Macroergonomics to Understand Factors Impacting Patient Care During Electronic Health Record Downtime

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ABSTRACT

Through significant federal investment and incentives, Electronic Health Records have become ubiquitous in modern hospitals. Over the past decade, these computer support systems have provided healthcare operations with new safety nets, and efficiency increases, but also introduce new problems when they suddenly go offline. These downtime events are chaotic and dangerous for patients. With the safety systems clinicians have become accustomed to offline, patients are at risk from errors and delays.

This work applies the Macroergonomic methodology to facilitate an exploratory study into the issues related to patient care during downtime events. This work uses data from existing sources within the hospital, such as the electronic health record itself. Data collection mechanisms included interviews, downtime paper reviews, and workplace observations. The triangulation of data collection mechanisms facilitated a thorough exploration of the issues of downtime. The Macroergonomic Analysis and Design (MEAD) methodology was used to guide the analysis of the data, and identify variances and shifts in responsibility due to downtime. The analysis of the data supports and informs developing potential intervention strategies to enable hospitals to better cope with downtime events.

Within MEAD, the assembled data is used to inform the creation of a simulation model which was used to test the efficacy of the intervention strategies. The results of the simulation testing are used to determine the specific parameters of the intervention suggestions as they relate to the target hospitals.

The primary contributions of this work are an exploratory study of electronic health record downtime and impacts to patient safety, and an adaptation of the Macroergonomic Analysis and Design methodology, employing multiple data collection methods and a high-fidelity simulation model. The methodology is intended to guide future research into the downtime issue, and the direct findings can inform the creation of better downtime contingency strategies for the target hospitals, and possibly to offer some generalizability for all hospitals.

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GENERAL AUDIENCE ABSTRACT

Hospitals experience periodic outages of their computerized work support systems from a variety of causes. These outages can range from partial communication and or access restrictions to total shutdown of all computer systems. Hospitals operating during a computerized outage or downtime are potentially unable to access computerized records, procedures and conduct patient care activities which are facilitated by computerized systems. Hospitals are in need of a means to cope with the complications of downtime and the loss of computerized support systems without risking patient care. This dissertation assesses downtime preparedness and planning through the application of Macroergonomics which has incorporated discrete event simulation. The results provide a further understanding of downtime risks and deficiencies in current planning approaches. The study enhances the application of Macroergonomics and demonstrates the value of discrete event simulation as a tool to aid in Macroergonomic evaluations. Based on the Macroergonomic Analysis and Design method, downtime improvement strategies are developed and tested, demonstrating their potential efficacy over baseline. Through this dissertation, the deficiencies in current contingency plans are examined and exposed and further the application of Macroergonomics in healthcare.

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1. INTRODUCTION

In the past seven years, over $30 billion has been spent in the United States to encourage the adoption of health information technology (HIT) and with it, electronic health records (EHR)(1,2). The investment has resulted in EHR adoption by 84% of hospitals as of 2015(3). With the substantial incorporation of EHR into healthcare activities, patient safety and quality of care have improved; however, EHR adoption has also introduced new risks to patients when EHRs experience any degree of system outage (4–8).

These system downtimes, which are periods where at least some functionality of the EHR system is not available, have become a growing concern for healthcare quality and safety (9). These downtimes can be caused by planned system maintenance and upgrades (planned), or by the unexpected loss of connectivity (unplanned) due to a variety of causes. EHRs, like other health information technologies, are susceptible to system failures. The unavailability of EHRs is disruptive to organizational processes, patient care and, above all, may present serious safety and health hazards. While well-designed and adequately implemented EHR systems have been able to improve the clinical care process with ready and comprehensive access to patient information (4), they have also exposed healthcare delivery systems to the negative consequences of system unavailability.

EHR vendors and users are working to prevent downtime events by increasing the reliability of hardware and software. Despite these efforts targeting a reduction in the frequency and duration of downtime events, it is likely healthcare providers will continue to experience downtimes.

In 2012, Hurricane Sandy exposed the need for detailed and comprehensive downtime planning. The storms caused widespread damage to hospitals in New Jersey and New York which resulted in lost network connectivity and power outages creating unplanned downtimes. In many hospitals, the downtime procedures were in electronic form only and thus not accessible. The hospitals had few staff members present who were capable of enacting the downtime procedures without referencing the unavailable manual (10–12). The situation made it clear that downtime procedures should be well developed and rehearsed to prevent the situation from repeating.

A more recent development has been the occurrence of virus-based cyber-terrorism targeting hospitals. Similar instances have occurred in retail establishments such as Target, and Home Depot, and financial institutions, where customer information was compromised and made public. Although inconvenient, retail targets lack the additional dangers that come with a healthcare target.

When a hospital is a target for cyber-terrorism, patient information can be made unavailable to the clinicians who need access. The hospital systems can be held hostage by the virus or hackers preventing computer-based workflows as was seen at Hollywood Presbyterian (13). In the virus attacks at MedStar Health, systems became so compromised that MedStar chose to shut down all of its computer systems and turn away non-critical patients (14).

Discussion with stakeholders also revealed that the downtime contingency plans in place at most hospitals do not have a plan for the situation in which there is a total loss of all access in all areas of the hospital. Hospitals have been operating under the assumption that a downtime incident will only impact a portion of the hospital rather than a total computerized system shutdown.

The focus of this study is on the handling of computer downtime incidents, with particular attention to the Clinical Laboratory and the Emergency Department. These areas were selected due to their requirement for rapid communication of information, and the potential for impact on their activities by a loss of computer systems. The lessons learned from this study are useful for the improvement of all downtime incidents. The goal of the proposed study was to optimize downtime procedures using an evidence-based approach that draws from clinical and operational data. Additionally, the purpose is to provide a means to evaluate and start creating evidence based downtime contingency plans for hospital managers.

This study differentiates itself from previous work involving Macroergonomics, simulation, and healthcare in that it focuses on the execution of procedures in a hospital related to patient care. The purpose-built simulation model possesses a high level of detail to encompass the sophisticated communications and movements of patients, data, and associated specimens across two physically separated work environments; and the impacts a sudden loss of computerized support systems can have on patient care activities.

1.1. Theoretical Perspective

The proposed study is framed in the postpositivist worldview. Postpositivism is a worldview presented by Creswell (2014) that most encompasses the fundamentals of the scientific method (15). It represents the process by which a researcher develops a theory about the real world, creates hypotheses to test the theory, and then conducts experiments to collect data to support or disprove the hypothesis. Using the postpositivist worldview, this study will collect data from hospitals to inform experiments intended to examine the research aims guiding the study.

The data collected for this study were both quantitative and qualitative, following a mixed-methods approach. Performance data collected from the hospitals were quantitative, numerical data depicting time to complete tasks for example. As part of the mixed methods approach, stakeholders provided insight as to the qualitative nature of their performance. Combining both inputs will enable a more accurate depiction of the impacts of a cyber-terrorism event at a hospital. The analytical approach for this study will follow the Macroergonomic methodology based on sociotechnical systems theory. A simulation was used to support the Macroergonomic methodology.

1.2. Purpose and Scope of the Study

The study is framed as an exploratory case study. The two target hospitals represent two anchors of possible hospital sizes and types of populations. Much of downtime is unknown; the interventions proposed may be specific to the target organizations. However, the information about downtime represents a significant contribution to the study of EHR downtime.

The purpose of this study was to explore factors that control the performance of patient care activities in a healthcare setting during a computer downtime event and provide evidence-based interventions for handling future incidents.

A combination of approaches from Macroergonomics and simulation were used to facilitate the study. Macroergonomics provides a foundational methodology for the exploration of the problem from a sociotechnical systems standpoint. This holistic approach is necessary due to the complex interactions present within the healthcare work system, especially as tasks usually

handled by the computer system need to be incorporated into the human task structure. Within the Macroergonomics Methodology, a methodology called "Macroergonomic Analysis and Design (MEAD) guides the collection of data for design interventions in the work system. Within MEAD, simulation acts as a tool, providing an experimental space in which the data set is queried, and theories can be tested in a consequence-free environment, without risk to patients or impractical cost.

The study was focused on the operations of two hospitals in the same healthcare network, specifically the linked operations of their clinical laboratory and emergency department. Hospital A is a large urban center with high-level trauma and burn unit capabilities; Hospital B is a smaller suburban hospital. Two different hospitals with different characteristics were selected because they represented two distinct but common healthcare environments. By applying the Macroergonomic methodology to studying both hospitals simultaneously the similarities and differences in their downtime handling approaches could be compared, and the suggestions for improvement made to be more generalizable. This study did not address the means by which a computer downtime event occurs, or preventive measures form the information technology and security perspective. Instead, this study was focused on maintaining consistent work quality, patient care, and safety during a computer downtime incident of any kind and the following recovery period. It is critical to focus on how to handle a downtime event once it has occurred rather than preventing them from happening. Downtime events will represent an ongoing issue in healthcare, regardless of their origin, and no system can be devised that will never experience any amount of downtime.

From discussion with stakeholders, downtime can be disruptive and can trigger significant delays to patient care. The source and extent of those delays are predominantly unknown and as of yet not significantly studied. The study aims to provide an initial entry into patient care level implications of downtime, to provide a Macroergonomic methodology for the analysis, identifying pitfalls for future researchers, and evidence-based initial suggestions based on the study findings.

The operationalization of interventions and methods that derive from this study was not a primary concern of the study. Results were provided to stakeholders involved, and the

stakeholders will make decisions about inclusion of any aspects of this study in the daily operations or downtime procedures.

Interventions developed as part of this study adhered to the following:

1. Interventions were based on Sociotechnical systems theory, and the Macroergonomics Analysis and Design (MEAD) Methodology.
2. Interventions were tested on simulation of hospital operations.

1.3. Research Questions

The primary research question for this study was:

Which interventions can prepare hospitals to better manage various degrees of computer downtime due to a variety of causes?

The study addressed this question with the following specific aims:

Aim 1: Examine the potentially avoidable risks patients and hospitals are exposed to during periods of computer downtime.

- *What is the nature and source of the risks patients are exposed to? (p 56)*
- *To what extent are risks avoidable with evaluation and intervention in the work system? (p 56)*

Aim 2: Examine the potential for the Clinical Laboratory performance to be a leading indicator of Emergency Department efficiency and the significance of the performance link between the two departments

- *How significant is any performance link for the Laboratory to be a leading indicator of ED performance? (p 58)*

Aim 3: Examine the execution of current downtime procedures with Macroergonomic Analysis and Design (MEAD) guidance.

- *Where are current downtime contingency plans not being properly executed? (p 62)*
- *What Macroergonomic based interventions can improve downtime planning? (p 69)*

Aim 4: Implement a high-fidelity simulation model capable of representing the complex communication, and patient and specimen movements involved in the linked operations of emergency and laboratory medicine.

- *How accurately can a simulation represent linked ED-Lab operations? (p 73)*
- *How accurately can performance during computer outage situations be represented in a simulation? (p 78)*

2. LITERATURE REVIEW

2.1. Sociotechnical Work Systems Theory

Sociotechnical work systems present a theory for the comprehension of a work environment which encompasses all of the necessary elements; people, technology, organization and their physical environment (16,17). To fully evaluate a work environment, its components must be considered as interconnected parts of a more extensive system. These parts must be considered concurrently in improvement efforts due to their interconnected configuration, as having too narrow a focus would result in complications rather than improvement.

Sociotechnical work systems, especially in healthcare are critical due to the complex nature of the numerous interactions that take place (17–21). With the continuing integration of technology in the healthcare field, especially with EHR adoption increasing, research has turned to sociotechnical work systems theory to evaluate the work environment. Many different methodologies for depicting the work environment have been presented, but they share a similar construction as seen in Figure 1 (16,17). The common themes are the elements of personnel, technology, organization, and physical environment subsystems, which comprise the internal environment which is the primary area of interest for study. Anything not within the internal environment is considered the external environment, and this area may include aspects which fall beyond the control or scope of the improvement effort.

A number of researchers have employed sociotechnical systems theory to healthcare with success in reduction of costs, increased efficiency, decreased fatigue in stakeholders (18). The positive outcomes were due to the holistic approach to evaluating the work system and ensuring that all elements were optimized together. This comprehensive approach is necessary for the completion of this proposed study.

2.2. Macroergonomics

Macroergonomics provides a holistic and well-established approach to evaluating all aspects of the socio-technical work system (16,22,23). Macroergonomics encompasses all of the potential interactions that require consideration beyond the human-system interaction, instead constructs an entire socio-technical system (16,17,22–24). This sociotechnical system depicted in Figure 1

incorporates interactions among the human elements and the machine, environmental and software elements.

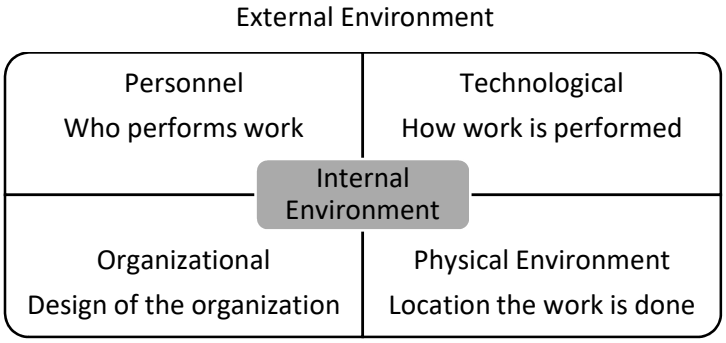

Figure 1 - The Sociotechnical Work System (16,17,25)

The primary focus of the sociotechnical systems-based Macroergonomics work systems model is to ensure that all aspects of the work system are evaluated simultaneously, and not improving one exclusively at the expense of others, similar to how the balanced scorecard functions in performance measurement (16,22,23,26). Macroergonomics also provides a means to analyze the structure of the organization of interest and to distill down a description of that organization using consistent metrics, facilitating systematic exploration of variances in the organization (16,22).

The Macroergonomic Analysis and Design (MEAD) methodology in Table 1 is a guide for the systematic evaluation of the entire sociotechnical work system from a Macroergonomic perspective (16).

Table 1 - The MEAD Methodology

Phase
1. Scanning Analysis
2. System Type and Performance Analysis
3. Technical Work Process Analysis
4. Variance Data Collection
5. Variance Control and Role Analysis
6. Organizational, Joint and Functional Design
7. Responsibility Perception Analysis
8. Support System and Interface Design
9. Implement, Iterate and Improve

The phases of the MEAD process guide the examination of the target organization through all aspects of the sociotechnical work system. Focusing a MEAD analysis on the work tasks and activities occurring during a computer downtime event in a hospital will enable the exploration of issues that contribute to patient risk during downtime. Other researchers have conducted Macroergonomic based analyses of healthcare operations and are summarized in the following section.

2.2.1. Macroergonomics in Healthcare

The application of Macroergonomics in healthcare environments has been established for some time. Carayon (2003) summarized numerous publications applying various parts of the Macroergonomic process to healthcare and patient safety and summarizing the common themes (27). A number of the works reviewed focused on the implementation of technology to resolve issues. Given that the publication was from 2003, healthcare technological implementation concerning EHRs was in its infancy. A key measure Carayon identified was related to work stress in clinical staff (27). During a cyber-terrorism initiated computer downtime, work stress levels will drastically increase as all staff has to cope with changes to their work tasks to maintain care.

Hallock, Alper, and Karsh (2006) applied a Macroergonomic analysis to the issues present in diagnostic testing for outpatient care (28). An in-depth study of the process and encountered in the clinical laboratory, pathology and radiology diagnostics revealed several variances that persist today. The variances involved delivery of specimens to the testing laboratory with appropriate packaging, labeling and making of the request, and also difficulties in the follow up reporting back of results (28). Among the final recommendations made by Hallock et al. was if financially possible to implement computerized physician order entry and electronic health record systems to improve the performance of diagnostics in medicine (28). Today healthcare has almost completely adopted both systems into workflows, and most of the issues identified by Hallock et al. persist.

A recent study completed by Jiménez (2014) in which Macroergonomic analysis was combined with an epidemiological simulation to study the propagation of *Clostridium difficile* (C-diff) in hospitals (29). The study employed a Macroergonomic evaluation of practices in a hospital

environment that were used to prevent the spread of C-diff among patients and workers and applied the interventions found in a commercial epidemiology simulation to assess their efficacy (29). The combination Macroergonomics and then employing simulation for testing improvement interventions is a novel concept. The simulation software employed was a commercially available model specifically designed for epidemiological studies. The simulated environment provided an experimental lab space where interventions could be tested without having to deploy the interventions in real-world hospitals and induce higher infection risks.

2.3. Simulation in Healthcare

Simulations can re-create the real world and capture the variability of human behavior. As such, simulations are becoming increasingly popular in healthcare settings, in particular for hospital operations (30–40). While simulations have not yet been developed for EHR downtime contingency planning, they have been successfully applied in other application domains, such as first responder coordination after bioterrorism attacks (41,42) and the spread of healthcare-associated infection during patient care (29). Despite their suitability and increasing popularity, simulations are still underutilized in healthcare compared to other industries like manufacturing (39).

Healthcare researchers looking to employ simulation models in their research have predominantly three options to select from, Discrete Event (DE), System Dynamics (SD), and Agent-Based (AB). All three of these methods have seen use in healthcare related applications but all in different aspects. Typically, epidemiological studies focusing on the spread of disease and other population-based issues have been modeled using SD methods. Performance and optimization of individual units are well suited to DE based approaches. AB models are relatively new, employing some of the aspects of both DE and SD methods and because of the unique coverage AB possesses, has seen use in both disease spread and unit optimization studies. In the paragraphs that follow all three methods are further explained and papers featuring them discussed.

2.3.1. Discrete Event Simulation

Discrete Event Simulation as it known today was derived from work initially developed by Geoffery Gordon in 1961 (43). The primary focus of DE is the flow of passive constructs known as entities through a system (44). These entities move through a block diagram stylization of the system being modeled where the various processes underwent by the entities may have contingent resource dependencies (44). DE is highly reliant on accurate data to model the system of interest correctly. Unlike the other methods all aspects need to be fully defined, and there is little tolerance for uneducated approximations. Typically, DE has been focused on improvement of emergency medicine both in the United States and abroad.

Jun, Jacobson, and Swisher (31) evaluated the recent applications of DE simulations to healthcare clinics. They discovered that the papers could be grouped into three major categories; (1) patient scheduling and admission, (2) patient routing and flow, (3) scheduling and availability of resources. All of the papers the authors reviewed shared the trend of focusing on a single unit within the healthcare environment. The narrow focus was attributed to the high-quality requirements for data used as inputs to the system making it challenging to have multiple units or even an entire healthcare facility modeled (31). Most of the papers were motivated by a desire to create a model to allow for "what-if" testing, allowing researchers to optimize the system to achieve a particular goal in an experimental environment rather than risking patient care (31).

The ability to test alternative plans makes DE methods particularly appealing to the application of emergency medicine. DE methods were found to be most useful for optimizing resource allocations with the goal of improving patient flow through a unit (31). Accepting that DE requires high-quality data sources to be reliable. Jun et al. found that papers utilizing time and motion studies and other means of obtaining observationally based data were the most reliable, and produced the most reliable results.

Another paper focused on emergency medicine and using DE methods was published by Duguay and Chetouane (30). The emergency department model they created included patients that arrived at different rates depending on the time of day and possessed attributes such as seasonal conditions and illnesses (30). DE does not have to only model a time evolution but can be used to model on a calendar based time frame. What this means for Duguay and Chetouane's

work is that in the summertime, patients are more likely to have suffered an outdoor-activity related injury, while in the winter, colds and the flu are more likely to present.

The approach taken by the authors was able to improve patient care by reducing waiting times, but it was not without limitations. Patient arrivals being modeled specifically to day and hour resulted in a model which never reached a steady state condition during the night shift or weekends. The authors compensated by only modeling Monday through Friday 8:00 am to 8:00 pm, and only looked at the impacts of delays caused by staff availability, not other physical resources (30).

Günal and Pidd (34) performed a more recent literature survey of DE applications in healthcare, finding that emergency medicine is still heavily favored by DE practitioners. They present an opinion that the body of DE work is not progressing forward, or at least is doing so far more slowly than other simulation approaches. They hypothesize this could be due to the specific nature of DE models, high-quality data from one location most likely will not translate to another directly (34). The result is that once a model is built for one specific environment only a very generalized case will translate to the next. The authors found that most of the current work is based on performing the same tasks and analyses over and over, with only a change in location. Most interestingly, of 200 papers found in the body of research focusing on DE simulations driving interventions in healthcare, only 16 resulted in successful implementations in the organization (34).

Swisher and Jacobson (33), like many other DE practitioners, focused on a single unit of a facility, a family practice clinic with the goal of determining the optimal configuration. The work they performed differs from most in that they acknowledge the difficulties in determining a warmup period for a model (33). Swisher and Jacobson found that there was no accepted method for determining ideal warmup and took it upon themselves to test a few of the different methods and compare the results obtained, indicating the bias if any each method may have put into the model (33).

Caro's (45) paper is unique in the DE literature. They propose that DE possesses more general flexibility in application than the other two methods and that it can more naturally model disease progression, a subject generally reserved for SD methods (45). The justification for the

change in approach is that DE methods provide for a higher level of uncertainty in disease progression. Events which in SD approaches have to happen in their specified order and can only happen one at a time can occur simultaneously and randomly in a DE model (45). Caro proposes that DE has the potential to expand the literature base in pharmacoeconomics due to the less restrictive environment it provides (45).

With the five papers previously discussed, Caro's (45) paper represents the most significant departure and contradiction to the existing literature. The claim that DE methods are more flexible than SD to model disease progression contradicts the work of most of the other DE researchers. Future work on applying DE methods will also potentially run into the same issue which is encountered by emergency medicine studies where the model created for one unit is specific to that unit and does not translate well to other emergency units. Günal and Pidd (34), and Swisher and Jacobson (33) are the only authors who acknowledge some of the DE shortcomings, but none attempted to address them. Future work in healthcare applications of DE will need to examine the possibility of translating one model to multiple units without involved data collections for each application.

2.3.2. Systems Dynamics

System Dynamics modeling is based on interconnected networks of differential and algebraic equations (44,46). Typically SD methods have been applied and appear to be best suited to studying the interaction of components as a more extensive system (44,47). SD is useful in experimentation driven by a desire to examine large-scale problems, and the impact policy changes may have (48).

Lane, Monefeldt and Rosenhead's (49) paper is a perfect example of a typical SD application. Motivated by the National Healthcare Service in the United Kingdom which wanted to examine the situation where hospitals were overloaded and patients complaining of bed shortages (49). While focused heavily on the impacts of the Accident and Emergency department, equivalent to the United States Emergency Department, impact on bed utilization in a hospital, the team sought to answer concerns that the current level of service was inadequate (49). When beds are in shortage, elective and non-emergency patients may be removed from facility schedules in favor of emergency patients.

The authors felt that previous work examining the issue which focused on DE methods was inadequate because they felt DE is too focused on individual patients and not the system as a whole (49). The expectation was that an SD approach would allow for initial modeling on a small scale with easier expansion to the overall hospital system. The project separated out the two hypothesized impact factors of bed shortages, the number of beds and the staffing levels of the emergency department. It was found that the number of the available beds in the unit did not have a significant impact on the overall outcome because other factors impacted how quickly the beds could be filled (49). The authors were able to demonstrate that claims about reduced waiting times were irrelevant in the face of reducing capacities across the system. Instead there needed to be a focus on multiple performance indicators to inform future decisions (49).

Another paper motivated by government interest in evaluating the state of healthcare is presented by Royston, Dost, Townshend, and Turner (48). The authors provide a summary analysis of several projects which the Department of Health in England engaged in SD methods to evaluate. SD methods were successfully implemented in projects seeking to inform policies regarding; assessment of public health risks, screening for disease, delays in hospital treatment, allocation in the health care workforce, and developing better emergency health and social care (48).

The authors found that SD methods were beneficial as a learning tool, allowing the researchers to explore the situations of interest quickly (48). Once the SD methods were mastered, rapid modeling of new issues became more accessible, and future projects could move more quickly. Unlike DE methods, even though the SD models were for entirely different problems, the learning curve is much easier to work through. It was the opinion of the authors that SD methods were capable of uncovering issues that other methods may not be able to (48). The caveat they felt was that results of SD models were best understood by the practitioner and required extensive work to make meaningful to the managers seeking to act on the SD results (48).

Dangerfield presents a summary of SD work in their (50) paper. Many researchers chose to employ SD modeling as a means to gain an understanding of an unknown influence in a system. One of the reviewed papers by Dangerfield presents a model seeking to evaluate the “revolving

door" phenomena in short-stay psychiatric care (50). The results of the simulation were able to motivate further discussion and improvement in how short stay care was handled in the United Kingdom.

A significant governmental interest in the United Kingdom is the growing motivation to move towards privatized healthcare. As was seen in other papers, the National Healthcare Service in the United Kingdom is fraught with delays and issues. Some patients are willing and able to pay for private medical care in order to receive their care faster than the public hospitals can provide it. The government was interested in trying to predict the potential impacts allowing privatized healthcare would have on their public healthcare system (50).

Most of the papers employing SD methods focus on the broader system impacts rather than the small unit improvement like DE methods. Brailsford (47) feels that SD and DE methods are very distinct and separate with no overlap. The opinion is somewhat justified based on DE models primarily focusing on entities moving through the system and SD models focus on the flows through the system (46,47). SD methods lend themselves to modeling systems in which more is unknown and requires approximation; this is due to the focus of SD being on the dynamic complexity of a system and not entirely focused on its minutia (46,47). SD is particularly useful and in the papers reviewed, heavily used by government and other similarly large organizations to inform policy decisions and test options.

2.3.3. Agent Based Modeling

Agent-Based modeling is a relatively new method, making healthcare specific applications of it less common. The primary difference in AB methods is that the active objects in AB models are intelligent, unlike the "dumb" entities of DE (44). Individual agents act independently based on their own encounters in the system. The agents are considered to be intelligent in that they can dynamically respond to changes they encounter. The papers employing AB methods primarily focus on population-based studies, such as infection control, possibly refining some of the models developed in SD methods.

One such paper that traditionally could be modeled with SD examines the spatial and agent-based spread of a pathogen within an intensive care unit. Because the model includes a physical location aspect, SD methods would not have been appropriate to model it. The model

presented allows for the consideration of how often based on the probability a given doctor will visit a patient, with patients starting in various locations in states of infection of healthy (51). With there being a set chance of transmission from each encounter with an infected party, the spread of disease throughout the unit can be modeled with a natural aspect not readily seen in SD models. The physical aspects of the AB model are similar to that of a DE approach.

Emergency departments can be modeled with AB methods as well. The opinions presented by the authors are that since AB models are based exclusively on defining the interaction of the agents which populate the model, AB methods are the ideal choice for social and biological interactions (51). Though the authors have not fully developed the model of the emergency department yet, they are hopeful for the insights that can be gained by its completion.

A more complete and successful application of AB methods to emergency medicine was performed by Cabrera, Taboada, Iglesias, Epelde, and Luque (52). The work presented was instrumental in expanding the AB application in healthcare, especially in modeling hospital operations at large. The model presented in the paper was able to be utilized to inform cost-effective staffing decisions, optimizing staffing by cost and experience level to attain greater patient care (52). The method and model presented in the paper are of similar complexity to a DE model, and the potential benefits and drawbacks merit exploration. The model presented is also simplified in such a way as to encourage management level practitioners to attempt to employ it themselves rather than hiring an optimization expert (52).

Of the three methods presented, each has benefits and detractors. At present SD approaches are best suited to population and biological studies, any situation where the flow and stock were of interest more than the explicit procedures. Disease propagation through a population will always be of interest and SD approaches answer the questions without requiring the involved data collection aspects of a DE model. DE models are ideal when the goal is to improve operations on a smaller scale, such as an individual hospital unit. DE is less recommended when the model called for will encompass a more complex system such as an entire hospital. The limitation is mainly due to the rigors of data collection necessary making the application unreasonable. AB methods, though new, have significant promise in healthcare. They

appear to possess the abilities to merge the best aspects of DE and SD approaches in a meaningful way. With the intelligent agents populating the system, epidemiological studies and process improvement studies could be reasonably accomplished. With more development, AB methods would be recommended in more areas, but for now, they are best applied by practitioners who understand the tool.

2.4. Adoption of Healthcare Information Technology and Electronic Health Records

Electronic Health Records are dependent upon their Healthcare Information Technology (HIT) infrastructure to function properly. HIT systems are generally beneficial but only when appropriately implemented. It is also important to note the difference between simple adoption and proper implementation.

Merely installing HIT systems in hospitals along with EHRs is not enough. While the potential for the reduction and prevention of healthcare-associated risks are present, without active measures taken to ensure safety, HIT and EHR cannot decrease patient safety (53). Without optimization of the specifics of the installation site, the benefits of EHR and HIT cannot be realized due to the increased hazards of improper implementation (53–55). Because people create HIT and EHRs, there is an inherent likelihood that there are software bugs and other issues that will require taking the system offline or worse will create errors (55).

In the United States, the implementation use of EHRs in healthcare is incentivized by the Office of the National Coordinator (ONC) and the Centers for Medicare and Medicaid Services (CMS). In order to qualify for the financial incentives, EHR installations need to meet Meaningful Use standards. The standards are staged to evolve over a five-year period and are currently about to transition to the final stage (4,56). Overall the goals of meaningful use aim to generate: better clinical outcomes, improved population health outcomes, greater transparency and efficiency, empowered individuals, and more robust research data on health systems (56). In reviewing the meaningful use requirements, however, the focus is entirely on normal operation functionality and does not consider the contingency plans for when EHRs go offline.

2.5. Hospital Computer Downtime

As of 2014, electronic health record (EHR) systems had been installed in 83% of hospitals and 72% of private practices (57,58). Hospitals looking to incorporate an EHR into their workflow have almost 800 different vendors to choose from (59). With the prevalence of EHRs, system downtime is a growing area of concern and is coming to the forefront of research in health information technology (IT) and health services management (9,11,60–64). Downtime is any period of unavailability or decreased functionality in the EHR system and, unfortunately, is not an uncommon event (9).

Downtime can result from events internal or external to the IT infrastructure of the hospital. Internal and unexpected downtime events can be caused by EHR system failures, or software and hardware problems in the wider IT network of the hospital. In addition to unexpected downtimes, planned downtimes are often necessary to perform system upgrades and updates. The EHR vendor can trigger an external downtime event; generally, hospitals choose not to operate their data management systems but purchase this service from the EHR vendor. EHR data is typically stored offsite at centralized data warehouses. Problems with Internet connectivity, or problems at the vendor's data warehouse, can result in limited or no data access for the hospital. Finally, downtimes can be caused by catastrophic events, such as earthquakes, fires, hurricanes, and flooding, or by terrorism, including deliberate cyber-attacks.

While most of the nearly 800 EHR vendors are working to prevent downtime events by increasing reliability of hardware and software, hospitals will continue to experience downtimes, both planned and unplanned, and must have adequate contingency plans in place. There is surprisingly little guidance in the literature or from EHR vendors on best practices for EHR downtimes. Regulatory mandates and recommendations for downtime contingency planning exist (CMS, HIPAA, IOM), but are vague, insufficient and not instructive (9,54,65). Regulations only require that a procedure be on file; performance, validation or practice requirements are not specified (66,67).

Hospitals are particularly susceptible to downtime events given the complexity of their EHR systems. Also, delays in time-sensitive care can result in serious patient safety hazards. Given

the complexity of and reliance on EHR systems in hospitals, effective contingency plans are crucial.

Unlike other computer-dependent operations, such as Nuclear Power Plants or the Federal Aviation Administration's Air Traffic Control systems, hospital downtime causes significant delays in time critical care for patients. Downtime can introduce work stoppages as equipment becomes unavailable, requiring patients to be transported off-site for procedures. When relying on unpracticed and at times incomplete downtime procedures, safety measures are taken offline, and clinicians are expected to maintain efficient, safe and timely treatment of patients under their care. Unfortunately, due to complications from downtime patients experience significant risk from the healthcare system during downtime.

2.5.1. Cyber-Attacks and Cyber-Terrorism

A number of hospitals and hospital networks have become the target for malicious virus based computer downtime. These viruses are capable of crippling a hospital computer network and in some instances require a system-wide shut down (13,14,68–70). Hackers have developed specific viruses referred to as *Cryptolocker viruses* because the virus locks down user access to files on the system until a ransom is paid. One of the first hospitals attacked with a cryptolocker virus was Hollywood Presbyterian in California, which after computer systems were held hostage for ten days, agreed to pay $17,000 to regain control of their computer systems and resume operations (13). MedStar Health was recently the target of another cyber-attack which resulted in a 48-hour shutdown of all computer systems across the entire MedStar healthcare network (14). MedStar was able to regain control of their computer systems without paying the ransom for their systems (14).

2.5.1.1. Cryptolocker Viruses

Cryptolocker viruses originated in 2013 in Russia, created by a group of cyber criminals seeking to voice anti-American sentiments over incidents occurring in Ukraine (71,72). The virus differs from prior similar versions in that the users' files are encrypted using a unique encryption key in possession of the group which developed it. Previously, similar types of viruses simply hid the user's files making recovery much simpler. Files encrypted by a cryptolocker virus are practically impossible to recover without getting the encryption key from the creator. The current

cryptolocker viruses have the ability to encrypt files physically on the infected machine, connected portable drives, networked shared files, and even files on cloud services (71). A 2.0 version of the virus has been found on computer systems recently which is capable of distributing itself across a network once one computer is infected (73).

Currently, the primary impacts of the cryptolocker genre of virus are economic. The virus and its creators rely on the value the users, who are usually businesses, place on their data, and the desire to regain access rather than risk data loss (71–73). The viruses typically target the professional work file types such as Excel and Word while usually ignoring music and images (73). At the moment, there is very little that can be done proactively to prevent a cryptolocker virus from spreading. The only protections available are to keep users from opening attachments from unknown sources and not running unknown programs on workstations.

2.5.2. Current State of Downtime Procedures

Research on EHR downtime, particularly in acute hospital settings, is in its infancy. It has been observed that EHR downtimes can be frequent, unpredictable, and pose threats to safety and quality (9,60,62,74). A study surveying 50 hospitals discovered that almost every responding hospital had experienced some unplanned downtime event within the past three years (9). Seventy percent of the hospitals indicated that they experienced an unplanned downtime longer than 8 hours. Worse still, three hospitals responded that downtime was the cause for injuries and adverse outcomes for one or more patients. There is also a financial cost to computer downtimes. A study focused on small private practices estimates that downtime costs are approximately $500 per physician hour (60).

