Test. There are two ways to check our hypothesis, first using the F* and second using the P-Value, here we use the p-value to check the hypothesis and, because it is less than 0.1, we reject the null hypothesis, and the explanation of this hypothesis will be explained in hypothesis section.

Table 4.18: ANOVA table for the mean times of completion for manual and auto system

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	13861848.92	1980264.13	38.63	<.0001
Error	40	2050491	51262.28		
Corrected Total	47	15912339.92			

4.3.2.2 Normal Probability Plot

The normal probability plot of the mean times of completion for the manual and auto systems is shown in figure 4.21. By analyzing this plot, it can be easily concluded that the normality is not satisfied and it is violated.

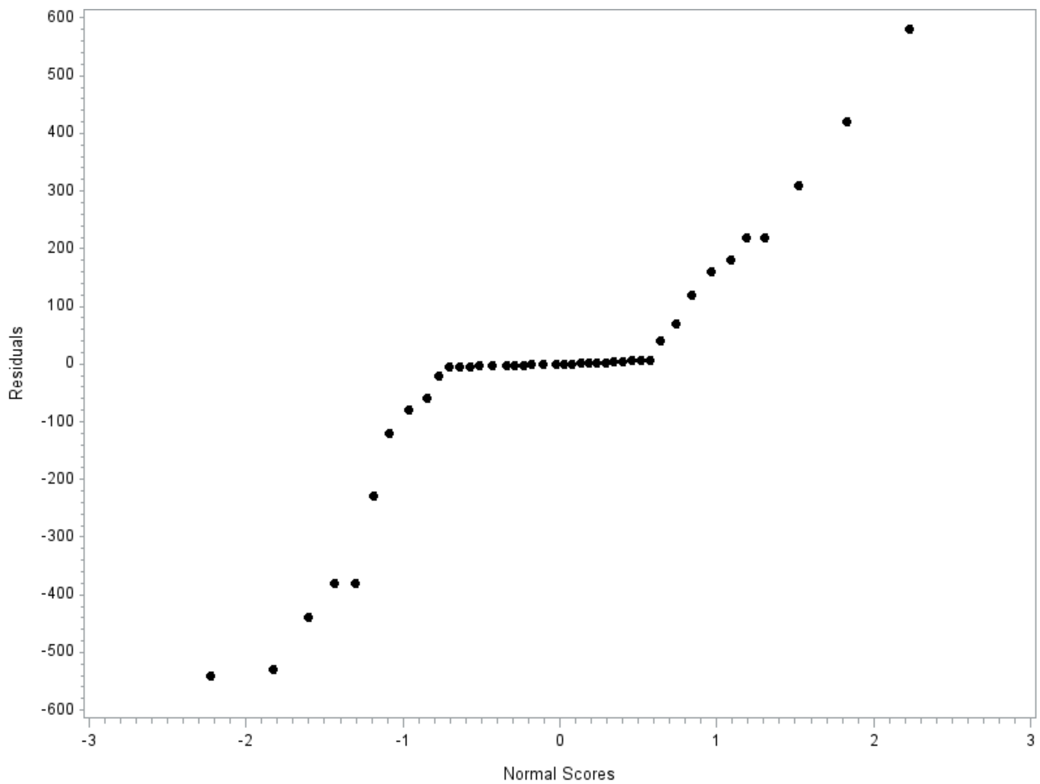

Figure 4.21: Normal Probability Plot for mean times of completion for manual and auto system

Although the normality is violated, it is not required assumption and it is not necessary for any kind of transformation.

4.3.2.3 Box Plot

The box plot of the mean times of completion for the manual and auto systems is shown in figure 4.22. By the analysis of this plot, it can be visually inferred that there is a significant difference between the mean times of completion for the first four categories with the last four categories. In other words there is a significant difference between the mean times of completions for the two systems. It can be also inferred that the mean times that it takes for the experiment for the manual system is much higher than the auto system. These are just guesses by visual analysis, and in order to confirm this statement, further analysis is required, which is done with Tukey's test

