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REPORT

Effects of Two Commercial Electronic Prescribing Systems on Prescribing Error Rates in Hospital In-Patients: A Before and After Study

1. Introduction

Prescribing errors are considered the most prevalent type of medical error in both primary and secondary healthcare services. In the US alone, medication errors accounts for at least one death per day and injures 1.3 million people annually. (U.S. Food and Drug Administration, 2009) Common causes of medication errors includes poor communication between actors, illegible medical writing from practitioners and poor work flow procedures.

These errors can be significantly reduced by electronic prescribing system with inbuilt decision support, electronic medication administration records, automated pharmacy systems, electronic discharge prescriptions and targeted patient information (Campbell, 2006). There is significant potential gains of adopting electronic prescribing system with decision support helping to reduce serious medication errors by 88% and saved $5-$10m each year. (Nick *et al,* 2006)

With the predominant adoption of e-prescribing system in all hospitals, it is important to evaluate its effectiveness via appropriate evaluation metrics. While ensuring the various benefits e-prescribing system has promised to deliver, it is also important to understand how the system can be implemented to in health-care setting to serve the best needs of hospitals, patients and healthcare services as a whole.

The main purpose of this research paper is to measure the effectiveness of two common e-prescribing systems in decreasing prescribing error rates and their tendencies for introducing new types of error. This research paper provides a unique perspective on how commercial e-prescribing system can assure patient safety in the hospital setting and how work practice of end-users can be associated with its effectiveness. However, as demonstrated from other studies (Nick *et al*, 2006), successful implementation of e-prescribing system depends on contextual and organizational factors such as work practices changes. More importantly, system design need to continually monitor and better refined to better suit the needs of end users in the long run.

2. Methodology

The research team conducted a pre- and post- study at two Australian teaching hospitals. Hospital A consisted of one intervention and three control wards. The Cerner Millennium e-prescribing system was implemented in Hospital A's invention ward. On the other hand, Hospital consisted of only two intervention wards with iSoft MedChart system implemented in both wards. A medication chart audit was done based on 3,291 admissions, with 1,923 at baseline and 1,368 post e-prescribing system. This audit is solely performed by three pharmacists independent to the hospitals.

2.1 Data Collection

Retrieval of inpatient medication charts took place in Hospital A between May - August 2006 and May-August 2008 for pre and post implementation of e-prescribing system respectively. Whereas for Hospital B, data collection took place between November 2007 - March 2008 and March 2008 - February 2010 for pre and post system introduction respectively. There were several delays in data collection for Hospital B due to system implementation and approval of human research ethics.

2.2 Error Classification

Based on the research study performed, the team had classified the errors into procedural clinical errors. Upon further study by the research team, the prescribing error collected from intervention wards were then further classified and assessed whether they were caused by issues revolving around system design.

2.2.1 Clinical Error

The US Institute of Medicine's report (Kohn *et al,* 1999) defined clinical error as 'the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim'. In essence, clinical errors can arise during the execution stage. Examples of such errors outlined in the research report includes wrong drug, wrong dose, by the wrong route of administration, with the wrong frequency and to the wrong patient. Such errors will impose serious consequences in intensive care units and operating rooms.

2.2.2 Procedural Error

In this study, the research team defined procedural error as unclear, incomplete order and illegible procedures. Such errors can happen when the medical practitioner made illegible writings or omit necessary drug information when administering drugs.

2.2.3 System-Related Prescribing Error

Poor system design or functionality can contribute to system-related prescribing errors by clinical manifestation. Example of these errors include wrong dose unit or a wrong drug order selected from the drop-down list by the practitioner. According to the research report, almost all system-related errors manifested as clinical errors and these accounts for the overall rate of clinical error found in the post-period evaluation.

2.3 Statistical Analysis

In this study, raw data consisting of number of admissions, number and type of errors surfaced during pre- and post- implementation phase as well as number and type of errors surfaced after the exclusion of system-related errors were collect. All the errors were summed by their relevant category – procedural and clinical errors.

There were also two types of statistical analysis involved in the study. The first one is for the calculation of 95% CIs for the average error rates per admission using the large sample approximation of **mean ± 1.96 x standard error**. The mean used in this case is found by dividing the number of prescribing errors (procedural or clinical) with the number of patient admissions during a particular period. While the standard error is found through the following steps:

1. Obtain the standard deviation:

$$Standard\ Deviation\ (\sigma) = \sqrt{\frac{\sum(x_i - \mu)^2}{n}}$$

$x_i = each\ individual\ number$

$\mu = mean$

$n = quantity\ of\ numbers\ in\ the\ group$

$\Sigma = summation\ (addition)\ sign$

2. Find the standard error:

$$\boldsymbol{Standard\ Error\ (\sigma_{\mu})} = \frac{\boldsymbol{\sigma}}{\sqrt{\boldsymbol{n}}}$$

$$\sigma = standard\ deviation$$

$$n = quantity\ of\ numbers\ in\ the\ group$$

Subsequently, for the pre- and post-implementation analysis, a two-sample t-test was being utilized. The baseline data was compared with post e-prescribing system data and the level of significance was set at 5%. The two-sample t-statistic formula used is as follow:

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)}{SE_{(\bar{x}_1 - \bar{x}_2)}}$$

Where:

$\bar{x}_1 - \bar{x}_2$ is the difference between the sample means

$\mu_1 - \mu_2$ is the difference between the hypothesized population means

$SE_{(\bar{x}_1 - \bar{x}_2)}$ is the standard error of the difference between the sample means

In order to compute the p-value of the results based on two sample t-test formula, we made use of additional two functions:

1. rnorm = (#errors, mean, sd)

This formula was used to stimulate the study by generating the exact number of samples with mean equals to as computed. The standard deviation was set to two as 95% of values fall within the range of two standard deviation.

2. t.test(x, y, alternative = “two.sided”)

The t.test() function was used to compare the significance of the data collected by returning a p-value. While using this function, the alternative was set to being a two-sided test with x and y representing the values of pre and post data based on rnorm() function.

3. Statistical Analysis of the Findings

Based on the methodology explained in the previous section, a thorough analysis was performed based on the statistical findings.

In general, the intervention wards experienced a significant ($p < 0.0000001$) reduction of 75.9% in total error rates from 4,270 to 1,029. This 75.9% reduction in total error rates include 95.1% reduction in procedural error rates and 19.0% reduction in clinical error rates, from 3,193 to 157 and from 1,077 to 872 respectively. Whereas for the control wards, only a reduction of 29.3% in total error rates from 6,898 to 4,876. This 29.3% reduction in total error rates include 27.3% reduction in procedural error rates and 34.5% reduction in clinical error rates, from 5,032 to 3,654 and from 1,866 to 1,222 respectively. Comparing the control wards to the intervention wards, e-prescribing system improved the procedural errors of the intervention wards but did no significant improvement to the clinical errors.

Ward	Sum(Pre Clinical Error)	Sum(Pre Procedual Error)	Sum(Post Clinical Error)	Sum(Post Procedual Error)	Sum Pre Errors	Sum Post Errors	%Drop inP	%Drop inC	%Drop
Control	1866	5032	1222	3654	6898	4876	27.38474	34.51233	29.31284
Intervent	1077	3193	872	157	4270	1029	95.08299	19.03435	75.90164

Table 1 – Overall Reduction in Error Rates

(Refer to Appendix 1 for clarification on variables)
(Refer to Appendix 2 for bar plot on overall reduction in error rate)
(Refer to Appendix 6 for Source Code)

Focusing on each individual wards, all intervention wards experienced at least 90.9% of reduction in procedural errors. However, Intervention Ward 1 and 2 had a negative reduction in clinical errors. The clinical errors in Intervention Ward 1 and 2 shot up by 13.4% and 43.4%, from 856 to 1094 and from 261 to 337 respectively.

Ward	Pre Clinical Error	Pre Procedural Error	Post Clinical Error	Post Procedural Error	sumPre Errors	sumPost Errors	%Drop inP	%Drop inC	%Drop
ControlX	434	1310	356	1141	1744	1497	12.90076	17.97235	59.17431
ControlY	356	1110	241	629	1466	870	43.33333	21.30337	67.12142
ControlZ	1076	2612	625	1884	3688	2509	27.87136	41.91450	66.10629
InterventA1	238	856	270	78	1094	348	90.88785	-13.44538	50.63985
InterventB2	76	261	109	10	337	119	96.16858	-43.42105	35.31157
InterventB3	763	2076	493	69	2839	562	96.67630	35.38663	65.26946

Table 2 –Reduction in Error Rates Based on Individual Wards (System-Related Error Included)

(Refer to Appendix 1 for clarification on variables)

(Refer to Appendix 3 for bar plot on individual reduction in error rate)

(Refer to Appendix 7 for Source Code)

During the analysis, 358 system-related errors were discovered and this number contributes to 26% of the total errors (Appendix 4 – Distribution of System-Related Errors) surfaced in the intervention wards after e-prescribing systems had been implemented. Analysing the statistical data after excluding 358 system-related errors, all intervention wards were seen to have a reduction rate of at least 21.1% to 60.2% instead of having an increase in clinical error rates. Unlike Table 2, a decrease of clinical errors was seen in all intervention wards after the exclusion of system-related errors. There was also significant decrease in overall error rate by at least 64.6%. The overall reduction in error rates was only 35.4% to 65.3% when system-related errors were included.