When a computer system in a hospital goes offline, workers need to adjust immediately due to the ongoing patient care activities. A Total work stoppage is not acceptable. Other computer-based industries can delay future work and have automated systems to facilitate the changeover to backup and contingency plans. Hospitals can prioritize certain patients over others and not admit new patients who are non-critical; however, they must maintain the quality of care for those already admitted.

EHR downtime affects laboratory turnaround time. With modern health IT systems capable of reporting test results upon completion, physicians have become accustomed to the

rapid reporting. During and after a downtime event, turnaround time can extend to hours as the lab falls behind with a backlog of specimens. Typically, the testing equipment in the laboratory is interconnected, creating laboratory information system (LIS), which processes the results and communicates them back to the EHR for physician review. During normal operation, the flagging of critical results on tests are handled based on preset tolerances, and tests are indicated as critical in the EHR before the physician reviews them (75). During downtime, paper reporting methods become necessary, and results have to be reported to clinicians by fax or phone instead of through the EHR (67). Physicians waiting for reports are not always notified that the EHR is down and contact by phone or fax is not always feasible. Consequently, patients in emergent situations, whose diagnosis depends on timely laboratory results, are exposed to significant risks.

Laboratory availability and turnaround time affect patient safety, but to date, research has primarily focused on clinician and laboratory personnel errors in test selection, execution, and interpretation (75–80). Few studies have indicated that there is a potential for risk to patients when results are delayed (28,81). Fewer studies have systematically examined the impact of EHR downtime on the laboratory and other clinical areas, such as the ED, that rely on the laboratory (82).

The ONC has published the *Safety Assurance Factors for EHR Resilience* (SAFER) Guide (83). The document provides guidance on EHR implementation and highlights the importance of contingency planning. Other regulatory bodies also address aspects of downtime contingency planning. For example, the College of American Pathologists (CAP) regulates the operations of clinical laboratories. CAP regulations mandate that downtime procedures be on file, but similar to the SAFER guide do not specify details on how to develop them (66).

Due to certification and inspection requirements, all clinical laboratory downtime procedures are CAP compliant. However, they are not informed by systematic analysis of existing data (67). Often downtime procedures are developed based on an administrators' intuition and existing knowledge of the organization. Typically, current downtime procedure for a laboratory state that specimens are prioritized based on where they came from in the hospital. ED requests are always prioritized for processing, while non-urgent testing is put on hold during short downtimes, arbitrarily considered to be periods less than four hours. For downtimes that exceed

4 hours, non-urgent testing is resumed. While this may be a reasonable rule, the window is selected arbitrarily, and testing prioritization would be better informed by current and expected testing demand rather than by a strict time cut-off.

The downtime procedure also includes recovery operation instructions. For example, if during downtime a specimen is accessioned (i.e., the process of assigning an identification number and testing needs) and the system comes back online before that specimen is processed, the specimen still needs to be processed under downtime procedures. While this rule may be effective under some conditions, it may not always be the best procedure.

2.6. Downtime in Other Computer-Dependent Industries

Computerized support systems are not exclusive to healthcare. Commercial aviation and the nuclear power industry have both adopted computerized systems to facilitate safer and more efficient operations. The Federal Aviation Administration (FAA) has been working to transition from their current 40-year-old legacy system to the new En Route Automation Modernization (ERAM) program. Nuclear power plants (NPPs) employ operational software to manage the plant and present operational data to the plant workers. The NPP software is twofold; first, it must accurately present operations data to the workers, but its second critical purpose is to operate the plant hardware physically. By examining the development and implementation of both of these highly critical technologies in these industries, insights could be translated into electronic health record (EHR) implementation and development.

2.6.1. Federal Aviation Administration Air Traffic Control Systems

After several accidents, the FAA was created in partial response to a desire to have a single body in control of air traffic across the country (84). To maintain safe monitoring of the nation's airspace and air traffic control centers in towers at airports and other strategic locations were constructed and installed, generally recognized by the physical radar workstation pictured in airport towers. Recently the over 40-year-old outdated systems were replaced with the ERAM system.

Development of ERAM was influenced by experiences from the previous system, and prior incidents which the FAA wanted to ensure weren't repeated. The old system severely

limited a controller's sphere of influence to only the boundaries of their sector, making it difficult for controllers in neighboring sectors to cover for a downtime incident. Additionally, the backup systems which went online in downtime were even more restrictive, less accurate and provided less information to the controller.

Based on prior experience, risk factors influencing downtime requirements for ERAM were identified. The primary motivation for the risk factors was based on worst case scenario outcomes if the system failed, and the issues that had been discovered during the operation of the old system.

The downtime issue is addressed by the means by which the ERAM equipment communicates. During normal operations, ERAM has two data channels, named A and B (85). Unlike the previous system where the downtime plan required activation of less capable hardware, data channels A and B are equivalent in capacity and quality. By being fully redundant, if the active communications channel fails, all data can be routed to the secondary channel with minimal impact to the individual controllers (85).

A significant goal for ERAM and any potential air traffic system is to maintain the automated alerting systems for aircraft proximity and potential collision in the airspace (86). The software routines for the alarms and tracking need to present the information to the controller for action. ERAM includes significantly more data for the controller than the legacy system and its back up capacity ever could. The operation of the backup systems and the normal operations components are established by federally mandated regulations for all of the equipment used for air traffic control (87).

Part of the desirability for ERAM is the improved communications. The legacy system allowed almost no overlap in operations. ERAM allows controllers to pass aircraft to each other directly, and in some cases, surrounding centers could redistribute workload from a malfunctioning center due to the improved communications. All of the requirements and features of ERAM were designed to satisfy the FAA's regulations on the capacities of an air traffic control system

The development and testing of downtime procedures related to ERAM were primarily handled by way of simulated and live shadowing activities. The FAA maintains several simulation

centers in which new procedures can be experimented with using computer-generated aircraft tracks and having volunteer controllers act as the surrounding center controllers (85). Initial testing for ERAM was handled in some cases at a backup tower facility at the Dallas Fort Worth (DFW) airport where the data feeds from the active controllers could be fed to the testing area (88). The FAA implements "shadow training" allows real controllers to simulate the handling of real traffic without having to obtain volunteers to staff the scenario. The shadow controllers hear the live traffic and see the real-time movements on their screens, but their responses and inputs do not go out to the aircraft. Researchers are observing the shadow controllers in how they respond to the real-world operations going on around them.

When conducting initial operations testing for the ERAM system in the simulated environments, the FAA employed specific metrics to track constructs of concern. The constructs were the safety risk, efficiency, and workload, their metrics are identified in Table 2 (85). In some instances, the researchers referenced "standard metrics" but further definitions were unable to be located.

Table 2 - Downtime Constructs and Metrics from (85)

Construct	Metric
Safety Risk	Standard Metrics
	Reportable incidents (near miss, collisions)
Efficiency	Standard Metrics
	Elapsed time from the HCS/Channel outage until the controller is working at the same efficiency as before
	Elapsed time from the restoration of the HCS/Channel until controller is working at the same efficiency as before the outage
Workload	Standard Metrics
	Elapsed time from the HCS/Channel outage until the controller is working at the same workload level as before the outage
	Frequency of commands related to executing the switch over
	Frequency of ground-ground communications

To examine the performance of an ERAM communication channel change over. The FAA operates technical centers which can function as simulated air traffic control and airspace environments (88). In the fully staffed mock operational center, all aspects could be simulated with all work tasks and an entire controller team working through the situation (89).

The FAA highly regulates the requirements for training, testing, and certification of air traffic controllers. The high level of regulation means that the protocols and procedures for training are already established in the organization and makes new procedure training easily implemented. Air traffic controllers are required to be certified for every individual piece of equipment they operate and for the particular airspace they control. Training for ERAM downtime and migration was incorporated into the regular training and recertification processes already in place within the FAA (85).

In addition to the thorough training and certification, the rollout of the ERAM systems was handled in a staged manner to ensure that the controllers and equipment were ready and in place at the same time (88). When some installations fell behind schedule, and ERAM started failing to meet milestone criteria, the project advancements were halted until the current stage could be completed, rather than continuing to advance and compounding issues.

2.6.2. Nuclear Power Generation

Nuclear power plants rely heavily on computerized systems to monitor and control their reactors. These operations are accomplished by heavy reliance on automated safety systems and computer redundancy. Similarly, to air traffic control, NPPs are heavily regulated in all aspects. High regulation comes from the risk levels if some function does not perform as expected. For NPPs, risk factors are identified and documented by industry experience, academic research and regulatory bodies (90). Two of the major regulatory bodies are the International Electrotechnical Commission (IEC) and Nuclear Regulation Commission (NRC), most countries with NPPs also maintain regulatory bodies for NPP oversight as well.

Generally, new risk factors are identified only after a safety incident occurs, such as the incident at Three Mile Island (91). The analysis of an incident provides information as to what aspects of the plant safety systems failed, and researchers work to improve upon them. One

major complication is that while researchers have called for a standardization of the safety software employed by NPPs, almost every NPP employs a similar but unique system to manage the specific aspects of that installation (92). Typically when a NPP experiences a failure on some level, it is when a downtime contingency requires the fallback onto a backup system, which operates in a passive but ready state (91). The system is functional when passive, but when called upon to activate, the system fails, triggering an emergency action.

Most of the NPP software acts as an analog to digital conversion, translating the control inputs of the plant workers into physical operations of plant hardware. Individual systems are stringently tested to ensure their simplicity and reliability due to the risks of failure (93). Simplicity is believed to increase reliability where computer programs are implemented (93). Reliability is necessary to maintain confidence in the emergency shutdown and other automated intervention systems (94,95). If the computer systems lose their ability to communicate with the plant hardware, the hardware needs to be configured so that the workers can access shutdown routines, or the plant goes into an automatic shutdown state on its own.

Training of procedures and operations is handled through the extensive use of simulators. The simulators used vary in complexity and nature in NPPs. Simple simulators may feed data into the automated systems to test their reaction, while a full-scale simulator will provide a high fidelity control room for the operators to practice in (90,92,96,97). The thorough pre-installation testing of these components is documented for their compliance with established regulations (90).

Though the IEC and NRC mandate software testing for plant certification, there is an alarming lack of specificity about what tests are necessary or how the results should be interpreted (98,99). In previous tests of a NPP, it was found that the computer system only passed 48% of the tests run on it (98). With the lack of direction for interpretation, however, researchers were unsure if the tests performed were adequate, or appropriate. Simulation of individual components and overall plant events are used extensively based on the previously identified risk factors, but the factors are primarily reactionary based on previous incidents (95,100).

As part of the extensive automation, NPPs employ computerized cross-checking and automatic backup switching (100). Components are cross and redundantly connected. During

normal operations, the primary computer is continuously consulting with the information being provided by the backup system. Discrepancies between the paired computers are reported to the plant operators for intervention.

Simulation facilitates operator training for the interventions necessary and is approached similarly to the hardware/software validations. Staff are trained on all contingency procedures on full scope simulators as part of the initial plant go live and certified as such to satisfy regulatory demands (90,97). The fidelity and nature of the training and retraining are such that it satisfies IEC, NRC, and local regulatory criteria.

In addition to the training of staff, many emergency intervention systems are automated. These safety functions include; “anti-core meltdown,” “containment integrity,” “indirect radioactive release,” and “ maintenance of vital auxiliaries” (91). While the operator can activate the anti-core meltdown program, if the computer systems go down, the anti-core meltdown routine may activate as a safety precaution (90–92,96). The focus of the training is not necessarily to be able to identify when an event has occurred, but that the operator knows which safety functions need to be activated based on the notifications and alarms from the NPP operation system (91).

Both NPPs and the FAA are involved in critical computer based operations. EHRs in hospitals are equally critical, based on the criteria of critical software suggested by Shafei, Moawad, and Sallam (101), Table 3.

Table 3 - Criteria for Safety Critical Software (101)

Safety Critical Software:
Implements a critical decision-making process
Controls or monitors safety critical functions or software or hardware
Can cause or contribute to hazards
Intervenes when an unsafe condition is present or imminent
Executes on the same system as safety critical software
Can mitigate damage if risk occurs

2.6.3. Lessons Learned from High Risk Industries

Both ERAM and NPP operating software are highly regulated, operational and downtime requirements thoroughly tested and established. EHRs, by comparison, are far more open. There has been little to no mention of a need to establish back up networks similar to the capacity of

ERAM's channel A and B configuration. EHRs also have nowhere near the level of automation of an NPP. Finally, hospitals can select the EHR they want but do not establish regulations, unlike the FAA which employs ERAM and has control over the regulations for its use and implementation exclusively.

Taking some of the lessons learned from ERAM implementation, specifically that of the staged development process. When ERAM implementations fell behind schedule, the FAA put a moratorium on continuing the process until the issues were resolved (88). EHR development could be put on hold while the current downtime issues and other performance aspects such as meaningful use are brought up to a consistent level. Properly staging the implementation would ensure that issues are resolved rather than compounded with each evolution.

A significant challenge of EHR implementation is that the use of an EHR is mandated, the specifics as to which EHR is not. Similarly, regulations currently state that a downtime procedure needs to be on file. The specifics of that downtime procedure are loosely indicated if at all. The FAA mandates all control centers must use ERAM, this allows for unified training and certification. Downtime procedures for ERAM are taught and practiced during certification. Though expensive, a redundant, even partial capacity network could be established that would take over the load and even work in concert with the primary channel. By dual channeling the data communications, change over processes would be a minimal interruption.

Many hospitals are in need of a Healthcare Information Technology (HIT) overhaul. Over time pre-EHR components were installed and implemented, eventually evolving and being combined into a full EHR. Since many times clinicians were making the initial purchasing decisions for their independent practices, IT selections were often ignored. The neglect of IT backbones has created a situation where an ever-growing data transfer need is being placed on older and insufficient hardware. While the situation is troubling, it does present an opportunity to learn from ERAM and create a complete backup system running in parallel with the primary.

NPPs use an operational software package, but the specifics are unique to each plant. Despite this, staff still are successfully trained and certified in the use and operation of the plant and the related software. In the case of the NPP, many of the downtime procedures are automated or require some level of physical interaction with plant hardware at another location.

The conversion to a downtime procedure is even in some cases handled automatically and without an operator's intervention. The decision process in a high-risk state NPP does not allow for the time for all operators to come to a consensus and proceed. The time critical nature mandated the implementation of automated backup and shutdown procedures. EHRs cannot shutdown when only part of the system goes offline, but the same critical need by HIT administrators is present. The sooner the EHR is brought back online, the better.

The actual impact of an EHR downtime should be measured similarly to how the FAA quantified the benefits of ERAM over the legacy system using the information in Table 3. by examining workload aspects before, during, and in recovery from a downtime; quantifiable improvements on downtime procedures can be made. Prioritization of critical functions similar to an NPP will facilitate the development of the downtime procedures to test, including automation where applicable.

Currently, there is no notification for anyone in the hospital when the EHR goes down. It would not be difficult to have a system in place which could notify the hospital staff through a standard pager list, a technology still in use in hospitals when an EHR component has gone down. Notifying staff would make downtimes easier to cope with since it would eliminate the disconnect some areas may have when only a partial downtime is encountered.

EHRs will eventually need to be unified to meet some of the distant future meaningful use requirements. Downtime issues will continue to occur and if not resolved early in the process, will continue to plague progress and development. Even though ERAM and NPPs are highly automated and strictly regulated, there are lessons worth learning from their respective uses and development.

2.7. Resilience Engineering

Resilience engineering as presented by Hollnagel Woods and Leveson (2006) is a series of constructs with the mutual aim to identify characteristics of an organizations ability to cope with the unexpected (102). A resilient system is one that can maintain operations despite disruptive events. In the case of this study, a hospitals resilience in the face of a computer downtime event

would be demonstrated in the ability to maintain normal operations and not introduce additional patient risk.

Resilience is a focus on the study of a systems capability to adapt to disruptions caused by the environment (102). Hollnagel et al. indicate that leading indicators are necessary to ensure resilience (103). The leading indicator concept suggests that attention to key performance indicators would enable advance notice of issues before they have the opportunity to become dangerous (104). Some work has been done involving repetitive survey systems and tracking minute variations in worker responses to identify when an event is about to occur (105). This work can be translated to the hospital environment and its ability to cope with a compromised computer system and maintain consistent patient care and safety.

3. PROBLEM STATEMENT

Despite increasing adoption of EHR systems in healthcare (currently 83% of hospitals (58)), there has been little exploration into the complications that arise from computer downtime. Recent work has shown that downtime is complex and difficult to manage and that the current state of contingency planning is insufficient. Regulations provide only high-level guidance that contingency plans should be in place but do not address development, practice, or efficacy. Some work has provided suggested best practices for maintaining contingency plans, but still, do not address their development (83,106,107). Sittig's work (9) found that some hospitals can attribute adverse patient outcomes to downtime. This study proposes that by taking a systematic approach to evaluating the clinical laboratory and emergency departments, employing Macroergonomic analysis methods including simulation, the significant factors impacting safe and efficient patient care during downtime can be identified. The current downtime plans can be evaluated for compliance and appropriateness, and stronger evidence-based downtime contingency plans can be developed, thereby making computer downtime safer and expanding the application of Macroergonomics in healthcare.

At present, most research is motivated by meeting the current meaningful use standards and improving HIT infrastructure. Both are necessary goals; however, the focus on improving HIT will require substantial time and money to achieve. The study aimed to improve downtime planning and execution in the more immediate time frame and with the resources currently available.

This dissertation is focused on exploring and understanding the factors which may cause patient care to slow down and introduce unnecessary risks to patients. The exploration adapted the Macroergonomic analysis and design methodology (MEAD) and implemented simulation as a supporting tool to provide a testing space for the evidence-based interventions and general access to the synthesis of the collected data. Guidelines for downtime, like SAFER, are focused on top-down approaches. There is little to no understanding or exploration of the impacts on patient care at the patient level. This dissertation aims to provide a foundational understanding of the downtime impacts, and evidence-based design interventions. In addition, the

identification of significant pitfalls of research at the patient care level research into downtime are identified for future research into downtime.

Even if HIT is made entirely resilient to downtime, upgrades to hardware and software will still require periodic downtime, and have the potential for extended unplanned downtime during maintenance as issues are encountered. The planned results of this dissertation will aid in improving the handling of downtime before HIT infrastructure can be revamped, and the handling of expected downtimes after resilient HIT has been installed.

4. ADAPTING THE MACROERGONOMIC ANALYSIS AND DESIGN FRAMEWORK

The following chapter details the adapted MEAD methodology, inputs and outputs as related to the exploration of downtime issues. Table 4 outlines the major activities and outputs of the following sections. The MEAD methodology was selected due to its ability to provide a holistic analysis of an entire work system. MEAD is based in the sociotechnical work systems theory, and facilitates the evaluation of all of the subdomain interactions possible, making it an ideal choice to explore a complex environment such as healthcare.

Table 4 - Adaptation of MEAD Methodology to Evaluate Downtime

MEAD Phase	Tools and Activities	Outputs
Scanning Analysis	Identification of Scope	
System Type and Performance Analysis	Observations Prior Performance Data Analysis	
Technical Work Process Analysis and Variance Data Collection	Stakeholder Interviews	Risk Identification Potential for Lab as leading performance indicator for ED
Variance Analysis and Control and Role Analysis	Variance Matrix and Variance Control analysis	MEAD analysis of the current state of Downtime procedure execution
Organization and Functional Design	Role Analysis	Intervention focus
Design, Iteration, and Improve		Intervention Design Simulation Testing
Implementation	Out of Scope	

In a downtime scenario, the complications and hindrances to patient care are predominantly unknown. By employing and adapting a methodology such as MEAD, based on a holistic view such as sociotechnical work systems, a more inclusive understanding of downtime can be captured. Both of the target hospitals encountered a long duration, total downtime event (TDE), during which all computer systems were shut down for 48 hours followed by an additional 48 hours of partial downtime as individual systems were reinitialized and brought back online. Both hospitals have also encountered many smaller planned and unplanned downtimes which the staff has had to work through. The archived performance data from these downtime events and the experiences of the staff working through them are the root data for the methodology.

4.1. Scanning Analysis

4.1.1. Location and Structure

The target hospitals are part of a larger not-for-profit entity managing multiple hospitals in the mid-Atlantic region. The larger of the two hospitals (Hospital A) is the primary emergency care facility for a major metropolitan organization and is involved in the emergency response plans for the local government entities. Hospital A operates over 900 beds and has advanced facilities including a burn unit and Trauma-1 designated emergency department with life-flight capability. The second hospital (Hospital B) is a smaller, 300-bed suburban acute care facility, with a 24-hour operating emergency department but no life-flight, major trauma, or other advanced emergency service capacity. Both hospitals have full-time operating laboratories to support the clinical needs of the clinicians in them. Hospital A operates an ED micro-lab within the ED workspace to support patient care, while Hospital B runs all testing in the same physical lab space, employing a vacuum tube delivery system that only moves between the ED and laboratory. By studying these two different facilities, with different populations, workflows, demands, and capabilities, the factors identified impacting patient care during downtime would be representative of a broader number of hospitals and could be generalized between both facilities and potentially for more hospitals in general.

Both hospitals operate a linked, customized installation of Cerner's EHR software. The specifics of the IT infrastructure are unique to each facility. All of the hospitals are still required to cross-connect to the same resources within and between facilities. An information flow diagram for one of the target hospitals is provided in figure 2 below.

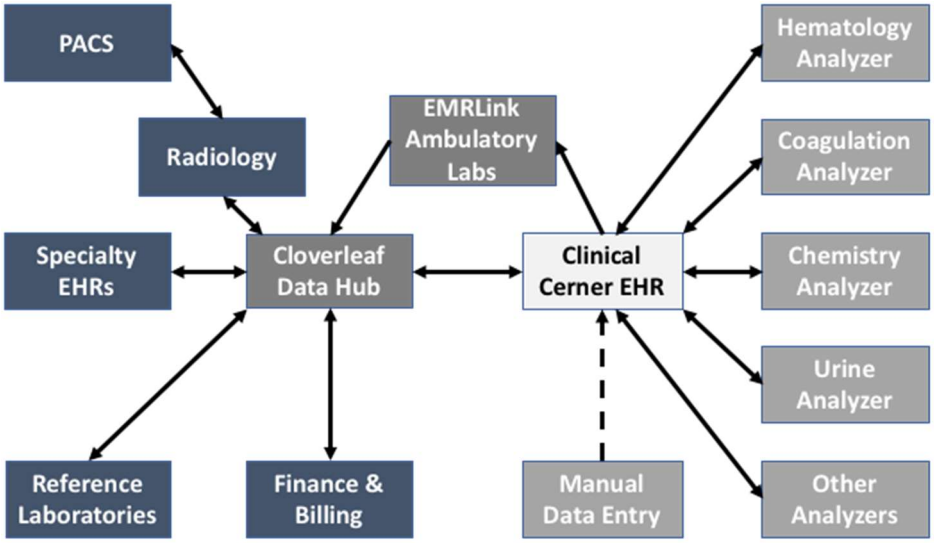

Figure 2 - HIT Structure and Data Flow for Hospital B

The specific departments of focus are the hospital emergency department and clinical laboratory. Organizationally, the ED and the laboratory exist within two different administrative structures, though operational decisions are made with some consultation between leadership teams. The clinical laboratory is responsible for performing work for areas beyond the ED, but for this study, those areas are considered to be outside the work system. Patient movement through the hospital is represented in Figure 3. To frame the boundaries of the problem space, Suppliers-Inputs-Processes-Outputs-Customers (SIPOC) charts were constructed for the ED (Figure 4) and Laboratory (Figure 5).

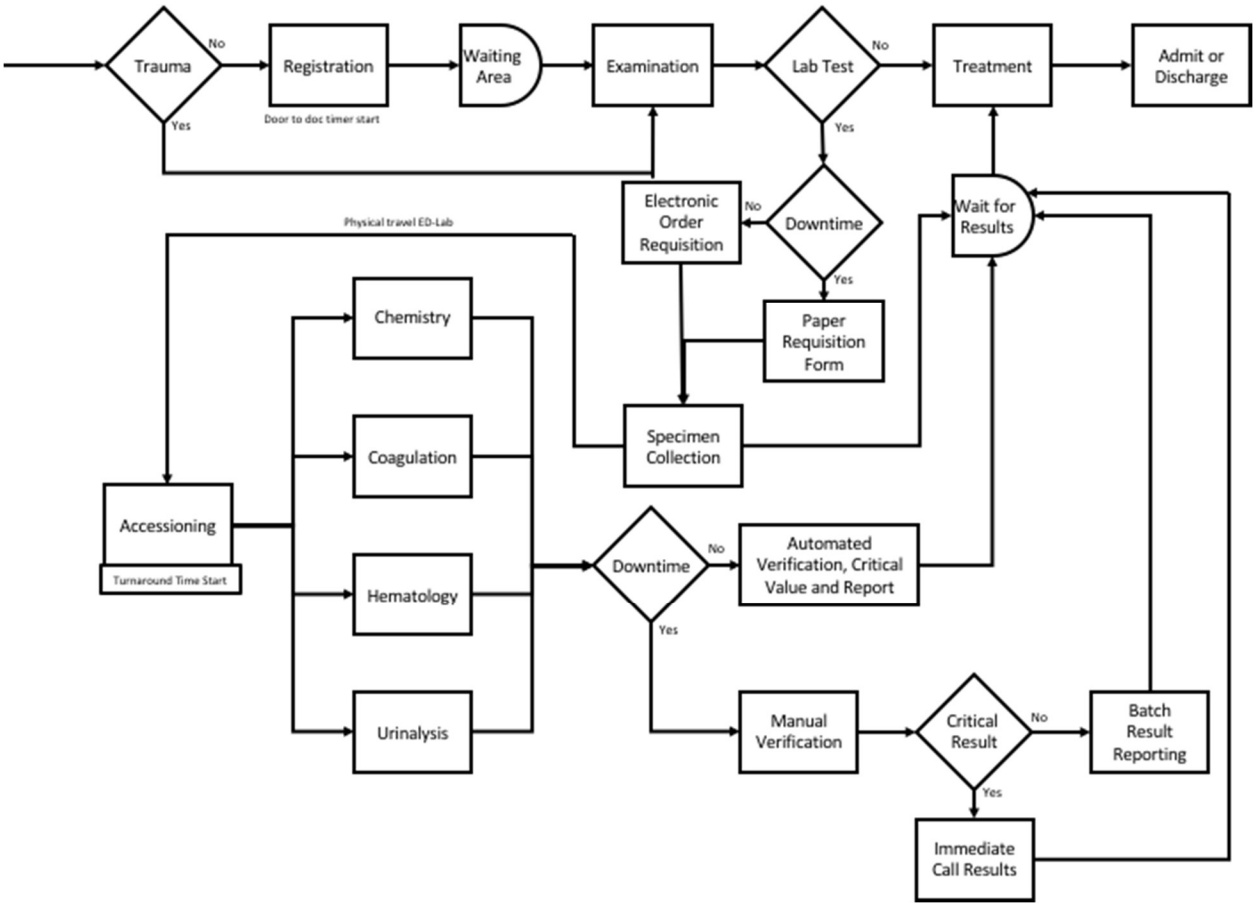

Figure 3 - Patient Flow Admit to Discharge with Lab Testing

Figure 4 - SIPOC Chart of Emergency Medicine

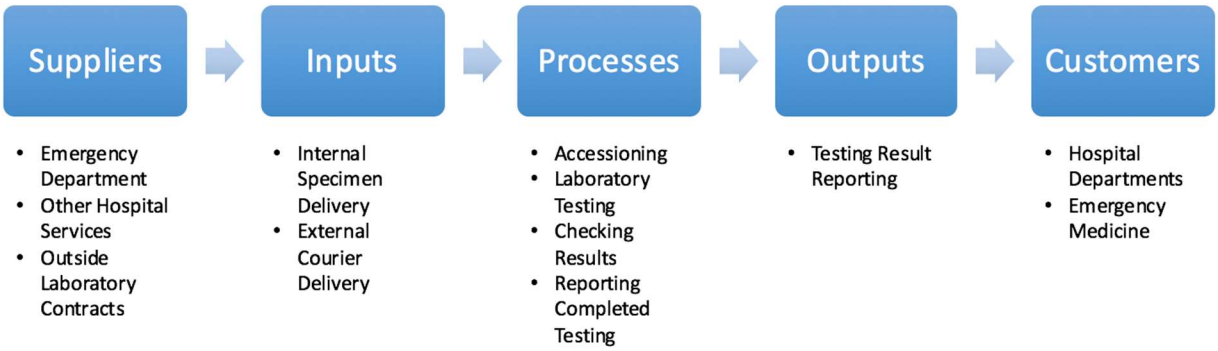

Figure 5 - SIPOC Chart of Clinical Laboratory

In addition to the SIPOC charts, a basic sociotechnical work system diagram has been constructed, representing the specific situation relative to this study in Figure 6.

Figure 6 - Sociotechnical Work System for Downtime (adapted from Kleiner and Hendrick (2001) (16))

Both of the target hospitals have encountered downtime events. The major TDE occurred a year before this study was initiated. In addition, several other smaller downtime events have occurred due to system upgrades, hardware changes, and unexpected outages. Hospital B laboratory keeps a running log of downtime events, with an indication of if they were scheduled or unscheduled. It is important to note that a scheduled event for an upgrade that runs longer than planned is still designated a scheduled event in this log. Due to the log being specific to the clinical

laboratory, it is likely that many of the downtime events impacted only the laboratory, and Table 5 should be taken as only an indication of laboratory impact downtime events. There is no hospital-wide downtime log available.

Table 5 - Hospital B Laboratory Downtime Events 2009 – 2016 (March)

	2009	2010	2011	2012	2013	2014	2015	2016
Scheduled	2	0	3	3	6	5	12	1
Unscheduled	2	2	3	3	0	1	0	1
Total	**4**	**2**	**6**	**6**	**6**	**6**	**12**	**2**

Scheduled downtime events typically occur during low demand, weekend, night-shift hours. All impacted departments are given at least a week notice the event is coming, multiple reminders, and ample opportunity to select which patient care activities need to be completed before the event and which can be completed after the downtime. By always having the scheduled downtime events occur during off-hours and night shifts, the day shift rarely has an opportunity to practice the downtime procedures. Those working through a night shift scheduled downtime have next to no workload due to the entire hospital receiving advance notice of the downtime and preparing accordingly.

Unscheduled downtime events are unpredictable and more disruptive. An unscheduled event can occur at any time, and there is no established protocol for notification of an unscheduled event in progress. Many workers discover the downtime when they attempt to report a computer issue to the helpdesk and are told the issue goes beyond their system. Due to the unscheduled events occurring without warning, no advance work is prepared for them, and predicting the duration is impractical, workers are left to attempt to continue patient care activities, as if the downtime were not occurring, in the hope for a short duration event.

4.1.2. Workplace Observations

Initial observations were conducted in the lab and ED of both hospitals to understand the physical capabilities and work processes that take place. The initial sessions took place during day shift operations when both departments and hospitals were at peak workload. During these initial observations, there was no structured plan; the goal was to observe everything and gain an understanding of how patient care worked and the interactions between the lab and ED.

In the laboratory, downtime drills were also observed; however, the sessions were not themselves informative, the details of lab operations during downtime are challenging to track visually and required additional information from the paper records generated. A plan was established to observe a real downtime event (Appendix A.3) where non-affiliated researchers could be dispatched to the hospitals and observe; however no unplanned downtimes occurred during this study.

Observation of a planned downtime event was also not possible due to the hospitals developing a "continuously available upgrade" mechanism. The details of how it works are beyond the scope of this dissertation, but it allows the hospital to continue to use HIT and EHR systems through the upgrade with only partial slow down rather than total disconnection. By having a continuously available upgrade, the only certain planned shutdown downtime events are for the changeover during daylight savings time twice a year, both instances lasting less than an hour and occurring during low impact weekend hours.

4.2. System Type and Performance Analysis

To evaluate the work taking place in the target hospitals, an evaluation of the nature of work is necessary. Perrow provides a framework for categorizing the nature of work; work tasks are classified into one of four categories (Figure 7)(108). Routine tasks are those with typically low variability and highly predictable outcomes. Tasks classified as Engineering tend to have higher levels of variability but still employ standard solution practices enabling easy analysis. Craft and Non-Routine are both more difficult to analyze due to Craft having few exceptions yet unpredictable outcomes and Non-Routine featuring a high rate of exceptions and unpredictable outcomes (16).

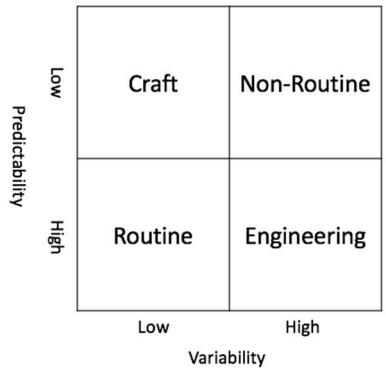

Figure 7 - Perrow's Framework (108)

In general, healthcare operations fall between routine and engineering as classified by Perrow (16). Laboratory procedures generally within the routine category, while ED operations fall within the engineering and non-routine classifications as problem-solving and reliance on training to draw conclusions is more likely, and the day to day operations may have high variability due to outside influences. Understanding the classification of the work tasks is critical as it will inform the developed interventions as to how rigid they need to be, or how much of the operationalization of the intervention should be handled by the workers. For example, in a routine work environment, additional support staff could be part of an intervention, and due to the high predictability and low variability, those support staff could be given specific roles every time the intervention is activated. In a non-routine environment, those same support staff would need to be given less structured parameters for their work tasks and may need to function as more on-demand work assistance.

From a performance perspective, patient care and safety are the primary factors of interest and must be maintained regardless of work system complications. In addition to accuracy, efficiency is of concern. When there are delays in laboratory testing, patients are likely to be admitted to the hospital unnecessarily while waiting for a test to return with information indicating their condition is not as severe as initially thought. Additionally, patients experiencing severe delays may choose to discharge themselves even though their care is not complete to return home or relocate to a different hospital that may care for them more efficiently.

Data was collected from a combination of qualitative and quantitative data to support the understanding of patient care activities, including the archival TDE data, workplace observations, and stakeholder focus groups. Multiple data sources and data triangulation reduce complications due to missing, incomplete or unreliable data, and enable cross-validation and consistency checks (109–111). Triangulation has been used in healthcare research in situations where quantitative data is desired in combination with qualitative data, such as in performance evaluations (112,113).

4.2.1. Care Process for an ED Patient

The ED represents the primary point of entry for many patients coming into the hospital system. The ED is also an area that, except in extraordinary situations, cannot be shut down regardless of the state of the EHR or other support systems within the hospital.