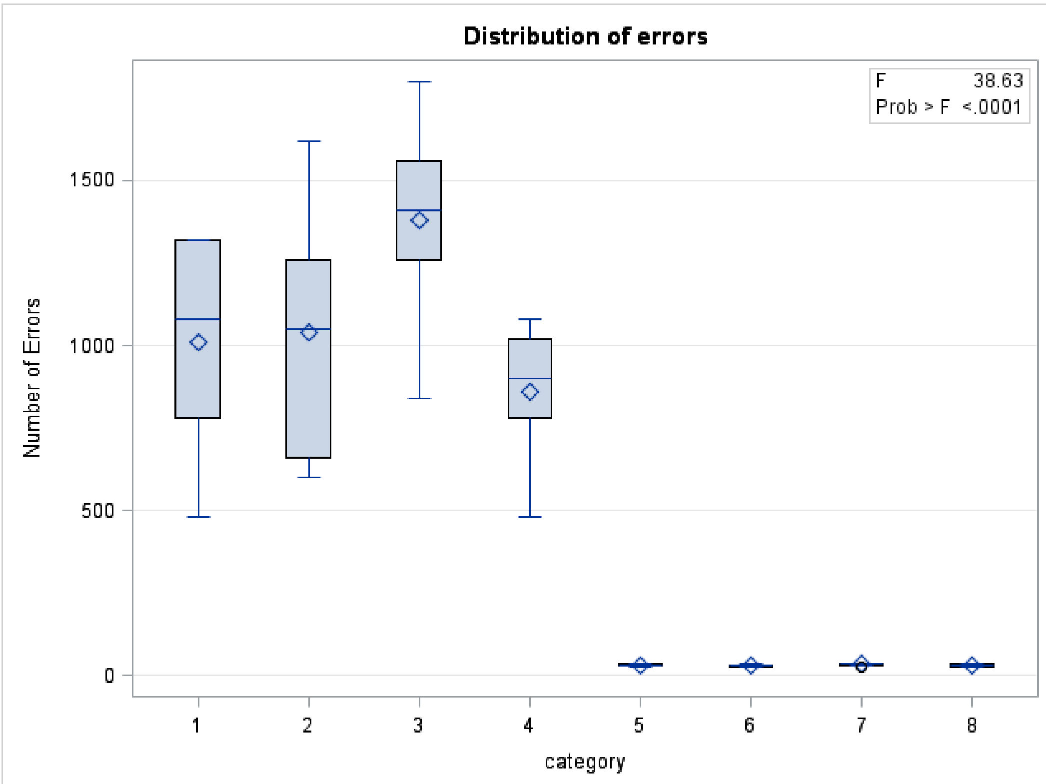

Figure 4.22: Box Plot of the mean times of completion for the manual and auto system

4.3.2.4 Tukey's Test

The results of Tukey's test are shown in table 4.19. As it mentioned before, Tukey's is a comparison test to recognize if there is any difference between the means of each category for specified significant level. Comparisons significant at the 0.1 levels are indicated by ***. This test controls the Type I experimentwise error rate. Table 4.19 shows only categories that have a significance difference between their means and also avoided repetitive rows. The complete table is attached to the appendixes.

Table 4.19: Tukey's Test for the mean times of completion of manual and auto system

Alpha	0.1
Error Degrees of Freedom	40
Error Mean Square	51262.28
Critical Value of Studentized Range	4.09852
Minimum Significant Difference	378.84

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
3-4	520.0	141.2	898.8	***
3-7	1346.3	967.5	1725.2	***
3-5	1347.8	969.0	1726.7	***
3-8	1348.5	969.7	1727.3	***
3-6	1349.7	970.8	1728.5	***
2-7	1006.3	627.5	1385.2	***
2-5	1007.8	629.0	1386.7	***
2-8	1008.5	629.7	1387.3	***
2-6	1009.7	630.8	1388.5	***
1-7	976.3	597.5	1355.2	***
1-5	977.8	599.0	1356.7	***
1-8	978.5	599.7	1357.3	***
1-6	979.7	600.8	1358.5	***
4-3	-520.0	-898.8	-141.2	***
4-7	826.3	447.5	1205.2	***
4-5	827.8	449.0	1206.7	***
4-8	828.5	449.7	1207.3	***
4-6	829.7	450.8	1208.5	***

From the analysis of this table, it can be inferred that the minimum significance difference for these categories is 378.84; therefore, if a difference between the means of each category fall beyond this number it shows that two categories have significant difference between their means. Table 4.19 shows that at 0.1 significant level, there are multiple categories that have a major difference between their means. The majority of these differences are between two systems, which are manual and auto texting. From these results it can be inferred that there is a significant difference between the means of errors in the manual and auto systems.