Ward	Pre Clinical Error	Pre Procedural Error	Post Clinical Error	Post Procedural Error	sumPre Errors	sumPost Errors	%Drop inP	%Drop inC	%Drop
ControlX	434	1310	356	1141	1744	1497	12.90076	17.97235	59.17431
ControlY	356	1110	241	629	1466	870	43.33333	21.30337	67.12142
ControlZ	1076	2612	625	1884	3688	2509	27.87136	41.91450	66.10629
InterventA1	238	856	155	74	1094	229	91.35514	34.87395	71.6632
InterventB2	76	261	60	9	337	69	96.55172	21.05263	64.39169
InterventB3	763	2076	304	69	2839	373	96.67630	60.15727	78.58401

Table 3 – Reduction in Error Rates based on Individual Wards (System-Related Errors Excluded)

(Refer to Appendix 1 for clarification on variables)
(Refer to Appendix 8 for Source Code)

Significance of Data

In order to investigate the significance of the data examined, we computed the p-values of all the intervention wards and the outcomes aligned with the results claimed in the paper.

Ward	C.pvalue	P.pvalue	T.pvalue
InterventA1	0.124	< 0.00001	< 0.00001
InterventB2	0.009	< 0.00001	< 0.00001
InterventB3	0.020	< 0.00001	< 0.00001

Table 4 – p-values of Intervention Wards

(Refer to Appendix 1 for clarification on variables)
(Refer to Appendix 5 for Source Code)

The set of data collected and its analysis had proved that e-prescribing system has helped in the reduction rates in errors significantly in all intervention wards. This reduction was attributed by a reduction in procedural errors – ambiguous, illegitimate, and incomplete orders. In contrast, although the control wards also experienced reduction in its procedural errors, this change is not significant. Overall, there was limited change in clinical error rates due to the system-related errors that surfaced after the implementation.

4. Relevance of Paper

This project helps to contribute to healthcare in terms of services by improving healthcare quality for both patient and physicians. Comparison study between commercial e-prescribing system are critical to identify system features associated with these errors. The research report is valuable as it offers insights of system design features which may increase the risk of prescribing errors. The two commercial e-prescribing system are currently used in hospitals in North America, the UK, and the Asia-Pacific region (Stephen, 2012). Contextual and organizational factors also played a crucial role in shaping work processes and its relationships to system-related errors. From the research study, changes have been identified and to be made as a result of the study. Drop-down menus were modified to bring the frequently used items to the top of the list and customization of drug orders were considered by vendors (Johanna et al, 2013).

4.1 Discussion

Implementation of e-prescription generally impacts the society and the global community in a number of aspects. We will categorize these impacts into three categories, namely socio-economics, health-care, and population.

4.1.1 Socio economics

From a comprehensive socio-economic perspective, the paper provides an evaluation procedure which examines e-prescribing not merely as a system but also as a service. It assures benefits for all stakeholders along with the sustainability and success of the intervention. Furthermore, it saves execution-time for clinicians and provides improved service such as better-informed patients, effectiveness of patient care and streamlined healthcare. The overall socio-economic impact can be measured by the estimated monetary benefits from its annual and cumulative benefits over time. The research report presents a benchmark for future research piece as it evaluates both the qualitative and quantitative analysis of the widely adopted commercial e-prescribing system.

4.1.2 Healthcare

The use of e-prescribing system improve the operational process for physicians as they no longer need to write prescriptions and lesser clarifications are needed for electronic prescriptions. At the pharmacy, the entering of prescriptions is more standardized as e-prescription allows automated processing. There is also increase in work efficiency after implementing e-prescribing, primarily due to less paperwork and fewer issues needed to be resolved. The use of e-prescribing system allows a physician to electronically transmit error-free, accurate and standardized prescriptions to the pharmacy. This helps to greatly reduce the risks which often happens in traditional prescription script writing. According to the study, both commercial e-prescribing systems have significantly reduced total prescription rates by over 55%, which is caused by incomplete and ambiguous orders from physicians.

4.1.3 Population

E-prescription continues to benefit the community at large, as it is able to consistently improve the efficiency and provision of healthcare services. Research data gathered from an e-prescribing system is particularly appreciated by clinicians and system designers. They are a good source of information to improve patient safety and reduce the risk of adverse events.

Additionally, this research study also helps system developers to identify error prone areas in the system. Subsequently, changes to the system design accordingly can help to improve its user friendliness. Examples of such improvements include listing the most frequent options first on drop-down menus or creating pre-orders to reduce the need for users to enter complex commands into the system. Vendors, like iSoft MedChart, have made software changes to display the pre-defined drug products on the prescribing screen to reduce the risk of clinicians making wrong selection.

5. Benefits & advantages

The benefits and advantages brought by e-prescribing systems to a healthcare organization are numerous. They would either contribute to reduce prescribing errors significantly or reduce cost incurred by both patients and hospitals. Greater details on the essential benefits and advantages enjoyed by hospitals that have implemented an e-prescribing system are listed below:

5.1 Use of E-prescribing and Patient Safety

E-prescription helps to improve patient safety by shortening the time spend to prescribe and dispense medications to patients, reducing adverse drug events (ADEs) and medication errors, and increasing prescription legibility (Kannry, 2011). In America, the National ePrescribing Patient Safety Initiative had developed a free e-prescribing online tool called eRx to assist physicians in learning how to write electronic prescriptions so as to decrease preventable prescription errors (Kaufman, 2007). Furthermore, when an e-prescription system is integrated with an EHR system, prescriptions can be monitored for its relationship with patient allergies, health status, and medications (Amirfar et al., 2011). A study conducted on 12 community-based practices found that after one year of implementing e-prescribing system, error rates dropped nearly by seven times from 42.5 per 100 prescriptions to 6.6 per 100 prescriptions (Kaushal et al., 2011). Another study conducted on 17 physicians from an ambulatory clinic also found that after one year of implementing the e prescribing system, prescription error rates dropped from 35.7 per 100 prescriptions to 12.2 per 100 prescriptions (Abramson et al., 2011).

Most E-prescription systems are equipped with the medication decision support (MDS) feature, which enables the system to check for drug-allergy, drug-disease, and drug-drug interactions. It can also provide services such as drug costs and dosage recommendations. Hence, MDS ultimately helps to reduce errors in the prescription process and ADEs.

5.2 Cost Savings Associated with Electronic Prescription

A study conducted by Surescripts between 2008 to 2010 found that the estimated cost saved by healthcare provider through improved medication adherence over a period of 10 years is ranged from $140 to $240 billion. Savings mostly comes from a reduction in ADEs, which results in decreasing number of visits to emergency rooms and primary care offices (Surescripts, 2012). A study by Massachusetts in 2006 indicated that each hospitalization from an ADE is about $9000, and each visit to the doctor's office is $111 (Weingart et al., 2009).

5.3 Efficiency of E-prescribing

E-prescribing improves the efficiency level of the process of prescribing. Although the average time required to enter a new electronic prescription is 20 second more than manually writing a prescription, much time is saved from the reduced in amount of clarifications required by E-prescriptions (Devine et al., 2010).

E-prescription also allows auto-processing, which streamlines the process of entering of prescriptions at the pharmacy. Efficiency will be improved because of lesser issues required to be handled and decreased in paperwork. The system will automatically match patient and prescriber names, and it will populate most of the fields including main fields such as drug name, medication instruction, and quantity (Grossman, Cross, Boukus, & Cohen, 2011). In terms of issues handling, less time is required to resolve issues faced with pharmacies involving refill requests and prior authorizations (Lapane, Rosen, & Dude, 2011). The e-prescription system will provide information on eligibility and prescription formularies to the prescribers, so that they are able to make an informed decision on the correct medication to administer and minimize the probability of receiving calls from pharmacy subsequently to change the earlier indicated medication.