4.2.1.1. Emergency Department

The emergency department is one of the points of entry for patients into the hospital. Patients arrive by air or ground ambulance or walk-in. Based on the diagnostic process that follows, a patient is dispositioned from the ED and admitted to the hospital, sent home, or expires due to their medical condition and is sent to the morgue.

Registration and Triage: Patients entering the ED register into the EHR and their condition assessed in Triage. The specific timing of triage and registration may vary in the care process depending on the patient condition and mode of arrival. The triage process establishes the severity of the patient condition, and an ESI number is assessed, the process is outlined in Figure 8. The ESI number will determine the priority of care the patient will receive and is based on an estimation of the condition, life risk, and expected resource demands the patient's care will place on hospital resources (114,115). Patients are moved to a waiting area after triage and before being brought into a room or bed for treatment.

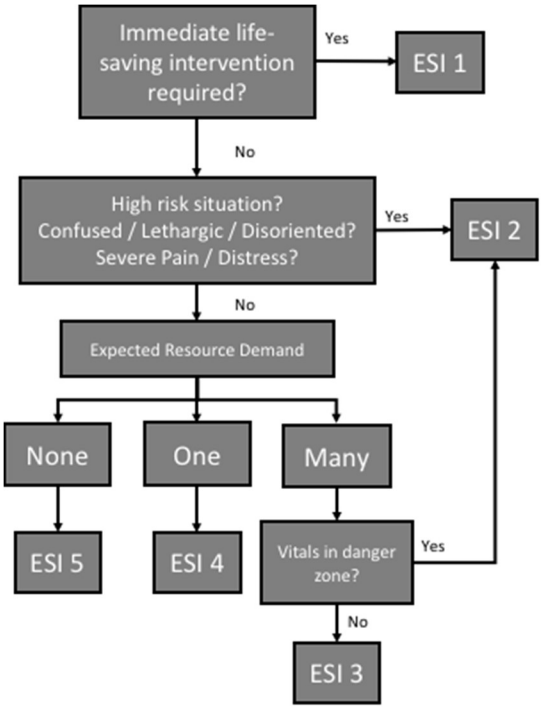

Figure 8 - ESI Assessment Process (Adapted from (115)**)**

Examination and Treatment: Typically handled in the same physical space, the initial examination will confirm the findings of triage and any necessary specimens are collected for testing. At this stage, the patients will wait in the assigned room until their testing results are returned, and the physician has enough information to make decisions and act on their condition.

Typically, the testing requests are handled by the computerized physician order entry system (CPOE), a downtime event, however, can take the CPOE and other systems offline. In that case, a paper requisition form is generated (Appendix C.1) and sent to the laboratory with the specimen. Regardless of downtime status, specimens must physically travel to the lab by vacuum tube or hand delivery.

4.2.1.2. Clinical Laboratory

All diagnostic testing is performed by the clinical laboratory. Many procedures and protocols are in place to ensure the laboratory maintains operational ability during downtime events.

Accessioning: Accessioning represents the point of entry for specimens accepted into the laboratory for testing. Specimens arriving physically into the lab are reconciled with their paper or digital requisition depending on the state of the EHR and routed internally to the appropriate

area for testing to be completed. The clinical laboratory consists of many specialized areas; however, the scope of this dissertation is limited to that of the "core-lab" which is the area which handles the majority of the ED testing demands.

Analyzers: The core lab consists of four main analyzer categories; each analyzer is configured for a specific type of testing. *Chemistry analyzers* handle tests related to the metabolic panel battery of tests, the particular assays of a metabolic panel will vary depending on the organization but typically are used to measure glucose (sugar), electrolyte balance, fluid level and kidney function. Tests run on a chemistry analyzer typically require extra time for the specimen to clot and to be run through a centrifugations step for blood component separation first. *Hematology analyzers* focus on blood cell counts. *Coagulation analyzers* run tests related to bleeding and clotting factors and are typically used for monitoring patients on blood thinning medications and unexplained bleeding. Finally, *urinalysis analyzers* are used to examine kidney function, sugar levels, and other preventative diagnostics. Each specimen will arrive at the lab in a specific vial for the intended analyzer. The vials contain may different compounds that the sample mixes with to prepare it for the analyzer which will process it.

Reporting: During normal operation, the analyzer machine performs an automated cross-check of control data for the service interval, and alerts the technician to any out of the ordinary results. If a testing result falls significantly outside of the established reference ranges the result is considered to be critical, and an additional alert is presented to the technician. All results are automatically pushed to the patient EHR upon verification for the ordering physician to review.

During downtime, the automated reporting systems are typically unavailable. Testing results are output, generated by an attached printer and must be hand reviewed to ensure control results are still valid, and a check for critical results is performed. If a critical result is found, the results must be reported to the ordering physician as soon as possible, usually by a direct phone call. Normal testing results and those that do not significantly fall outside the reference ranges are collected and batch delivered by either fax or internal courier to a central location for each department of the hospital.

Once the results are reported, either to the EHR by the analyzer or by downtime protocols, the physician in the ED can continue the patient care process once the testing results have been communicated.

In support of the performance analysis phase, quantitative, archival data obtained from the EHR system has been combined with qualitative and quantitative data from pilot workplace observation and focus groups. Workplace observation facilitated general work task and environment understanding, while focus groups enabled the estimation of data not otherwise available.

4.2.2. Review of Archived Paper Records from Prior Downtime

During a downtime event, the clinical laboratory converts to paper-based reporting for all activities. The emergency department, however, does not have as rigorous paper record keeping as the laboratory. When evaluating the computer records for patient movements during the downtime, many anomalies were found which suggested that the records for patient movements would be inaccurate. A simulation model is implemented to help address the gaps in the downtime archival data available in the completion of this study.

Information collected from the paper records were procedural only, i.e., time-based metrics. For a given patient report, the time of specimen collection, label creation, delivery into the lab, lab testing start, and completion were documented. During the review of the paper records, it was discovered that the time stamps from the TDE were too fragmented to provide the desired resolution. For example, none of the records from either hospital had an indication when the results were faxed or called up to the physician who requested them; most lacked a definite time of collection from the patient, and at least half were missing the time the laboratory accepted the specimen for testing. For Hospital B, the computer tracked over 6000 testing requests during the TDE, of them 940 were related to the emergency department, and of those only 617 (65% of ED) had paper records to support or correct the computer-based information. At Hospital A, the computer tracked 8,842 testing requests from the ED, of which none of the paper records were found to be intact enough to contribute to the database of downtime performance.

Since tracking of clinical laboratory quality metrics is required by the Clinical Laboratory Improvement Amendments (CLIA) and College of American Pathologists (CAP), there is detailed and comprehensive archival data that were used to assess laboratory operations during EHR uptime (i.e., normal operations) and downtime. A key performance metric of the laboratory is *turnaround time*, which is the time from specimen arrival in the laboratory to reporting of results (116,117). The TAT for lab tests during normal operation and downtime during the TDE is compared using a Kruskal-Wallis test. Kruskal-Wallis is a one-way Analysis of Variance (ANOVA) equivalent for data sets which exhibit signs of skew, in addition to lacking homogeneous variance and do not fit a normal distribution, all requirements for the ANOVA test to be valid.

Due to the partial records available, only some high-volume tests were able to be analyzed. Kruskal-Wallis tests require a minimum of five observations per treatment to be valid. Due to the n=5 restriction, 15 different tests were able to be compared. Of those 15 tests, 11 showed some amount of delay during downtime, 9 of the test types were delayed by a significant (α=0.05) amount. On average, the delay to TAT during downtime was 20 minutes which represents a 62% delay over the normal operation. The specific testing delays ranged from Complete Blood Counts being delayed by 32.5% (8 minutes) to Magnesium level resulting being delayed by 173% (36 minutes). The full table of the tests compared and their results are in Table 6 and Figure 9.

Table 6 - Hospital B Downtime TAT Performance (* denotes significant delay)

Laboratory Test Type	*p* value	Percent Difference in TAT from Normal vs Downtime
Amylase Level*	.021*	44.74%
Basic Metabolic Panel*	*p*<.001*	38.50%
Beta HCG Qualitative Urine*	*p*<.001*	15.88%
Complete Blood Count w/ Differential*	*p*<.001*	32.50%
Comprehensive Metabolic Panel*	*p*<.001*	19.21%
Drug Abuse Screen Urine	.064	41.46%
Lipase Level*	.0014*	57.65%
Magnesium Level*	*p*<.001*	173.02%
Phosphorus Level	.15	146.54%
PT and INR	.49	-37.10%
PTT	.90	-8.25%

Troponin-I*	$p<.001$*	100.65%
Urinalysis Iris Complete	$p<.001$	-37.28%
Urinalysis Iris Microscopic	$p<.0013$	-20.83%
Urinalysis Iris Reflex Microscopic*	.0042*	10.99%

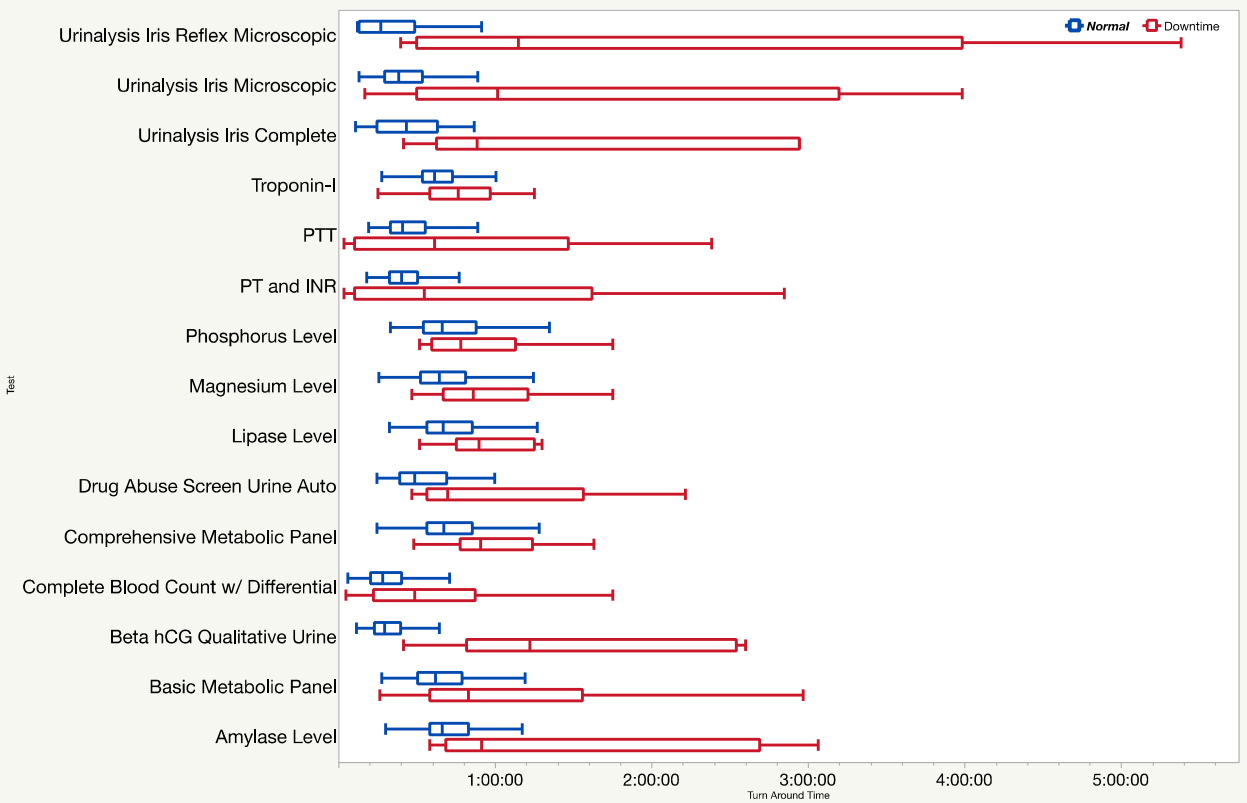

Figure 9- Turn Around Time by test, normal vs downtime

Downtime analysis of Hospital A performance was not possible. After reviewing all of the retrieved paper records from downtime at Hospital A, it was found that none of the records had the required information to track performance during downtime. The lack of viable data is an indication of a breakdown in the downtime procedures in Hospital A as these records are required both by the internal downtime procedure and as regulatory mandates. Further analysis through the MEAD methodology was possible, but direct simulation representation for Hospital A operations during downtime is not possible until additional and more intact downtime records become available.

4.3. Technical Work Process Analysis and Variance Data Collection

The previous phase of the MEAD methodology helped to establish the quantifiable impacts and variances that may occur during downtime. As part of the triangulation of data collections for this dissertation, interviews with the stakeholders can provide additional insight and explanation. These interviews are especially important as they have the potential to provide insight as to why there were issues with downtime related data from Hospital A.

4.3.1. Stakeholder Interviews

The interview sessions for the study were comprised of 17 personnel from the laboratory and ED. Over several days, multiple sessions were conducted to accommodate participant schedules. The sessions were intended to be conducted as larger focus groups; however, due to scheduling and work coverage restrictions, all sessions were conducted with only one or two participants at a time. ED interviews focused on physicians and nurses; laboratory sessions focused on technicians from the core laboratory and supervisors. The interviews focused on feedback from stakeholders about their perceptions of downtime operations, desires for potential improvements, and the activities that take place during downtime, especially those during a recent TDE.

The stakeholders of the hospital, representing the internal personnel element of the sociotechnical system, are in the best position to help identify variances in how EHR downtime events are handled in the internal environment. The stakeholders are intimately familiar with the needs of their jobs and many of the regulatory restrictions in place guiding operations. Additionally, as the personnel responsible for executing any potential improvement interventions, they would have insight as to what may work best to facilitate the execution of their job tasks while remaining compliant to any regulatory restrictions.

Archival data provides a performance-centered depiction of previous downtime work but must be combined with other sources to gain the complete representation of downtime events. Quantitative performance measurement combined with the more qualitative feedback of the focus group sessions enables the construction of a variance matrix and other tools to assess the significant discrepancies between expectations, stated procedures, and reality.

4.3.1.1. Recruitment

After receiving Virginia Tech IRB approval (Appendix A.1), potential participants were contacted through email with IRB approved recruitment materials. Originally planned to be conducted as focus group sessions grouped by job role, individual work responsibilities precluded the focus group format, and most sessions were either individual or two participants at a time while participants traded coverage with their coworkers to participate in the study. Participants were not compensated for their time but participated as part of their regular work day.

4.3.1.2. Participants

Participants were all employees of the target hospitals and had experience working through some level of downtime event. All but one participant had been in the organization during the large TDE which had occurred the year prior. The original design for the sessions was to recruit at least 12 participants between ED physicians and laboratory staff. During the first laboratory sessions, it became clear that the nurses also played a critical role in downtime care and the option to recruit them from the IRB was activated. In total 17 participants including nurses were recruited, a balanced number of participants across locations and roles was intended, however, due to scheduling conflicts and an employee union at one of the hospitals, an unbalanced number of participants was recruited between the two sites.

Though no direct analysis was performed to ensure sufficient participants were recruited, the details of the conversations with all participants rapidly converged by the completion of the initial 12 participants. The additional five participants provided insight from a different work role; however, their comments did not deviate from the previous participants.

4.3.1.2.1. Deviation from Focus Group Plan

The sessions conducted were intended to be formatted as focus groups, with participants from the same job role and hospital of employment grouped together. Due to limitations in work schedules and availability of participants, more sessions were conducted as interviews with fewer participants in each session. The change became necessary as there were many workers interested in participating in the study, but they had to coordinate amongst themselves to cover each other's work tasks to enable participation. From this point on, all intended focus group

sessions were conducted and referred to as interviews, the prepared focus group scripts in Appendix A.2 were still used to guide all interview sessions.

4.3.1.3. Interview Session Procedure

The researcher scheduled potential participants through email communication. Coordination of any shift covering was handled between the participant and their direct supervisor. As participants were contacted through their corporate account, their employment status with the hospital, the only exclusion criteria, was already known. Participants were met in their departmentally managed conference rooms which were reserved on the scheduled days and times.

Upon arrival, participants verbally consented to the research project and session with IRB approved scripts and verbal consent forms, and were introduced to the research team, consisting of the primary researcher and a research assistant from the AHRQ R21 team who documented the session. To preserve participant anonymity, verbal consent was received and the only recording employed was a typed transcript handled by the AHRQ R21 research assistant. The questions asked (Appendix A.2) were intended to elicit responses relevant to specific topics indicated in Table 7.

Table 7 - Interview Topics

Interview Topics
Communication
Technology
Efficiency and Work Stress
Patient Safety
Downtime Preparation

4.3.1.4. Codebook Development

Due to the semi-structured format, it was possible that responses would not conform to the original topics which influenced the questions asked. An iterative, open coding approach was used to account for the potential variations (15,118–120). The responses were coded independently, and an initial codebook developed and cross-checked with the AHRQ R21 research assistant. Once the codebook was established, a third research assistant from the AHRQ R21 simulation development team who had no prior exposure to the study, or medical

terminology, was asked to apply the developed codebook independently. The details of the codebook development is explained in the sections that follow.

4.3.1.4.1. Personnel

The researcher initially reviewed the session transcripts and extracted statements made by participants and performed the initial rounds of coding. The AHRQ R21 research assistant who was present for all focus group sessions made secondary reviews of the codebook and provided feedback. Upon finalization of the codebook, a third research assistant, whose primary role was simulation development for the AHRQ R21 team and was not involved in the sessions or initial coding, made an independent coding by using the developed code book and was cross-checked for interrater reliability.

4.3.1.4.2. Codebook Development Process

Following the open code approach (Figure 10), the researcher reviewed all transcripts and extracted statements. Through multiple iterations first the broad themes were identified, then through an additional iterative process, the subcodes for each theme were defined (Table 8). Once the initial codebook was developed, it was reviewed by the AHRQ R21 research assistant who was present for all focus groups. The AHRQ R21 research assistant provided feedback on the subcodes and definitions based on their knowledge of the sessions and project.

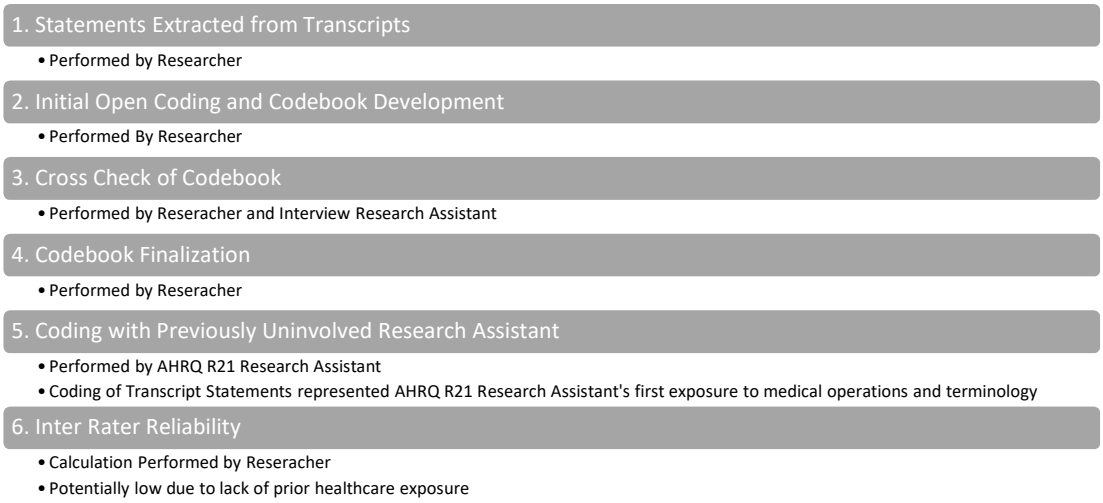

Figure 10 - Codebook Development Process

4.3.1.4.3. Codebook Finalization

When both the researcher and AHRQ R21 research assistant reached consensus on the codebook, the excerpts and codebook were provided to a third research assistant, responsible for the simulation for the AHRQ R21 and had no prior exposure to the transcripts, sessions, or codebook development process. The independent third research assistant coded the same excerpts as the researcher and provided comments on the codebook. The codebook was finalized as shown in Table 8 and interrater reliability calculated for the primary and independent researchers.

Table 8 - Downtime Interview Code Book

Theme	Sub-Code	Definition	Frequency of Occurrence
Downtime - *downtime operations, such as the support for, discovery or recovery from downtime operations*	Discovery	How the beginning scenario of a downtime incident is generally or specifically discovered	20
	Initiation	Once a downtime situation is identified, what are the factors surrounding the implementation of the downtime procedure	13
	Recovery	Resolution/completion of the downtime incident, recovery/transition back to normal operations	7
	Communication	Relay of non-diagnostic information during downtime, general, such as person to person communication	36
	Handling	Comments on behaviors or actions during a downtime incident, such as execution of downtime procedures	25
	Infrastructure	Comments about critical equipment to maintaining operations	16
	General	Downtime related statements that do not conform to the other sub codes	10
	Labeling	Statement refers directly to the labeling of a specimen	9

Specimen Handling - *issues relating to the labeling, tracking, testing and reporting of specimens moving between the ED and laboratory*	Documentation	Other documents that accompany the specimen, such as the requisition form	7
	Positive Patient Identification	Specific mention of positive patient identification or demographic information being incorrect or missing	4
Workload and Workflow – *work tasks, work stress, and concerns about the implications to patient safety resulting from stress and workload*	Patient Safety	Reference to patient care and safety concerns	26
	Job Role	Reference to specific job role or desire for there to be prescribed downtime job role	38
	Interruption	Work interruption during downtime	12
	Result Reporting	Reporting of clinical or diagnostic patient information during downtime	18
	Volume	Volume of workload encountered during downtime	27
Communication - *transfer of information, both clinical and general information such as understanding between the departments about needs and limitations*	Transparency	Indication of the level of communication and work task understanding, trust between hospital areas	19
	General	Communication related statements that don't conform to the other sub codes	10
Preparation - *activities related to the training, practicing and creation of downtime procedures, and issues from their*	Training	Discussion surrounding past/current/future downtime protocol training	33
	Document Control	Issues with version control of documents for downtime protocol and training specifically mentioned	2
	Procedure	Downtime procedure concerns, related to suitability of current procedures or shortcomings	15
	Improvement	Opportunities for improvement to downtime procedure or noted improvement occurrences developed during downtime, i.e. "did X during last downtime and it worked well"	21
	General	Preparation related statements that don't conform to the other sub codes	4

4.3.1.4.4. Interrater Reliability

The primary and independent researcher compared their coding to establish interrater reliability. The content coded consisted of 372 individual statements where both the researcher and the unrelated research assistant agreed in 196 instances. The disputed codes were discussed, and all discrepancies settled, final codes aligned with the researcher 87 times and the independent research assistant 85 times, in four instances it was determined that the initial coding was incorrect and reached consensus on a different coding. A Cohen's Kappa statistic was calculated based on the two researchers coding, and the interrater reliability between the two researchers was found to be κ=0.48. Cohen's Kappa is the accepted measure for how often two coders have agreed on the coding of material while negating the likelihood of random chance generating the same results (121). A Kappa statistic of κ=0.48 is considered to fall in the moderate agreement range.

The moderate level of agreement achieved by the researcher and the independent research assistant may be partially explained by the lack of prior exposure to healthcare by the

independent research assistant. The transcripts and excerpts contained a significant amount of medical jargon unfamiliar to the independent research assistant. During the sessions comparing and establishing a consensus of the coding, the independent researcher indicated that when the jargon of the excerpt was explained, they would have revised the initial coding, often in agreement with the researcher's coding.

4.3.1.5 Interview Results

The feedback from the interviews fixated primarily on the issues of downtime itself and concerns about workload and workflow, accounting for 34.1% and 32.5% of the statements made based on the frequency of the code occurring in the overall table of excerpts (Appendix B.2). The next most prevalent topic was downtime preparation representing 20.2%, the entire composition of the themes in the focus groups is depicted in Figure 11.

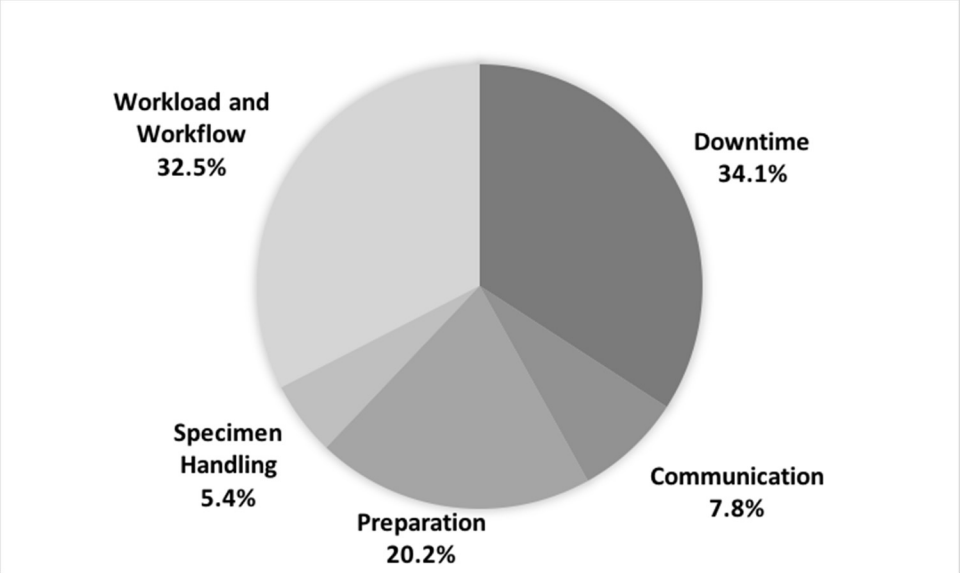

Figure 11 - Breakdown of Themes from Interview Statements

Downtime: Statements were primarily focused on the issue of downtime itself, encompassing issues with communication both intra and extra departmentally (28.3%). The next most frequent comments concentrated on specifics about handling downtime events (19.7%), discovering a downtime event is ongoing (15.7%), what infrastructure would be needed at minimum to continue what the participant considered safe care (12.6%) and what the process to initiate a downtime protocol entails (10.2%). The remainder of the downtime themed discussions were

coded as general downtime topics (7.8%) and the process of resuming from downtime to normal operations (5.5%).

Workload and Workflow: Concerns regarding the continuance of work and changes to the workload represented almost as much of the discussion as the general downtime theme. The comments focused on issues with downtime specific job roles (31.4%), concerns with the volume of work during downtime (22.3%). 21.5% of comments were attributed to concerns for maintaining patient safety during a downtime event. The remaining topics of workload and workflow discussion were about how the laboratory reports results (14.8%), and interruption to work tasks due to downtime specific sources (10%).

Downtime Preparation: When participants raised issues with how they are prepared to handle downtime, the primary focus was on the general training for downtime events (44%). Possibilities and suggestions for improvement were raised 28%, while 20% specifically mention issues with the current procedures in place that have been previously activated. The remaining discussion was general topics that occurred too infrequently to code individually (5.3%) and finally issues with document control for the procedure, such as having outdated copies of the procedures in the binder alongside the current (2.7%).

Communication: Communication during downtime was frequently referred to during the focus group sessions; however, the comments predominantly fixated on issues with the lack of understanding between departments of needs and limitations during downtime representing 65.5% of communication themed comments. The remaining statements that fell in the communication theme were coded as “general” (34.5%).

Specimen Handling: Statements regarding specimen handling represented the smallest theme in the discussions. It is worth noting that specimen handling issues have the potential to make widespread impacts and could be related to all of the other topics. The correct labeling of specimens, required for the laboratory to complete testing requests and report the results back

to the clinician represented 45%. General documentation issues such as filling out the paper requisition form (Appendix C.1) accounted for 35%. The remainder of the statements (20%) were related to the maintaining proper patient identification for care actions (i.e., medication administration, specimen collection and labeling, imaging requests and execution).

4.3.2. Phenomenological Analysis

As a secondary analysis, a phenomenological approach was also used to evaluate the transcripts in parallel to provide a separate study to compare to the open coding approach. The phenomenological approach is based on the dissertation work of Alice Haskins Lisle and provides a means to empirically analyze the shared experiences of individuals who have worked through a significant computer downtime event (122). Typically the approach used for a phenomenological analysis is to identify the method at the onset of the research and design the interview questions specifically to support the analysis (122–125). For the secondary analysis of the interview transcripts, the phenomenological study has been employed as a post-hoc analysis for sessions which were not deliberately designed for it.

Through the phenomenological analysis, design criteria for future downtime event plans can be elicited from the transcripts of previous interviews. The transcripts collected for the initial downtime coding were re-evaluated collaboratively by the researcher, Dr. Haskins-Lisle, and an additional assistant who had worked for Dr. Haskins-Lisle performing phenomenological coding previously, using the phenomenological approach and processed using the flowchart in Figure 12.

Figure 12 - Identification of Design Criteria from Phenomenological Analysis

The categorizations of the phenomenological analysis are provided in Table 9 below.

Table 9 - Phenomenological Analysis Categories From (122)

Criteria Category	Description	Example
Functional Needs	What the individual or system needs to do	Receive text alerts

Non Functional Needs	How is the functional need met	Receive text alerts from administration
Barriers	Impediments to meeting needs	High stress
Challenges	Complex impediments to meeting needs	Binders impede efficiency
Contextual Information	Background or additional information to where/how the needs and obstacles occur	Waiting for information

The analysis revealed 403 unique criteria from the interview transcripts. Of the design criteria, 45.9% were obstacles, 33% were needs, and 21.1% represented contextual information. By tabulating frequency counts and cross-referencing by job role, patterns can be shown in a heat map layout, Table 10.

Table 10 – Heat map of 60 Most Common Criteria by Job Role (F=Functional Need, NF=Nonfunctional Need, B=Barrier, C=Challenge, X=Contextual Information)

Criteria	Type	Phys	Nurse	Lab Mgmt	Lab Tech
Communication issues	B				
Assign downtime role	F				
High work volume	B				
Preparing for scheduled downtime	X				
Access critical work system	F				
Delayed results	B				
Staff compensates for system responsibilities	C				
Paper records impede efficiency	C				
physically distributed hardware	B				
Train staff	F				
High stress	B				
Train staff on downtime procedures	NF				
Discovering system is down from computer freeze	X				
Practice downtime drills	F				
Assign downtime role to organize paperwork	NF				
Faxing impedes efficiency	B				
Flag critical information	F				
Receive text alerts	F				
Result communication delay	B				
Laboratory communication issues	B				
Redundant lab orders	B				
Staff pressures lab for results	C				
System dependence	B				
Unscheduled downtime duration variability	B				
Assign downtime role to answer phones	NF				
Create electronic backup system	F				
Establish central phone	F				
Identify down system(s)	F				
Inaccessible patient information	B				
Inform charge nurse	F				

Criteria	Type	Phys	Nurse	Lab Mgmt	Lab Tech
Maintain interdepartmental communication	F				
Manual data entry	B				
New staff lacks downtime experience	C				
organizing paperwork	X				
Patient care delay	B				
Patient identification issues	B				
Phone communication	B				
Setting up for scheduled downtime	X				
Standardizing temporary workflow	X				
Using whiteboard	X				
Workload mismanagement	B				
Assign downtime role to handle administrative/clerical duties	NF				
Communicate downtime status	F				
Divided attention impedes efficiency	C				
Downtime delays	B				
Evaluating effectiveness of downtime procedure	X				
Find additional staff	F				
generating large amounts of paper	X				
High stress impedes efficiency	C				
Label specimen	F				
Managing stress	X				
retrieve medication information	F				
Standardize procedures	F				
Transitioning work mode	X				
Untrained staff	B				
Adapting to downtime procedures	X				
Admin provides alert only for scheduled downtime	C				
Binder use impedes efficiency	C				
Brainstorming course of action during scheduled downtime	X				
Calling IT for information	X				

Examining the heat map allows for rapid identification of trends and patterns in how frequently the different roles indicated different criteria. The concentrations of different criteria for different work roles support the comments by a number of participants that not all downtime specific work roles are appropriately distributed during an event. The barrier of communication issues was a more dominant criterion identified in the phenomenological analysis as compared to being the fourth most prevalent category in the open coding focus group. The change in

significance may be explained due to the more regimented criteria identification process and previously vetted procedures used by the phenomenological analysis, as opposed to the codebook developed from the transcripts.

4.3.3. Research Aim 1: Examine the avoidable risks patients and hospitals are exposed to during periods of computer downtime

4.3.3.1. Nature and source of the risks to which patients are exposed

Based on the results of the archival record analysis and interviews, patients are exposed to a number of risks focused on delays, missing or lost information, errors in treatment and overworked overstressed staff. A large number of participants from the focus groups expressed concerns about their ability to maintain work efficiency during a downtime, especially in the laboratory.

During a computer downtime, the safety systems which many clinicians may be accustomed to are offline, but in addition to this, basic record keeping methods are susceptible to error. A clinician may not know when the last time a patient was administered a medication, if it was the correct dose, or if the dosage had changed. Staff creating their own unapproved workarounds for downtime limitations can also introduce extra risks as was seen in a recent paper (120).

Several areas of the hospital rely on the ability to retrieve patient records for even basic demographic information. Medication dosages may be different for height and weights; laboratory test results have critical values set based on age, gender, and other demographics. When the computer system is in a downtime mode, this information is unable to be retrieved and must come from the associated requisition forms. The requisition forms all have fields for the required information, but a frequent complaint was that the document was not often filled out. The issue of requisitions not being appropriately completed also lead to the lack of viable data from downtime in Hospital A.

Participants in the interviews indicated that they often had issues with continuity of work through shift changes. One laboratory technician stated that coworkers were “making up procedures” when they couldn’t remember the established downtime protocol, rather than retrieving the downtime work aid with the complete procedures inside. Without knowing what

work was being done before their shift, fresh workers found themselves having to repeat previous work to complete the steps that previous shifts had done improperly before moving on to completing new work.

4.3.3.2. Extent the risks may be avoidable with evaluation and intervention in the work system

In many cases, the issues of downtime are likely to be avoidable. Additional training and support can be provided to workers don't know the entire downtime procedure and have been creating their own protocols to complete work. All interview participants felt that additional practice during downtime events could be beneficial in general. With the currently planned downtime events being used as training sessions, only the night and graveyard shifts get regular downtime experience as that is when those planned events occur.