4.3.2.5 Residual Plot

The other important plot that should be considered is a residual plot, to be sure that we have a constant variance for the data. The residual plot for the mean times of completion of the manual and auto systems is shown in figure 4.23.

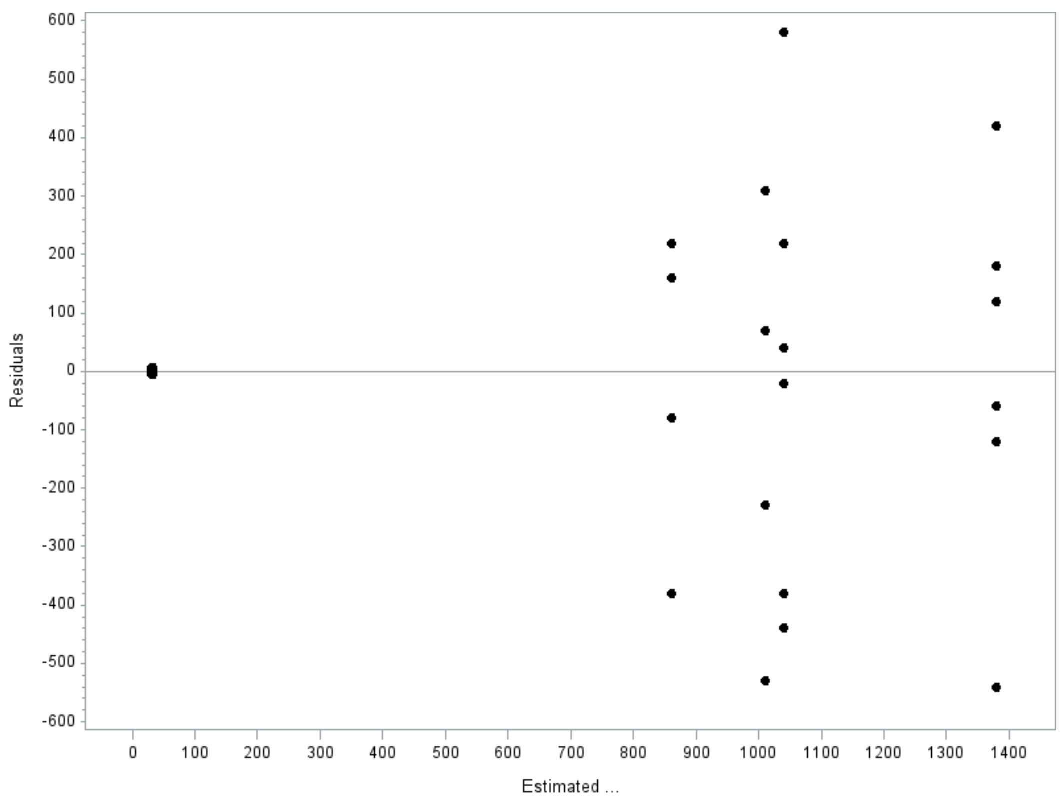

Figure 4.23: Residual Plot for the mean times of completion of manual and auto system

It seems that we have non-constant variance, in order to test the constant variance we use Modified-Leven test and the results are shown in table 4.20

4.3.2.6 Modified-Levene test

Modified-Levene test is used to check whether the variances of the samples increase or decrease. For conducting the "Modified-Levene" test, we should first divide the data in to groups of same population. In this research, the data are divided in two groups of 24, which are manual versus auto.

Table 4.20: F-Test and T-Test for Modified-Levene test for the mean times of completions for manual and auto system

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	23	23	6.08	<.0001

Group	N	Mean	Std Dev	Std Err	Minimum	Maximum
1	24	327.1	248.9	50.7994	29.25	869.3
2	24	200.2	100.9	20.604	95.25	304.8
Diff (1-2)		127	189.9	54.8188		

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	46	2.32	0.0251
Satterthwaite	Unequal	30.368	2.32	0.0275

The results are shown in table 4.20. Since $\alpha = 0.1$ and the p-value is less than 0.0001, which is obviously less than α Hence, it can be concluded that we are in an unequal variance situation and should use unequal variance t-test. The computed P-value for T-test is presented in Table 4.20, in which for unequal t-test is p=0.0251. Since we reject H_0. It means that we can say that our constant variance assumption is violated or test detects non-constant variance assumption.

4.3.2.7 Dot Plot

The last but not least analysis for this data is a dot plot, which shows the scattering of data on each category. There is not much information to be inferred from this plot but it is important to have it in order to check outliers and gaps among the data.