5.4 Increase in Patient Cost Savings and Patient Medication Adherence

Another benefit from medication adherence is a reduction in the cost beared by patients. Additionally, according to a study conducted between 2008 and 2010 by Surescripts, prescriptions pick up rate increased by 10% through electronic prescribing (Surescripts, 2012).

A combination of medication adherence together with less costly formulary greatly reduces cost for patients. An e-prescribing system helps a physician to select a low-cost alternative for the patient and eliminate potential bias. In a study involving 19 clinician, prescription for high-cost drugs decreased by 17.5% in the intervention group as compared to control group (McMullin, Lonergan, & Rynearson, 2005). This decrease is equivalent to savings of $482 per subscriber in a month or $109,897 annually.

6. Issues

Although an e-prescription system offers great potential in reducing medication errors, there are a number of issues face in the implementation of an e-prescription system. These might become barriers to achieve the system's best performance and reduce its effectiveness in minimising errors. Some of criticals issues are as follow:

6.1 Cost of Implementing an E-prescription System

While e-prescribing technology provides a wide range of benefits, not all hospital managements are eager about adopting an e-prescribing systems. More than 80 percent of the primary care physicians reported the lack of financial support as a major obstacle (Anderson, 2007). New system implementation requires support for installation and maintenance, users also need to undergo training. The hospital management must factor in these expenditures when they are considering whether to implement such a system, and deciding whether to build a standalone e-prescription system or to integrate it into their existing EHR system. In a 2007 study, reported by the Health Resource and Services Administration (US), the overall cost for implementing an e-prescription system in a non-profit public mental health agency with ten full time psychiatrists was $42,332, with a further post-implementation cost of about $14,725 annually (Health

Resources and Services Administration, 2013). The system was implemented with the necessary wiring for internet connectivity already set up, yet the cost was still considerably high.

The lack of complete patient record being uploaded and make available through e-prescription system combining with the complexity of technology, these posed great challenge to the users of the system (Center for Healthcare Research and Transformation (CHRT), 2011). It is inadequate to simply rely on policies and financial rewards to encourage the adoption of e-prescription systems.

6.2 E-prescription System Errors

Rather than resolving current errors, new errors may arise if the e-prescribing system has not been designed correctly. One of such error is related to the phenomenon called “alert fatigue”, which is resulted from overwhelming number of alerts and lack of alert specificity. The prescribers are presented with large number of alerts for each prescription entered, as time goes by, they tend to just scroll through them without reading through for detail (Brooks, and Sonnenschein, 2010). Essential information may be missed when alerts are taken lightly in this manner. A study conducted in 2010 identified that design issues were part of the reasons in stopping the use of e-prescription software (Jariwala, Holmes, & Banahan, 2013).

6.3 Legal and Privacy Issues

When providers prescribe controlled substance through the system, they have to comply strictly with the legal procedures set by the local authority. For example, in June 1, 2010, a ruling with respect to the e-prescribing of controlled substances took effect in United States (American Medical Association (AMA), 2010). This ruling legalised the electronic transmission of controlled substance prescriptions, however, many standards were brought along with the ruling which makes the execution process very complicated. Some of such standards include monthly logs, requirement to keep two years of records, third-party audits of software, digital certificates, two-factor authentication and identity proofing. In 2010, Drug Enforcement Administration (DEA, U.S.) estimated that the cost of implementing these systems ranged from $43 million to $1.54 billion for various options with features such as authentication protocols, numerous security requirements and identity proofing (Drug Enforcement Administration (DEA), 2010).

The privacy of patient's personal data is another major concern of both patients and providers. Since most Electronic Health Record systems are web based, some even transmit data wirelessly, a leakage might happen along any part of the communication nodes and processes. Information may also be easily stolen if firewalls and Intrusion Detection and Prevention System are not set up to prevent unauthorised access (Nataraj, 2011). But even with all these security measures deployed, it is still not possible to entirely resolve the problem of information breaches. Most of these breaches were the result of actions by internal staffs, either through unethical act of selling information for money or the careless attitude towards handling a system; therefore, additional costs may be incurred to provide frequent trainings on security for hospital staffs, but this is necessary.

7. Challenges

With all the cost, system and user issues face in the implementation of an e-prescription system, they are a great challenge for providers to utilize the system at its full efficiency and capacity.

7.1 Cost

One of the most prominent challenges is the cost associated with implementation. To overcome this, it is critical to obtain management's support over the implementation project. Sufficient support provides a firm foundation for the project team to carry out change within the health organization. The team may want to install a champion for the project. This champion will be someone from the top management team, who is influential and able to convince other stakeholders in the management to believe that implementing an e-prescription system will benefit the organization. Hence, they will be more willing to allocate the required resources on demand.

In addition, a detailed funding paper has to be drafted, vet and signed by the management. With this funding paper, the management will be clearer about the direction of the project and how resources are being deployed. Hence, building up trust among the management towards the implementation team. While governed by this funding paper, the implementation team cannot make any unjustified claim once the implementation is in progress. And the team has to carry out thorough planning right before initiating the project.

7.2 System-Related Errors

Unless major system problems arise due to a system-related error, it will be difficult to identify one. Nevertheless, it is still necessary to conduct system testing regularly to discover such an error as early as possible.

Besides hidden and undiscoverable system errors, human error because of intentionally ignoring system alert is another major concern. Overwhelming amount of system-generated alerts lower users' vigilance level, they may carelessly dismiss messages as useless. However, some of these messages could contain important information related to a patient's safety. Hence, during the system-design phase, the project team has to critically evaluate the type of system alerts to be included, so that false-positives are reduced.

7.3 User Resistance

The implementation of a new system means that the original workflows would have to be reinvented. Employees need to accustom to these changes. If an employee could not get used to the new workflow, it usually would result in resistance or workarounds. This typically happened to older workers who are not familiar with the use of new technologies, which caused them to pick up these new workflows at a much slower pace.

Thus, in this case, a change management team should be set up. Members within the team are required to be from different departments of the practice, so that a broader scope of opinions are taken into consideration. They have to be sensitive to the different propensity in learning of the individuals who are affected by the implementation of new workflows. With the right perspective in mind, the change team would plan and execute activities that are critical to the adaptation of changes among different stakeholders. They would have to constantly monitor and obtain feedback from users regarding their work at each phase of implementing the e-

prescription system. From these feedback, they would come out with new solutions to help users who may be facing different kinds of difficulties from time to time. Thus, reducing the chance of employee coming out with their own shadow systems, which renders the system useless and defeats the purpose of deploying an e-prescription system to improve efficiency.

7.4 Legal and Security Compliance

As highlighted in earlier text, compliance with legal standards is essential for a company, including a healthcare organization, to continue its function. Organizations need to set up policies to govern the appropriate usage of information, aligned with the law of a country. Step by step guides or handbook may be created for users, so that they would not miss out any essential procedures and breach a legal provision.

Under Personal Data Protection Acts (PDPA), providers also have to fulfill a list of requirements to ensure that data in their care are well-protected. However, there are a wide varieties of security features available in the market today. Hence, providers would have to carefully evaluate, filter and prioritize critical features required by the system to execute a suitable level of security. This would help to reduce expenses incurred from implementing unnecessary features.

In an increasingly connected world today, privacy and personal data are of the utmost concern of patients. Information leakage and theft may happen if data are not secured properly. Therefore, besides implementing the right security features, providers would also need to devise security policies to govern the appropriate usage of the system. In addition, employee also need to be constantly reminded of the consequence of their careless behaviours, warned at the same time of the punishment in any illegal act or intention to misappropriate patient's personal information

Threats are constantly present and ever changing. Hence, security policies also need to be continuously updated to include new and potential threats that may arise.

8. Limitations

Statistics, figures and tables were provided by the study, attempting to prove that commercial e-prescription system did help hospitals to reduce prescription error rates. However, there were also several limitations in this study that could affect its results. This section aims to discuss the limitations present in the study, so that future research and study can take note of such problems and be able to gather better quality experimental data.

8.1 Lack of Control Wards in Hospital B

Three control wards are used in hospital A, however, none are used in hospital B. This would result in bias of result, because what is obtained by the control wards in hospital A is not an actual representation of the situation in hospital B. For example, a number of factors are varied from hospital to hospital such as size, specialization, patient groups, medical equipments available, and level of knowledge for handling technology among users. Hence, it is highly recommended that hospital B should have its own control wards to ensure a fair experimental setup for the before and after observations on the prescription errors in the hospital.

Another noteworthy point is that the number of intervention wards should be standardized. In the case of our study, hospital B uses two intervention wards. This allows hospital B to make an internal comparison of the statistical significance of the results, and affirmed that e-prescription system is capable to reduce prescribing errors at the individual hospital level. But this does not apply to the case of hospital A, which has only one intervention ward.