Possibly most critically, communication is a correctable issue. Through all of the interview sessions, issues related to communication were raised. Communication within a department suffers as individuals became overworked and stressed, but also between departments there has been a lack of communication. A physician in the emergency department indicated that the only way they find out that the lab is in downtime and operating slower than usual is when they realize it has been three hours since they sent a specimen down and called the lab. A communication plan could ensure that the entire hospital knows when a downtime event is ongoing and what they can expect for efficiency from the impacted areas.

Finally, with communication, a mutual understanding of limits and capabilities during downtime could be established. Several laboratory participants indicated that they felt the hospital tried to continue ordering all tests regardless of downtime during the TDE rather than considering what was medically necessary. Some intervention allowing for an altered and reduced testing menu may be able to reduce workload in the laboratory so that closer to normal operation efficiency can be maintained.

4.3.4. Research Aim 2: The Clinical Laboratory as a leading indicator of Emergency Department efficiency

Due to the dependence on laboratory testing in medical diagnostics, laboratory tests are consulted in approximately 70% of diagnostic medical decisions (75–77). In order to support the demand for laboratory testing, it is estimated that 7 billion laboratory tests are run in US hospitals

(76). With the reliance on laboratory testing, there is a strong potential for the performance of the clinical laboratory to influence on other areas of the hospital, such as the emergency department.

To test the strength of any performance link between the two areas, analysis of the existing data was intended to be implemented to establish the existence and significance of a connection. When comparing the work loading in the ED and lab, no fluctuations were observed either immediately or with any delay in effect. The lack of impact may be explained by the clinical laboratory having a large capacity for a workload that is rarely tasked. Any minor fluctuation originating from the ED can be absorbed without issue. To further explore the potential for a link between the ED and lab, a means of artificially adjusting patient flow and workload is necessary; this need can be addressed by constructing a simulation model.

A simulation model was constructed by a research team funded by an Agency for Healthcare Research and Quality (AHRQ) R21 grant award which this dissertation is supporting. Simulations are frequently used as an industrial and systems engineering tool for process analysis and improvement. Hospital operations are well-suited for simulation modeling (126–129). Simulations can capture the complex interdependencies of people, processes, and equipment to assess the performance of current or envisioned systems. The advantage of a simulation is that it can quickly, cost-effectively, and safely test and evaluate different process designs.

The simulation model which is detailed more in section 4.6.2 was adapted for testing the link between the ED and laboratory. By handicapping the laboratory significantly, as is the case in a downtime event, the potential link to the ED should result in a decrease in ED performance as the laboratory is forced to cope the sudden loss in efficiency. The downtime simulation model, created for the design phase of the MEAD methodology, has been tasked with analyzing the performance of patient care in the ED while the laboratory experiences a downtime.

With the simulation model in an unmodified downtime mode to establish downtime baseline performance, a slowdown in the laboratory was observed. Fifty simulation runs were executed and the measures for the longest running turnaround time (Chemistry), Door to Doc, and Total Treatment time were tracked on a timescale. The averages of the 50 iterations were taken and plotted as a time series as seen in Figure 13.

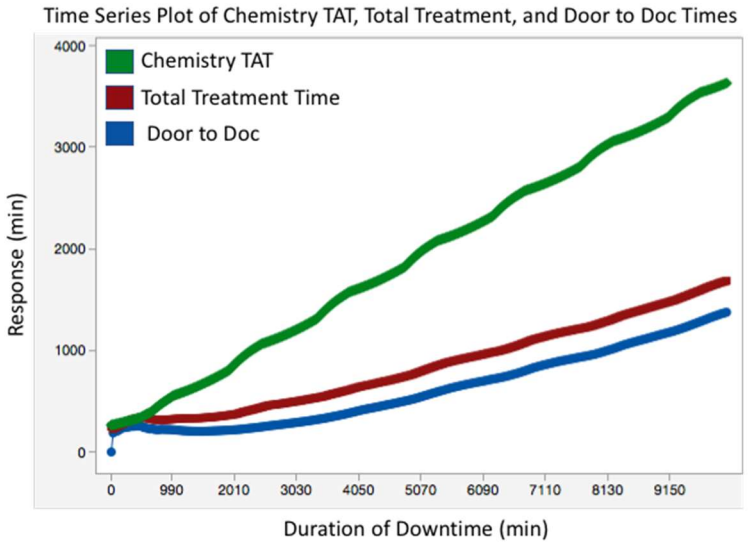

Figure 13 -Time Series of Chemistry TAT, Total Treatment Time and Door to Doc Time

As the time for a test to be resulted extends, the time a patient waits to see a doctor and the time they spend within the ED extends. The trend is further substantiated by a test for correlation between the three measures, Table 11, for Chemistry TAT compared to Door to Doc, ($r(335) = .973$, $p<.0001$). A correlation value of .973 is an extremely strong correlation, suggesting that there is support for the hypothesis that laboratory performance can have an impact on the ED performance.

Table 11 -Correlation tests for Door to Doc vs Total Treatment Time vs Chemistry Turnaround Time

	Door to Doc	Total Treatment Time
Total Treatment Time	0.995794	
	<0.0001	
Chemistry TAT	0.973850	0.989863
	<0.0001	<0.0001

Cell Contents: *Pearson correlation*
P-Value

Based on the analysis, and combined with the anecdotal evidence provided by hospital stakeholders, it is reasonable to assert that the clinical laboratory performance has a significant impact on the performance of the ED, and can function as a leading indicator of ED performance.

4.4. Variance Control and Role Analysis

MEAD has been used as a methodology guiding the data collection to ensure a holistic understanding of the entire work system and potential downtime impacts are collected. The data from interviews, EHRs, and paper records, in addition to the observations facilitate the understanding and analysis of significant workplace variances and key roles. The major variances are those that have the most impact to the performance of patient care tasks during downtime, identification of those variances allows for future intervention designs to target them for improvement. The key roles are the workers within the system who are directly impacted by the variances and have the most influence and ability to enact changes and whose work would benefit from the interventions.

With an understanding of the processes necessary during patient care and feedback from stakeholders, a list of major variances encountered can be compiled (Table 12). The variances have been identified from the interviews conducted with stakeholders lead by the researcher.

Table 12 -Variance Control Table for Normal Operation

Key Variance	Data Source	Unit Operation	Responsible	Technical Support
Interdepartmental Communication	Observed/Interview	Both	EHR	EHR
Patient Arrival	Interview	ED	Nurse	EHR
Patient Registration	Interview	ED	Nurse	EHR
Patient Triage	Interview	ED	Nurse	EHR
Patient History Retrieval	Observed/Interview	Both	Nurse	EHR
Patient Diagnostics	Observed/Interview	ED	Physician	EHR
Specimen Collection	Observed/Interview	ED	Nurse	EHR
Specimen Labeling	Observed/Interview	Both	Nurse	EHR and Printer
Lab Testing Request	Observed/Interview	Both	Physician	EHR and CPOE
Patient Tracking	Interview	ED	EHR	EHR
Patient Disposition	Interview	ED	Physician	EHR
Testing Request Delivery	Observed/Interview/Documentatior	Lab	EHR	EHR and CPOE
Specimen Delivery	Observed/Interview/Documentatior	Lab	Courrier	Vac-Tube
Lab Specimen Labeling	Observed/Interview/Documentatior	Lab	EHR	EHR
Specimen Processing	Observed/Interview/Documentatior	Lab	Accessioning Tech	EHR
Laboratory Testing	Observed/Interview/Documentatior	Lab	Bench Tech	EHR and CPOE
Patient Demographic Retrieval	Interview	Both	EHR	EHR
Result Validation	Interview/Documentation	Lab	Analyzer	EHR and Analyzer
Result Verification	Interview/Documentation	Lab	Analyzer	EHR and Analyzer
Result Reporting	Interview/Documentation	Lab	Analyzer	Analyzer
Testing Request Tracking	Interview	Lab	EHR	EHR
Downtime Training	Interview/Documentation	Lab	Lab Manager	None
Downtime Procedure Availability	Interview	Lab	Lab	None

With the variances of the work system identified, the responsible roles to manage those issues, and what technology in the work system supports those variances can be determined.

A variance matrix was constructed to understand the links between the variances and identify the major variances (Table 12). Variances which are related to each other are indicated with an "X" at their intersection; the key variances are boxed. The key variances are those which have the greatest impact on operations and potentially the other variances as well. In this case, patient history and demographic information retrieval have been identified as the key variances.

Patient history and demographics are critical to the care process. When a patient arrives in the emergency department their prior encounters are included in the medical record; the history can include prescribed medications, prior procedures, food and drug allergies and any other notes from previous physicians. While most of the information can be recollected bedside, it represents a loss of efficiency to have to collect information a second or even third time. For the clinical laboratory, patient demographic markers such as age, weight, gender, and ethnicity can influence the results reported on many tests. The control limits for what is considered normal and safe levels are different depending on the demographic information, and in many cases, the laboratory does not send out results if the demographic information is not included with the testing requisition.

Table 13 - Variance Matrix for Combined Care Operations

	Unit Operation		Overall Variance																						
			Interdepartmental Communication	1																					
	Unit Operation		Emergency Department Variance																						
		input	Patient Arrival		2																				
		Input	Patient Registration		X	3																			
		Input	Patient Triage			X	4																		
		Input	Patient History Retrieval			X	X	5																	
		throughput	Patient Diagnostics					X	6																
		throughput	Specimen Collection			X				7															
		throughput	Specimen Labeling		X	X					8														
		throughput	Lab Testing Request	X	X	X		X	X	X	X	9													
		throughput	Patient Tracking	X		X			X	X		X	10												
		throughput	Patient Disposition	X	X	X								11											
	Unit Operation		Clinical Laboratory Variance																						
		input	Testing Request Delivery	X						X	X	X	X		12										
		input	Specimen Delivery	X					X		X	X			X	13									
		input	Specimen Labeling						X		X	X	X		X	X	14								
		throughput	Specimen Processing						X		X	X						15							
		throughput	Laboratory Testing			X			X		X	X		X					16						
		throughput	Patient Demographic Retrieval			X		X			X	X	X		X		X			17					
		throughput	Result Validation																	X	18				
		throughput	Result Verification			X		X	X		X	X	X	X							X	19			
		throughput	Result Reporting	X		X					X	X		X									20		
		throughput	Testing Request Tracking	X					X		X	X				X								21		
		throughput	Downtime Training												X		X	X		X	X	X	X	X	22	
		throughput	Downtime Procedure Availability												X		X	X		X	X	X	X	X	X	23

Based on prior events, the hospitals are resilient enough to function through a downtime event, the issue to resolve is concerns for the ability to maintain patient care and safety while not overworking or stressing workers during the downtime event.

4.4.1. Research Aim 3: Macroergonomic analysis of the current state of downtime procedure execution

As shown in the variance table and matrix (Tables 12 and 13), there are a number of major issues that occur during downtime. The most critical issue is the availability of patient records and information. Both of the departments examined in this research are reliant on patient history to complete their work effectively. Without access to patient history, clinicians in the ED are forced to recollect information from the patient, potentially multiple times in a single encounter. At least one participant indicated that patients have negative reactions to redundant and repeated questioning during a downtime.

Another recurring issue in the analysis was that there is a pervasive lack of communication, trust, and comprehension of limitations within and between the ED and lab. Fundamentally, there is no notice given to departments when the lab is in a downtime mode; staff in the ED discover that the lab is operating in downtime when they realize it has been several hours since a request was sent and contact the laboratory to obtain more information. Organizationally the workers have no support for any situational awareness to downtime events, often left to discover one is in progress when the helpdesk is consulted for a technical issue.

The lack of trust between departments was raised in several sessions and is related to the lack of effective communication. In some cases, a specimen is sent to the lab in a condition where it is not viable for testing. When that occurs, the lab has to discard it, contact the physician and request a recollection. Both workers in the lab and ED think that the other area is reporting unviable specimens deliberately. One focus group participant conveyed an anecdote in which the ED staff even believe specific laboratory workers recognize their specimens and deliberately reject them. Both areas are too reliant on each other for safe patient care to have suspicions and animosity between them.

There is no communication of the limitations during downtime; there is an expectation that all areas can maintain full operations regardless of the severity of downtime. The lack of

established restrictions led to clinicians to "order the rainbow" meaning that they would order the entire array of tests to get a thorough diagnostic understanding, even though clinically, not all of the tests were necessary for that patient's care process. With the excess ordering, workload in the lab held at near normal operation levels throughout a major TDE. Laboratory managers indicated that the lab is capable of handling a typical workload of 8,000 individual tests per hour, but only 15% of that workload will require manual intervention by a worker. Downtime of any nature in the lab typically shifts that manual workload to near 100%; there is no physical space or capacity of workers to support the normal workload at 100% manual intervention.

Downtime training was referred to by several participants; prior to the seminal TDE that triggered organizational focus on downtime readiness, there was little to no formal training on downtime events. The lab training consisted of using planned downtime events to practice; however, those events occur exclusively during off hours, with low demand, and with notice, so the workload is lower than normal. Previous training for other shifts consisted of ensuring all workers were aware of the location of the downtime operations binders. ED staff have boxes of downtime paperwork that gets placed on the nurses' station during a downtime event; no formal training is provided.

Post TDE downtime, training has improved, the laboratories run regular drills for all shifts. Despite the practice, some staff are unaware of the full procedures and have been observed creating their own workarounds rather than consulting the binders. ED downtime training is now partially present, some of the senior nurses educate the junior nurses on pre-EHR paperwork methods as downtime contingencies. ED training, however, is not formalized and varies depending on which senior nurse a junior nurse was assigned to for their first few shifts. Collectively, the older nurses who worked pre-EHR voiced no issues or concerns with reverting to paper-based work.; however, the junior nurses who have only ever worked using EHRs have problems with the transition.

4.5. Organizational Joint and Functional Design

During a downtime event, the degree of computer support and assistance for work tasks changes. The nature and severity of the change need to be understood to devise interventions. Function

allocation examines the tasks necessary to the work and what level of technical support is required or provided. The taxonomy for function allocation is an application of the taxonomy used by Kleiner and Shewchuk in their 2001 study (130) and is shown in Table 14.

Table 14 - Function Allocation Taxonomy (From Kleiner and Shewchuk (2001))

Human Dominant				**Technology Dominant**
Human supplies power, decision making, and control	**Mechanical support for power or control, human decision making**	**Machine supplies power and information, human controls**	**Machine supplies power, information, decisions, and control, human monitors and/or supplies information**	**Machine supplies power, information, decisions, and control, no monitoring required**
Direct Performer	Manual Controller	Partner	Supervisory Controller	Executive Controller

Accounting for the function allocation in the developed interventions is necessary to support the situational awareness of the workers impacted by downtime. Downtime requires a transition in function allocation from the technology dominant side of the spectrum, to the human dominant side of the spectrum. Much of the work only needs the human element to load the next batch of tests and remove the old batch. However, during downtime, the technology is just performing the analysis task, and it is left to the human element to determine accuracy and validity in addition to the loading and unloading. Also, the workers are not always made aware that a downtime event is in progress until they begin to receive downtime paperwork. Facilitation of improved situational awareness would enable the hospital to proactively enact downtime protocols rather than react to downtime upon discovery when work moves downstream with downtime forms.

4.5.1. Roles and Responsibilities

Once the level of technology available and allowed for given tasks is determined, the tasks must be assigned to roles, and if necessary, additional roles created. During previous downtime events, a number of new roles have organically developed and were conveyed during focus group sessions. In some cases, these roles may be of value as part of a downtime plan. In addition to

the job roles, other tasks may not need a dedicated role in the intervention but do need to be allocated to personnel.

Workload shifts significantly in both the ED and lab from high levels of automation and computer support to significant levels of manual intervention and work. Table 15 provides a comparison of the major work tasks and their function allocation (Table 14 above) in both normal and downtime work modes.

Table 15 - Function Allocation of Key Tasks in Normal and Downtime

Task	Normal	Downtime
Interdepartmental Communication	Direct Performer	Direct Performer
Emergency Department		
Patient Arrival	Direct Performer	Direct Performer
Patient Registration	Manual Controller	Direct Performer
Patient Triage	Manual Controller	Direct Performer
Patient History Retrieval	Partner	Direct Performer
Patient Diagnostics	Partner	Direct Performer
Specimen Collection	Manual Controller	Manual Controller
Specimen Labeling	Partner	Manual Controller
Lab Testing Request	Supervisory Controller	Manual Controller
Patient Tracking	Executive Controller	Direct Performer
Patient Disposition	Partner	Direct Performer
Clinical Laboratory		
Testing Request Delivery	Supervisory Controller	Manual Controller
Specimen Delivery	Supervisory Controller	Partner
Specimen Labeling	Partner	Manual Controller
Specimen Processing	Supervisory Controller	Manual Controller
Laboratory Testing	Supervisory Controller	Manual Controller
Patient Demographic Retrieval	Executive Controller	Direct Performer
Result Validation	Executive Controller	Direct Performer
Result Verification	Executive Controller	Direct Performer
Result Reporting	Executive Controller	Direct Performer
Testing Request Tracking	Executive Controller	Manual Controller
Downtime Training	Direct Performer	Direct Performer
Downtime Procedure Availability	Direct Performer	Direct Performer

In all cases, systems which typically support patient care become unavailable in downtime. During patient triage, as the nurse assesses the patient, the clinical decision support system is provided information about specific parameters a patient may present with, matching the parameters to expected diagnoses and treatments. The clinical decision support system will prepare testing requests, print labels and prepare a CPOE requisition for the clinician to review at the first physician encounter. During downtime, none of those systems are functional, and the requisitions are handled on paper forms instead of the computer. The automation of the clinical decision support system likely saves a significant amount of time as patients are triaged and enter

the ED, but during downtime all of those automated tasks have to be addressed manually and potentially wait until the first physician encounter, extending the length of stay key performance metric (KPI).

Role network diagrams were created to understand the dynamics of the key roles related to patient care; the roles of a Nurse (Figure 14), ED Physician (Figure 15), and Laboratory Technician (Figure 16) are represented. The role networks were generated by the researcher, based on observation of interpersonal interactions in the workplace, discussion during interview sessions and cross-checked with organizational charts, and established work aids where available in the hospitals. For example, during a patient's care, the nurse on the care team will receive orders from the physician, check in with their charge nurse, receive additional information from the triage nurse either directly or through notes, and call the laboratory to check on a testing request. During normal operation all of the necessary information and communication is facilitated through the EHR.

Table 16 - Role Network Label Key

Role Network Key
V – Vertical hierarchical separation
E – Equal hierarchical level
C – Cross Departmental
O – Outside the work system
N – Non human component
G – Goal of variance control
A – must adapt to short-term fluctuations
I – Interpersonal
L – long term development

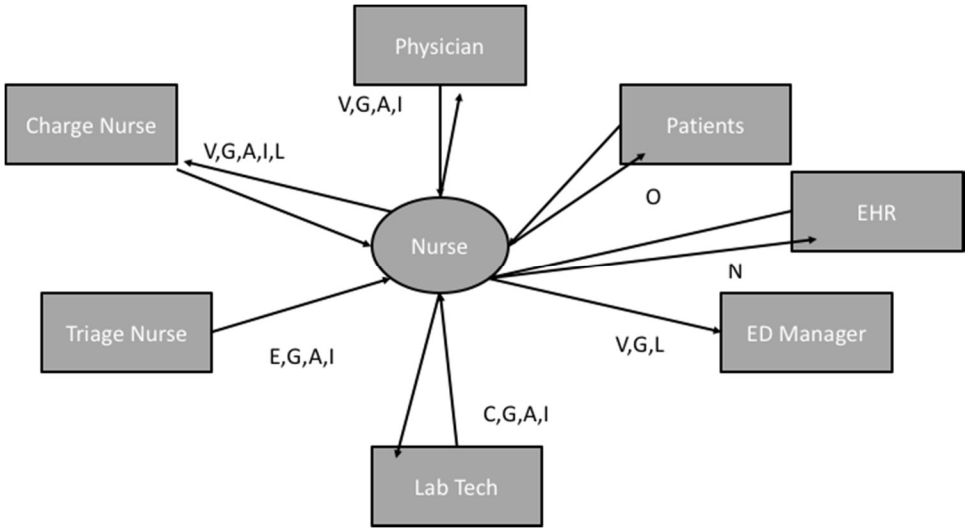

Figure 14 - Nurse Role Network

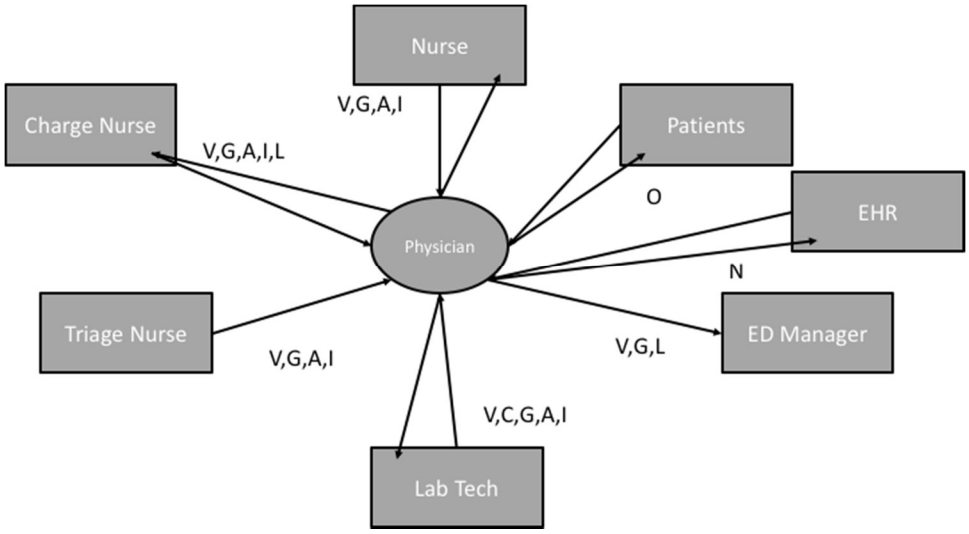

Figure 15 - ED Physician Role Network

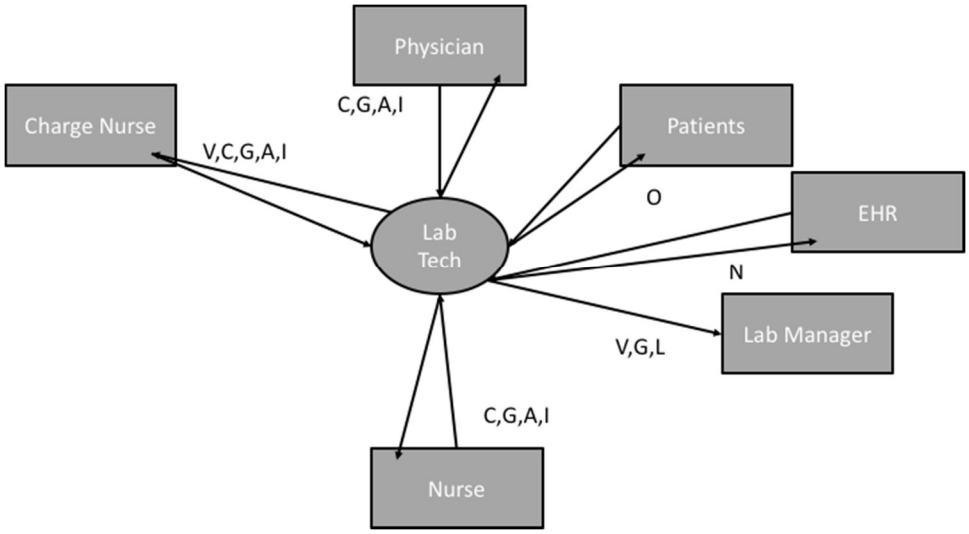

Figure 16 - Laboratory Technician Role Network

The three roles identified are critical to patient care both during normal and downtime operations. Each role has a different hierarchical position but needs to interact both officially and unofficially with each other. The different roles may have varying interpretations of their own work responsibilities during different times.

While the charge nurse appears in all three diagrams, they are not typically part of the patient care team which is the focus of this analysis. The charge nurse acts as a manager for the department they are assigned, though during downtime in many cases also took on secretarial responsibilities.

4.6. Design, Iterate and Improve

In order to address the variances identified, interventions are developed and tested in simulation. As previously stated, the development of the simulation is outside the scope of this dissertation and was handled by a separate team as part of the AHRQ R21 project. The data collections, analysis, and interventions from this dissertation are used to construct, inform, verify and validate the model; the outputs are used as a measure of the potential effectiveness of the interventions themselves.

4.6.1. Research Aim 3.1: What Macroergonomic-based interventions can improve downtime planning

4.6.1.1. Patient History and Information

The access and retrieval of patient records are vital to both the ED and lab work processes. When in normal operation the transfer of automation is handled via CPOE and EHR systems, downtime requires paper transcription of patient information. During downtime events, the nursing staff has to rely on pre-EHR methods of patient care. The creation of a designated form to support ED and lab operations should be created and included in the downtime workflow. The form should be able to be easily copied from the paper chart and be included with the lab requisition form. Including the patient demographics with the requisition form would reduce the number of rejected requisitions due to insufficient information.

This intervention represents a patch for a downtime deficiency in the technology sub-system and supports the personnel sub-system in maintaining organizational and external environmental compliance.

Additional data is necessary to implement this intervention in the simulation. Specifically, more information is needed regarding the frequency of documentation missing patient demographics arriving in the lab, and how often nursing staff have to recollect patient history. Some measure of how often incomplete information was sent to the laboratory is available based on how incomplete the available paper records are; however there is not a reliable measure of how often a testing request was rejected for insufficient information. For bedside information collection, observation in patient rooms is typically difficult or not permitted, the only measures available are anecdotal recall from nursing staff about the frequency of repeated collection from patients.

Implementing this intervention in the simulation is impractical due to the limitations of the data available. However, in function, it could be achieved with probabilistic rework loops, representing the repeated information collection by nursing staff and the rejection and resubmission process for requests sent to the laboratory. Having a reliable measure for how frequently to trigger the loops is unknown at this time and a potential area of future study.

4.6.1.2. Communication

Downtime complicates communication within the hospital. During normal operation, communications facilitated by the EHR become unavailable. Paper requisition forms are sent with incomplete information, any suspicion that the computer is going into downtime is not voiced to the department at large, and all of the paperwork related to communicating results is left to fax and couriers to relay. By designating a fixed communication distribution "tree" by which downtime issues can be transmitted, and assigning specific downtime communication roles such as identifying individuals as departmental resources, downtime communication issues can be alleviated. These designated roles for downtime can be responsible for communicating the downtime operating state of their given department to the rest of the hospital and collating the immense amount of paperwork generated related to the reporting of patient results in downtime. The role would also take responsibility for managing phone calls in the assigned department, reducing the distractions caused by unnecessary phone calls going to the clinical staff who are focused on providing patient care.

This intervention represents a patch for a deficiency in the technology sub-domain, assisting the personnel, physical environment and organizational sub-domains to compensate and continue operation. The additional staff support communication between personnel, workload management in the physical environment, and overall the organizational culture for a desire to maintain patient safety.

In the simulation, this is implemented by including additional personnel during downtime to support the downtime specific roles for communication within the system, moving specimens and paperwork between the care areas. The expected outcome would be that the designated clinical staff would be able to remain on their clinical tasks and the overall efficiency of the departments would remain nearer normal operation levels.

4.6.1.3. Intra-Organizational Trust and Understanding

There were indications that a lack of trust and understanding of requirements and expectations is present. The lack of trust and understanding compounds the issues when incomplete testing requests are sent to the lab and returned, or results are not reported in a timely fashion.

This intervention addresses a significant deficiency in the organizational and personnel sub-systems. The weakness is not exclusively present during downtime, but it is made more evident by the additional stresses that come with it. Other initiatives which encourage interaction and open dialog between the departments could be beneficial in facilitating understanding between coworkers in different departments, so that expectations and requirements are understood in addition to the particular requirements of the work tasks.

The testing of this intervention in the simulation is not feasible as this intervention represents a cultural shift rather than a technical process change. The simulation model is not equipped to explore interventions of this nature.

4.6.1.4. Downtime Expectation Management

During a downtime event, the clinical laboratory has to shift from an almost entirely automated work-flow to a fully manual one, and as a result, their productivity slows down. A complaint received during the focus group sessions was that physicians continued to "order the rainbow" on their patients, meaning that the full spectrum of tests was ordered, even when the results were not necessarily diagnostically relevant to the patient's case. The ordering of "the rainbow" and maintaining the full testing menu for the lab meant that while workflow shifted to a manual bias, the quantity of work remained near constant.

A potential intervention to address the expectation management would be to have the laboratory develop and offer a limited testing menu for reduced throughput conditions like a downtime event. The limited testing menu would be restricted to the core tests necessary to establish a patient's status in the ED and Intensive Care Units. While there would need to be some capacity to still order from the entire testing menu in a limited number of cases, reducing the menu for most of the hospital to only the most necessary tests would allow the laboratory to focus on the most requested tests specific to emergency care.

In the hospitals, this intervention would need to be developed in conjunction with the other departments to establish what they each feel their necessary tests are and if they would need an ability to override the reduced menu. In the simulation, a reduction in the workload of the non-ED centric tests which are being fed into the simulation to represent a full workload would simulate this intervention. The expected outcome is that TAT would remain at or near

normal operation levels, while not requiring significant increases in staff work levels in the laboratory.

4.6.1.5. Downtime Training and Proficiency

A recurring issue observed and discussed is that knowledge of the downtime procedures is inconsistent across all front-line stakeholders. Staff were found to be creating their own procedures as they worked whenever they were unable to remember the procedures during a downtime event. Other staff receive no training for downtime and are only provided paperwork when necessary and expected to work through. An intervention to resolve the lack of training and provide a demonstration of proficiency would be to implement an organization-wide downtime training and proficiency program. In many areas of the hospital, this could be included in the regular proficiencies and training that occur annually. Also, downtime events can be included in periodic disaster drills in which both target hospitals regularly engage.

Interventions designed to address this issue focus on the organization and personnel sub-systems. Personnel lacking knowledge of the organizational requirements related to downtime impact the organization and physical environment. Some measure of training, retraining, and proficiency system could help to address the issue.

Implementation in the simulation is not feasible at this time. In theory, the increased training and proficiency would result in reduced rework. A reduction in rework to reflect training would be focused in the laboratory testing area and ED bedside. Like the information collection mechanisms, a probabilistic rework loop could represent the process. Also like the information collection intervention, there is not sufficient information at this time to inform the frequency and volume of work being delayed due to this issue and an empirical measure may not be possible outside of an actual major downtime event.

4.6.2. Research Aim 4: Examine normal and downtime operations in the simulation model

The details of the simulation model and the implementation of the interventions fall outside the scope of this dissertation and were the responsibility of the AHRQ R21 team. The AHRQ R21 team received the data sets compiled by this dissertation and used them to construct, verify, and validate the model according to established literature (131). The simulation model was created in AnyLogic, representing the ED as an Agent-Based model and the clinical laboratory as a

Discrete Event model. The two models are linked together by the patient care process where the clinical care team in the ED may request a battery of laboratory tests and must wait for the results to be generated before care can continue.

The simulation was validated to a data set from September 2015 in Hospital B. Hospital B was selected to be modeled first due to the unavailability of downtime data from Hospital A. Existing key performance indicators (KPI)s monitored by the hospitals were used to baseline the simulation performance. Table 17, details the KPIs followed for quality assurance in the ED and laboratory.

Table 17 - Key Performance Indicators for Simulation Evaluation

Key Performance Indicator	Definition
Door to Doc Time	Time from patient registration to first clinician encounter
Total Treatment Time	Total time patient spends within ED care
Analyzer Turn Around Time	Time for a test request to go through lab processing and have results reported
Laboratory Throughput	Count of the number of testing requests the laboratory handled in the simulation period
Percent of Critical Results Reported Within 15 Minutes	Tabulation of the percent of tests returned with a critical result that were able to be reported to the physician within the established 15 minute window

Modeling of Hospital A requires additional assumptions to fit the available data and is considered future work due to the increased investigatory time needed to ensure accuracy.

The historical data sets were used to perform the validation of the model to prior performance and ensure the level of fidelity was acceptable for the research. The details of the validation of the model are outside the scope of the dissertation and were handled by the AHRQ R21 team. All KPIs from the model achieved consistent performance within 95% confidence intervals created for the historical data. Each simulation configuration iterated 1,500 times and the results are compared for analysis later in this chapter.

4.6.2.1 Using Simulation within MEAD

Employing simulation within the MEAD methodology enables access to the assembled data collected throughout the process in a consequence free-test environment. The simulated environment is especially helpful in healthcare study as interventions can be vetted before

implementation in the real world where there can be impacts to patient care. However, a simulation environment is only as accurate as the simplifying assumptions allow, and does not encompass the unpredictability of the human element well. Even the most realistic simulation will require simplifying assumptions, and the random chance that the human element introduces is near impossible to completely capture. While the results of intervention testing in the simulation are helpful, the ultimate results must be framed with the lens of the potential shortcomings of any simulation model.

4.6.2.2. Simplifying Assumptions

Due to the complex reality of healthcare operations, the simulation model constructed has been required to incorporate a number of simplifying assumptions. The assumptions are necessary as it is not feasible or reasonable to build a model with perfect fidelity. The goal of a high-fidelity model is to achieve a reasonable approximation making only the most necessary simplifying assumptions possible. During the construction of the model, several issues were encountered due to data availability and limitations of simulation software in general, necessitating simplifying assumptions.

For the scope of the entire model, the areas of interest are only the ED and laboratory, all other departments of the hospital are not included, regardless of their role in patient care. The model is validated to real-world historical performance. In some cases, achieving model validation required the addition of delay steps which may be representative of out of scope patient care activities such as radiology and pharmacy interactions.

In the ED, the model only represents the direct patient care teams and the resources directly available. The time to turn over a bed for a new patient or the availability of administrative level staff such as charge nurses were not included as simplifications to the model.

If a patient receives a laboratory test, they are assumed to receive a full battery of testing which will require a specimen run on all four analyzer types. The details of what specific tests are ordered for a patient depends heavily on the conditions the patient presents with, beyond their ESI triage score. It was necessary to simplify the request menu to be probability based on ESI to receive all or no tests.

In the laboratory, specific tests are not modeled. The average of all testing run on a particular analyzer is batched and averaged together. Similar to the specific patients and individual tests, the simplification of the menu to an aggregated average allows for all testing to be approximated without requiring detailed patient information about care and diagnoses.

Hourly arrival rates represent all patient care load in the ED and the entire hospital's testing demands on the laboratory. The hourly arrival rates are based on the historical data set from the same timeframe as the KPIs used for validation.