The dot plot of the mean times of completion of manual and auto systems is shown in figure 4.24.

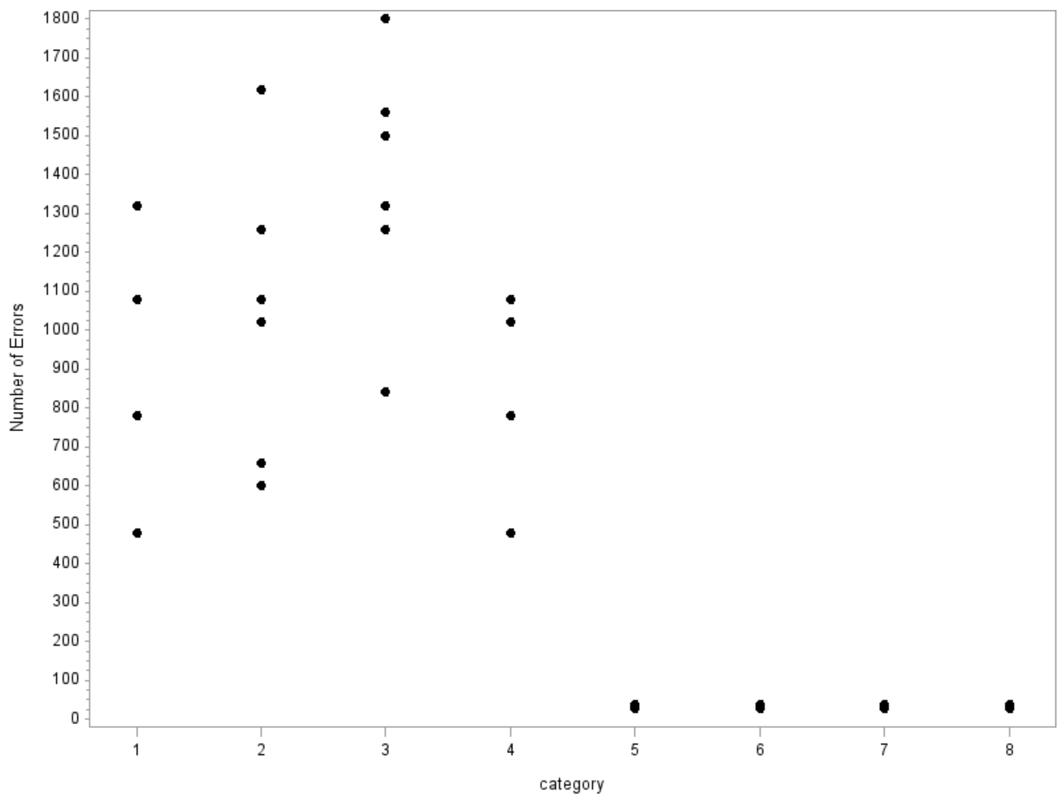

Figure 4.24: Dot Plot for the mean times of completion of manual and auto system

<u>4.4 Hypothesis results</u>

Based on the results of each Specific Aim, hypothesis tests now have all the requirements to be tested. The explanation for each individual aim is provided in the following.

4.4.1 Specific Aim #1

4.4.1.1 Hypothesis Result for the Number of Errors in Manual System

Regarding to the results and analysis for the aim #1 and the first hypothesis that is stated for this aim, about the mean number of errors for each time slot in manual system, we reject the null hypothesis because the P-Value that is calculated is 0.0325 in table 4.2 is less than the P-Value that is considered for this study, which is 0.1. Results show that not all means of errors are equal in each time slot. Many things could cause this variation between the means, for instance one guess for high errors in time slot A could be drowsiness or another guess for having low errors in time slot C could be that the experimenter just ate meals and they are fresh to work.

4.1.1.2 Hypothesis Result for the Times of Completion in Manual System

The second hypothesis for this aim is about testing the mean times of completion in each time slot. We reject the null hypothesis because the P-Value that is calculated 0.065 in table 4.5 is less than the P-Value that is considered for this study, which is 0.1. Results show that not all of means of times to complete the experiments are equal in each time slot.