8.2 Small Sample Size

The two commercial electronic prescribing systems mentioned in our study, Cerner Millennium and iSoft MedChart, are e-prescription systems deployed globally across many countries. Given the experimental model set up in our study, it may be sufficient to support that these systems would help to reduce prescription errors in Australia only, which is the country where the two experimented hospital are located. However, the study cannot conclude that these commercial systems are effective at improving e-prescription and thus reducing errors at a global level. This is because many aspects change from country to country, such as legal-binding conditions, language barriers, and technology landscape (level of knowledge and familiarity with technology). These factors are critical to whether the prescription systems are effective at reducing errors in a country.

In order to broaden the scope and produce a more concrete claim for the effectiveness of commercial e-prescription systems, it is necessary to extend the research and include findings from other countries to justify the claim.

8.3 Different Specialty Wards Selected

Between wards of different specialties, a number of characteristics differ from ward to ward as well, examples include different workflow, range of drugs prescribed, and types of patients admitted. Variations among these factors give rise to different sets of errors. Hence, it is inappropriate to make direct comparison between two unrelated wards. However, wards used in the study were all of different specialties.

Since the aim of the experiment is to investigate the effect of commercial e-prescription systems on reducing prescription errors, the only variable that should be changed in the intervention wards during the pre and post phase of the experiment is the presence of an e-prescription system. While all other factors should stay constant, this includes the specialty of the intervention wards. As for the control wards, everything should also stay constant for pre and post phase. Additionally, the specialty of the control wards have to be the same as the intervention wards.

8.4 Unable to Randomize Wards to the Intervention

Randomization in an intervention trial refers to utilizing a probability tool/device to allocate subjects in an experiment. Subsequently, we can apply statistical analysis/methods to produce valid statements about the various treatments to this set of subjects. This helps to prevent both intentional and unintentional biasness.

In the study, researchers were unable to randomize their intervention wards because they have no control over which intervention wards to be selected. In hospital A, only one intervention ward joined the research, it was the first ward in that particular hospital to deploy an e-prescription system. On the other hand, several wards in hospital B had already implemented the e-prescription system before the study took place. Another factor that had impact on the selection of wards is active clinician leaders who are willing to participate.

8.5 Different Data Collection Period for Hospital A and B

There is a difference in the post-implementation data collection periods at the two hospitals. The difference refers to the time duration required for “settling in” to the actual post-implementation data collection. The timing difference may affect the results obtained. As highlighted in the previous point, hospital B had already implemented e-prescription system in a number of its wards. Thus, they have shorter post-intervention periods because most of the problems they faced were examined in earlier implementations.

The impact of time from intervention to outcome measurements is still unclear, existing studies have limited evidence to show a clear relationship. Hence, this should be a consideration for future studies.

9. Relevance to Singapore

Singapore had always been a pioneer in exploring new technology to provide better healthcare. In 2014, Singapore was ranked to have the most efficient healthcare system in the world (Most Efficient Health Care 2014: Countries - Bloomberg Best, 2014). IHiS, together with Ministry of Health, manage the integrated systems and IT solutions used by Singapore's public healthcare sectors.

9.1 Healthcare

With Singapore's advanced healthcare model, the electronic prescribing systems are widely adopted by healthcare providers. Major hospitals like KK Women's and Children's Hospital (KKH), National University Hospital (NUH) and Tan Tock Seng Hospital (TTSH) have all implemented CDSS (Clinical Decision Support System) which has a built in e-prescribing function.

Inevitably, new prescription errors occur while old prescription errors disappear after implementing the e-prescribing mechanism. Like the researchers who write this paper, some scholars in Singapore also dedicate their research and study on the effects on error rates of e-prescribing and how to reduce the errors as many as possible. For example, the paper "Clinical Quality Improvement Project to Reduce the Rate of Electronic Prescription Errors in Primary Care Practice" focuses on determining the root cause of prescription errors after using a e-prescribing system called Electronic Prescription Manager in Bukit Merah Polyclinic and finding a way to reduce such errors. The study in Australia showed similar findings as this paper and both emphasized that such a system could indeed improve the hospital's control on prescription errors but system design problem could cause new errors.

9.2 Scioeconomics

Despite the high cost, Singapore is still pushing for an island-wide implementation of e-prescribing systems. According a research done in 2009 to evaluate Singapore healthcare users' satisfaction with e-prescribing system, 118 doctors and 61 pharmacy staff were interviewed and majority of them acknowledged that e-prescribing was highly effective in reducing prescription errors and would prefer not like to switch back to their traditional paper prescription. Although there were some pharmacy staff who highlighted that the new system

had disturbed their usual workflow, we can conclude that in general, Singapore's healthcare providers and receivers are quite satisfied with the e-prescribing systems and they agree with the benefits brought about by such a technology. Many socio-benefits also compensated the less obvious economic gain.

9.3 Population

With more than five million residents in Singapore and considering its national territorial area, Singapore has a very high population density compared to other countries like United States and China. With this context, having an e-prescribing system becomes advantageous and essential.

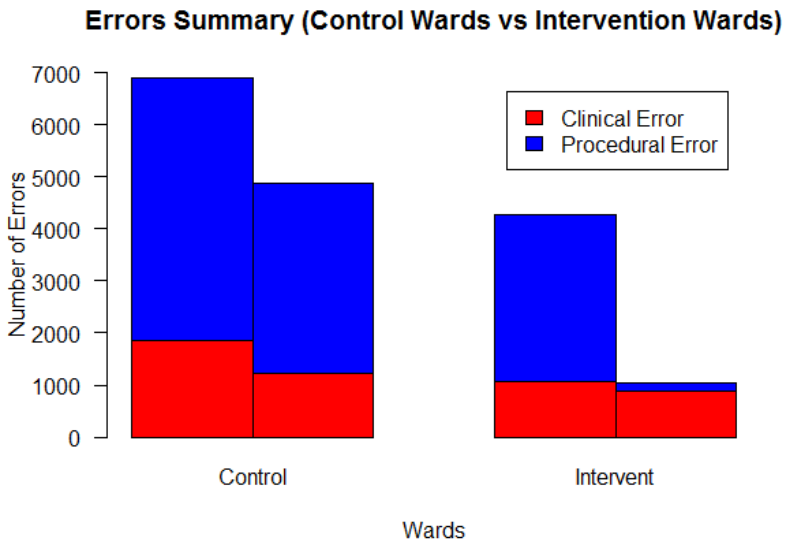
High population density naturally resulted in large volume of patients seeking for medical assistance. While attempting to ensure the safety of these patients, keeping prescription errors controlled and reduced to a minimal is a must. Prescription errors can be solved using e-prescribing. Not only that, e-prescribing could increase hospital efficiency to a great extent. From doctors using electronic system for prescribing to pharmacy staff receives electronic prescribing scripts; every step in the medication prescription process is being streamlined and standardized. With the above analysis, it is reasonable for us to conclude e-prescribing is responsive, efficient and should be recommended in Singapore's population situation.

Appendix

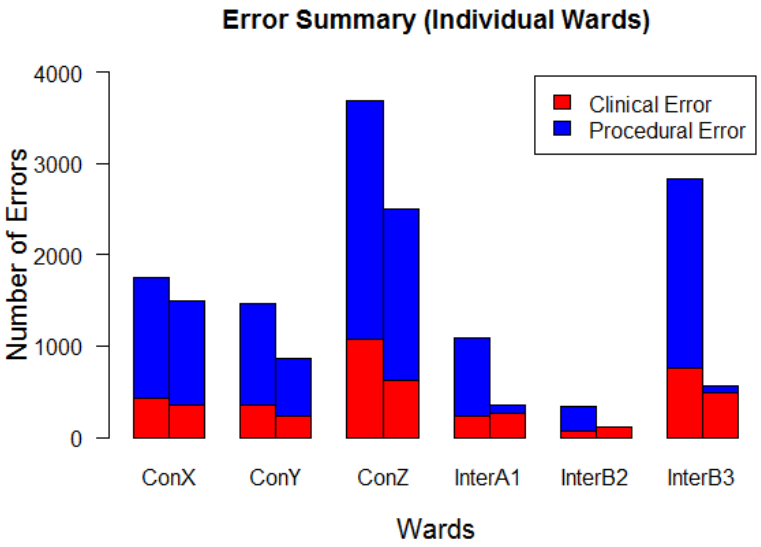
Appendix 1 – Description of Variables

Variable	Description
Sum(PreClinicalError)	Sum of Clinical Errors surfaced during Pre-Phase
Sum(PreProcedualError)	Sum of Procedural Errors surfaced during Pre-Phase
Sum(PostClinicalError)	Sum of Clinical Errors surfaced during Post-Phase
Sum(PostProcedualError)	Sum of Procedural Errors surfaced during Post-Phase
SumPreErrors	Sum of Total Errors surfaced during Pre-Phase
SumPostErrors	Sum of Total Errors surfaced during Post-Phase
%DropinP	% Drop in Total Procedural Error
%DropinC	% Drop in Total Clinical Error
%Drop	% Drop in Total Error Rate
C.pvalue	p-value of Clinical Error Rate
P.pvalue	p-value of Procedural Error Rate
T.pvalue	p-value of Total Error Rate