4.6.2.3. Normal Operation Simulation Model

The base model used in this dissertation is the normal operation model. It reflects the combined patient care activities of the ED and laboratory. Utilizing the information collected in the scanning earlier phases of the MEAD methodology, a functional simulation flow was created for patient movement through the ED based on the ESI score assessed at patient triage, Figure 17.

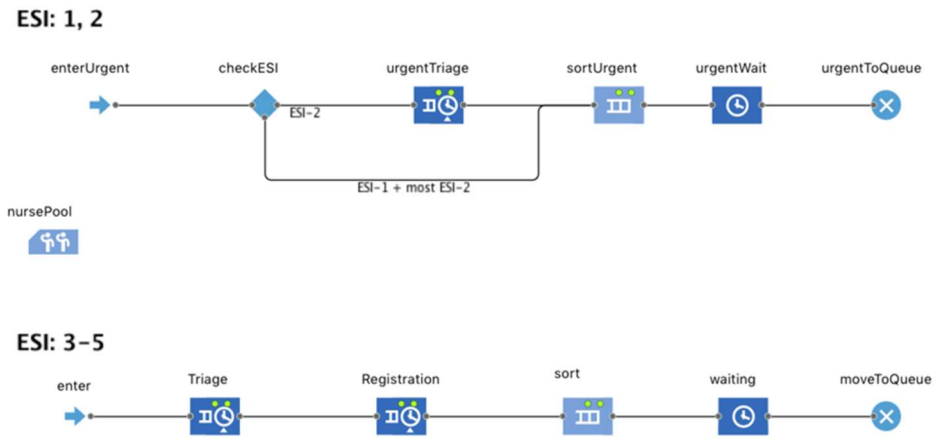

Figure 17 - Patient Entity Entry to the ED

Once patients have been added to the queue based on their ESI, the physician and nurse entities have work lists and priorities based on their roles to select and treat patients based on severity and time of arrival. As care proceeds, if a patient requires a lab test, the specimen and request are sent to the model of the laboratory, depicted in full in Appendix C.2 and in a simplified graphic Figure 18.

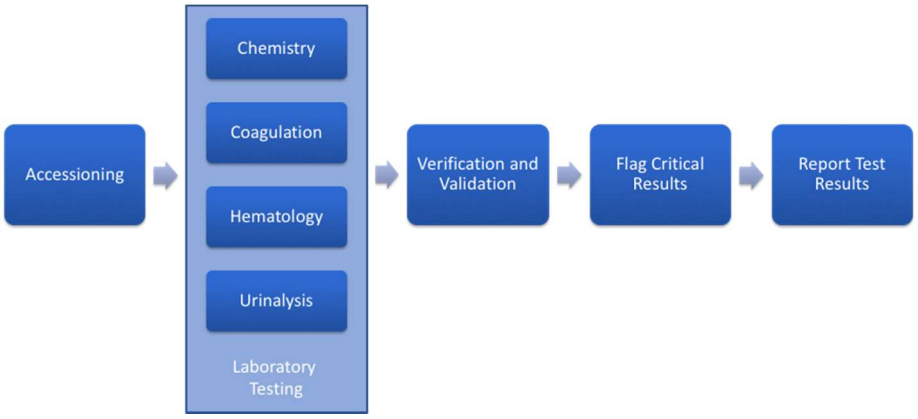

Figure 18 - Simulation Model of the Clinical Laboratory

Reflective of the Hospital B laboratory, the current model has the four primary analyzer types in a paired configuration for eight total analyzers. Technicians run the accessioning bench and analyzers from separate resource pools based on the Hospital B staffing levels and shift schedules. As a specimen travels through the lab, it will require intervention and seize available resources as necessary. During normal operation, most of the work processes are automated and need only minimal interaction from the staff to process specimens.

The entire simulation was calibrated and baselined to be reflective of a week in September 2015. September 2015 was selected as it represents a window in which the most reliable data was available for comparison to the simulation model. It is a period when the Hospital B laboratory was tracking coagulation and hematology testing separately and most importantly, was before the major downtime event experienced in March 2016. Hospital operations after the event in March 2016 include a number of procedural changes as a response to better handle downtime events. The KPIs used for model validation and the results from the simulation are shown in Table 18.

Table 18 - Simulation KPI Baseline and Validation Data

Door to Doc (min)	
Sept 2015	Simulation
95% CI [64.95, 68.46]	95% CI [65.95, 67.31]

Total Treatment Time (min)	
Sept 2015	Simulation
95% CI [252.42, 267.38]	95% CI [255.38, 259.11]

Analyzer Turnaround Time (min)	
Sept 2015	Simulation
Chemistry	
95% CI [45.35, 46.15]	95% CI [44.85, 47.01]
Coagulation	
95% CI [28.52, 29.28]	95% CI [28.78, 29.06]
Hematology	

Laboratory Throughput (count per 30 days)	
Sept 2015 (observed)	Simulation (avg over 2000 runs)
32,533	31,323

95% CI [21.00, 21.98]	95% CI [21.62, 21.92]
Urinalysis	
95% CI [36.73, 40.75]	95% CI [37.50, 37.77]

Delivery of Critical Results within 15 minutes (percent)	
Sept 2015 95% CI	Simulation
95% CI [99.79, 99.79]	95% CI [99.99, 99.99]

4.6.2.4. Downtime Operation Simulation Model

Downtime has significant impacts on the patient care tasks in a hospital, the more frequent unplanned downtimes are brief, most lasting no more than two hours. The events caused by a cyber attack or other mechanism requiring a total shutdown or TDE, however, are pervasive and tend to be significantly longer, measured on a scale of days rather than hours. Many interventions can have brief impacts on the short-term downtimes, but may not be reasonable for longer TDEs. In order to ensure that the interventions are tested for the worst case TDE scenario, downtime simulation tests are representative of a seven-day TDE.

In addition to the seven-day TDE, the staffing and work tasks are fixed at the start of the simulation, by making no changes during the seven day simulation run for the long-term sustainability of the specific intervention can be revealed. While having a seven-day downtime with no operational changes occurring is unrealistic, as a hospital would find ways to cope with the downtime event, the fixed parameters allow observation of efficiency and operations throughout a downtime. The outputs of the simulation model consist of an average for each KPI (Table 19) over the entire simulated run, each experiment was run for 1,500 iterations, in addition to a control scenario for normal operation, and control downtime scenario.

Table 19 - Descriptive Statistics for Normal vs Downtime in Simulation

	Normal Control	Downtime Control
Door to Doc (min)	(M=75.35, SD=22.06)	(M=1418.04, SD=263.79)
Total Treatment Time (min)	(M=255.45, SD=41.86)	(M=1731.50, SD=247.07)

Lab throughput (count)	(M=7311.61, SD=99.20)	(M=4529.40, SD=67.03)
Critical Calls in 15min (%)	(M=99.99, SD= 0.022)	(M=78.78, SD=2.88)
Chemistry TAT (min)	(M=44.85, SD=23.89)	(M=3637.57, SD=129.39)
Coagulation TAT (min)	(M=28.32, SD=2.99)	(M=2041.41, SD=116.36)
Hematology TAT (min)	(M=21.39, SD=3.29)	(M=2724.59, SD=127.03)
Urinalysis TAT (min)	(M=36.88, SD=2.79)	(M=1424.81, SD=95.20

It is clear that a downtime left unresolved for an extended period makes a significant impact on healthcare operations within the hospital. Though the control downtime scenario remaining unaltered for seven days is unlikely, the investigation of long-running downtime events ensures that the solutions provided in the next section are sustainable in the long term, and not just impactful for the shorter downtime events only hours in duration.

4.6.3. Research Aim 4.1: Implement Macroergonomic interventions in simulation model

4.6.3.1. Limited Testing Menu

The first downtime scenario of interest is that of a reduced testing menu. In this scenario, the testing menu offered during downtime is drastically reduced to a selection of the most often ordered, and crucial menu, and limited availability to only critical care areas such as the ED and ICU. Other areas of the hospital would be asked to limit their testing requests to the minimum necessary to maintain care. By reducing the load on the laboratory, ED specimens can be prioritized, and unnecessary effort into tests for patients without emergent conditions can be delayed until resources are more readily available.

Within the simulation model, at the laboratory entry point, the source "*enter1*" represents the requests and specimens coming from the ED, the source "*source1*" represents the entry of tests from all departments other than the ED, Figure 19.

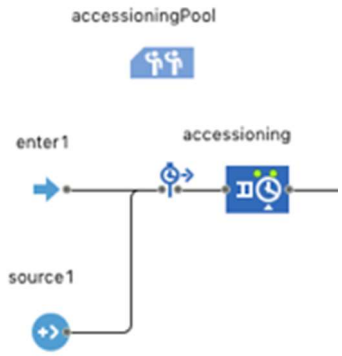

Figure 19 - Specimen Entry into Simulation Laboratory

Systematic reduction of the influx of requests from “source1” will allow for a representation of reduced workload in the laboratory. The reality of which areas to prioritize, and what specific testing to offer would be left to the real hospital to assess collaboratively with the other departments.

Multiple experiments were conducted with varying levels of workload reduction. Simulated workload reductions were examined for 0% (control), 10%, 20%, 30%, 40%, 50%, and 75%. The simulation KPIs for each experiment were checked by One-way ANOVA for the possibility that one of the means of the KPIs were unequal between experimental conditions. During the reduced workload downtime, staffing levels were kept constant, and the laboratory technicians were responsible for conducting all of the work tasks such as reporting all results which are normally automated. The ED operationally does not see a shift in procedures for the workload reduction experiments as Hospital B has a direct ED-lab specimen delivery system. The only change encountered by the ED is the shift from the use of the CPOE to submit testing requests, to the completion of paper requisition forms (Appendix C.1) which travel to the laboratory in the same delivery system as the specimens for testing.

The individual outputs for the statistical analysis of the limited testing menu experiments are in Appendix D.1.1 through D.1.8. For many of the KPIs, the limited testing menu achieved a significant jump in effectiveness at a 40% reduction. By examining the Tukey groupings of the means for each KPI, the potential optimal workload reduction can be identified, Table 20 below details the findings.

Table 20 – Variable Workload Experiments by KPI

Key Performance Indicator	Optimal Experiment	Improvement vs Control
Door to Doc Time	40% Workload Reduction	95% (-1336 min)
Total Treatment Time	50% Workload Reduction	85.2% (-1466.08 min)
Laboratory Throughput	No Plateau	
Critical Results Reported within 15 min	No Plateau	
Chemistry Turnaround Time	No Plateau	
Coagulation Turnaround Time	40% Workload Reduction	98.5% (-2012.65 min)
Hematology Turnaround Time	40% Workload Reduction	99% (-2700.67 min)
Urinalysis Turnaround Time	40% Workload Reduction	97.4% (-1388.96 min)

It is clear that workload reduction alone has the potential to address some of the delays induced by downtime events, but workload reduction alone still shifts considerable additional work onto staff who must cope with the sudden shift in work tasks from fully automated to a manual condition.

A reduction of the downtime workload by 40% enabled the model to regain 95% of its performance loss during downtime as measured by Door to Doc times ($F_{Downtime,40\%}(1,2998)=402967.8$, $p<.0001$), ($F_{Normal,40\%}(1,2998)=54.08$, $p<.0001$). Keeping the time a patient waits for their first encounter with a doctor in the ED low is critical. As wait times extend, patients are more likely to leave the ED untreated, before seeing a physician. In the model, this phenomenon is not represented, due to the documentation issues present in downtime records, an approximation for the number of patients leaving before the start of care or before completion of care was not available. In the simulation, all patients who enter the system wait for a consultation with a physician and remain in the system until disposition by the ED care team.

Most test scenarios demonstrated an optimal threshold at which significant improvements were no longer seen. For many of the KPIs this occurred around the 40% workload reduction; the results of the workload reduction experiments on Door to Doc time is shown in Figure 20.

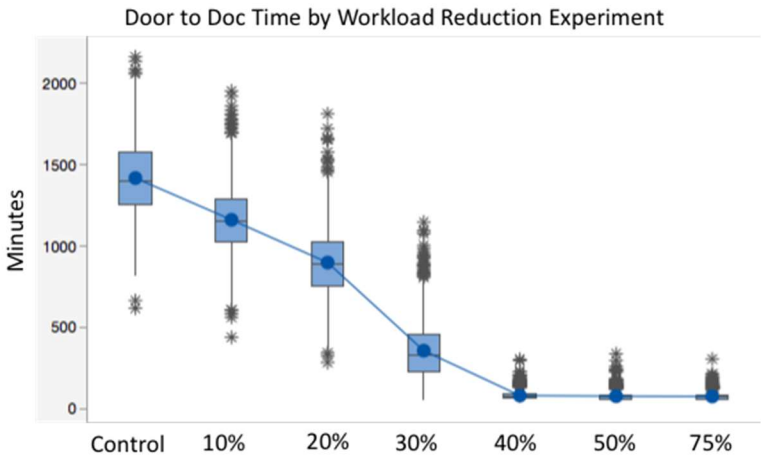

Figure 20 - Door to Doc Box Plots by Experiment

How a hospital may achieve a significant reduction in workload for the laboratory is a challenge. One approach would be to arrange a formal limited testing menu during downtime; this limited testing menu would consist of only the commonly needed tests for emergent care, potentially already identified as the bold-faced items on the requisition form shown in Appendix C.1. In addition to limiting the variety of tests, restrictions could be placed on the sources of tests, outside of the critical care areas. That is, ED and intensive care units, other departments could be asked to severely reduce their testing demands to critical care needs only. Operationally, there would need to be a mechanism to continue to request any test from the full menu, as it is not rational to restrict testing completely. Instead, asking the clinical staff to evaluate the actual need before submitting orders during a stressful time such as downtime, is preferred.

Another KPI providing insight into the workload of the laboratory is the reporting of critical results. During normal operation, reporting a critical result is expected within 15 minutes of the result being identified as critical. The benchmark for critical reporting is 100%. During downtime, tracking the reporting time of testing was not possible due to inconsistent documentation. Since the reporting of critical results is performed by the technician who is running the analyzer, some inferences can be drawn from how frequently tests can be reported within the established 15 minute window.

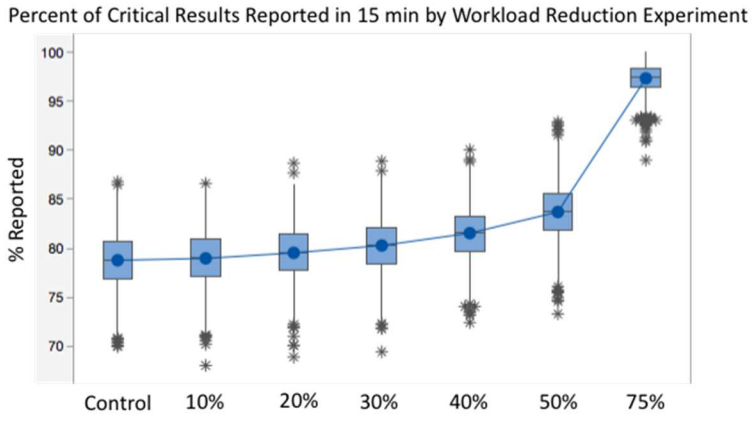

Figure 21 - Reporting of Critical Results by Workload Reduction Experiment

Figure 21 shows the result for the percent of critical results reported based on the reduction experiment. Statistically, the control and 10% were equal, and each subsequent test was statistically different from the other trials.

Based on the critical reporting KPI, the technicians are overloaded with all of the normally automated tasks and require some measure of assistance to enable them to focus on delivering critical results in the required time frame.

4.6.3.2. Support Staff for Downtime Roles

A number of work tasks are typically automated during normal operation, but when a downtime event occurs the hospital workers are forced to incorporate those tasks into their workload and execute the tasks without computer system support. In the emergency department, the tasks that are usually automated are the documenting and transmitting of patient information. ED downtime workflows shift to paper-based documents that look similar to the EHR interfaces the personnel have previously experienced. In the clinical laboratory the process for reporting patient results is automated, but during downtime, result reporting is allocated to the technician running the particular analyzer as a manual task.

During a downtime event, the technician must cross-check all reports coming from the analyzer for critical results, manually deliver the critical results, and also ensure that all of the reporting from their workstation is being sent to the appropriate location. All of the reporting must be handled while also continuing to run and manage the analyzer.

A major issue during the initiation of a downtime event is the lack of information. In many cases, staff are not aware a downtime event is in progress until a downtime specific document arrives at their workstation. Considering the need to adopt the shift of autonomous functions to manual rapidly, some mechanism to facilitate the necessary situational awareness of conversion to downtime must be included. During observation of prior downtime drills and the associated debrief sessions, personnel requested the potential for an overhead alert to downtime event initiation. While such an alert mechanism would be effective, it requires a higher level of communication from the rest of the hospital than is currently present regarding the initiation of downtime events.

One of the central themes from the focus group sessions was the desire for a fixed downtime role responsible for handling the collection, collation, and reporting of the reports that come from the analyzers. In the simulation, the role was created with a variable number of personnel; the additional staff would check the output stack of all analyzers; collect and collate the paperwork for transmission in batches and transmit via fax or courier to the destination, the modification to handle this is depicted in Figure 22. The downtime support roles are responsible for regular reporting of results, calling critical results is still managed by the technician who is running the analyzer and the regulatory benchmark is still for reporting of critical results to occur within 15 minutes.

The initial condition of the added downtime role for result reporting is to orbit the laboratory space, checking the output bins at each station. A more effective solution could involve the use of a visual signal that could be triggered by some combination of the output printer, and the technician running the analyzer. Once activated, the signal would indicate to the downtime reporting support personnel that their attention was required at a specific location. In addition to improving the efficiency of the report collection and transmission, a signal based approach could have the potential to reduce the number of people moving through the lab during a chaotic period.

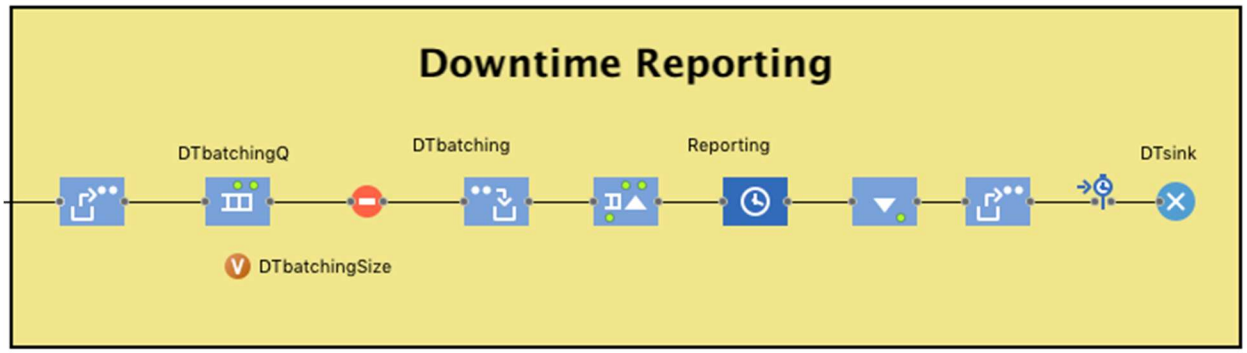

Figure 22 - Downtime Reporting Modification

During the initial validation of the model, it was noticed that the chemistry analyzer has a significant impact on the operation of the rest of the model. The chemistry analyzer is tasked with 42% of all testing through the laboratory and the tests it handles have longer TAT measure than other tests by at least ten minutes. The additional staffing experiments also included the potential for increased technician support for this high demand analyzer.

The experiments conducted for additional staff focused on adding to an on-call pool of downtime support staff to handle the reporting of regular results. Additional staffing of the chemistry analyzer due to its essential nature and significant influence in the model was also incorporated into the experiments. All other staffing and workload balancing levels were kept constant throughout the four staffing variation experiments.

Table 21 - Variable Staffing Experiments

Experiment	Support Staff	Additional Chemistry Technicians
1	1	0
2	1	1
3	2	1
4	2	2

Similar to the reduced workload experiments, the variable staffing showed definite plateaus where additional staff had no significant impact. The full details of the variable staffing experiments can be found in Appendix D.2.1 through Appendix D.2.9. The summary of the plateau reaching experiment and effects are in Table 22.

Table 22 - Variable Staffing Experiments by KPI

Key Performance Indicator	Optimal Experiment	Improvement vs Control
Door to Doc Time	1 Support + 1 Tech	93.6% (-1328.16 min)
Total Treatment Time	1 Support + 1 Tech	82.4% (-1426.65 min)
Laboratory Throughput	1 Support + 1 Tech	58% (+2636.52 units)
Critical Results Reported Within 15 min	1 Support + 1 Tech	16.4% (+12.95 % called)
Chemistry Turnaround Time	1 Support + 1 Tech	88% (-3193.18 min)
Coagulation Turnaround Time	1 Support + 1 Tech	95.6% (-1952.06 min)
Hematology Turnaround Time	1 Support + 1 Tech	96.1% (-2618.57 min)
Urinalysis Turnaround Time	1 Support + 1 Tech	93.5% (-1332.97 min)

The addition of a single staff member to handle downtime reporting and providing additional support to the chemistry bench appears to be the optimal opportunity for impact to improve overall KPI performance during extended downtime events.

Participants in the interview sessions repeatedly voiced desires to formalize the work roles that developed during the extended downtime event. Hospital B has also started to experiment with formalizing those roles in the downtime procedure as part of their independent response to the downtime incident. As part of the Hospital B simulated experiment, a new role is created for a nonclinical staff member who is responsible for managing the collection, organizing and reporting of testing results. By removing this labor-intensive manual task from the technicians running analyzers, the lab overall can handle a higher number of tests during downtime.

Similar to the reduction in workload, the results of the experiments showed a definite point where adding more staff stopped providing significant benefit. Adding an individual to handling the downtime reporting responsibilities and one additional technician to assist on the chemistry analyzers achieved a substantial improvement to all KPIs. Conversely, only adding support for the addition of the reporting position in most cases did not produce a significant difference from the performance of the control for downtime.

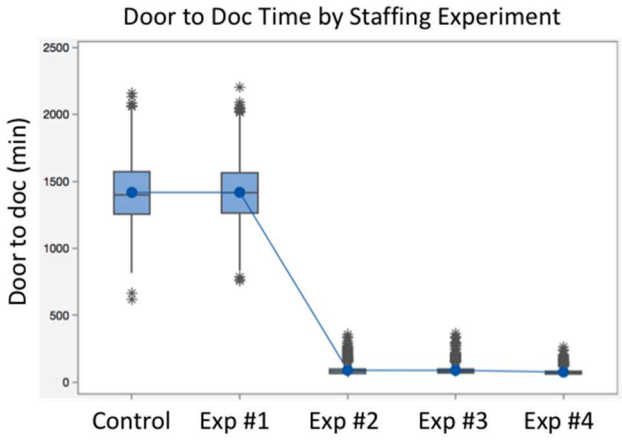

Figure 23 - Door to Doc Time by Staffing Experiment

The door to doc time shows a much more definite benefit at the addition of a reporting support role and a chemistry analyzer technician. With the lab able to process a normal demand load for testing at nearly the normal TAT, the ED is able to maintain a more normal patient care time through downtime, ($F_{Downtime,Exp\#2}(1,2998) = 46123.56$, $p < .0001$), ($F_{Normal,Exp\#2}(1,2998) = 173.17$, $p < .0001$).

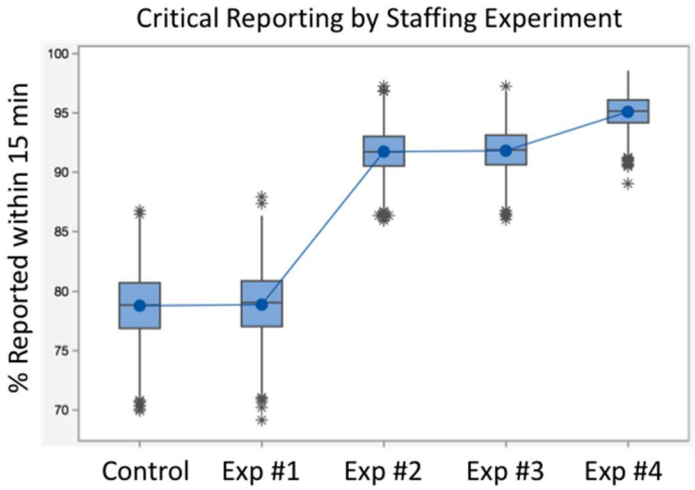

Figure 24 - Critical Reporting by Staffing Experiment

Additionally, the percent of critical results reported within 15 minutes saw significant improvement with the addition of support and chemistry analyzer staffing. In the simulation the analyzer technician is still responsible for contacting the physician with critical results, explaining the benefits of adding staff to the analyzer for reporting of critical results. In reality, the analyzer

technician would still benefit from the support staff handling normal result reporting as only 3-5% of testing requests generate a critical result.

Unlike the reduction in testing demand, adding additional staff does not require the reduction in workload for the laboratory. By not reducing workload the hospital has a stronger potential to operate all services and departments at nearly normal operation levels despite the downtime event.

After identification of the potential optimal solution to have one individual handle result reporting and one additional technician running the chemistry analyzers, a further analysis was conducted to investigate the impacts of additional staffing for the result reporting role.

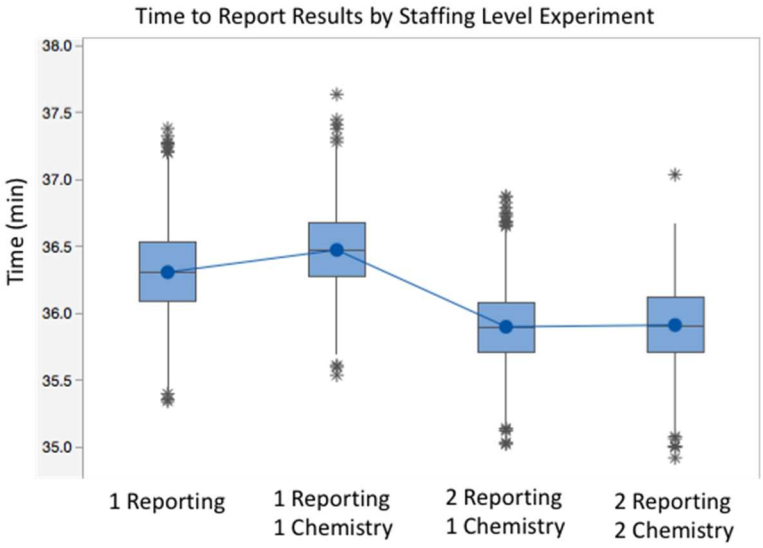

Figure 25 - Time to Report Results by Staffing Level Experiment

The box plot of the means for time to report results is provided in Figure 25, a measure of the time to report results is not available for the control downtime experiment as the measure presented is specifically the time the staff in the result reporting support role spend reporting the results. Statistically, the trials with one individual handling the reporting role are different from each other, the experiments with two support reporting workers are similar.

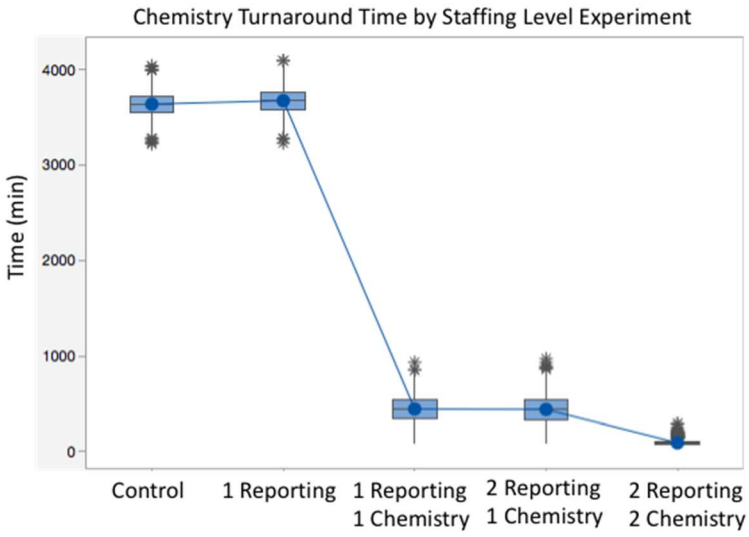

Figure 26 - Chemistry Turnaround Time by Staffing Level

Figure 26 depicts the impacts on the turnaround time of a chemistry test based on the staffing levels. Based on the analysis, the results of the experiments with one reporting worker and one supplemental chemistry worker, and two reporting workers with one additional chemistry worker are statistically similar.

Adding a technician to the chemistry analyzer appears to enable that analyzer to operate nearer the normal operation efficiency level; letting the staff coping with manual work better compensate for the lack of computer systems. In all cases adding additional staff aids in the reporting process and alleviates stress on the laboratory, enabling faster throughput and having a smaller impact on patient care in the ED.

4.6.3.3. Other Interventions

The remaining interventions previously identified have not yet been tested in simulation. Interventions targeting improving downtime training and preparation, and the access to patient history and demographics are undoubtedly necessary to improve care during downtime. Unfortunately, with the data available, it is not possible to implement them into the simulation with any measure of confidence. Future work may be able to determine parameters for testing the interventions in simulation, however, based on the presently available records, empirically performing the analysis is not possible.

The intervention targeting improvement of trust and understanding between the departments relies on a cultural shift and falls outside the scope of the simulation environment. In reality, the development of trust and understanding should be addressed during if not before the process of identifying any reduction in the testing menu. Part of the solution may involve reinstituting the programs that allowed staff to shadow coworkers in other departments to understand the work processes in other areas. Based on comments from interview participants, neither the laboratory nor the ED have an understanding of how the other department functions or insight into why some actions or tasks may be required. Encouraging interaction between the two departments may help to resolve some of these issues.

4.7. Implementation

Implementation in the work system of the target hospitals is beyond the scope of this dissertation. However, the interventions are tested in a simulation model of the target hospital environment. Based on the findings of the simulation runs, the simulated interventions have been iteratively adjusted to determine the potential optimal configuration. The resulting interventions and configurations represent a possible starting point for the development of contingency plans for downtime operations at the target hospitals and may be generalizable for healthcare in general.

5. DISCUSSION AND CONCLUSIONS

All stakeholders within the hospital agree that downtime is disruptive. The significance of that disruption and the real risks patients are exposed to, however, have been mostly unknown and prior to this dissertation not directly studied. While there are new risks related to downtime, neither of the target hospitals had any reportable events or fatalities related to their previous downtimes. The lack of these incidents is a testament to the resilience of the hospital systems and the personnel. Presently, the desire to maintain safe and effective patient care means that work needs to slow down to enable the staff to manage the safe care of their patients. This work sought to provide some initial suggestions that could allow downtime care to continue with fewer delays.

This dissertation aimed to employ the MEAD methodology for the exploratory study of downtime and conduct an examination of risks patients are exposed to during a downtime event. Also, the performance link between the emergency department and clinical laboratory was examined. Based on the data collected through the MEAD methodology, the construction of a simulation model was supported. The model was designed to represent the data extracted from the hospitals and provide an experimental space to test possible interventions. The final stages of the MEAD methodology devised potential intervention strategies which were examined by implementation in the simulation model. The results of this dissertation as depicted in figure 27, are an adaptation of the MEAD methodology, informed by simulation, specialized for examining the unknown situations of downtime in a hospital, providing the results of an initial exploration of the issues of downtime at the patient care level.

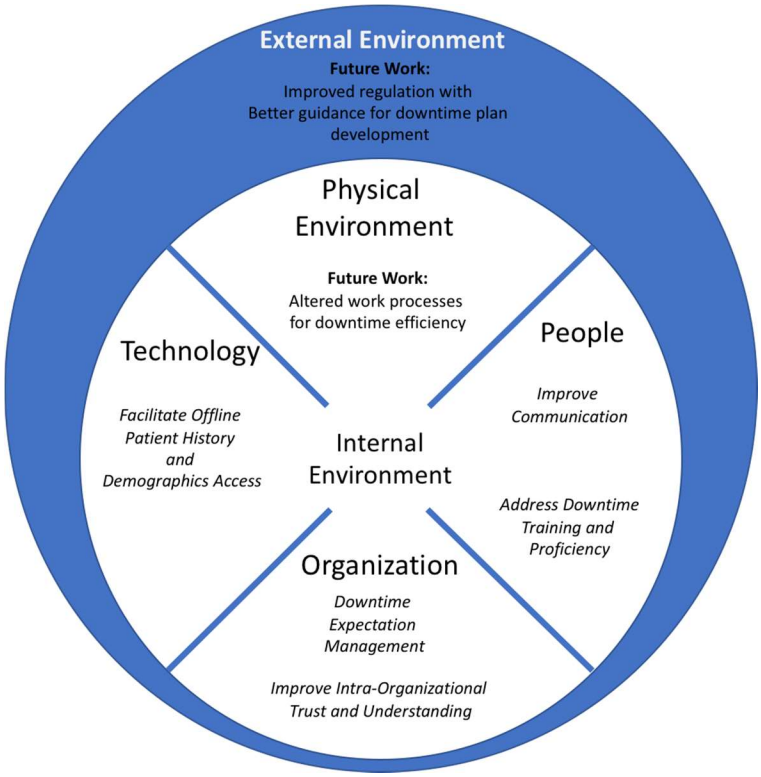

Figure 27 - Sociotechnical Work System Model with Interventions and Potential Future Work

5.1 Study Limitations

There are some limitations to this research which must be acknowledged to provide context to the results provided and address the generalizability of the results of this dissertation.

5.2.1 Study Site Selection

The two study sites, Hospital B and Hospital A, were initially selected due to their outwardly apparent different operational parameters. Hospital A is a large, urban, 1,000-bed facility with advanced ED services such as a Trauma-I capacity. Hospital B represents a smaller suburban acute care 300-bed facility which handles far fewer patients than Hospital A.

The expectation was that by examining two very different hospitals, more generalizable downtime solutions could be developed. As data collection and observation commenced, it was learned that Hospital B represented a consolidation point for centralized laboratory medicine for the corporation, handling non-emergent laboratory testing for Hospital B and three additional surrounding hospitals. The consolidated laboratory in Hospital B handles very nearly as many

specimens as the Hospital A lab handles and is the nearest equivalent laboratory within the corporation.

The similarity of the two site laboratories creates the possibility that the interventions and issues identified may be particular to larger, high volume labs and their associated hospitals.