4.4.2 Specific Aim #2

4.4.2.1 Hypothesis Result for the Number of Errors in Auto System

The first hypothesis for aim #2 is about the difference between the mean numbers of errors in auto texting system. According to the results and analysis for this Specific Aim we fail to reject the null hypothesis because the P-Value that is calculated 0.2461 in table 4.8 is greater than the P-Value that is considered for this study, which is 0.1. Results show that the means of errors have no difference in each time slot for the auto system.

4.4.2.2 Hypothesis Result for the Times of Completion in Auto System

The second hypothesis for this aim is about to check if there is nay difference between the mean times of completion for auto system in each time slot. We fail to reject the null hypothesis because the P-Value that is calculated in table 4.11 0.5094 is greater than the P-Value that is considered for this study, which is 0.1. Results show that the means of times to complete each experiment have no difference in each time slot for the auto system.

4.4.3 Specific Aim #3

4.4.3.1 Hypothesis Result for the Number of Errors in Manual and Auto System

The last but not least aim for this research is evaluating the manual texting versus auto-texting. As it was stated before, the first hypothesis of this aim is to compare the mean number of errors for each system and based on the results and analysis that is addressed in previous section, we reject the null hypothesis because the P-Value that is calculated is 0.0016 in table 4.14 and is less than the P-Value that is considered for this study, which is 0.1. It can be concluded that not all of means of errors are equal in each category. By analyzing the results from Tukey's test, we conclude that except for one category, all other categories that have a different mean for errors are dedicated to different systems, for example we have a major difference between the means of error for category 5 and category 1, with category one dedicated to manual system and category 5 dedicated to auto system, therefore it can be concluded that auto-texting using RFID technology can reduce human errors for hospital operations.

4.4.3.2 Hypothesis Result for the Times of Completion in Manual and Auto System

For the second hypothesis of this aim, which is comparing the mean times of completion for each system, we reject the null hypothesis because we have very small P-Value in table 4.17, which is less than 0.0001, and it is obviously smaller than the P-Value that is considered for this study, which is 0.1.

It can be concluded that not all of the means of times that it takes for the experiments to be completed are equal in each category. By analyzing the results from Tukey's test, we conclude that except for one category, all other categories that have a different means for completion are dedicated to different systems, for example we have a major difference between the means of completion for category 1 and category 7, with category one dedicated to manual system and category 7 dedicated to auto system, therefore it can be concluded that auto-texting improves the process of texting in hospital operations effectively.

CHAPTER 5

CONCLUSIONS

We met the specific aim #1 step 1 by investigating the research hypothesis that there is a significant difference between the means of human error for each time slot. The result is that we rejected the null hypothesis and could not reject our alternate hypothesis. This means that the time of day had an impact. Specifically results indicate that the after lunch times (1pm-3pm) had better performance for the manual systems.

We met the specific aim #1 step 2 by investigating the research hypothesis that there is a significant difference between the means of mean times of completion for each time slot. The result is that we rejected the null hypothesis and could not reject our alternate hypothesis. This means that the time of day had an impact.

We met the specific aim #2 step 1 by investigating the research hypothesis that there is a significant difference between the means of auto system error for each time slot. The result is that we failed to reject the null hypothesis. This means that the time of day had no impact for auto system.

We met the specific aim #2 step 2 by investigating the research hypothesis that there is a significant difference between the mean times of completion for each time slot. The result is that we failed to reject the null hypothesis. This means that the time of day had no impact on auto system.

We met the specific aim #3 step 1 by investigating the research hypothesis that there is a significant difference between the means of errors from manual texting and auto-texting. The result is that we rejected the null hypothesis and could not reject our alternate hypothesis. This means that auto-texting had an impact and could make the process more reliable.

We met the specific aim #3 step 2 by investigating the research hypothesis that there is a significant difference between the mean times of completion for each system. The result is that we rejected the null hypothesis and could not reject our alternate hypothesis. This means that auto texting had huge impact on the means of completion of the process.

Patient safety is a growing anxiety in health care due to the fact there is an increasing number of medical errors. This research proposes a unique approach that decreases medical errors in hospital operating rooms using an RFID-based technology to alert doctors and nurses when the wrong tool enters to the operating area, via text message. The goal is to develop a methodology that measures parameters, which determine reliability and effectiveness of automated texting technologies. Results show that the reliability and effectiveness of auto-texting is higher than manual texting for hospital operations.

5.1 Limitations

Although the research has reached its aims, there were some limitations for this research. First of all, the reader that was used for auto texting is not equipped with a software that could generate a text message, therefore it is assumed that the reader sends text messages by 100 percent accuracy. In this research, we tried to simulate the actual environment, but it was not completely the same setting. Accordingly, the other limitation was running the experiment with actual tools and an operating room environment.