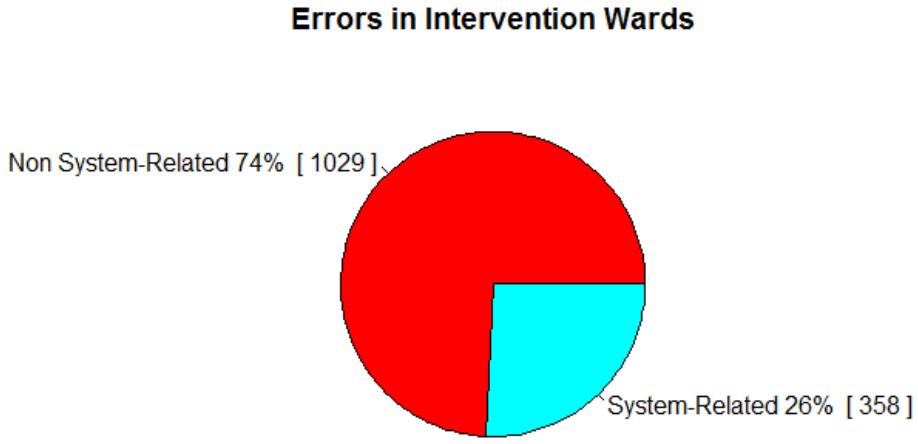
Appendix 2 - Overall Reduction in Error Rate



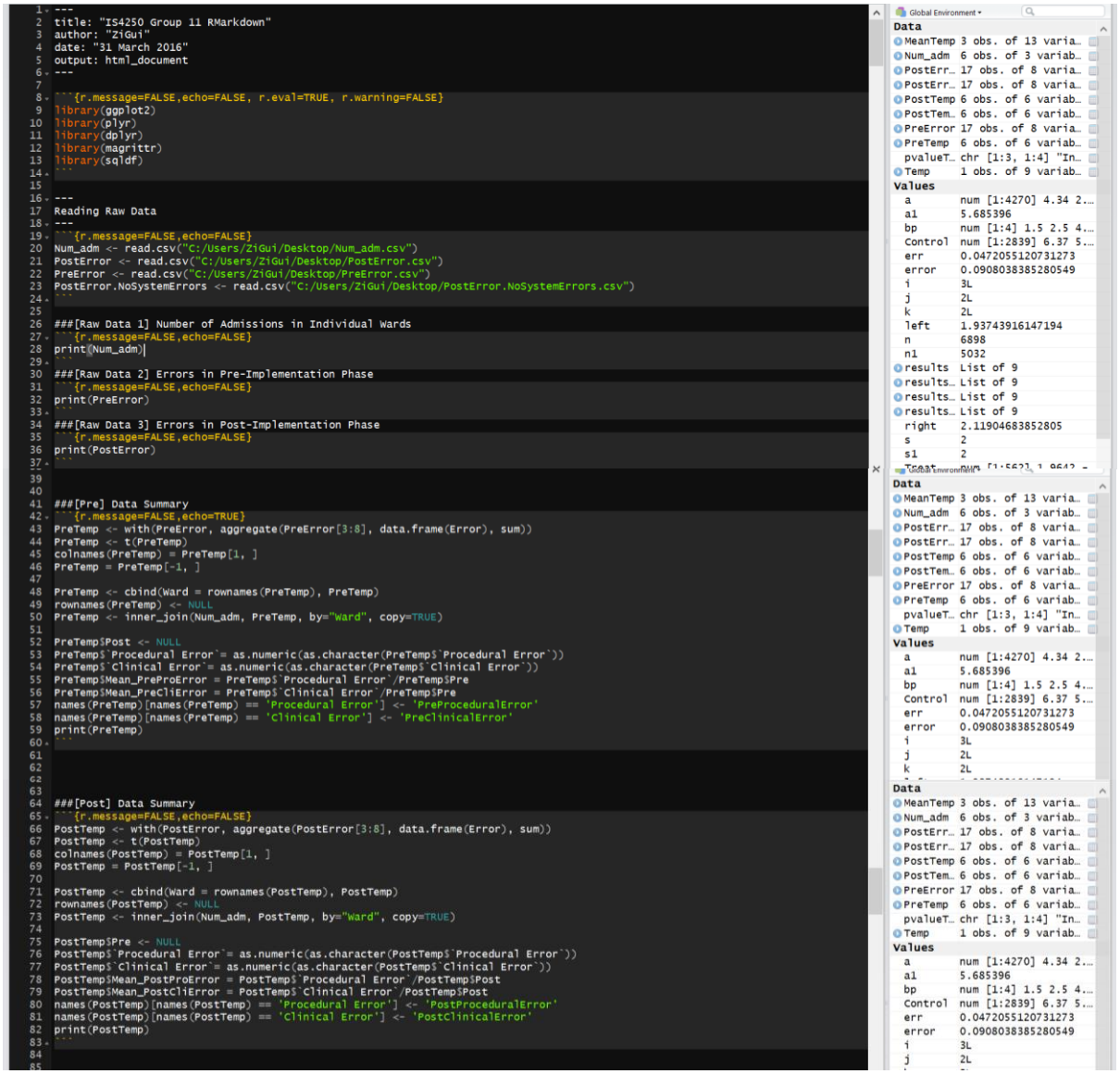
Appendix 3 – Reduction in Error Rate for Individual Wards



Appendix 4 – Distribution of System-Related Errors)



Appendix 5 – Source Code (1)



```
---
title: "IS4250 Group 11 RMarkdown"
author: "ZiGui"
date: "31 March 2016"
output: html_document
---

```{r.message=FALSE,echo=FALSE, r.eval=TRUE, r.warning=FALSE}
library(ggplot2)
library(plyr)
library(dplyr)
library(magrittr)
library(sqldf)
```

Reading Raw Data

```{r.message=FALSE,echo=FALSE}
Num_adm <- read.csv("C:/Users/ZiGui/Desktop/Num_adm.csv")
PostError <- read.csv("C:/Users/ZiGui/Desktop/PostError.csv")
PreError <- read.csv("C:/Users/ZiGui/Desktop/PreError.csv")
PostError.NoSystemErrors <- read.csv("C:/Users/ZiGui/Desktop/PostError.NoSystemErrors.csv")
```

###[Raw Data 1] Number of Admissions in Individual Wards
```{r.message=FALSE,echo=FALSE}
print(Num_adm)
```
###[Raw Data 2] Errors in Pre-Implementation Phase
```{r.message=FALSE,echo=FALSE}
print(PreError)
```
###[Raw Data 3] Errors in Post-Implementation Phase
```{r.message=FALSE,echo=FALSE}
print(PostError)
```


###[Pre] Data Summary
```{r.message=FALSE,echo=TRUE}
PreTemp <- with(PreError, aggregate(PreError[3:8], data.frame(Error), sum))
PreTemp <- t(PreTemp)
colnames(PreTemp) = PreTemp[1, ]
PreTemp = PreTemp[-1, ]

PreTemp <- cbind(Ward = rownames(PreTemp), PreTemp)
rownames(PreTemp) <- NULL
PreTemp <- inner_join(Num_adm, PreTemp, by="Ward", copy=TRUE)