5.2.2 Data Availability

As data collection proceeded, artifacts were found in the normal operation EHR datasets which impacted the quality of the raw EHR data. These artifacts were identified by patients with abnormally long total treatment times, i.e., measured in days or even weeks. Another artifact was laboratory tests that were reported significantly faster than they physically could have been completed, i.e., a 45-minute chemistry test reported in 15 minutes. It is suspected that these data abnormalities represent an artifact of the way the EHR was fundamentally built, scripting together several independent programs. The master EHR database has entries for every interaction, but the data itself may be representing the time the data was written rather than the time the action took place. While the data was cleaned for obvious abnormalities by consultation with subject matter experts in the hospitals, there is still potential for irregularities to have remained in the dataset.

Review of paper records found that stated downtime procedures were not being adhered to during downtime events. Many of the paper records lacked information that was expected and, in some cases, mandated to be present. In the case of the laboratory downtime paper records, all paperwork out of Hospital A lab was reviewed, and none of it was found to be complete enough to provide any information for a downtime performance database. The lack of viable downtime data has led to this study being primarily focused on the issues related to Hospital B; further study and identification of potential alternate data sources will be necessary to include Hospital A.

5.2.3 Participant Selection

Participants for interviews were found based on a volunteer basis, and sessions conducted during work hours. While a balanced number of participants across roles and sites was sought, the result was an imbalanced participant pool across sites. Due to the presence of a workers' union at Hospital A, contacting and conducting focus groups with the nursing staff there was not possible.

Previous researchers had attempted to contact unionized staff at Hospital A for prior studies and were unsuccessful in recruiting participants. Based on the experiences of those studies, it was made clear that contacting the unionized staff was not a possibility. Therefore, the interview data from the nursing staff only represents the opinions and experiences of the smaller Hospital B ED.

Participants were recruited as they volunteered for sessions when the researcher was available. Hospital employees coordinated amongst their coworkers to manage shift and care coverage to participate, causing the initially designed focus groups to be conducted as interviews. The incentive for stakeholders to participate was only the potential for improvement to their work environment; future research may benefit from less intrinsic incentive to encourage greater participation in future studies.

5.2.4 Simulation Modeling

The simulation model was created using data collected from the Macroergonomic methodology. The model for normal operation was able to be validated and verified relative to prior historical performance. Downtime records, however, were not as intact or reliable as the normal operation data. Much of the downtime model performance is based on normally automated operations requiring a worker entity to execute, which reflects reality; however, the specific time impacts of every step of downtime work is unavailable.

5.2. Policy Recommendations

At present, even after the recent revision, ONC's SAFER guides remain vague in how downtime protocols should be developed. The recent revision added that the creation of communication plans to alert staff to a downtime event should be part of the downtime readiness preparation done by the hospital. Unfortunately, the details of how to develop downtime plans are still entirely left to the individual hospital to develop. The MEAD methodology in this dissertation establishes a framework for studying downtime; additional studies can employ the methodology and develop a comprehensive list of intervention strategies cross-referenced by hospital size, location, and population they serve.

By creating a reference list of interventions, hospital administrators can work to select and test which interventions fit their needs in conjunction with support from operational

researchers. More comprehensive downtime contingency plans that also align with the other suggestions of The SAFER Guides, such as periodic practice and review of downtime plans, will help to increase safety during downtime and mitigate the risks patients are exposed to from the current need to significantly slow care operations.

This dissertation has provided a foundation for patient care level study of downtime events. While many of the suggestions and recommendations developed within are still considered preliminary and specific to the target hospitals, there is potential for generalization to other facilities. Significant additional study is necessary to reliably expand the conclusions and recommendations to other hospital departments and more hospitals. Inference of this dissertation's findings towards policy should be carefully evaluated and informed by additional research following the framework established herein at other facilities.

5.3. Hospital Recommendations

Several recommendations can be made to both of the target hospitals based on the findings of this study. First and foremost, incorporation of training on downtime into the existing regular competency checks in place. The number of interview participants who voiced issue with downtime workloads due to rework is a concern. The number of instances where individuals chose to implement other protocols on the fly rather than using the established and available ones is a variance that should not be occurring. Regular training of downtime plans is also a recommendation made by the SAFER guides.

Facilitation of the development of a limited testing menu will enable the laboratory to manage workload as they are most significantly impacted by the forced shift of an automated workload to a manual one. Managing the demand on the laboratory will enable the more critical testing to be delivered in a timely fashion while non-emergent cases that can be safely deferred to another time can be handled when appropriate.

Establish communication support, going beyond the SAFER guides suggestion of communicating when a downtime event is in place; have a plan for support staff to facilitate the communication of patient information between departments as needed. While this study has been focused on the laboratory and ED and the information movement between those areas, all

departments are involved in downtime care and the movement of patients and information. Having established communication facilitation roles for all departments can help to keep information flowing appropriately and allows the clinical staff to continue to focus on their standard tasks without having to also take on secretarial and communication responsibilities during a downtime event.

Review downtime plans regularly as in many cases the downtime plan is placed on a shelf and nearly forgotten until it needs to be activated. After the event is resolved some hospitals have a debrief, make revisions to the protocol, and place it back onto the shelf until it needs to be activated again. The plan should be updated and kept up to date periodically as equipment, and other policies shift in the hospital. A periodic review would also help to keep all administrators aware of the downtime plan and its contents, potentially making future downtime events run more effectively.

5.4. Suggestions for Future Study of Downtime

Any future study of downtime events can benefit from the use of the adapted MEAD methodology supported by simulation. Future researchers should be mindful of the significant pitfalls and recommendations provided through the execution of this study when examining downtime themselves.

To optimize site selection, before finalizing site selection, a brief deep dive into some of the available data and policies could be beneficial. Though a time-consuming process, if Hospital A could have been identified as having no viable downtime data earlier in the study, an alternate facility could have been identified. A deep dive into the details of the hospitals would have also identified the similarities in the laboratories of the two target hospitals in this study. If future research has a similar goal to provide generalizable contributions, ensuring that outwardly different hospitals are genuinely as different as they seem will be critical.

Computers are only as good as their programming. From the clinician interface, the EHRs provide all of the necessary information in a format that facilitates their work. When leveraged for research purposes, EHR data needs to be continuously questioned and checked for validity. Even though the end to end data in the clinical interfaces is correct, when checking procedural

time stamp and other "back-end" data in the EHR, artifacts of their origins and other abnormalities start to manifest. All data obtained from EHRs need to be questioned and cross-checked with subject matter experts for validity.

Healthcare knowledge, partnering with a domain related subject matter expert, or even several experts will provide insight not usually available to an outside researcher in healthcare. Having access to a physician, nurse or technician can provide guidance regarding regulations, requirements, and identify issues that otherwise would not be apparent to the researcher.

Participant recruitment, making more sessions and times available, in addition to more formal incentive than a potential improvement to the work environment is necessary. Many healthcare professionals are motivated by a desire to care for their patients, but that alone may not be incentive enough to participate in a research session, especially if they have also to arrange coverage of their patients during their participation.

Use the tools available; the MEAD methodology is just that, a methodology. The tools identified in this study are not the only tools available. Future researchers should make use of the tools they are familiar and comfortable with to gain the information necessary to satisfy the requirements in the methodology.

5.5. Summary of Research and Contributions

The objective of this research was to explore the issues of EHR downtime in hospitals and the impacts those events may have on patient care. In order to accomplish the research, data from several sources was collected to ensure the ability to address discrepancies and other errors or gaps in the available data sets, figure 28. By combining the EHR data, paper records generated during downtime, interview responses, and workplace observations; a holistic depiction of hospital operations and specifically those during downtime can be created.

From the collected data sets, the performance aspects of downtime in a hospital were used to construct a high-fidelity simulation of the linked services of the ED and clinical laboratory. Simultaneously, the data sets were analyzed through the Macroergonomic Analysis and Design methodology, facilitating the development of evidence-based contingency strategies for coping

with downtime. Feeding the strategies into the simulation allowed for a measure of empirical testing of those downtime strategies under extreme downtime conditions.

This research makes several distinct contributions to the field of healthcare engineering and management research, specifically in the sub-field of EHR safety:

1. Empirical study of previous downtime events from a performance and qualitative perspective
2. Macroergonomic analysis of the current state of downtime readiness in hospital environments
3. Development of evidence-based recommendations for best practices in designing future downtime contingency plans
4. Demonstrated ability to test hospital operations and contingency strategies within a simulation model and gain meaningful insight as to the efficacy of those strategies

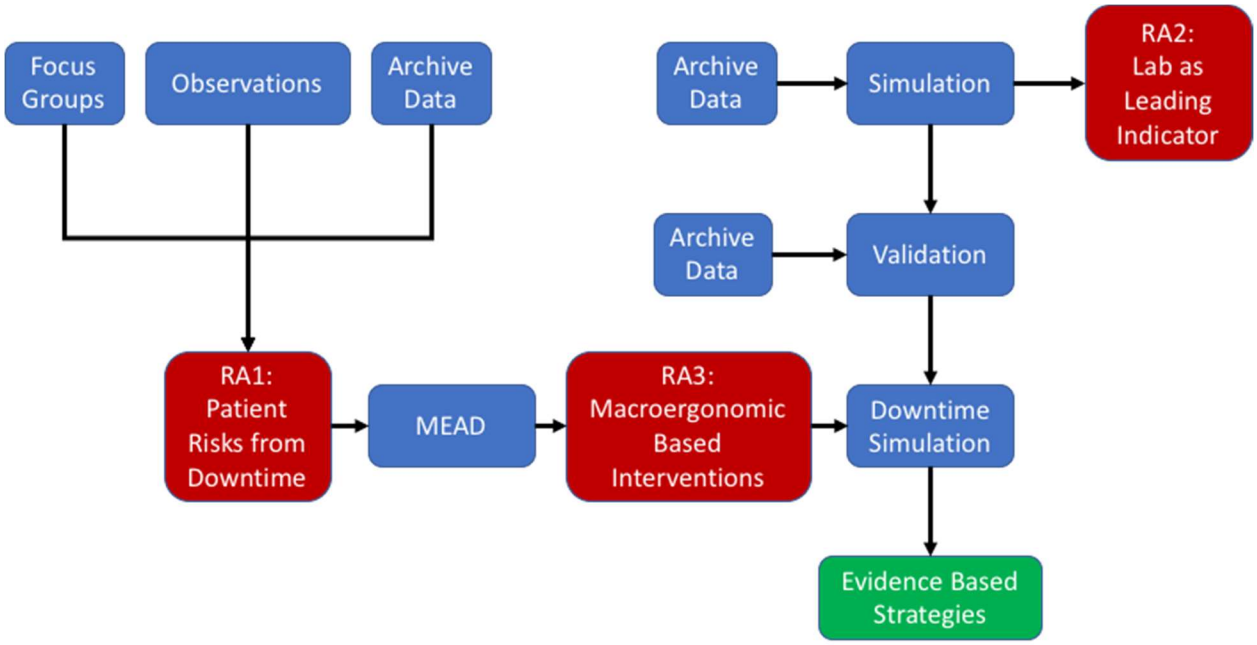

Figure 28 - Conceptual Diagram of Data, Analysis Tools, Research Aims, and Outcomes

5.5.1. Study of Prior Downtime Events

Previous downtime events have been significantly disruptive to hospital operations. To date, in many cases, that statement represents the extent of the scientific knowledge behind downtime.

A cornerstone of this research is that prior events must be understood, especially the significant hurdles encountered by the hospital trying to maintain efficient and safe patient care.

In previous downtimes, hospitals have tried to function as if the only change were that the EHR went back to being a paper form. Fundamentally, this assumption is not incorrect, but it is inefficient. Many workers lack formal training or even familiarity with the paper mechanisms of healthcare that are typically managed through the EHR. Situational awareness is required for this type of role change relative to an automated or semi-automated system. Some young physicians during downtime were handed paper prescription pads which they had never seen before or even been trained on how to complete. Similarly, nursing staff only had familiarity with paper methods if they had been working in nursing long enough to pre-date the EHR implementation. Younger nurses relied on the older staff to assist them in paper record keeping.

When reviewing potential safety events that occurred during downtime, some staff indicated significant patient care events occurring as a result of operational shortcuts taken to circumvent the safety steps in place during downtime. Downtime events have caused several near-miss incidents that are not required to be reported but are of enough concern to investigate further.

From a performance standpoint, all care activities slow down and patients experience significant delays in the hospital during downtime. Information transmission falls back to fax machines, copiers and couriers, none of those mechanisms are prepared for the load placed on them during a downtime event. In previous events, hardware such as copiers and fax machines became so overloaded they shut down, and couriers were unable to keep up with their rounds through the hospital. The performance data that is available to track indicates only a portion of the delays experienced in the hospital. Laboratory tests may only be measured to experience a 62% delay, but that delay does not encompass using the fax machines or couriers to transmit the results, adding hours to the time to complete the task.

5.5.2. Evidence Based Suggestions for improving Downtime Planning

Based on the findings of this research, several key evidence-based recommendations for best practices can be made. These recommendations for best practices fit within the structure of the ONC endorsed SAFER guides. The recommendations provide additional detail to the SAFER guide

suggestion that a downtime plan should be on file and practiced. This dissertation provides guidance on areas to focus downtime plan development for a hospital looking to conform to the SAFER guides.

5.5.2.1. Limited Downtime Testing Offering

If a downtime event causes hospital resources to be reduced, the expectation that the clinical laboratory can satisfy a normal workload without computer systems is not logical. Some amount of reduction is necessary based on the duration and impact of the downtime. On its own, a 40% reduction was shown to allow the laboratory to deliver the remaining testing at a 90% improvement of the control downtime efficiency.

In reality, achieving a 40% reduction in testing demand of the clinical laboratory is unlikely, and the hospital should work with the laboratory and critical care departments to achieve as much of a testing load reduction as possible. It is worth noting that beyond 40% reduction, the gain on performance for the reduction was significantly less than in the 10-40% range.

5.5.2.2. Formalization of Downtime Work Roles

During previous major downtime events, the hospitals implemented unofficial job roles for workers from other non-clinical areas to support care operations. The tasks are predominantly focused on additional couriers and coordinators for paperwork and communication within the hospital. In the case of the clinical laboratory, having an additional technician working the highest demand analyzer and creating a new role for the collection collation and reporting of the completed laboratory testing had a significant impact on performance.

The individual hospitals would need to identify their high demand analyzers and set the intervals for when the communication coordinator collects and transfers results to the specified locations. Once the additional downtime roles are developed, plans to train and practice downtime operations will be vital to the sustainability of the contingency plans.

5.5.2.3. Formal Downtime Procedure Training and Proficiency

Many participants in this research voiced issues with the lack of downtime training and proficiency tracking in previous events. Some participants indicated that their coworkers would merely make up steps when they could not remember them, leaving the next shift to rework the

previous work that was incorrectly completed. Based on the paperwork available, several workers were also not following the standing procedures for completing paperwork during a downtime. The lack of adequately completed paperwork impacted the data available for this research. However, the reason for the lack of completed paperwork is not known.

Some mechanism for formal training, providing detailed documentation for all downtime specific job roles and the continuation of all clinical work during downtime is necessary. The procedures should be more than binders on a shelf, they should be incorporated into regular drills, similar to the SAFER guides, and if necessary included in regular staffing proficiency checkups. Downtime drills are already used and developed in both hospitals. When enacted, the personnel either follow downtime protocols in parallel with the computer systems or practice exclusive use of downtime procedures on fictional patients and specimens. Increasing the frequency of the drills either in actual practice or through proficiency checkups and ensuring that all shifts gain experience on downtime drills is necessary for downtime performance.

5.6. Future Research

This dissertation focused only on the linked operations of the ED and clinical laboratory within two hospitals to assess impacts to performance in both areas due to downtime. While a basic understanding of downtime can be gained from the approach used by this research, there are a number of opportunities for future research.

An area for future research would focus on expanding the simulation model to incorporate the other departments that are involved in emergency care. Presently, the simulation model represents the unknown other activities beyond laboratory testing as a variable delay step to achieve model validation. Collecting data on and evaluating the other areas that are consulted for care such as radiology, pharmacy and in general the ability to request a consultation with other non-ED physicians.

Due to the limitations of the data available, the simulation model currently reflects specifically the operations at Hospital B. Altering the existing model to accurately represent Hospital A would require additional iteration with stakeholders and broader data access to find alternate means of validation and is best suited as a future research endeavor.

The combination of Macroergonomics and simulation in healthcare safety research, even beyond the implications of EHR implementation and downtime is an open space for further exploration. Healthcare provides numerous opportunities for expanding research, but also ethical issues when implementing changes to operational behaviors. Simulation, when correctly implemented, can provide an experimental "lab" to test operational changes without the issue of safety impacts. Macroergonomics provides a methodology to explore the work system holistically and develop strategies to improve the healthcare system. Triangulating the two methods together creates a healthcare exploration medium with the ability to take on any issue the domain presents.

5.7. Conclusion

Through this study a revised MEAD methodology has been created, tools specific to this exploration of downtime impacts identified, and results tested in simulation. Future research can employ the MEAD methodology for downtime study and incorporate more areas of the hospital to evaluate. Some potential issues that occur during downtime have been identified in addition to potential strategies to reduce their impact. Finally, those strategies have been evaluated and some possible suggestions to inform future policy created. Downtime has been and will continue to be an issue in EHR based medicine. Hospitals will need to cope with the situation to maintain patient care. With this and future study of downtime incidents, patient care will be able to be maintained by more than the organizational resilience protecting patients during downtime.

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APPENDICES

APPENDIX A: IRB DOCUMENTS

A.1 – IRB Approvals

A.1.2 – Virginia Tech IRB

VirginiaTech

Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: May 22, 2015

TO: Christian Wernz, Ethan Larsen, Raj Ratwani

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)

PROTOCOL TITLE: Mitigating the Impact of Electronic Health Record System Downtimes: Simulation and Modeling

IRB NUMBER: **15-531**

Effective May 22, 2015, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the New Application request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Exempt, under 45 CFR 46.110 category(ies) 4**
Protocol Approval Date:	**May 22, 2015**
Protocol Expiration Date:	**N/A**
Continuing Review Due Date*:	**N/A**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: July 13, 2017

TO: Christian Wernz, Ethan Larsen, Raj Ratwani, Rollin Fairbanks, Carlos Misael Rivera

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: 1R21 HS24350-01A1 - Evidence-Based Contingency Planning for EHR Downtime

IRB NUMBER: **16-558**

Effective July 13, 2017, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Amendment request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 5,7**
Protocol Approval Date:	**September 2, 2016**
Protocol Expiration Date:	**September 1, 2017**
Continuing Review Due Date*:	**August 18, 2017**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

A.2 – Focus Group Script

Goal(s) of focus groups (for internal purposes only):

- To understand the handling and impacts of downtime operation in the clinical laboratory and emergency department.
- To gain input from clinical staff about downtime preparedness and suggestions for improvements to downtime contingency planning.

Focus Group Question Guide/Moderator Script

Opening

(Estimated time – 5 minutes)

[Welcome, thank you for participating, mutual introduction – moderator(s), participants, remote members]

Purpose statement/directions

(Estimated time – 5 minutes)

We are funded through the Agency for Health Research in Quality to study the impacts of computer downtime on the combined operations of the clinical laboratory and emergency department.

Today we will be asking a series of questions to better understand what you have encountered in previous downtime situations, and what you think could improve future events. Specifically we are interested in collecting information about the general topics of Communication, Technology, Work Stress and Efficiency, Patient Safety, and Downtime Preparation.

We will be taking notes on the discussion today for use in our research, however there will be no ability to identify who specifically said anything. This session is being conducted solely for the purpose of research, and is in no way shape or form an evaluation of you or your work.

Your participation here constitutes your consent to be a part of this session, if at any time you no longer want to participate or want to withdraw your consent you may leave the session without question.

(Budget 12 min for Communication)

Prompt: First we are going to talk about the communication of a downtime event and the information you need to complete your work tasks.

Question: How is the start of a downtime communicated to you?

Follow-up probe:

- Are there specific things that need to be communicated
- How are they communicated now

(Budget 12 min for Technology)

Prompt: Now we are going to move into talking about the technology that supports your work tasks.

Question: What hospital technology hardware/software elements are most critical to your operations

Follow-up probe:

- What procedures involving these procedures are most critical

(Budget 15 min for Efficiency and Work Stress)

Prompt: We would like to move on to discussing your work stress and efficiency during a computer downtime event.

Question: How does your work Efficiency and Stress compare during downtime to normal operation

Follow-up probe:

- Are there aspects that improve
- Are there aspects that are more difficult
- Are there things you feel could be done to improve

Question: How do you feel overall efficiency was day to day throughout the March/Malware downtime

(Budget 15 min for Downtime Preparedness)

Prompt: We would like to move on to discussing your preparedness for a computer downtime event.

Question: How are you currently trained for downtime operations

Follow-up probe:

- Is there anything you would want to change

Question: What changes did you make to how you did your job during the March/Malware downtime.

Follow-up probe:

- Ie: extra staff, changes in technology use, hours worked, order of operations etc

(Budget 15 min for Patient Safety) (time permitting in lab sessions)

Prompt: At this time we would like to discuss your perceptions of patient safety during downtime.

Question: How do you feel about patient safety during downtime compared to normal operation?

Follow-up probe:

- Are there specific causes you can identify
- What could be useful to assist you

A.3 – Downtime Observation Plan

Locations: HOSPITAL A and HOSPITAL B ED

Participants: ED Physicians and Nurses

Time: As announced, plan to capture recovery phase as well as full downtime

General Descriptive Observation with focus on specific elements:

Elements	Focus
Lab Test Requisition Form	• Who is completing it • If possible: is it actually complete
Patient Specimen Collection	• When does it happen, before or after Requisition Form • Where are the samples labeled, pt bedside or elsewhere • Are the samples immediately sent to lab or are they placed somewhere else
Communication Coordination	• Does anyone take on a role of coordinator for communication, if so who, what is their original role, were they told to take it on or did they choose it • What other tasks are they handling as well, i.e. phone, collation of paperwork
Patient history	• How are patient records being maintained: printouts, some level of computer involvement
Patient Care and Movement	• How many patients are actively being cared for simultaneously • How many patients are waiting for procedures, lab/radiology results • if and when the space feels crowded • how full are the waiting and overflow areas
Downtime Coping Strategies	• significant changes from standard computerized work, i.e. whiteboard and paper charts coming out • what is being tracked by strategies like the whiteboard, are new elements added or removed through the course of the downtime event.
Callouts	• what information is being yelled in the area, I.e “is your computer down?” • complaints or mention of issues with downtime, or downtime practices
Leadership roles	• Does anyone step up and lead the downtime activities

Excess personnel	• Are there any employees in the area not contributing to pt care, i.e. managers coming to observe • Do they get approached by care providers and asked to help

Observer: _____

Time: _____

Date: _____

Downtime Requisition Form (tick marks):

Who Filled out the Requisition Form (Integrated Laboratory Services Form)

Nurse:_____

Physician:_____

Others (indicate role): _____

If you can see it was the form header (pt info) complete:

Yes: _____

No: _____

Specimen Collection (tick marks):

When was the specimen collected:

Before Req Form: _____

After Req Form: _____

Where were the specimens labeled:

PT Bedside: _____

Not bedside: _____

After labeling when are the specimens sent to lab:

Immediately: _____

Delayed: _____

Patient History:

How many times do you overhear PT being asked for history/allergy info due to EHR being offline:

_____

Indicate any personnel taking on unusual leadership roles and what tasks they are performing: i.e. coordinating communication, paperwork collation, phone management, general coordination through downtime:

Indicate any downtime coping strategies replacing offline technologies: i.e. whiteboard for PT tracking, paper charting.

Overheard callouts from staff regarding computer systems:

Roughly how many patients are being cared for by a single physician:

How many patients are waiting for lab tests/radiology results

How full/crowded is the space (estimate %)

If present, how many non clinical staff are in the space, i.e. management, and are they assisting the downtime operations:

APPENDIX B: FOCUS GROUP DATA

B.1 – Focus Group Notes

P1 - HOSPITAL A Lab Manager

P2 - HOSPITAL A Lab Workers

P3,4 – HOSPITAL B Lab Managers

P5 – HOSPITAL B Lab Division Manager

P6,7 - HOSPITAL B Lab Techs

P8 - HOSPITAL B ED Doc

P9 – HOSPITAL A ED Doc

Q1 - How is the start of a downtime communicated to you?

P1 - Communication is a big problem. Usually we find that the system is down whether it's the ordering system (amalga etc) or cerner. We usually find out it is down because we are suffering, then we call (IS or someone else) and they say that the system is down. If it is scheduled then we can plan. Either we experience problems with cerner and call in and inquire or we get lots of stuff on paper and inquire and then IS says "oh yeah the system is down, just fyi".

P2 - Well the communication is the same, they will make an announcement and say to operated downtime procedure. Everybody let's huddle and here is what we are going to do.

P3 - ideally they send us alerts via text and pager system in the main lab. ideally. what actually happens, they get call from IS team giving alert. The one thing is, "why we are going down" - not communicated well. Then at end of day they say "oh we were down because xyzzy"

P4 - we have electronic everbrdige alert system that we receive by email and cell phone. They always setup a call, send an alert, one line message, then 20 mins will have call. 1 line alert will have info on what system is going to be down. What gets hairy is slowness, when do we get from slowness to down. "It is only this site and not systemwide". If accessioning is having a problem, they will call me and then I will put in a IT ticket. Don't assume that IT knows that we have an issue so that we are all aware what systems are down.

P5 - We probably discover downtime when the computer stops doing what it needs to do. Scratch heads wonder what is going on. Wait for someone to contact us (admin) and been told to call someone in admin to inform something wrong with the computer. No set way to communicate. Recently though, the rule is not to be "if downtime, go downtime" to take guesswork out of when we start our downtime process.

P6/7 - Depends at beginning. Most of the time a heads up. Team huddle, today we have a downtime. Just inform us when downtime then we take out binders. Big mess. Binders don't solve problem Utter confusion. Entering label slows the process. Once you have instrument data you can transfer, but there is no backup method. You can fax 2 pages not 200 pages! When

computer comes back online you can transfer. Backup system to build better than this binder idea. When they built corner they didn't understand "what is your backup system". In the vista machine you can do many information but again is cheap to do backup. We have a 50's communication with the phone system. All this other stuff they come with an idea (don't worker here and nothing practical), important for specimen to have backup label. In sysmex you can scan barcode.

P8 - General downtime, we just see that computer goes down and the CN then informs everyone. Lab downtime, we don't really get any notification in a timely manner. Until I kept calling and calling and then they told me the lab is down. Usually the lab doesn't let the ED know that they are down.

P9 - Grades of downtime. Planned - week/monthly on nights, not long. Then Planned that become Unplanned - un frequent that were planned but go longer that expected. Unplanned - echo of staff saying "medconnect isn't working, is yours working?" screen freezes and then we find out it is down. Reflexively if I hear the echo (not working) then I automatically do a screenshot of the system in case the system goes down so we have a reference list of our patients. No communication from the lab, but usually it is "hey are you feeling like the lab is slow today" then usually we call down to ask and then we find out there is a system down. If over a shift change (nursing mainly) then the CN will do a status report that will include lab status to next change. Otherwise, it is adhoc where I will be told "hey the lab is just slow today". Nothing within EHR that warns you. Don't recall any alerts via hospital administrations other than planned downtimes. Daily email of "click link to get status of downtime" so you can see retrospectively of outages around the system.

Q1.1 - Could it be handled better?

P1 - I would like to handle it better but I don't know if there is a better way. It is healthcare so you can't stop taking care of the patient just because the system is down. Bigger issue is that once it is determined that something isn't working, then the information that we do get is extremely lacking. For example - they have to give you paper requisitions but they don't actually fill them out. We got in trouble because we didn't send the results back on paper because they never filled out the location on the requisition form. Folks out front don't fill it out properly. 1 - Delay in getting results back. 2 - When system does come back up we can't enter information because it's all missing. Getting time of collection is important, really unsafe. Other problem is a result of that in not getting results back. We had a string of doctors down here lining up and demanding results. Instead of asking for their single worst patient they wanted all their patients event though the situation was not normal (malware). Be understanding. It's the beginning and the end user that needs to fill out the paperwork correctly. Its being shot down through a tube, no idea where it comes from so no way to clarify any sort of information.

P2 enters room

P1/2 - The biggest problem, is that everything is coming (all labs no matter what) and maybe we should just accept STAT. We should really do cortical such as BMP/CBC. Front (clinical staff) was continuing as "business as normal, ordering TPA's etc" instead of critical labs such as BMP/CBC. Now the patient that needs that critical test is not getting it in a timely manner. Our systems are all computer interfaced so it all needs to be manually input at the end so the more information we get on the onset

(labeling, downtime alert, etc) the better setup to succeed we are.

Q1.2 - Are there specific things you want to know when a downtime starts?

P3 - how long we are going to be down for, that makes a difference on how we anticipate everything. With the unscheduled, one we had no idea how long it was going to be.

P4 - yes, work in progress. often IT talks in their lingo of "system", i wouldn't expect other admins to know what IT is speaking of. Make sure that when we approach downtime that we actually know that it is "down". If it is down then what does it affect? This is what we need to understand from a systemwide perspective. We are getting more and more complicated so knowing this is key.

P5 - Would be nice if we knew sooner that it was a serious issue. Knowing that its not always know though. So hard to know sooner.

P8 - Specific to lab/instrument delays should be communicated to the CN as soon as possible. Calling the CN is the best way when the lab knows that it's down.

Q2 - For equipment, how during downtime make sure that you can keep running, are the procedures optimal? Benefit from analysis/change?

P1/2 - I don't know how you prioritize labs, they are all important. Everyone has been reliant on them. We are all computer based so if there is a downtime then we have to move to paper because if we don't we can't result any labs. We have to look to the instruction manual on how to hand write them (paper results). For us, we have to remember we have to keep up with the reference ranges that are there. Usually we rely on the computer to do it all, but by hand (reference ranges/criticals) it is very hard and is not as accurate. Remembering to maintain the system, because right now it pulls it all from the computer. We have to tell it to start printing paper. We have to have multiple copies of paper forms so we have to Xerox all of these reports so we have copies. Same with requisition, sometimes it has multiple labs from difference places so that we can give copies to everyone, then we make copies of the results to send out. We don't have a dedicated ED tube. Usually a laminated card in the carrier with location/stat etc. We had a few lost specimens but none from your example of 20 years.

P3 - Refer back to big downtime, not realizing how much of an impact we had on pharmacy in terms of providing them with results. What we did was hand them a stack of results and then have them interpret the stacks. Not having internet capability, not able to know phone number for key unit personnel to communicate information. How much of we were just stuck in the water.

P4 - Harbor is where the servers are and HOSPITAL A (hardware). Medconnect (KC). Keeping those 2 sites with full connectivity is key. IS can divert service between HOSPITAL A and Harbor in cases. For the lab -> we have deck servers. If deck servers are

down, doesn't mean medconnect is down, but still chance for error because manual input. It is understanding the deck servers but the IS is not responsible for deck, the lab service team is responsible. IS only for closet servers. Lab level -> to take out lab, if we lose connectivity to KC then we are down. Other servers such as POC and IDX are at Harbor then if we lose connectivity then we are down for this services.

P5 - if one area of the hospital isn't working then it could impact us if they are down. need to know which part of the computer process impacts us. Concerned that we don't have leadership at the normal time, so the workers have to call help desk to log ticket. Whenever the IS related downtime then admin is on-call. From there we follow up and get additional updates from IS and get more realtime info to the lab team. "Do we wait anymore, do we go to next phase of the process?" <- important questions

P6/7 - In the lab, these instruments problem is transfer information to ER etc. In closed system you have list of printers (can print to ER, OR) no one knows to use, very useful instead of faxing and scanning out. For the UA, interface not friendly to reconnect etc. Most frequently we just don't use when in downtime. Other stuff you don't have option to run specimen. How do I transfer? That's the problem.

P8 - The computer system/medconnect is most critical for work. Nothing else is really affected other than amalga, radiology and such.

P9 - Downtime is where only a connection goes down, labs can still be done but is there a way to have some sort of auxillerary system to plug into lab so we can see the logs of the machines. Example - medicalis wordlist pack system. This status flags don't work - you know when image is done but you don't know if it is read. We are now on the same system so now I can write my prelim interpretation of the X-ray and when the radiologist opens it up they will see my comments. And I can see the wordlist of the radiologist so I can see where my image is in their workflow. Something similar to that in the lab such as one way lab view to see lab testing status. So if we get a feed of the lab display that would be great and see how it relates to the other tests because usually can't see other individuals. Mental model of 1 hour in the lab usually results based on experience then if lab time takes longer than usual then I will know here things are.

Q2.1 - For patient care/lab/ed critical equipment/technology?

P3 - internet is essential. Keeping updated phone information to reach correct unit personnel to relay results. Up to date information critical.

P5 - the telephone. internet (to get to outside companies that manage instrumentation)

P9 - Phones, Computer, PACS system (medicales for radiologist), amalga, fax machine, whole host of behind the scenes systems such as ADT system that feeds into Cerner so we won't get any new patient whereby we are half paper and half electronic since we can input electronically new patients if ADT is down. Specifically when we had big downtime, we ran into problem with throughout of fax machine. line got clogged up with all the results and also used to fax notes to other floors. way they fixed it

was printing results to our floor. understanding limitations of the fax machine so maybe having multiple fax lines. love the idea of having a window onto the lab and understanding what their workflows and knowing where they are. ridealongs in the lab - fun to do with clinicans to spend time in lab to understand their work. Could you use issue of hemolyzed samples with animosity/blame/mistrust with it and translate it to downtime issue. If we are trying to work on transparency and communication around missing sample/hemolyzed to improve workflow currently so the downtime does hit we are better prepared.

Q3 - How do you feel in terms of work stress/efficiency? Difficulty? Improve?

P1/2 - To improve, I don't know because it is such a high volume (you have to program dozens of values) look out for criticals and they don't flag without the computer. The phone rings constantly, I can't be helpful to the person on the phone because I am running this test. If customer service transfers call to me to ask for lab/paper etc I can't help because I don't know where it is if it was completed (results are handed down the line and sent off somewhere). Phone is a problem. It would be nice to have a central phone. During scheduled downtime we bring in extra forms, staffing etc but with unplanned we don't have anyone extra. Nice to have dedicated phone team. Phone ringing distracts me from finding critical value references. During downtime they shouldn't order everything under the sun. Everyone that calls down here thinks that their lab is the only one being run.

P3 - I am different, when situation becomes stressful that is when I become calmer. Unique for me.

P4 - I think the way to keep stress down is to be organized. Put things in place, plan. Central person fro rounding, divert calls to one line. The more control you have of the downtime then you can maintain standard workflow. Be able to provide updates to the Nursing Administration also helpful. Other things during malware, we didn't have phones centralized, but we had routine updates to Nursing Administration that would then disseminate status to nursing so that they will be understanding of key lab preferences. Held team huddles.