5.2 Contribution to the body of knowledge

There is a very limited research on the impact of texting in comparison to other automation technologies. People are looking at texting as a social means but not necessarily a means for efficiency. We are contributing as an alternate inventory control process. We are enhancing RFID automation with texting and our contribution is modernizing RFID by combining it with additional technology, which is text messaging.

5.3 Future Work

The work performed in this research provides basis for future research in several areas. At least two such areas can be identified. These areas are as follow:

5.3.1 Network Free

One of the important areas for future work is to employ a method other than text messaging to alert nurses because this method highly depends on the service provider. In some situations, because of the high network traffic, the text message will not deliver and it could cause a problem. One solution for this problem is to design an application for smart phones to notify the nurses by a push notification center that is designed for these devices. This method works as long as the user accesses to the Internet. Since smart phones are growing more and more, this area could be a hot topic for future work.

5.3.2 Hospital Management

The other area that could be considered for future work is implementing an auto text message system, not only for operating rooms, but for all sections of hospitals as well. After interviewing with anesthesiologists of University of Texas Southwestern, they declared that texting within the organization occurs a lot and they are looking for some solutions to automate some of these texts. For instance, the current process of informing physicians for the availability of lab results is that the laboratory sends a text to the nurses that the lab results are ready, then the nurse will inform the physician via text message that lab results are prepared. This process is not an efficient way and most of the times it’s annoying based on the anesthesiologists opinion.

APPENDIX A

COMPLETE TABLES OF TUKEY’S TEST

Alpha	0.1
Error Degrees of Freedom	40
Error Mean Square	0.433333
Critical Value of Studentized Range	4.09852
Minimum Significant Difference	1.1014

Category Comparison	**Difference Between Means**	**Simultaneous 90% Confidence Limits**		
1-2	0.3333	-0.7681	1.4348	
1-4	0.5000	-0.6014	1.6014	
1-8	0.8333	-0.2681	1.9348	
1-5	1.1667	0.0652	2.2681	***
1-3	1.3333	0.2319	2.4348	***
1-6	1.3333	0.2319	2.4348	***
1-7	1.5000	0.3986	2.6014	***
2-1	-0.3333	-1.4348	0.7681	
2-4	0.1667	-0.9348	1.2681	
2-8	0.5000	-0.6014	1.6014	
2-5	0.8333	-0.2681	1.9348	
2-3	1.0000	-0.1014	2.1014	
2-6	1.0000	-0.1014	2.1014	
2-7	1.1667	0.0652	2.2681	***
4-1	-0.5000	-1.6014	0.6014	
4-2	-0.1667	-1.2681	0.9348	
4-8	0.3333	-0.7681	1.4348	
4-5	0.6667	-0.4348	1.7681	
4-3	0.8333	-0.2681	1.9348	
4-6	0.8333	-0.2681	1.9348	
4-7	1.0000	-0.1014	2.1014	
8-1	-0.8333	-1.9348	0.2681	
8-2	-0.5000	-1.6014	0.6014	
8-4	-0.3333	-1.4348	0.7681	

8-5	0.3333	-0.7681	1.4348	
8-3	0.5000	-0.6014	1.6014	
8-6	0.5000	-0.6014	1.6014	
8-7	0.6667	-0.4348	1.7681	
5-1	-1.1667	-2.2681	-0.0652	***
5-2	-0.8333	-1.9348	0.2681	
5-4	-0.6667	-1.7681	0.4348	
5-8	-0.3333	-1.4348	0.7681	
5-3	0.1667	-0.9348	1.2681	
5-6	0.1667	-0.9348	1.2681	
5-7	0.3333	-0.7681	1.4348	
3-1	-1.3333	-2.4348	-0.2319	***
3-2	-1.0000	-2.1014	0.1014	
3-4	-0.8333	-1.9348	0.2681	
3-8	-0.5000	-1.6014	0.6014	
3-5	-0.1667	-1.2681	0.9348	
3-6	0.0000	-1.1014	1.1014	
3-7	0.1667	-0.9348	1.2681	
6-1	-1.3333	-2.4348	-0.2319	***
6-2	-1.0000	-2.1014	0.1014	
6-4	-0.8333	-1.9348	0.2681	
6-8	-0.5000	-1.6014	0.6014	
6-5	-0.1667	-1.2681	0.9348	
6-3	0.0000	-1.1014	1.1014	
6-7	0.1667	-0.9348	1.2681	
7-1	-1.5000	-2.6014	-0.3986	***
7-2	-1.1667	-2.2681	-0.0652	***
7-4	-1.0000	-2.1014	0.1014	
7-8	-0.6667	-1.7681	0.4348	
7-5	-0.3333	-1.4348	0.7681	
7-3	-0.1667	-1.2681	0.9348	
7-6	-0.1667	-1.2681	0.9348	