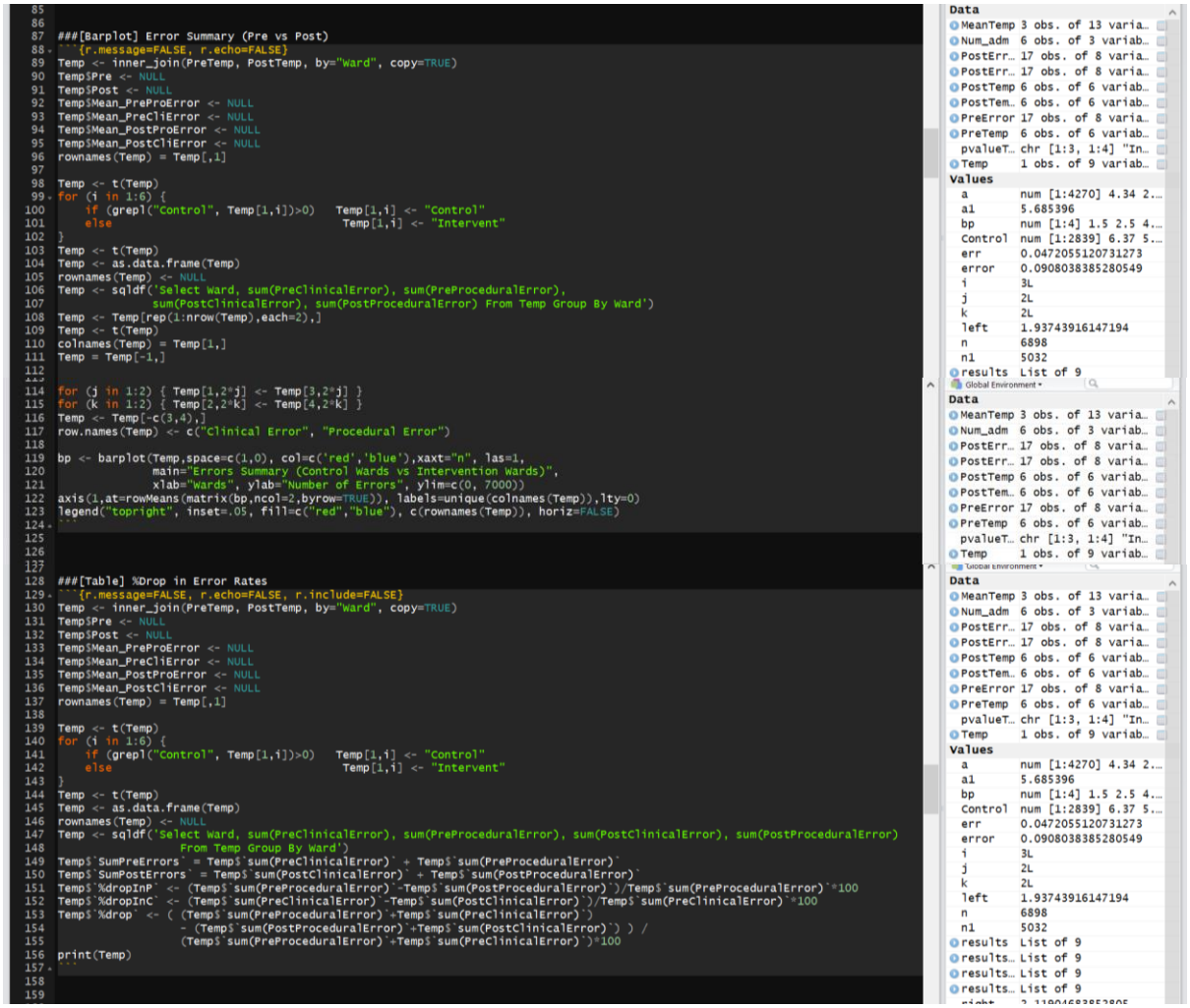
PreTemp$Post <- NULL
PreTemp$`Procedural Error`= as.numeric(as.character(PreTemp$`Procedural Error`))
PreTemp$`Clinical Error`= as.numeric(as.character(PreTemp$`Clinical Error`))
PreTemp$Mean_PreProError = PreTemp$`Procedural Error`/PreTemp$Pre
PreTemp$Mean_PreCliError = PreTemp$`Clinical Error`/PreTemp$Pre
names(PreTemp)[names(PreTemp) == 'Procedural Error'] <- 'PreProceduralError'
names(PreTemp)[names(PreTemp) == 'Clinical Error'] <- 'PreClinicalError'
print(PreTemp)
```


###[Post] Data Summary
```{r.message=FALSE,echo=FALSE}
PostTemp <- with(PostError, aggregate(PostError[3:8], data.frame(Error), sum))
PostTemp <- t(PostTemp)
colnames(PostTemp) = PostTemp[1, ]
PostTemp = PostTemp[-1, ]

PostTemp <- cbind(Ward = rownames(PostTemp), PostTemp)
rownames(PostTemp) <- NULL
PostTemp <- inner_join(Num_adm, PostTemp, by="Ward", copy=TRUE)

PostTemp$Pre <- NULL
PostTemp$`Procedural Error`= as.numeric(as.character(PostTemp$`Procedural Error`))
PostTemp$`Clinical Error`= as.numeric(as.character(PostTemp$`Clinical Error`))
PostTemp$Mean_PostProError = PostTemp$`Procedural Error`/PostTemp$Post
PostTemp$Mean_PostCliError = PostTemp$`Clinical Error`/PostTemp$Post
names(PostTemp)[names(PostTemp) == 'Procedural Error'] <- 'PostProceduralError'
names(PostTemp)[names(PostTemp) == 'Clinical Error'] <- 'PostClinicalError'
print(PostTemp)
```
```

Appendix 6 – Source Code (2)



```
###[Barplot] Error Summary (Pre vs Post)
```{r.message=FALSE, r.echo=FALSE}
Temp <- inner_join(PreTemp, PostTemp, by="Ward", copy=TRUE)
Temp$Pre <- NULL
Temp$Post <- NULL
Temp$Mean_PreProError <- NULL
Temp$Mean_PreCliError <- NULL
Temp$Mean_PostProError <- NULL
Temp$Mean_PostCliError <- NULL
rownames(Temp) = Temp[,1]

Temp <- t(Temp)
for (i in 1:6) {
    if (grepl("Control", Temp[1,i])>0)   Temp[1,i] <- "Control"
    else                                 Temp[1,i] <- "Intervent"
}
Temp <- t(Temp)
Temp <- as.data.frame(Temp)
rownames(Temp) <- NULL
Temp <- sqldf('Select Ward, sum(PreClinicalError), sum(PreProceduralError),
              sum(PostClinicalError), sum(PostProceduralError) From Temp Group By Ward')
Temp <- Temp[rep(1:nrow(Temp),each=2),]
Temp <- t(Temp)
colnames(Temp) = Temp[1,]
Temp = Temp[-1,]

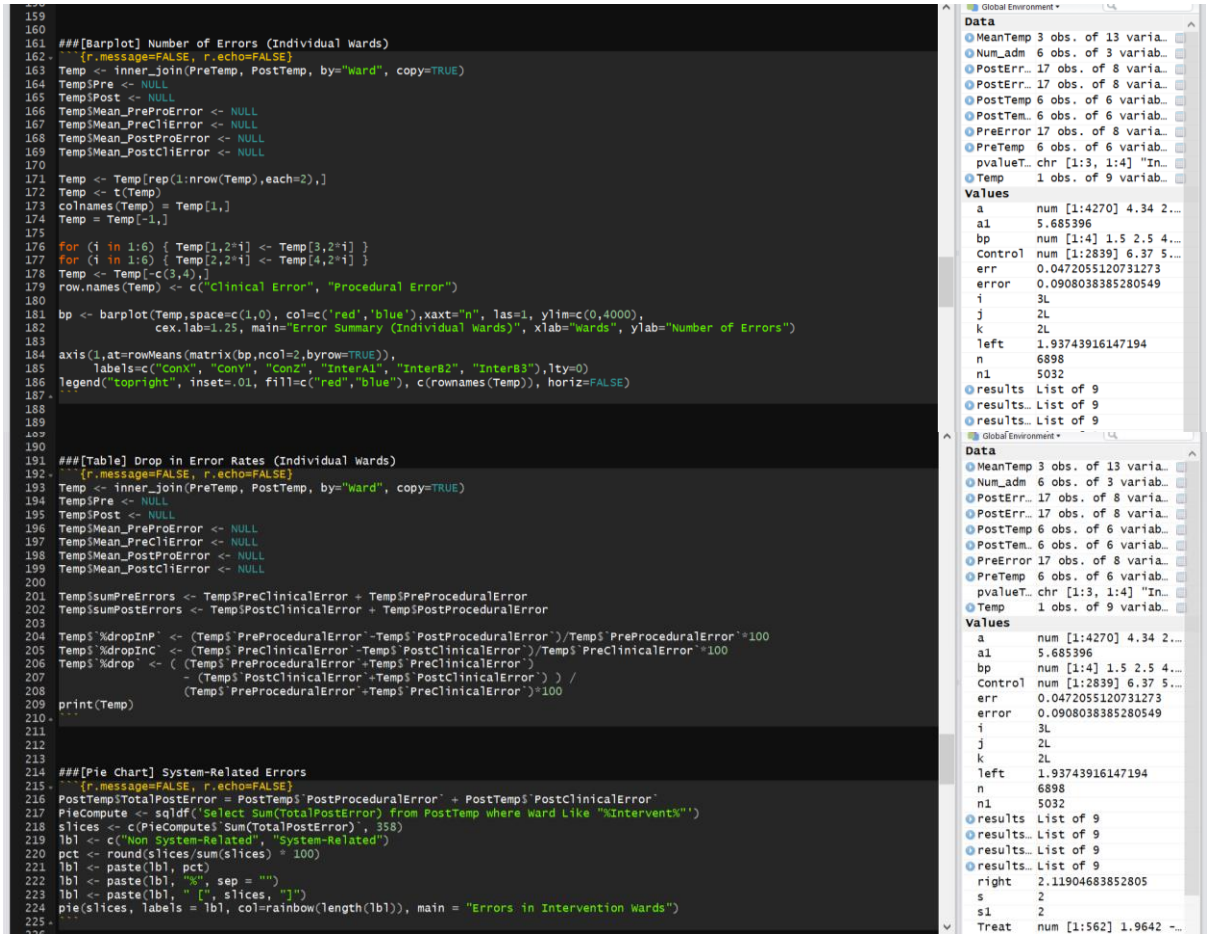
for (j in 1:2) { Temp[1,2*j] <- Temp[3,2*j] }
for (k in 1:2) { Temp[2,2*k] <- Temp[4,2*k] }
Temp <- Temp[-c(3,4),]
row.names(Temp) <- c("Clinical Error", "Procedural Error")