P5 - Felt like i was running around managing multiple people, today personally i was supposed to be training someone but then several needed assistance here and there. If i know what Im doing i can help others but when i don't know how it ought to be managed then it is more stressful. Back to malware time. Remember it was never going to end, and the fact that to come back and backfill the information. Really stressful aspect.

P6/7 - terrible. kind of stressful in beginning to read manual etc and remember all these things but over time its fin since usually it is just an hour or so. People don't label the specimen at all, don't pay attention. Wish we had another backup system, stressful is doctor waiting for result, nurses calling constantly, and stressful just doing when downtime. You can't do much with current backup system, binders and printout lead to more work later on. Most important is specimen labeling.

P8 - Increases work stresses and efficiency decreases. Multiple calls back and forth with time wasted that can affect patient safety. Yesterday, a downtime with pregnancy taking 2 hours but one side was down so I saw the test but the other side didn't see it. Do you resend the same lab over and over? -> Doesn't occur that often, but happens for some folks.

P9 - Stress goes up. efficiency goes down. depends on how busy the ED is and how many active patients i have. i rely on tracking information through corner to track status of my patients so when there is downtime i have period of disorientation for couple hours until we have new system fro tracking patients and recreating what was on the screen (patients, where they are, labs, meds, care plan). If small census then you can do this very quickly but with large volume then it can take time. There are various downtimes where you can have multiple systems down or up and you have to establish your workflow to adapt. Then you get into a groove but then you shift is almost done or the system is back up. Usually no timeframe on knowing when labs entered into system. Saying is "when on paper stay on paper". SO when you start seeing value pop up in the system then you move back off paper. Lack of true between clinical departments and lab with lack of tranperency of where exactly the lab is in the system. There is alack of trust so that is where tempers flare up. Not much positives though. In ED, when ED switched over to dry erase board you go to a wide SA to a narrow SA where whiteboard becomes focus and community with increased communication between people. I preferred to have more routine rounding with my team as a result of the whiteboard. Instead of electronic it was forced to be F2F communication. I do not call the lab during downtime, i hand that off to the clerks.

Q4 - So is there anything that gets easier in a downtime scenario?

P1/2 - No, need to concentrate so you don't make a mistake.

Q4.1 - Anything worked well?

P9 - What worked well? well back to SA and A is system down and B if it is down then how does it impact us? Because of that SA then there is a delay in falsehope in maybe it will come up soon so wait. Confusion period on it you should go to these procedures or not. If that could be better communicated of what is down, how long, etc, why not a mass alert sent out to staff. Seems like it is word of mouth and hitting refresh to see if system is back up. Guess work.

Q4.1 - Day 1 vs next day of malware downtime

P1/2 - 1st days wasn't as bad because they could still order things, still slightly normal. Things were already in the system and labeling was already printed off. Second day bad. 3rd day worse. Didn't get better, lines got longer. For us, the whole snag was that they were ordering business as usual and we were not getting slips filled out completely. We are the biggest so our volume is pretty hefty, we are running thousands. Then you got a doctor comes down and want all the labs for PT A, do you really need a UA for the PT to get what you are wanting? Then they want the rest of the patients on our unit, sorry can't do that! We are totally paperless, so then we got to xerox our results. Longer it went on then the worse is got, doctors asking for not just today's labs but this morning and the day before.

P3 - whole time i was in shock that it even happened, no one imagined to not have technology for a whole week. but we realizer certain things like 'hey we need to do this better or this process could be refined'

P4 - we thought we were doing better than we actually were. We had unique situation with outpatient volume where we held

off testing on these. However, we became more organized and work stress was better as the downtime continued. We organize don the fly to get through, not ideal though.

P5 - it got easier each day because we knew we had another day of downtime. we were into he new process at this point. don't think stress got worse as it went on.

P8 - it got better because communication got improved, expectations, everyone following the same process, consistency with the process with all people.

P9 - noticed changes, but not very busy. Actually it got ugly later on. Unique situation because we had to turn off all the computers so we couldn't see any other information/systems. In that case no computers, so whiteboard only and no historical records. So we had trying to regain SA, then afternoon busy. Getting people admitted was a challenge, because they couldn't see any patient information other than what you tell them. Admitted many people without labs, idk if we even had access to labs. So it was gut reactions based on clinical impressions. Next time I worked, everything was back to "normal".

Q5 - Downtime preparedness?

P1/2 - I think we are okay, there is a procedure in place so we are okay. But the problem is the volume. We have downtime box, and in there we got the procedure, preprinted cerner labes/barcodes (dummy assceecccioning number) pack of maybe 500 (More than 3 day downtime though and we gonna run out!), have all the forms (list of reference ranges, list of critical, lots of forms we want you to fill out), under normal circumstances if I tell them the sample is compromised i can enter that all in the computer but if downtime then i have to write it out with the tech and then staple it to the requisition form and so many steps just for a compromised sample that with a computer is simple. I don't feel safe with the workflow. Can they (ordering physician) read my handwriting? Are they taking this under advisement (acting responsibly on this information)? Are they writing this down?. In hematology we are reading off 20 results over the phone, so is the doctor getting understanding accurately, recorded accurately, and acted upon accurately? Unsafe.

P3 - Actively done drill simulations, ask leaders to look at process and have teams look at process 'is this going to be successful'. lots of feedback from these drills. since we can't do the drills as ofter, but i don't feel like we are as far ahead as we should be. Premalware was utter chaos. The preparation? Had malware, plus new people throughout the department. So when it did hit, half of us sort of knew what to do but after action review showed that we were not really doing things as we should have. We need to have more drills so we are better next time it happens.

P4 - We had always had downtime as part of training, for small downtime though (not days). We had corner upgrade, so known corner downtimes that were systems wide. Worked with IT to come up with a plan, each site work with nursing informatics to come up with plan as well. We liked aspects of both sides form Union and Good Sam. I think that has been helpful, but we have gotten more into the nitty gritty of longer downtimes rathe than short ones. Transcription errors at Union where many things were manual steps.

P5 - since malware they have written up elaborate plan. previous there was absolutely no training/drills. no detailed procedures. all in one document for the lab areas. now they have it broken out by area with own procedures. it is now a training checklist item for hematology. can't expect too much more as a new employee since there are so many procedures/policeis to remember, drills have really helped.

P6/7 - out of 800 you only lose 1 or 2 is acceptable. but current downtime procedure isn't sustainable. can't fax 200 out all the time. reality of today you need the closed system. regarding prepardness, we have to be ready regardless. in downtime everyone needs to know the process and how it takes, inter-departmental awareness. important step is labeling of the specimen everything else will follow. Anything to change? -> If we can do it, then make LAN for the instruments. Started with backup labels, which is important to have.

P8 - no training that we undergo for a downtime scenario. Could be better with simple plan and plan with communication between lab, ed, radiology, e tc.

P9 - We probably got trained, not sure. do not recall. not annual sites teaching thing module. but usually when there is downtime they say "please see downtime procedures". maybe in handbook somewhere. Generally when we use these procedure we have this whiteboard that is taped off that is brought out onto the floor. and then there is a cart filled with a lot of the paperwork forms in bins, not always super conducive because people still ask "where is this form?". idk what happens when we move to electronic only charts. vertical chart means order to do, landscape then that is chart rests. subtle difference, then so could get missed by new folks.

Q6 - Make safer/easier during downtime?

P1/2 - If they designate a person for each unit that would be responsible. ED runners and their purpose, OR etc. Designated person for 2E, the lab liaison they will be responsible for communicated with the lab for results etc. Basically streamline communication between departments through single points of contact.

P3 - reorganizing the work. Knowing who would be the right person to give the job do efficiently so that there would not be hiccups in the process. Identifying key smart people.

P4 - more face to face contact then you would usually have. Rounded each day with staff. You can express yourself easier to other departments, and able to diffuse a situation more so. One positive thing.

P5 - Nothing worked better.

P6/7 - Getting extra manpower needed to take care of extra things that occur during a downtime. Oncall list of bench techs, emergency plan. Coag you can put data in and save then later on update to the corner system.

P8 - nothing gets easier. there needs more communication. Any improvements? -> Developed plan with specific roles and communication and somebody central keeping tracks of patients and where they are at, an organizational person, we don't know whats going on.

Q6.1 - Improvements to preparedness?

P3 - communication, buy-in by staff, i have been encouraging department head to review processes so that on an ongoing process we can be up to date. It is harder since we are multi-site in gaining buy-in.

P4 - unit testing and system testing. we have done unit lab downtime testing. Only focused on our team. System downtime is cross department and we don't actually train on this.

P5 - Had drills, and we discover little details that need to be fixed but next drill they won't be addressed/fixed. Quite a detailed plan but people have not availed them to understand what the details are. Because of the glitches we have had, and it is a distractor from normal practice. Hard to weave into workflow immediately, practice needed. I felt there wasn't any nervousness as much with the drill but that's because we have practiced before. If only people read the binder/kit and go. Just read the instructions and go step by step. Consider simplifying the instructions. Too much text?

P9 - Downtime is where only a connection goes down, labs can still be done but is there a way to have some sort of auxillerary system to plug into lab so we can see the logs of the machines. Example - medicalis wordlist pack system. This status flags don't work - you know when image is done but you don't know if it is read. We are now on the same system so now I can write my prelim interpretation of the X-ray and when the radiologist opens it up they will see my comments. And I can see the wordlist of the radiologist so I can see where my image is in their workflow. Something similar to that in the lab such as one way lab view to see lab testing status. So if we get a feed of the lab display that would be great and see how it relates to the other tests because usually can't see other individuals. Mental model of 1 hour in the lab usually results based on experience then if lab time takes longer than usual then I will know here things are.

Q6.2 - Anything more challenging during downtime?

P3 - What's challenging is that we are not able to touch every person. but those brand new to the process are slower than usual, not knowing that exactly is needed to know for the downtime process.

P4 - Hard to stay organized. Once the lab results leave to the unit and if they go into a pile then that defeats our organization scheme. Has to be organized on both sides. People were asking for the same thing multiple times but the results were on the unit but they couldn't find it (HOSPITAL A).

P5 - Overall in general people don't know how to setup instrumentation to alternate process. what do we have written down and do they follow the process? takes some time to overhaul the process, wouldn't take as long if you just read the procedure. takes

a while to transition to the other process. No one understands he implications of lab label transition and those that do not (during the downtime transition/intake)

P6/7 - Most stress on receiving end of specidment since they don't know proper labeling/asscessioing.

Q6.3 - Any changes during downtime?

P3 - Since we are the hub for micro, first noticed work from multiple sites with no organization on what goes to whom. Needed colored binders for each facility (Union, HOSPITAL A, etc). Identifying key people for key roles, a person dedicated to handling phone calls (constant calls). We had one person in the front area that knew what to do in the downtime, and when shift change comes then transitions with the person more experienced so "we have done 1-5 correctly, but 6-10 we forgot'

P4 - Need continuous improvement. We are always adding new test, instrument, etc. But with each new addition we need to add that to the downtime plan with the job aid on how to transmit results etc. We have a validation test document that we have for all new instruments and make sure that we sign off on it. During downtime -> change especially for here is the outpatient client reporting, shear volume of that. Massive volumes so organizing that was a struggle. Can't have it mixed together so on the fly we separated all the visiting nurses work. VNA, nursing home, and outpatient organized in three buckets.

P5 - More drills. reading the procedure isn't as effective. if there was easy way to go through process 1 on 1 with a trainee. Kind of risky though because you are messing with interfaces. Pretty signifcant chunk of time. Detailed 1 on 1 trainings ideal.

P6/7 - Started to be more friendly in working with the instruments. Problem is the workload (fax, etc). Matching of patient information was lost. It would be best with backup core to switch to LAN.

P8 - Anything that worked well? -> Again I think it was organization, consistency with all patients on how we handled them which improved efficiency. Normal staffing levels continued, no one really worked extra hours - business as usual

Q7 - Patient Safety?

P1/2 - Hope that no-one missed crticials now that is paperless. On the computer the system pops up red for abnormal/criticals, computer highlights it for the lab personnel but in downtime it is hard to distinguish critical (black and white with no clear alert). In some cases both, but we have to see that it is critical on the paper. Lab can miss things too, doctor can miss the read, or both can miss. The more tubes the worse it is. For planned downtime we have someone get in to setup intstruments to do paper print and get everything arranged.

P3 - Should be priority one. Just during malware in the recovery pieces, nursing was sending 2 identifier that were mixed (men + fin) where it should be standardized (Name + other). mixed identifiers that could be huge risk since we are getting from different sites. Fin's could look like MRN at diff site. Huge potential for error there.

P4 - Day 1 was most conference. We were not receiving samples with appropriate identifiers. That's when i initiated to get manual census reports because everyone was taking shortcuts to get the samples to them. You may have away to share samples so we were having admin calls to share information. 1) externally our sample were correct patient 2) lab side, to communicate any testing that have critical results that need action. So the critical result job aides were not up to date. Make sure all the downtimes stuff is covered in the job aide.

P5 - Manual errors, in terms of identifying results. Have to write demographics in, printer only has asseccioning number, no identifyer. Then built in delay getting stat results.

P6/7 - Didn't have criteria on to separate ED/ICU etc, outside nursing adds extra volume. Next day we could handle specimen. More communication between lab and floor because it doesn't seem like they care. Big volume here, need to take care of test and be 100%. Just by doing manually you have chance for error Labeling most important.

P8 - Deff compromises safety with critical labs other labs through we could get a way with not having. But critical labs could affect safety if we don't get them done in a timely manner. Delays in XRAY readings unless you walked back to see (radiology readings).

P9 - It never feels as safe when there are delays in and lack of information. If this impacts patient safety, not sure other than it slows things down. worried about missed information, even in uptime system but no way to know that rate, no audit trail. Time from order written to time to draw could be interesting metric to measure.

Q7.1 - Anything suggestions/successes for patient safety?

P3 - communication to nursing, letting them know that we are looking for patient name and DOB on all lab forms. getting info on expectations to nursing, and same with the share sites. Everyone ought to be on the same page so that it can help situation move smoother.

P4 - biggest is identification. just to make sure that we follow all the other processes as we usually do. Everyone focused on other things they forget about the normal patient safety steps. Some reports were not inputted as the correct form and so certain patient information was not carried over in the system.

P5 - add in patient demographics would be nice. because CV are triggered by LIS and not the instrument so we won't geta flag of CV.

P8 - Yeah, non-clinical person sexting patients to organize labs/charts/organization person (secretary person). Person whose only job is to organize everything would be ideal and was helpful during malware. Instead of us calling down, we should have one central communication channel with lab.

Q8 - Anything else?

P2 - Someone mentioned to me that maybe they shouldn't come down here anymore. Doctors were getting aggressive when they were in line and some in line for duplicate patients. Maybe they shouldn't be allowed to come down, need to have a central liaison for communication. Need to get security.

P3 - The one things we practice no system capability for orders. But we will have circumstance where we have order in the system and barcode, but how are tracking when downtime starts. How do you reconcile labs when they are already passed the asseccioning desk in normal situation but then we fall into downtime. This transition part. We don't really have training on this part. We had tried to get feedback from ED, and saw some example from HOSPITAL A to use. One thing outlier, is the nursing home clients and if we can use same procedure with them. Because we didn't have idea of how long this was going to be down, we kept offering our regular test menu for the week. And we had a lot of specialty tests that we send out to referral sites that sat for a week or more. Having a more tailored menu would be essential to have. Again because of unscheduled are so few, we don't get opportunity to practice, even for all staff (nursing etc). Nursing didn't have functionality to their procedures, so they would call us one "how do you do this, which tube?", now our staff don't remember which test goes in which tube so having a test catalog of "this tube goes to this and this test needs this tube". Pharmacy didn't have anything visible or in place during the downtime, didn't have sense of what is needed to be done.

P4 - I think working on outpatient client piece. Drills with them. With healthcare changes in BMORE region, we are doing more cross sharing of patient Union to FSH etc. With recent renal change we haven't tested a downtime in these regional settings. It can get very complicated. Im not sure how much they are doing HOSPITAL A/GUH but in BMORE we are doing a lot more. Thinking about that we stilll need as a system. We learning a lot, We need to implement a limited test menu that work with downtime. Exteranlly to act as business as usual is fine but internally we need to work on limited lab menu/ disaster downtime form. If it is not critical then (reference lab stuff is crazy to do during a downtime) we shouldn't be focused on it. Like to look at the shared piece and system testing of downtime forms/guides/etc make drills part of competency. If we can do this and be organized then we are good. We will still have frustrated people if we are unorganized.

P5 - People were not following the procedures, admin didn't know exactly where things were going. Add a few details to the instructions on secondary actions that are not explored. There are 2 versions of the box maps in the binders - document control - keep them up to date and stocked. Feel like they have designed a pretty good process so far but there are just so many moving parts. Like we got downtime forms that were not marked stat and could have been missed - that is a manual process at the beginning to mark it. If specicment isn't properly marked at start then there will be problems. Hematology has specific procedures for both "identical" machines but the software is slightly different so the procedure doesn't work for the second machine. And we just got a new instrument that we don't even have downtime procedures for yet, no binder etc.

P6/7 - Return would be huge with LAN because no lost speciemens etc. To make it convertible - we need to have extra manpower to ensure quality of work. lot of expense but necessary for patient safety. Over phone it is hard to reconcile if the other party hears and interprets exactly what you stated. Make sure all individuals are informed of downtime. After second day the labs

were less and more prioritized but people still ordered "unnecessary labs".

P8 - I think it was just a learning experience. Really due to organization and plan that helped us get through malware and having a dedicated person. Awareness that things will take a while, figuring out which critical elements you need to take care of the patients. Everything was basically on the fly, we developed our own workflow with dedicated person and on the fly decision to only go fro critical labs.

P9 - Thing was fun is neat seeing evolution of the downtime tracking board. different information. first people just care about name and room number then it translates to care team over a period of 30 mins. thinking back EHR, all of this was developed over years. in downtime you start from scratch but we revert back to these white board ideas, maybe add in a lab status column to the whiteboard.

B.2 – Coded Focus Group Excerpts

Role	Location	Code	Subcode	Detail quote
Lab Manager	HOSPITAL A	Communication	General	Communication is a big problem
Lab Manager	HOSPITAL A	Downtime	Discovery	We usually find out it is down because we are suffering
Lab Manager	HOSPITAL A	Preparation	General	If its scheduled we can plan
Lab Manager	HOSPITAL A	Downtime	Discovery	…experience problems with cerner and call in… or we get lots of stuff on paper and inquire
Lab Tech	HOSPITAL A	Communication	General	Communication is the same
Lab Tech	HOSPITAL A	Downtime	Initiation	make an announcement and say to operate on downtime procedure
Lab Tech	HOSPITAL A	Downtime	Communication	Everybody lets huddle and here is what we are going to do
Lab Manager	HOSPITAL B	Preparation	Improvement	Ideally they send us alerts via text and pager systems in the main lab
Lab Manager	HOSPITAL B	Downtime	Discovery	we get a call from IS team giving alert
Lab Manager	HOSPITAL B	Downtime	Communication	why we are going down is not communicated well
Lab Manager	HOSPITAL B	Downtime	Communication	oh we were down because of XYZ
Lab Manager	HOSPITAL B	Downtime	Discovery	electronic everbridge alert system that we receive by email and cell phone
Lab Manager	HOSPITAL B	Downtime	Initiation	what gets hairy is slowness, when do we get from slowness to down
Lab Manager	HOSPITAL B	Downtime	Communication	is it only this site and not system wide
Lab Manager	HOSPITAL B	Downtime	Discovery	if accessioning is having a problem they call me and I put in a IT ticket
Lab Manager	HOSPITAL B	Downtime	Communication	don’t assume that IT knows that we have an issue

Division Manager	HOSPITAL B	Downtime	Discovery	discover downtime whe the computer stops doing what it needs to do
Division Manager	HOSPITAL B	Communication	General	no set way to communicate
Division Manager	HOSPITAL B	Downtime	Initiation	rule is now to be "if downtime go downtime" to take gueswork out of when we start downtime process
Lab Tech	HOSPITAL B	Downtime	Communication	most of the time a heads up, team huddle
Lab Tech	HOSPITAL B	Preparation	Improvement	take out binders, binders don't solve the problem
Lab Tech	HOSPITAL B	Specimen Handling	Labeling	entering label slows process
Lab Tech	HOSPITAL B	Downtime	Recovery	instrument data can transfer but there is no backup
Lab Tech	HOSPITAL B	Workload and Workflow	Volume	can only fax 2 pages, not 200
Lab Tech	HOSPITAL B	Downtime	Recovery	when the computer comes back online you can transfer
Lab Tech	HOSPITAL B	Communication	General	we have a 50s communicaiton system with the phone
Lab Tech	HOSPITAL B	Specimen Handling	Labeling	important for specimen to have a backup label
ED Doc	HOSPITAL B	Downtime	Initiation	we see that the computer goes down and the chief nurse informs everyone
ED Doc	HOSPITAL B	Downtime	Communication	lab downtime we don't really get any notification in a timely manner
ED Doc	HOSPITAL B	Downtime	Discovery	find out when I keep calling [about test results] and they told me the lab is down
ED Doc	HOSPITAL B	Downtime	Communication	usually the lab doesn't let the ED know they are down
ED Doc	HOSPITAL A	Downtime	General	planned downtime - week/monthly on nights, not long

ED Doc	HOSPITAL A	Downtime	General	planned that become unplanned - unfrequent that were planned but go longer than expected
ED Doc	HOSPITAL A	Downtime	Discovery	unplanned - echo of staff saying "medconnect isnt working" screen freeze and then we find out its down
ED Doc	HOSPITAL A	Downtime	Initiation	I automatically do a screenshot of the system in case the system goes down so we have a reference list of our patients
ED Doc	HOSPITAL A	Communication	Transparency	no communication form the lab
ED Doc	HOSPITAL A	Downtime	Discovery	usually "hey are you feeling the lab is slow today" then we call and ask and find out tehre is a system down
ED Doc	HOSPITAL A	Downtime	Communication	during a shift change the chief nurse will do a status report that includes lab status to new shift
ED Doc	HOSPITAL A	Downtime	Communication	nothing in EHR warns you
ED Doc	HOSPITAL A	Downtime	Communication	don’t recally any alerts via hospital administrations other than planned downtime
Lab Manager	HOSPITAL A	Preparation	Improvement	I would like to handle it better but I don’t know if there is a better way
Lab Manager	HOSPITAL A	Workload and Workflow	Patient Safety	cant stop taking care of the patient just cause the system is down
Lab Manager	HOSPITAL A	Communication	General	the information that we get is extremely lacking
Lab Manager	HOSPITAL A	Specimen Handling	Documentation	have to give you paper requisitions but they don’t fill them out
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	got in trouble because we didn’t send the results back on paper, because they had never

				filled out the location on the requisition form
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	[because not filling out requisition form] delay in getting results back, when the system does come back we cant enter information because its all missing
Lab Manager	HOSPITAL A	Workload and Workflow	Patient Safety	time of collection is important, [not having it] really unsafe
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	instead of asking for their single worst patient they wanted all of their patients
Lab Manager	HOSPITAL A	Specimen Handling	Documentation	it's the beginning and end user that need to fill out all the paperwork correctly
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	The biggest problem is that everything is coming (all labs no matter what) and maybe we should just accept STAT
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	Front [clinical staff] was continuing "business as normal" ordering everything
Lab Tech	HOSPITAL A	Workload and Workflow	Patient Safety	patient that needs that critical test is not getting it in a timely manner
Lab Tech	HOSPITAL A	Downtime	Communication	manually input at the end so the more information we get at the onset the better sertup to succeed we are
Lab Manager	HOSPITAL B	Downtime	Communication	how long are we going to be down for?
Lab Manager	HOSPITAL B	Downtime	General	unscheduled we have no idea how long its going to be
Lab Manager	HOSPITAL B	Communication	General	IT often talks in their "system" lingo
Lab Manager	HOSPITAL B	Downtime	Initiation	When we approach downtime we actually know what is down, if it is down then what does it affect?

Division Manager	HOSPITAL B	Downtime	Communication	would be nice if we knew sooner that it was a serious issue
ED Doc	HOSPITAL B	Downtime	Communication	specific to lab/instrument delays should be communicated to the chief nurse as soon as possible
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	how do you prioritize labs, they are all important
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	everyone is reliant on them [labs]
Lab Tech	HOSPITAL A	Workload and Workflow	Result Reporting	we have to move to paper because if we don't we cant result any labs
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	have to look to the instruction manual on how to hand write paper results
Lab Tech	HOSPITAL A	Workload and Workflow	Result Reporting	we have to remember we have to keep up with the reference ranges that are there
Lab Tech	HOSPITAL A	Workload and Workflow	Result Reporting	it [paper reporting] is very hard and is not as accurate
Lab Manager	HOSPITAL A	Workload and Workflow	Volume	we have to have multiple copies of paper forms so we have to xerox al of these reports so we have copies
Lab Manager	HOSPITAL A	Specimen Handling	Documentation	we don't have a dedicated ED tube, usually a laminated card in the carrier indicates location and STAT flag
Lab Manager	HOSPITAL B	Communication	Transparency	not realizing how much of a impact we had on pharmacy, in terms of providing them with results
Lab Manager	HOSPITAL B	Workload and Workflow	Result Reporting	hand them [pharmacy] a stack of results and then have them interpret the stacks
Lab Manager	HOSPITAL B	Downtime	Infrastructure	because of no internet connectivity we didn't know the phone number for key unit personnel to communicate

Lab Manager	HOSPITAL B	Downtime	Infrastructure	keeping those 2 sites with full connectivity is key [harbor and HOSPITAL A]
Lab Manager	HOSPITAL B	Downtime	Infrastructure	if the deck server goes down it doesn't mean medconnect is down, but still chance for error due to manual input
Lab Manager	HOSPITAL B	Downtime	Infrastructure	deck servers are lab responsibility not IS
Division Manager	HOSPITAL B	Downtime	Communication	if one area of the hospital isnt working we need to know which parts of the computer process impact us
Division Manager	HOSPITAL B	Downtime	Discovery	the workers have to call the help desk to log a ticket
Division Manager	HOSPITAL B	Downtime	Initiation	do we wait anymore, do we go to the next phase of the process
Lab Tech	HOSPITAL B	Downtime	Communication	problem is transfer of information to the ER
Lab Tech	HOSPITAL B	Preparation	Improvement	closed system, list of printers (could print to ER) very useful instead of faxing and scanning out
Lab Tech	HOSPITAL B	Preparation	Procedure	other stuff you don't have the option to run specimen, how do I transfer?
ED Doc	HOSPITAL B	Downtime	Infrastructure	Computer/Medconnect most critical, nothing else really affected other than amaga, radiology and such
ED Doc	HOSPITAL A	Preparation	Improvement	one way lab view to see lab testing status
ED Doc	HOSPITAL A	Downtime	Discovery	mental model of 1 hr in the lab usually resulted back based on experience, if takes longer call and usually down
Lab Manager	HOSPITAL B	Downtime	Communication	eeping updated phone information to reach correct unit personnel
Division Manager	HOSPITAL B	Downtime	Infrastructure	Telephone, internet important

ED Doc	HOSPITAL A	Downtime	Infrastructure	Phones, Computer, PACS, fax
ED Doc	HOSPITAL A	Downtime	Infrastructure	ADT system that feeds Cerner so we don't get any new patient
ED Doc	HOSPITAL A	Workload and Workflow	Volume	ran in to problems with fax machine throughput
ED Doc	HOSPITAL A	Workload and Workflow	Volume	limintations of the fax machine so maybe having multiple fax lines
ED Doc	HOSPITAL A	Communication	Transparency	window into the lab process and understanding their workflow
ED Doc	HOSPITAL A	Communication	Transparency	get clinicians to understand lab
Lab Tech	HOSPITAL A	Workload and Workflow	Patient Safety	look out for criticals and they don't flag without the computer
Lab Tech	HOSPITAL A	Workload and Workflow	Interruption	phone rings constantly
Lab Tech	HOSPITAL A	Workload and Workflow	Interruption	cant be helpful to the person on the phone because I am runnings tests
Lab Tech	HOSPITAL A	Workload and Workflow	Result Reporting	I cant help [customer service] because I don't know where [the lab] is if it was completed
Lab Manager	HOSPITAL A	Workload and Workflow	Interruption	phone is a problem would be nice to have a central phone
Lab Tech	HOSPITAL A	Workload and Workflow	Job Role	scheduled downtimes we bring in extra forms, staff, etc but with unplanned we don't have anyone extra
Lab Tech	HOSPITAL A	Workload and Workflow	Interruption	phone ringing distracts me from finding critical value references
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	during downtime they [clinical] shouldn't order everything under the sun
Lab Tech	HOSPITAL A	Communication	Transparency	everyone that calls down to the lab thinks that only their requests are being run

Lab Manager	HOSPITAL B	Workload and Workflow	Volume	when a situation becomes stressful that's when I become calmer
Lab Manager	HOSPITAL B	Preparation	Improvement	I think the way to keep stress down is to be organized
Lab Manager	HOSPITAL B	Workload and Workflow	Job Role	central person for rounding
Lab Manager	HOSPITAL B	Preparation	Improvement	divert calls to one line
Lab Manager	HOSPITAL B	Downtime	General	more control you have of the downtime then you can maintain standard workflow
Lab Manager	HOSPITAL B	Downtime	Communication	provide updates to the nersing adminstration also helpful
Lab Manager	HOSPITAL B	Workload and Workflow	Interruption	we didn't have phones centralized
Lab Manager	HOSPITAL B	Communication	Transparency	routine updates to nursing administration that would disseminate status to nursing so that they will be understanding
Division Manager	HOSPITAL B	Workload and Workflow	Job Role	felt like I was running around managing multiple people
Lab Tech	HOSPITAL B	Downtime	Initiation	stressful in the beginning to read manual etc and remember all these things
Lab Tech	HOSPITAL B	Specimen Handling	Labeling	people don't label the specimen at all, don't pay attention
Lab Tech	HOSPITAL B	Workload and Workflow	Interruption	nurses calling constantly
Lab Tech	HOSPITAL B	Specimen Handling	Labeling	most important is specimen labeling
ED Doc	HOSPITAL B	Workload and Workflow	Patient Safety	multple calls back and forth with time wasted that can affect patient safety
ED Doc	HOSPITAL B	Downtime	Discovery	a downtime with a pregnancy test taking 2 hours but one side was down so I saw that a test had been requested but the other side [lab] couldn't see it

ED Doc	HOSPITAL A	Downtime	Infrastructure	I rely on tracking information trhough cerner to track status of my patients so when there is downtime I have a period of disorientation
ED Doc	HOSPITAL A	Downtime	Handling	have to recreate what was on the screen [as an alternate coping strategy]
ED Doc	HOSPITAL A	Downtime	Initiation	various downtimes where you can have multiple systems down or up and you have to establish your workflow to adapt
ED Doc	HOSPITAL A	Downtime	Communication	usually no timeframe on knowing when labs were entered into the system
ED Doc	HOSPITAL A	Communication	Transparency	lack of transparency between clinical depts and lab for test tracking
ED Doc	HOSPITAL A	Communication	Transparency	lack of trust
ED Doc	HOSPITAL A	Downtime	Handling	ED switched to dry erase board which becomes community focus with increased communication between
ED Doc	HOSPITAL A	Downtime	Communication	more routine rounding with my team because of the whiteboard
ED Doc	HOSPITAL A	Downtime	Communication	forced face to face communications
ED Doc	HOSPITAL A	Workload and Workflow	Job Role	I don’t call the lab during downtime, hand that off to clerks
ED Doc	HOSPITAL A	Downtime	Initiation	confusion period on if you should go to these procedures or not
ED Doc	HOSPITAL A	Downtime	Communication	could be better communicated what is down, how longl, etc
ED Doc	HOSPITAL A	Downtime	Communication	why is there no mass alert sent out to staff
Lab Tech	HOSPITAL A	Specimen Handling	labeling	things were already in the system and labeling was already printed off

Lab Tech	HOSPITAL A	Workload and Workflow	Volume	whole snag was that they were ordering business as usual
Lab Tech	HOSPITAL A	Specimen Handling	Documentation	not getting slips filled out completely
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	they want the rest of the patients on their unit [at the same time as one critical]
Lab Manager	HOSPITAL B	Downtime	General	was in shock, never imagined to have no technology for a whole week
Lab Manager	HOSPITAL B	Downtime	Handling	became more organized and work stress was better as the downtime continued
Lab Manager	HOSPITAL B	Downtime	Handling	organized on the fly, not ideal
Division Manager	HOSPITAL B	Downtime	Handling	got easier each day because we knew we had another day of downtime, knew the process
ED Doc	HOSPITAL B	Communication	General	communication got improved
ED Doc	HOSPITAL B	Downtime	Handling	everyone following the same process, consistency with the process and all people
ED Doc	HOSPITAL A	Workload and Workflow	Patient Safety	getting people admitted was a challenge because they couldn't see any patient info other than what you tell them
ED Doc	HOSPITAL A	Workload and Workflow	Patient Safety	admitted many people without labs, don't know if we even had access to labs so it was gut reactions based on clinical impression
Lab Manager	HOSPITAL A	Preparation	Procedure	there is a procedure in place so we are ok
Lab Tech	HOSPITAL A	Workload and Workflow	Volume	problem is volume
Lab Manager	HOSPITAL A	Downtime	Handling	prepreinted cerner labels and barcodes, but only maybe 500

Lab Tech	HOSPITAL A	Downtime	Handling	under normal circumstances if I tell them the sample is compromised I can enter that all in the computer but for downtime I have to write it out with the tech and then staple it to the requisition form, so many steps, with the computer its simple
Lab Manager	HOSPITAL B	Preparation	Training	actively done drill simulation
Lab Manager	HOSPITAL B	Preparation	Improvement	don't feel like we are as far ahead as we should be
Lab Manager	HOSPITAL B	Downtime	General	downtime was total chaos
Lab Manager	HOSPITAL B	Preparation	Procedure	sort of knew what we were doing but after action showed we were really not doing things as we should have
Lab Manager	HOSPITAL B	Preparation	Training	need to have more drills
Lab Manager	HOSPITAL B	Preparation	Training	always have had downtime as part of our training, but small downtime onlny
Lab Manager	HOSPITAL B	Downtime	General	we know cerner downtimes are system wide
Lab Manager	HOSPITAL B	Preparation	General	worked with IT to come up with a plan
Lab Manager	HOSPITAL B	Downtime	Recovery	transcription errors at union where many things were manual steps
Division Manager	HOSPITAL B	Preparation	Training	previously [pre-malware] there was no training
Division Manager	HOSPITAL B	Preparation	Procedure	[pre malware] no detailed procedures, all in one document in lab areas, now broken out by area
Division Manager	HOSPITAL B	Preparation	Training	drills have really helped
Lab Tech	HOSPITAL B	Preparation	Procedure	current procedure isnt sustainable
Lab Tech	HOSPITAL B	Preparation	Training	in downtime everyone needs to know the process