Alpha	0.1
Error Degrees of Freedom	40
Error Mean Square	51262.28
Critical Value of Studentized Range	4.09852
Minimum Significant Difference	378.84

Category Comparison	Difference Between Means	Simultaneous 90% Confidence Limits		
3-2	340.0	-38.8	718.8	
3-1	370.0	-8.8	748.8	
3-4	520.0	141.2	898.8	***
3-7	1346.3	967.5	1725.2	***
3-5	1347.8	969.0	1726.7	***
3-8	1348.5	969.7	1727.3	***
3-6	1349.7	970.8	1728.5	***
2-3	-340.0	-718.8	38.8	
2-1	30.0	-348.8	408.8	
2-4	180.0	-198.8	558.8	
2-7	1006.3	627.5	1385.2	***
2-5	1007.8	629.0	1386.7	***
2-8	1008.5	629.7	1387.3	***
2-6	1009.7	630.8	1388.5	***
1-3	-370.0	-748.8	8.8	
1-2	-30.0	-408.8	348.8	
1-4	150.0	-228.8	528.8	
1-7	976.3	597.5	1355.2	***
1-5	977.8	599.0	1356.7	***
1-8	978.5	599.7	1357.3	***
1-6	979.7	600.8	1358.5	***
4-3	-520.0	-898.8	-141.2	***
4-2	-180.0	-558.8	198.8	
4-1	-150.0	-528.8	228.8	
4-7	826.3	447.5	1205.2	***
4-5	827.8	449.0	1206.7	***
4-8	828.5	449.7	1207.3	***

4-6	829.7	450.8	1208.5	***
7-3	-1346.3	-1725.2	-967.5	***
7-2	-1006.3	-1385.2	-627.5	***
7-1	-976.3	-1355.2	-597.5	***
7-4	-826.3	-1205.2	-447.5	***
7-5	1.5	-377.3	380.3	
7-8	2.2	-376.7	381.0	
7-6	3.3	-375.5	382.2	
5-3	-1347.8	-1726.7	-969.0	***
5-2	-1007.8	-1386.7	-629.0	***
5-1	-977.8	-1356.7	-599.0	***
5-4	-827.8	-1206.7	-449.0	***
5-7	-1.5	-380.3	377.3	
5-8	0.7	-378.2	379.5	
5-6	1.8	-377.0	380.7	
8-3	-1348.5	-1727.3	-969.7	***
8-2	-1008.5	-1387.3	-629.7	***
8-1	-978.5	-1357.3	-599.7	***
8-4	-828.5	-1207.3	-449.7	***
8-7	-2.2	-381.0	376.7	
8-5	-0.7	-379.5	378.2	
8-6	1.2	-377.7	380.0	
6-3	-1349.7	-1728.5	-970.8	***
6-2	-1009.7	-1388.5	-630.8	***
6-1	-979.7	-1358.5	-600.8	***
6-4	-829.7	-1208.5	-450.8	***
6-7	-3.3	-382.2	375.5	
6-5	-1.8	-380.7	377.0	
6-8	-1.2	-380.0	377.7	

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BIOGRAPHICAL INFORMATION

Hamid Ghoraishi, raised in Iran, graduated in 2000 from Pooyandegan High school. He entered Najafabad University in 2001 and started studying Industrial Engineering with the emphasis in Industrial Production. He graduated in 2005 and he began working in one of the famous companies in producing power plant components as a project manger. He worked for three years and then he immigrated to United States of America. He started his Masters degree in Industrial Engineering at University of Texas at Arlington in 2011. During his Masters degree he got an Industrial Engineering Honor Society (Alpha Pi Mu) and also the Engineering Honor Society (Tau Beta Pi) membership. He graduated in 2013 and because of his achievements in designing applications for smart phones he was hired in one of the large companies for online flight reservations as a software developer.