bp <- barplot(Temp,space=c(1,0), col=c('red','blue'),xaxt="n", las=1,
              main="Errors Summary (Control Wards vs Intervention Wards)",
              xlab="Wards", ylab="Number of Errors", ylim=c(0, 7000))
axis(1,at=rowMeans(matrix(bp,ncol=2,byrow=TRUE)), labels=unique(colnames(Temp)),lty=0)
legend("topright", inset=.05, fill=c("red","blue"), c(rownames(Temp)), horiz=FALSE)
```


###[Table] %Drop in Error Rates
```{r.message=FALSE, r.echo=FALSE, r.include=FALSE}
Temp <- inner_join(PreTemp, PostTemp, by="Ward", copy=TRUE)
Temp$Pre <- NULL
Temp$Post <- NULL
Temp$Mean_PreProError <- NULL
Temp$Mean_PreCliError <- NULL
Temp$Mean_PostProError <- NULL
Temp$Mean_PostCliError <- NULL
rownames(Temp) = Temp[,1]

Temp <- t(Temp)
for (i in 1:6) {
    if (grepl("Control", Temp[1,i])>0)   Temp[1,i] <- "Control"
    else                                 Temp[1,i] <- "Intervent"
}
Temp <- t(Temp)
Temp <- as.data.frame(Temp)
rownames(Temp) <- NULL
Temp <- sqldf('Select Ward, sum(PreClinicalError), sum(PreProceduralError), sum(PostClinicalError), sum(PostProceduralError)
              From Temp Group By Ward')
Temp$`SumPreErrors` = Temp$`sum(PreClinicalError)` + Temp$`sum(PreProceduralError)`
Temp$`SumPostErrors` = Temp$`sum(PostClinicalError)` + Temp$`sum(PostProceduralError)`
Temp$`%dropInP` <- (Temp$`sum(PreProceduralError)`-Temp$`sum(PostProceduralError)`)/Temp$`sum(PreProceduralError)`*100
Temp$`%dropInC` <- (Temp$`sum(PreClinicalError)`-Temp$`sum(PostClinicalError)`)/Temp$`sum(PreClinicalError)`*100
Temp$`%drop` <- ( (Temp$`sum(PreProceduralError)`+Temp$`sum(PreClinicalError)`)
                - (Temp$`sum(PostProceduralError)`+Temp$`sum(PostClinicalError)`) ) /
                (Temp$`sum(PreProceduralError)`+Temp$`sum(PreClinicalError)`)*100
print(Temp)
```
```

Appendix 7 – Source Code (3)



```
###[Barplot] Number of Errors (Individual Wards)
```{r.message=FALSE, r.echo=FALSE}
Temp <- inner_join(PreTemp, PostTemp, by="Ward", copy=TRUE)
Temp$Pre <- NULL
Temp$Post <- NULL
Temp$Mean_PreProError <- NULL
Temp$Mean_PreCliError <- NULL
Temp$Mean_PostProError <- NULL
Temp$Mean_PostCliError <- NULL

Temp <- Temp[rep(1:nrow(Temp),each=2),]
Temp <- t(Temp)
colnames(Temp) = Temp[1,]
Temp = Temp[-1,]

for (i in 1:6) { Temp[1,2*i] <- Temp[3,2*i] }
for (i in 1:6) { Temp[2,2*i] <- Temp[4,2*i] }
Temp <- Temp[-c(3,4),]
row.names(Temp) <- c("Clinical Error", "Procedural Error")

bp <- barplot(Temp,space=c(1,0), col=c('red','blue'),xaxt="n", las=1, ylim=c(0,4000),
              cex.lab=1.25, main="Error Summary (Individual Wards)", xlab="Wards", ylab="Number of Errors")

axis(1,at=rowMeans(matrix(bp,ncol=2,byrow=TRUE)),
     labels=c("ConX", "ConY", "ConZ", "InterA1", "InterB2", "InterB3"),lty=0)
legend("topright", inset=.01, fill=c("red","blue"), c(rownames(Temp)), horiz=FALSE)
```

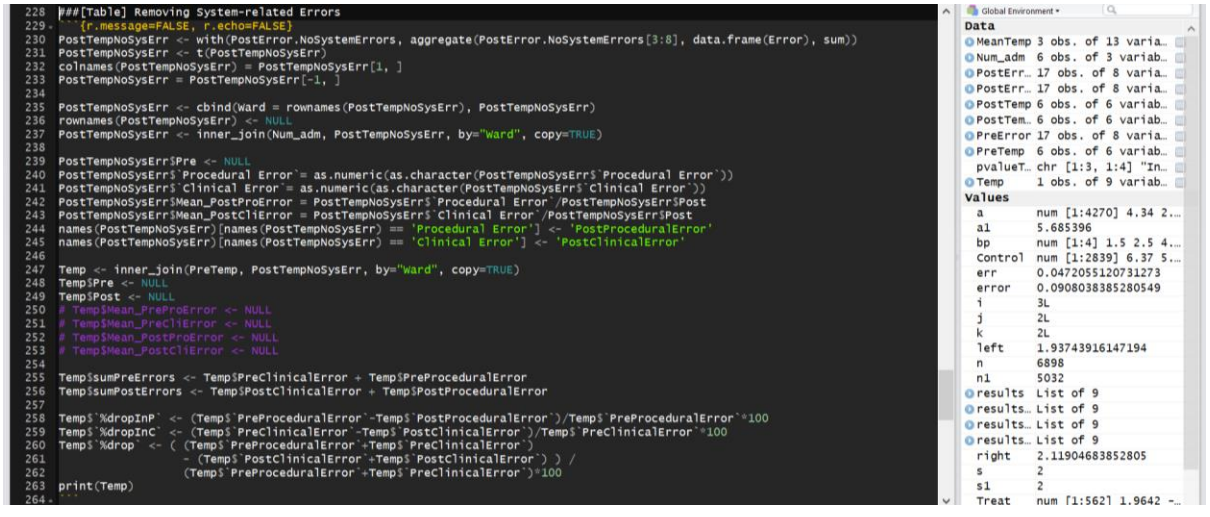
```
###[Table] Drop in Error Rates (Individual Wards)
```{r.message=FALSE, r.echo=FALSE}
Temp <- inner_join(PreTemp, PostTemp, by="Ward", copy=TRUE)
Temp$Pre <- NULL
Temp$Post <- NULL
Temp$Mean_PreProError <- NULL
Temp$Mean_PreCliError <- NULL
Temp$Mean_PostProError <- NULL
Temp$Mean_PostCliError <- NULL

Temp$sumPreErrors <- Temp$PreClinicalError + Temp$PreProceduralError
Temp$sumPostErrors <- Temp$PostClinicalError + Temp$PostProceduralError

Temp$`%dropInP` <- (Temp$`PreProceduralError`-Temp$`PostProceduralError`)/Temp$`PreProceduralError`*100
Temp$`%dropInC` <- (Temp$`PreClinicalError`-Temp$`PostClinicalError`)/Temp$`PreClinicalError`*100
Temp$`%drop` <- ( (Temp$`PreProceduralError`+Temp$`PreClinicalError`)
                  - (Temp$`PostClinicalError`+Temp$`PostClinicalError`) ) /
                  (Temp$`PreProceduralError`+Temp$`PreClinicalError`)*100
print(Temp)
```

```
###[Pie Chart] System-Related Errors
```{r.message=FALSE, r.echo=FALSE}
PostTemp$TotalPostError = PostTemp$`PostProceduralError` + PostTemp$`PostClinicalError`
PieCompute <- sqldf('Select Sum(TotalPostError) from PostTemp where Ward Like "%Intervent%"')
slices <- c(PieCompute$`Sum(TotalPostError)`, 358)
lbl <- c("Non System-Related", "System-Related")
pct <- round(slices/sum(slices) * 100)
lbl <- paste(lbl, pct)
lbl <- paste(lbl, "%", sep = "")
lbl <- paste(lbl, " [", slices, "]")
pie(slices, labels = lbl, col=rainbow(length(lbl)), main = "Errors in Intervention Wards")
```
```

Appendix 8 – Source Code (4)



```
###[Table] Removing System-related Errors
```{r.message=FALSE, r.echo=FALSE}
PostTempNoSysErr <- with(PostError.NoSystemErrors, aggregate(PostError.NoSystemErrors[3:8], data.frame(Error), sum))
PostTempNoSysErr <- t(PostTempNoSysErr)
colnames(PostTempNoSysErr) = PostTempNoSysErr[1, ]
PostTempNoSysErr = PostTempNoSysErr[-1, ]

PostTempNoSysErr <- cbind(Ward = rownames(PostTempNoSysErr), PostTempNoSysErr)
rownames(PostTempNoSysErr) <- NULL
PostTempNoSysErr <- inner_join(Num_adm, PostTempNoSysErr, by="Ward", copy=TRUE)

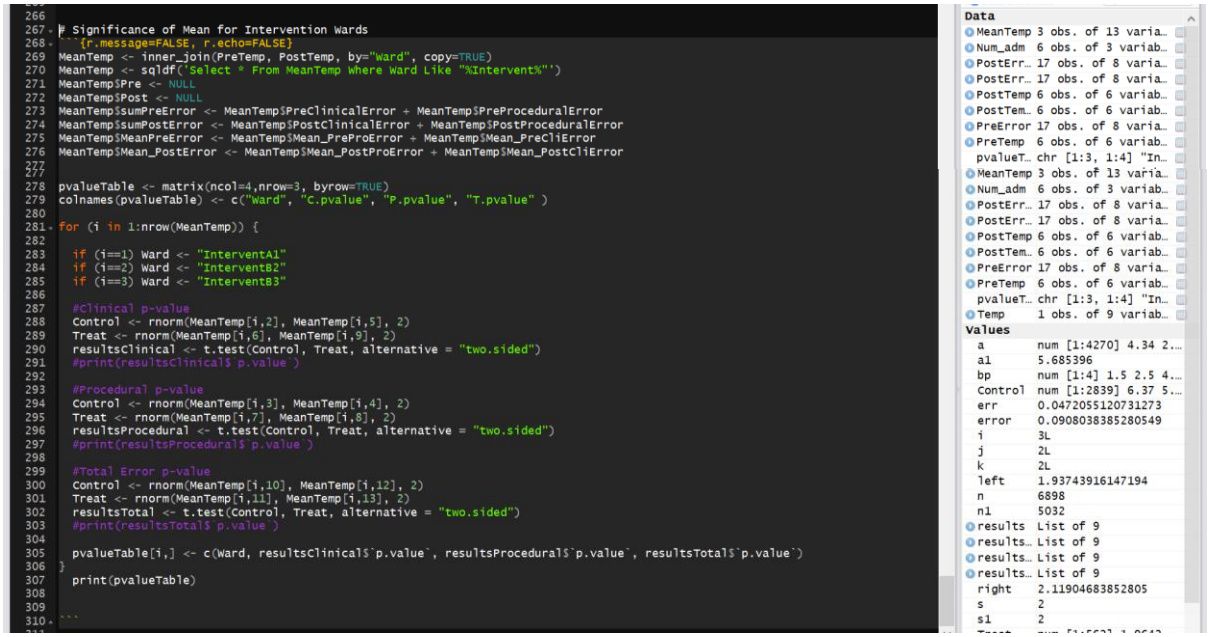
PostTempNoSysErr$Pre <- NULL
PostTempNoSysErr$`Procedural Error` = as.numeric(as.character(PostTempNoSysErr$`Procedural Error`))
PostTempNoSysErr$`Clinical Error` = as.numeric(as.character(PostTempNoSysErr$`Clinical Error`))
PostTempNoSysErr$Mean_PostProError = PostTempNoSysErr$`Procedural Error`/PostTempNoSysErr$Post
PostTempNoSysErr$Mean_PostCliError = PostTempNoSysErr$`Clinical Error`/PostTempNoSysErr$Post
names(PostTempNoSysErr)[names(PostTempNoSysErr) == 'Procedural Error'] <- 'PostProceduralError'
names(PostTempNoSysErr)[names(PostTempNoSysErr) == 'Clinical Error'] <- 'PostClinicalError'

Temp <- inner_join(PreTemp, PostTempNoSysErr, by="Ward", copy=TRUE)
Temp$Pre <- NULL
Temp$Post <- NULL
# Temp$Mean_PreProError <- NULL
# Temp$Mean_PreCliError <- NULL
# Temp$Mean_PostProError <- NULL
# Temp$Mean_PostCliError <- NULL

Temp$sumPreErrors <- Temp$PreClinicalError + Temp$PreProceduralError
Temp$sumPostErrors <- Temp$PostClinicalError + Temp$PostProceduralError

Temp$`%dropInP` <- (Temp$`PreProceduralError`-Temp$`PostProceduralError`)/Temp$`PreProceduralError`*100
Temp$`%dropInC` <- (Temp$`PreClinicalError`-Temp$`PostClinicalError`)/Temp$`PreClinicalError`*100
Temp$`%drop` <- ( (Temp$`PreProceduralError`+Temp$`PreClinicalError`)
                  - (Temp$`PostClinicalError`+Temp$`PostClinicalError`) ) /
                  (Temp$`PreProceduralError`+Temp$`PreClinicalError`)*100
print(Temp)
```
```

Appendix 9 – Source Code (5)



```
# Significance of Mean for Intervention Wards
  ```{r.message=FALSE, r.echo=FALSE}
MeanTemp <- inner_join(PreTemp, PostTemp, by="ward", copy=TRUE)
MeanTemp <- sqldf('Select * From MeanTemp where Ward Like "%Intervent%"')
MeanTemp$Pre <- NULL
MeanTemp$Post <- NULL
MeanTemp$sumPreError <- MeanTemp$PreClinicalError + MeanTemp$PreProceduralError
MeanTemp$sumPostError <- MeanTemp$PostClinicalError + MeanTemp$PostProceduralError
MeanTemp$MeanPreError <- MeanTemp$Mean_PreProError + MeanTemp$Mean_PreCliError
MeanTemp$Mean_PostError <- MeanTemp$Mean_PostProError + MeanTemp$Mean_PostCliError


pvalueTable <- matrix(ncol=4,nrow=3, byrow=TRUE)
colnames(pvalueTable) <- c("Ward", "C.pvalue", "P.pvalue", "T.pvalue" )

for (i in 1:nrow(MeanTemp)) {

  if (i==1) Ward <- "InterventA1"
  if (i==2) Ward <- "InterventB2"
  if (i==3) Ward <- "InterventB3"

  #Clinical p-value
  Control <- rnorm(MeanTemp[i,2], MeanTemp[i,5], 2)
  Treat <- rnorm(MeanTemp[i,6], MeanTemp[i,9], 2)
  resultsClinical <- t.test(Control, Treat, alternative = "two.sided")
  #print(resultsClinical$`p.value`)

  #Procedural p-value
  Control <- rnorm(MeanTemp[i,3], MeanTemp[i,4], 2)
  Treat <- rnorm(MeanTemp[i,7], MeanTemp[i,8], 2)
  resultsProcedural <- t.test(Control, Treat, alternative = "two.sided")
  #print(resultsProcedural$`p.value`)

  #Total Error p-value
  Control <- rnorm(MeanTemp[i,10], MeanTemp[i,12], 2)
  Treat <- rnorm(MeanTemp[i,11], MeanTemp[i,13], 2)
  resultsTotal <- t.test(Control, Treat, alternative = "two.sided")
  #print(resultsTotal$`p.value`)

  pvalueTable[i,] <- c(Ward, resultsClinical$`p.value`, resultsProcedural$`p.value`, resultsTotal$`p.value`)
}
  print(pvalueTable)


```
```

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