Lab Tech	HOSPITAL B	Specimen Handling	Labeling	labeling of the specimen is key, everything else will follow
ED Doc	HOSPITAL B	Preparation	Training	no training that we undergo for a downtime scenario
ED Doc	HOSPITAL B	Preparation	Procedure	better with a simple plan in place
ED Doc	HOSPITAL B	Communication	Transparency	communication between lab, ed, radiology, etc
ED Doc	HOSPITAL A	Preparation	Training	probably got trained, but I don't recall
ED Doc	HOSPITAL A	Downtime	Handling	generally use whiteboard fall back
ED Doc	HOSPITAL A	Preparation	Procedure	cart filled with paperwork and bins, not always useful since people still ask where things are
Lab Manager	HOSPITAL A	Workload and Workflow	Job Role	designate a person in each unit that would be responsible [for communication]
Lab Manager	HOSPITAL A	Workload and Workflow	Job Role	ED runners, designated personnnel
Lab Tech	HOSPITAL A	Workload and Workflow	Job Role	lab liason would be responsible for communicating to the lab for their department
Lab Manager	HOSPITAL A	Communication	Transparency	streamline the communication between departments
Lab Manager	HOSPITAL B	Workload and Workflow	Job Role	knowing who the right person to give the job to do efficiently so there are no hiccups
Lab Manager	HOSPITAL B	Communication	Transparency	more face to face contact so you can express yourself easier to other departments and difuse situations
Lab Tech	HOSPITAL B	Workload and Workflow	Job Role	extra manpower needed to take care of the extra [workload and roles]
ED Doc	HOSPITAL B	Communication	General	needs to be more communication
ED Doc	HOSPITAL B	Workload and Workflow	Job Role	developed plan with specific roles and communication and central person keeping track of patients etc

ED Doc	HOSPITAL B	Downtime	General	we don’t know whats going on
Lab Manager	HOSPITAL B	Communication	General	communication
Lab Manager	HOSPITAL B	Preparation	Improvement	go beyond unit testing and do system testing
Division Manager	HOSPITAL B	Preparation	Improvement	drills discover little details that need fixing, but not fixed by the next drill
Division Manager	HOSPITAL B	Preparation	Procedure	people have not studied the procedure to understand what the details are
Division Manager	HOSPITAL B	Preparation	Improvement	consider simplifying the downtime plans
ED Doc	HOSPITAL A	Communication	Transparency	some sort of auxilary system that allows transparancy to see lab process
Lab Manager	HOSPITAL B	Preparation	Training	not able to touch [train] every person
Lab Manager	HOSPITAL B	Workload and Workflow	Result Reporting	once lab results leave the unit they go into a pile that defeats our organization scheme
Division Manager	HOSPITAL B	Preparation	Training	in general people don’t know how to set up instruments to alternate process
Division Manager	HOSPITAL B	Downtime	Initiation	takes a while to transition to the other [downtime] process
Division Manager	HOSPITAL B	Specimen Handling	Labeling	no one understands the implications of lab label transition
Lab Tech	HOSPITAL B	Specimen Handling	Labeling	most stress on receiving of specimen since they don’t know proper labeling
Lab Manager	HOSPITAL B	Workload and Workflow	Job Role	identifying key people for key roles
Lab Manager	HOSPITAL B	Workload and Workflow	Job Role	person dedicated to handling phone calls
Lab Manager	HOSPITAL B	Downtime	General	had one person in front area who knew what to do in the downtime

Lab Manager	HOSPITAL B	Downtime	Handling	shift change people more experienced realize did 1-5 correct but 6-10 forgot
Lab Manager	HOSPITAL B	Workload and Workflow	Volume	organization of massive volumes
Division Manager	HOSPITAL B	Preparation	Training	more drills, reading procedure alone isnt effective
Division Manager	HOSPITAL B	Preparation	Training	risky to do on the job training because downtime procedure involves altering machine interface
Lab Tech	HOSPITAL B	Workload and Workflow	Volume	problem is the workload
Lab Tech	HOSPITAL B	Downtime	Recovery	matching of patient information was lost
ED Doc	HOSPITAL B	Downtime	Communication	organization, consistency with patients on how we handled them improved efficiency
Lab Tech	HOSPITAL A	Workload and Workflow	Patient Safety	hoped no one missed criticals
Lab Tech	HOSPITAL A	Workload and Workflow	Patient Safety	computer identifies critical results and flags, downtime operation hard to distinguish
Lab Manager	HOSPITAL A	Workload and Workflow	Patient Safety	lab can miss things, doctor can miss read
Lab Tech	HOSPITAL A	Preparation	Procedure	planned downtime can do advance instrument setuip and prep
Lab Manager	HOSPITAL B	Specimen Handling	Positive Patient Identification	during malware nursing was sending 2 identifiers that were mixed, when it should be standardized
Lab Manager	HOSPITAL B	Specimen Handling	Positive Patient Identification	specimens coming in without apropriate identifiers
Lab Manager	HOSPITAL B	Preparation	Document Control	critical job aids were not up to date
Division Manager	HOSPITAL B	Workload and Workflow	Result Reporting	manual errors in terms of identifying results
Lab Tech	HOSPITAL B	Communication	Transparency	more communication between lab and ED because if seems like they don’t care

Lab Tech	HOSPITAL B	Workload and Workflow	Patient Safety	increased risk by doing work manually
ED Doc	HOSPITAL B	Workload and Workflow	Patient Safety	compromise to patient safety with critical labs, other labs could get away without having
ED Doc	HOSPITAL B	Workload and Workflow	Patient Safety	critical labs could affect safety if not done in timely manner
ED Doc	HOSPITAL A	Workload and Workflow	Patient Safety	never feels as safe when there are delays in and a lack of communication
ED Doc	HOSPITAL A	Workload and Workflow	Patient Safety	worried about missed information
Lab Manager	HOSPITAL B	Specimen Handling	Positive Patient Identification	Communication to nursing for labeling and ident requirements
Lab Manager	HOSPITAL B	Specimen Handling	Positive Patient Identification	patient identification
Lab Manager	HOSPITAL B	Workload and Workflow	Result Reporting	some reports were not input as corect form so patient info was not carried over into the system
Division Manager	HOSPITAL B	Specimen Handling	Documentation	add in patient demographics because critical values are triggered by them
Division Manager	HOSPITAL B	Workload and Workflow	Result Reporting	LIS manages critical value check, not individual instrument
ED Doc	HOSPITAL B	Workload and Workflow	Job Role	get a non clinical person to organize paperwork
ED Doc	HOSPITAL B	Workload and Workflow	Job Role	only role is to keep everything organized would be ideal
ED Doc	HOSPITAL B	Workload and Workflow	Job Role	instead of everyone calling down [to lab] one dedicated person to contact lab
Lab Tech	HOSPITAL A	Workload and Workflow	Interruption	keep clinical staff from coming down [security incident]
Lab Tech	HOSPITAL A	Workload and Workflow	Job Role	need to have central liason for communication
Lab Manager	HOSPITAL B	Preparation	Procedure	how do you handle labs that accessionined normal but lab went into downtime

Lab Manager	HOSPITAL B	Preparation	General	tried to get feedback from ED and saw some examples from HOSPITAL A to use
Lab Manager	HOSPITAL B	Workload and Workflow	Volume	no idea how long we would be down, kept offering full testing menu
Lab Manager	HOSPITAL B	Preparation	Training	nursing didn't know their procedures, sending wrong tubes for test
Lab Manager	HOSPITAL B	Preparation	Training	work on the outpatient client, drill with them
Lab Manager	HOSPITAL B	Preparation	Training	more cross patient sharing happening, need to practice
Lab Manager	HOSPITAL B	workload and Workflow	volume	implenent a limited testing menu for downtime
Lab Manager	HOSPITAL B	Workload and Workflow	volume	clinical needs to prioritize testing to critical need only
Lab Manager	HOSPITAL B	Preparation	Training	system wide testing of accepted downtime forms and procedures
Lab Manager	HOSPITAL B	Preparation	Training	get more organized and comfortable with downtime procedure
Division Manager	HOSPITAL B	Preparation	Procedure	people don't follow procedures, admin didn't know where things were going
Division Manager	HOSPITAL B	Preparation	Document Control	document control, 2 versions of document in the box
Division Manager	HOSPITAL B	Specimen Handling	Documentation	downtime forms not marked stat could have been missed
Division Manager	HOSPITAL B	Specimen Handling	Labeling	if specimen not properly marked from start there will be problems
Lab Tech	HOSPITAL B	Workload and Workflow	Job Role	need extra manpower during downtime to handle extra work
Lab Tech	HOSPITAL B	Communication	General	phone relay of information is inconsistent
ED Doc	HOSPITAL B	Preparation	Procedure	due to organzation plan that helped us get through malware
ED Doc	HOSPITAL B	Workload and Workflow	Job Role	having dedicated person

ED Doc	HOSPITAL B	Workload and Workflow	Patient Safety	figuring out what is critical that you need to take care of patients
ED Doc	HOSPITAL A	Downtime	Handling	seeing the evolution of a downtime adaptation like going back to white board
ED Doc	HOSPITAL A	Preparation	Improvement	maybe adding a lab status column to white board
ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	during the day [when a downtime happens] out of the blue it's a huge safety concern
ED Nurse	HOSPITAL B	Downtime	Handling	got this board writing peoples names on there
ED Nurse	HOSPITAL B	Workload and Workflow	Result Reporting	lab is faxing things everywhere and you don't know where things are
ED Nurse	HOSPITAL B	Downtime	Handling	charge nurse drags it [the whiteboard] out, then we put up the pt info and complaint
ED Nurse	HOSPITAL B	Downtime	Discovery	computer just freezes and things wont work
ED Nurse	HOSPITAL B	Downtime	Initiation	asked "hey my computer just froze" so you start writing things down before yours freezes
ED Nurse	HOSPITAL B	Downtime	Handling	have downtime boxes with pre populated items and forms
ED Nurse	HOSPITAL B	Downtime	Communication	no announcement needs to be made because veryone goes crazy
ED Nurse	HOSPITAL B	Downtime	Infrastructure	firstnet has everything [we need] in there, once that goes down then shuffled papers everywhere
ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	secretary trying to get things to the right charts and faxes everywhere
ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	it is stressful… we are now in an unsafe environment

ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	not only run charge nurse [role] but now you have to keep track of an exponential amount of items that normally would be caught by the system
ED Nurse	HOSPITAL B	Preparation	Training	day shift doesn't really get any [practice with downtime] they [planned downtime] are all scheduled on nights
ED Nurse	HOSPITAL B	Preparation	Improvement	there has to be a better way [than the whiteboard] to keep track of patients and their information
ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	we do have a rep from disaster response who comes down and helps but that doesn't get activated for every single outage
ED Nurse	HOSPITAL B	Preparation	Procedure	no procedures written in stone, have boxes that have everything in them [forms]
ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	people were working extra hours but as far as additional staff there werent any
ED Nurse	HOSPITAL B	Specimen Handling	Documentation	[requisition forms] easy to use, pretty straightforward
ED Nurse	HOSPITAL B	Workload and Workflow	Volume	I as the charge nurse cant check through the patient charts so I cant track my nurses and I just have to trust what they are working on
ED Nurse	HOSPITAL B	Workload and Workflow	Volume	labs going missing because you cant really track them like you usually do
ED Nurse	HOSPITAL B	Preparation	Improvement	needs to be a better tracking system in place because it gets chaotic
ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	doctors appear to not step up and shunt the work of resolving the downtime to the nurses

ED Nurse	HOSPITAL B	Downtime	Recovery	registration is ultimate responsible for trasncribing paper forms back into electronic chart
ED Nurse	HOSPITAL B	Downtime	Communication	downtime is announced in advance [for planned downtime]
ED Nurse	HOSPITAL B	Downtime	Handling	prior to that [planned downtime] we get ready with the paper boxes and put them in areas everyone can access and roll out the white board and print out firstnet so we have an idea where patients are located
ED Nurse	HOSPITAL B	Downtime	Handling	if it [downtime] is not announced then we do what we can do, we are still using the chart and we go through the charge nurse
ED Nurse	HOSPITAL B	Downtime	Discovery	when you click on the patient information and then nothing happens it "froze"
ED Nurse	HOSPITAL B	Downtime	Discovery	everyone asks "whats wrong with the internet" but until the charge nurse calls the IT desk we don’t know for sure if the system is down
ED Nurse	HOSPITAL B	Downtime	Infrastructure	the computer makes everything easier in terms of documentation
ED Nurse	HOSPITAL B	Workload and Workflow	Volume	multiple paper forms when the computer is just one screen [pt intake]
ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	when the dr orders medicine there is a lot of info being passed between different areas that is automated with the computer, but by hand it takes a while
ED Nurse	HOSPITAL B	Preparation	Procedure	I don’t think we can be prepared all the time, though

				no procedure saying get the box out, everyone just knows
ED Nurse	HOSPITAL B	Preparation	Training	would love to get formal training with drills, training is the best to increase efficiency
ED Nurse	HOSPITAL B	Downtime	Handling	[duplicate/similar names] we have a board with 3 pts named "brown" we put cautious words to make us aware and be carefulw ith age and birthdate
ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	pt medicaiton, have instances where wrong dose given during downtime
ED Nurse	HOSPITAL B	Preparation	Training	planned downtime we are prepared for, we review procedure in advance
ED Nurse	HOSPITAL B	Downtime	Discovery	unplanned are interesting, we find out the same time as everyone else
ED Nurse	HOSPITAL B	Downtime	Initiation	charge nurse pulls out paperwork and we start downtime
ED Nurse	HOSPITAL B	Preparation	Training	new nurses have never done paper charting, no ideas on whats acceptable, abbreviations, communication with other departments or how things are to be done
ED Nurse	HOSPITAL B	Preparation	Training	should have drills every month or so on how paper charting is done and what is acceptable
ED Nurse	HOSPITAL B	Downtime	Discovery	ask everyone "is your computer working? You frozen?" and call IT to see whats going on, you cant wait and cant stop writing things down
ED Nurse	HOSPITAL B	Downtime	Recovery	what happens when you transcribe an erorr?
ED Nurse	HOSPITAL B	Downtime	Communication	mostly keeping patients informed that everything will be slower, nursing slows down

ED Nurse	HOSPITAL B	Downtime	Communication	communication [is critical] between the departments, especially radiology
ED Nurse	HOSPITAL B	workload and Workflow	interruption	hard to put a [phone] caller on hold when you have to go find the provider
ED Nurse	HOSPITAL B	workload and Workflow	job Role	not really [any new job roles] just losing what we have become dependent on
ED Nurse	HOSPITAL B	Preparation	Procedure	"here is the box" that's it, you have some nurses who know what you need
ED Nurse	HOSPITAL B	preparation	training	best if we have a hour drill, no classes, just actually doing it so we have some experience that is how we learn
ED Nurse	HOSPITAL B	Preparation	Training	when you have 80% of staff never documenting on paper before that slows things down
ED Nurse	HOSPITAL B	Workload and Workflow	job role	noticed a lot of people standing around and doing nothing
ED Nurse	HOSPITAL B	Workload and Workflow	Interruption	management standing around "making sure everything is being done" and talking
ED Nurse	HOSPITAL B	Communication	Transparency	nursing resents when management comes down and does nothing
ED Nurse	HOSPITAL B	workload and Workflow	patient Safety	riskier during downtime, so many things in the computer that you have to ask the pt about
ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	don't know whats been done for the patient
ED Nurse	HOSPITAL B	workload and Workflow	volume	have to double check everything
ED Nurse	HOSPITAL B	Downtime	Infrastructure	no flags or alerts when working under downtime on paper
ED Nurse	HOSPITAL B	Downtime	Communication	sometimes it just shuts down without anyone telling us when it comes back up

ED Nurse	HOSPITAL B	downtime	infrastructure	if registration goes down we cant do the ID band scanning, lab goes down we call for each value
ED Nurse	HOSPITAL B	downtime	infrastructure	armband scanning is important because it will alert you "wrong medication" "wroing dose" etc
ED Nurse	HOSPITAL B	workload and Workflow	volume	paper requires me to write every single thing down, computer has checkboxes to go faster
ED Nurse	HOSPITAL B	workload and Workflow	job Role	instead of focusing on care you focus on logistics and gathering information
ED Nurse	HOSPITAL B	preparation	training	they all [new nurses] need to be training on paper charting.
ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	life of the patient is the priority and [they] shouldn't get stressed on the computer, life goes on and we can still work without the comptuer
ED Nurse	HOSPITAL B	preparation	training	maybe have a "inservice" on how to handle downtime
ED Nurse	HOSPITAL B	workload and Workflow	patient Safety	didn't feel any shift in patient risk during downtime
ED Nurse	HOSPITAL B	downtime	handling	you have to be very careful and not rush on paper charting
ED Nurse	HOSPITAL B	downtime	handling	paper charting requires you to communicate with the patient more
ED Nurse	HOSPITAL B	downtime	discovery	try to communicate to the charge nuse if computer freezes or forced logout
ED Nurse	HOSPITAL B	preparation	improvement	should have a guideline that if freeze or failure multiple times in a row it gets reported to charge nurse and MIS
ED Nurse	HOSPITAL B	downtime	discovery	need to figure out if its individual computer or system wide

ED Nurse	HOSPITAL B	Workload and Workflow	Job Role	everyone is on the phone with MIS but it should just be the charge nurse
ED Nurse	HOSPITAL B	Downtime	Communication	sometimes people struggle throughout the department because they just keep it [their computer freezing] to themselves
ED Nurse	HOSPITAL B	downtime	infrastructure	need medconnect to be able to pull pt history
ED Nurse	HOSPITAL B	downtime	handling	as a staff nurse it [downtime stress] doesn't concern me much because I will just write everything down ASAP (allergies etc)
ED Nurse	HOSPITAL B	preparation	training	no standardized orientation for downtime for new staff
ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	there is some anxiety in triage because it is the most dangerous part of the ED because you can lose track of a pt
ED Nurse	HOSPITAL B	Preparation	Training	share my downtime practices with new nurses I am training
ED Nurse	HOSPITAL B	preparation	improvement	would be useful to have a standard form for nurses that have the items that they need
ED Nurse	HOSPITAL B	downtime	recovery	the transition from downtime back to computer causes confusion, no standard plan
ED Nurse	HOSPITAL B	preparation	training	a lot of nurses have never been trained on or experienced paper charting
ED Nurse	HOSPITAL B	workload and Workflow	job Role	lab procedures work pretty well but its difficult when we don't have a delegated secretary to take the lab results
ED Nurse	HOSPITAL B	downtime	communication	need more communicaiton with EMS [ambulance], we lose revenue if we divert EMS

ED Nurse	HOSPITAL B	Workload and Workflow	Patient Safety	should classify as a mini disaster in terms of patient safety
Lab Manager	HOSPITAL A	downtime	discovery	find out about downtime from our own feeling, if its front end [in the ED] we know before it hits us
Lab Manager	HOSPITAL A	Downtime	Communication	planned downtime advance notifications are adequate
Lab Manager	HOSPITAL A	downtime	handling	for planned downtime the floors do a pre rush to get their testing done before the downtime
Lab Manager	HOSPITAL A	downtime	infrastructure	blood bank needs the ability to look at past medical history which is unavailable during downtime
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	we can still use the instrumentation but the cant push results to the EHR
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	even with a normal result we have to walk them through it because normally they would see it on a range in the system to know what it means
Lab Manager	HOSPITAL A	downtime	general	unscheduled was a nightmare, the technology and notification and sorting of the paperwork was bad
Lab Manager	HOSPITAL A	Workload and Workflow	Result Reporting	there is no system in place for the dissemination of results during downtime
Lab Manager	HOSPITAL A	workload and Workflow	job Role	we have to imitate what the computer does automatically
Lab Manager	HOSPITAL A	Preparation	Improvement	should have a backup system in place that we can pull the trigger and activate and set the system to run
Lab Manager	HOSPITAL A	downtime	handling	have multiple shifts coming in, all doing their own workaround system for the unscheduled event

Lab Manager	HOSPITAL A	workload and Workflow	volume	having to keep track of paperwork for up to 2,000 tests every 20 min and all of the paperwork that is normally automated
Lab Manager	HOSPITAL A	workload and Workflow	volume	everything is not essential [labs ordered by floors]
Lab Manager	HOSPITAL A	Downtime	Communication	we have never met as one group to establish expectations during downtime
Lab Manager	HOSPITAL A	workload and Workflow	volume	it has always been order a rainbow [all possible tests] in case you need it so then you are bogged down with tests the patient doesn't even need
Lab Manager	HOSPITAL A	downtime	handling	some results were coming off the analyzer even after the patient had been discharged, so that shows the test wasn't even necessary to establish disposition
Lab Manager	HOSPITAL A	Workload and Workflow	Patient Safety	some patients may have left AMA [against medical advice] because of wait time
Lab Manager	HOSPITAL A	preparation	general	planned downtime we are prepared for in advance, we have researhed
Lab Manager	HOSPITAL A	workload and Workflow	job Role	we ask for additional staff to volunteer to come in for planned downtime
Lab Manager	HOSPITAL A	workload and Workflow	job Role	for unplanned downtime we had multiple people came in early and or stayed late but still chaotic
Lab Manager	HOSPITAL A	preparation	training	need to have personnel trainied on each shift so we arent playing telephone, losing out on what system we out to stick to during downtime
Lab Manager	HOSPITAL A	preparation	improvement	if there is a standard we could prioritize labs where they need to be, it could flow easier

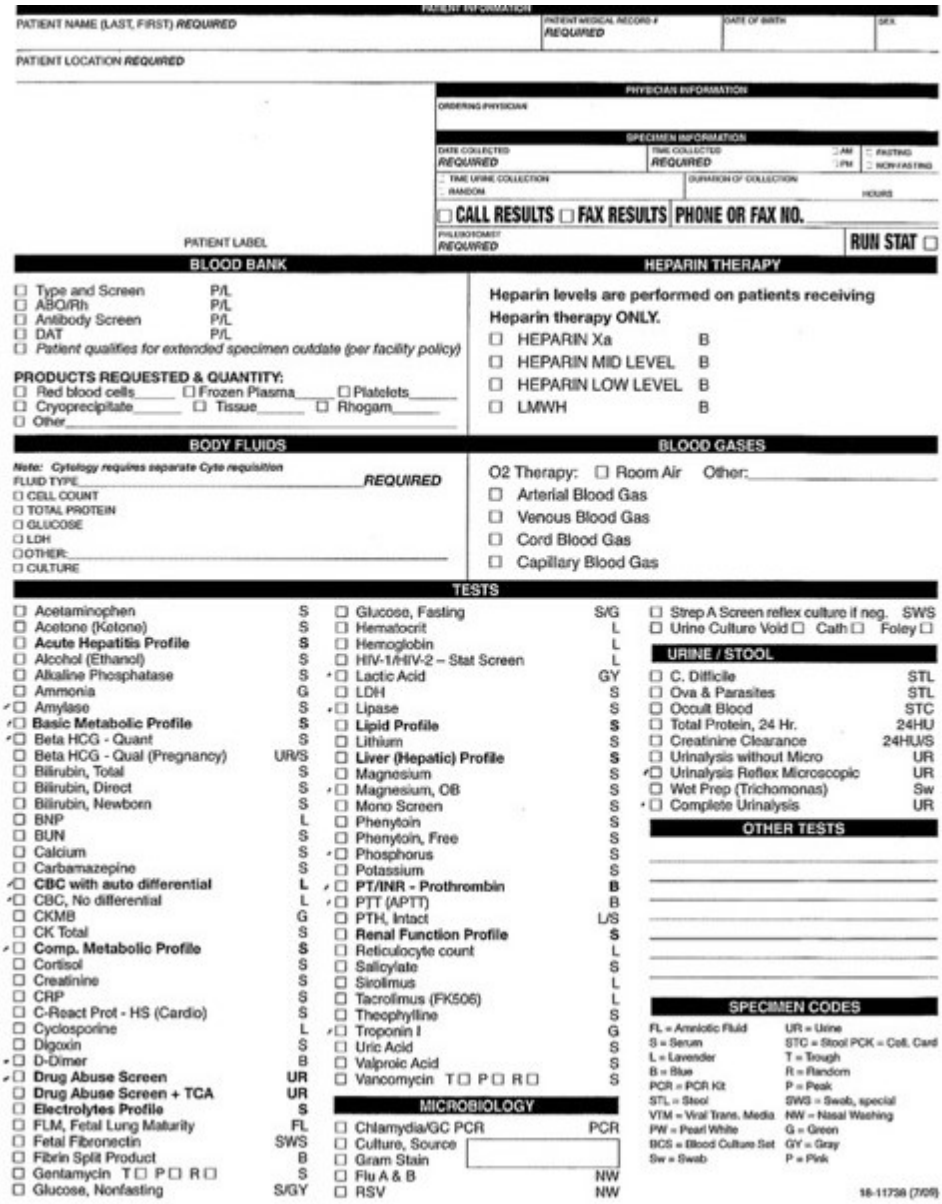
Lab Manager	HOSPITAL A	communication	transparency	we don't have a system established with the rest of the hospital, they know our capabilities during normal
Lab Manager	HOSPITAL A	Preparation	Improvement	need a downtime menu of labs that folks can know can be easily turned around and resulted back
Lab Manager	HOSPITAL A	Communication	Transparency	foks don't realize that the lab is entirely run by computers
Lab Manager	HOSPITAL A	workload and Workflow	volume	at least 85% of results auto-verifym we are staffed for the 15% that need manual review, when we have to go to 100% verify it gets challenging
Lab Manager	HOSPITAL A	communication	transparency	there is a disconnect with the floors, they don't think the lab is part of the system
Lab Manager	HOSPITAL A	workload and Workflow	interruption	you have to drop everything to get results for the clinicians in line in the lab
Lab Manager	HOSPITAL A	Downtime	Communication	teamwork increased during the malware downtime
Lab Manager	HOSPITAL A	downtime	handling	as the week went on, expectations got lower and we had a guy up front and a system in place to manage the crowds
Lab Manager	HOSPITAL A	workload and Workflow	job Role	need someone to help organize the paperwork
Lab Manager	HOSPITAL A	workload and Workflow	job Role	not everyone is trained on the instrumentation so extra personnel to help organize paperwork and disseminate results
Lab Manager	HOSPITAL A	Workload and Workflow	Job Role	the tech is running an analyzer, they also have to run tests to quality check the machine, they have to specify reference ranges on labs

Lab Manager	HOSPITAL A	workload and Workflow	job Role	single operator has to take on multiple responsibilities normally handled by the computer but could be helped by additional personnel
Lab Manager	HOSPITAL A	Workload and Workflow	Interruption	have to have personnel who arent scared of intimidating physicians demanding results
Lab Manager	HOSPITAL A	workload and Workflow	job Role	taking communication/admin/clerical from the techs to a designated person would help
Lab Manager	HOSPITAL A	Communication	Transparency	one doctor had a specific list of needs and was understanding, very helpful
Lab Manager	HOSPITAL A	preparation	training	downtime training happens during planned downtimes
Lab Manager	HOSPITAL A	preparation	training	procedures on file but not drilled
Lab Manager	HOSPITAL A	preparation	training	they don't understand the background processes since they have never gone through planned downtime
Lab Manager	HOSPITAL A	downtime	handling	we hold our breath and run samples like a computer would just crossing fingers that the system will come back up
Lab Manager	HOSPITAL A	preparation	Improvement	ideal scenario is the downtime procedures will be simple enough that you don't need to be trained on it, you can just do it
Lab Manager	HOSPITAL A	communication	transparency	have a understanding of what the expectations are for lab turnaround time during downtime
Lab Manager	HOSPITAL A	workload and Workflow	result Reporting	the delays are in the reporting of results to the floors
Lab Manager	HOSPITAL A	workload and Workflow	job Role	would be nice if there was a clerical group so that during downtime they know they are responsible for papers and phones

Lab Manager	HOSPITAL A	Workload and Workflow	Interruption	current system says we tube things up to the floors but they come down to us anyway
Lab Manager	HOSPITAL A	downtime	communication	have designated points of contact in each department for clerical and dissemination
Lab Manager	HOSPITAL A	preparation	improvement	standardized sheet of paper with all the necessary info for downtime and fill it out properly

APPENDIX C: ADDITIONAL DOCUMENTS

Appendix C.1 – Paper Laboratory Testing Requisition Form



PATIENT INFORMATION

PATIENT NAME (LAST, FIRST) *REQUIRED* | PATIENT MEDICAL RECORD # *REQUIRED* | DATE OF BIRTH | SEX

PATIENT LOCATION *REQUIRED*

PHYSICIAN INFORMATION

ORDERING PHYSICIAN

SPECIMEN INFORMATION

DATE COLLECTED *REQUIRED* | TIME COLLECTED *REQUIRED* ☐ AM ☐ PM | ☐ FASTING ☐ NON-FASTING

☐ TIME URINE COLLECTION ☐ RANDOM | DURATION OF COLLECTION HOURS

☐ CALL RESULTS ☐ FAX RESULTS | PHONE OR FAX NO. _____

PATIENT LABEL

PHLEBOTOMIST *REQUIRED* | RUN STAT ☐

BLOOD BANK

☐ Type and Screen P/L
☐ ABO/Rh P/L
☐ Antibody Screen P/L
☐ DAT P/L
☐ *Patient qualifies for extended specimen outdate (per facility policy)*

PRODUCTS REQUESTED & QUANTITY:
☐ Red blood cells_____ ☐ Frozen Plasma_____ ☐ Platelets_____
☐ Cryoprecipitate_____ ☐ Tissue_____ ☐ Rhogam_____
☐ Other_____

HEPARIN THERAPY

Heparin levels are performed on patients receiving Heparin therapy ONLY.

☐ HEPARIN Xa B
☐ HEPARIN MID LEVEL B
☐ HEPARIN LOW LEVEL B
☐ LMWH B

BODY FLUIDS

Note: Cytology requires separate Cyto requisition

FLUID TYPE_____ *REQUIRED*
☐ CELL COUNT
☐ TOTAL PROTEIN
☐ GLUCOSE
☐ LDH
☐ OTHER:_____
☐ CULTURE

BLOOD GASES

O2 Therapy: ☐ Room Air Other:_____
☐ Arterial Blood Gas
☐ Venous Blood Gas
☐ Cord Blood Gas
☐ Capillary Blood Gas

TESTS

☐ Acetaminophen	S	☐ Glucose, Fasting	S/G	☐ Strep A Screen reflex culture if neg.	SWS
☐ Acetone (Ketone)	S	☐ Hematocrit	L	☐ Urine Culture Void ☐ Cath ☐ Foley ☐	
☐ **Acute Hepatitis Profile**	**S**	☐ Hemoglobin	L	**URINE / STOOL**	
☐ Alcohol (Ethanol)	S	☐ HIV-1/HIV-2 – Stat Screen	L	☐ C. Difficile	STL
☐ Alkaline Phosphatase	S	☐ Lactic Acid	GY	☐ Ova & Parasites	STL
☐ Ammonia	G	☐ LDH	S	☐ Occult Blood	STC
☐ Amylase	S	☐ Lipase	S	☐ Total Protein, 24 Hr.	24HU
☐ **Basic Metabolic Profile**	**S**	☐ **Lipid Profile**	**S**	☐ Creatinine Clearance	24HU/S
☐ Beta HCG - Quant	S	☐ Lithium	S	☐ Urinalysis without Micro	UR
☐ Beta HCG - Qual (Pregnancy)	UR/S	☐ **Liver (Hepatic) Profile**	**S**	☐ Urinalysis Reflex Microscopic	UR
☐ Bilirubin, Total	S	☐ Magnesium	S	☐ Wet Prep (Trichomonas)	Sw
☐ Bilirubin, Direct	S	☐ Magnesium, OB	S	☐ Complete Urinalysis	UR
☐ Bilirubin, Newborn	S	☐ Mono Screen	S	**OTHER TESTS**	
☐ BNP	L	☐ Phenytoin	S	_____	
☐ BUN	S	☐ Phenytoin, Free	S	_____	
☐ Calcium	S	☐ Phosphorus	S	_____	
☐ Carbamazepine	S	☐ Potassium	S	_____	
☐ **CBC with auto differential**	**L**	☐ **PT/INR - Prothrombin**	**B**	_____	
☐ CBC, No differential	L	☐ PTT (APTT)	B	_____	
☐ CKMB	G	☐ PTH, Intact	L/S	_____	
☐ CK Total	S	☐ **Renal Function Profile**	**S**	_____	
☐ **Comp. Metabolic Profile**	**S**	☐ Reticulocyte count	L	**SPECIMEN CODES**	
☐ Cortisol	S	☐ Salicylate	S	FL = Amniotic Fluid	UR = Urine
☐ Creatinine	S	☐ Sirolimus	L	S = Serum	STC = Stool PCK = Cell, Card
☐ CRP	S	☐ Tacrolimus (FK506)	L	L = Lavender	T = Trough
☐ C-React Prot - HS (Cardio)	S	☐ Theophylline	S	B = Blue	R = Random
☐ Cyclosporine	L	☐ Troponin I	G	PCR = PCR Kit	P = Peak
☐ Digoxin	S	☐ Uric Acid	S	STL = Stool	SWS = Swab, special
☐ D-Dimer	B	☐ Valproic Acid	S	VTM = Viral Trans. Media	NW = Nasal Washing
☐ **Drug Abuse Screen**	**UR**	☐ Vancomycin T☐ P☐ R☐	S	PW = Pearl White	G = Green
☐ **Drug Abuse Screen + TCA**	**UR**	**MICROBIOLOGY**		BCS = Blood Culture Set	GY = Gray
☐ **Electrolytes Profile**	**S**	☐ Chlamydia/GC PCR	PCR	Sw = Swab	P = Pink
☐ FLM, Fetal Lung Maturity	FL	☐ Culture, Source			
☐ Fetal Fibronectin	SWS	☐ Gram Stain			
☐ Fibrin Split Product	B	☐ Flu A & B	NW		
☐ Gentamycin T☐ P☐ R☐	S	☐ RSV	NW		
☐ Glucose, Nonfasting	S/GY				

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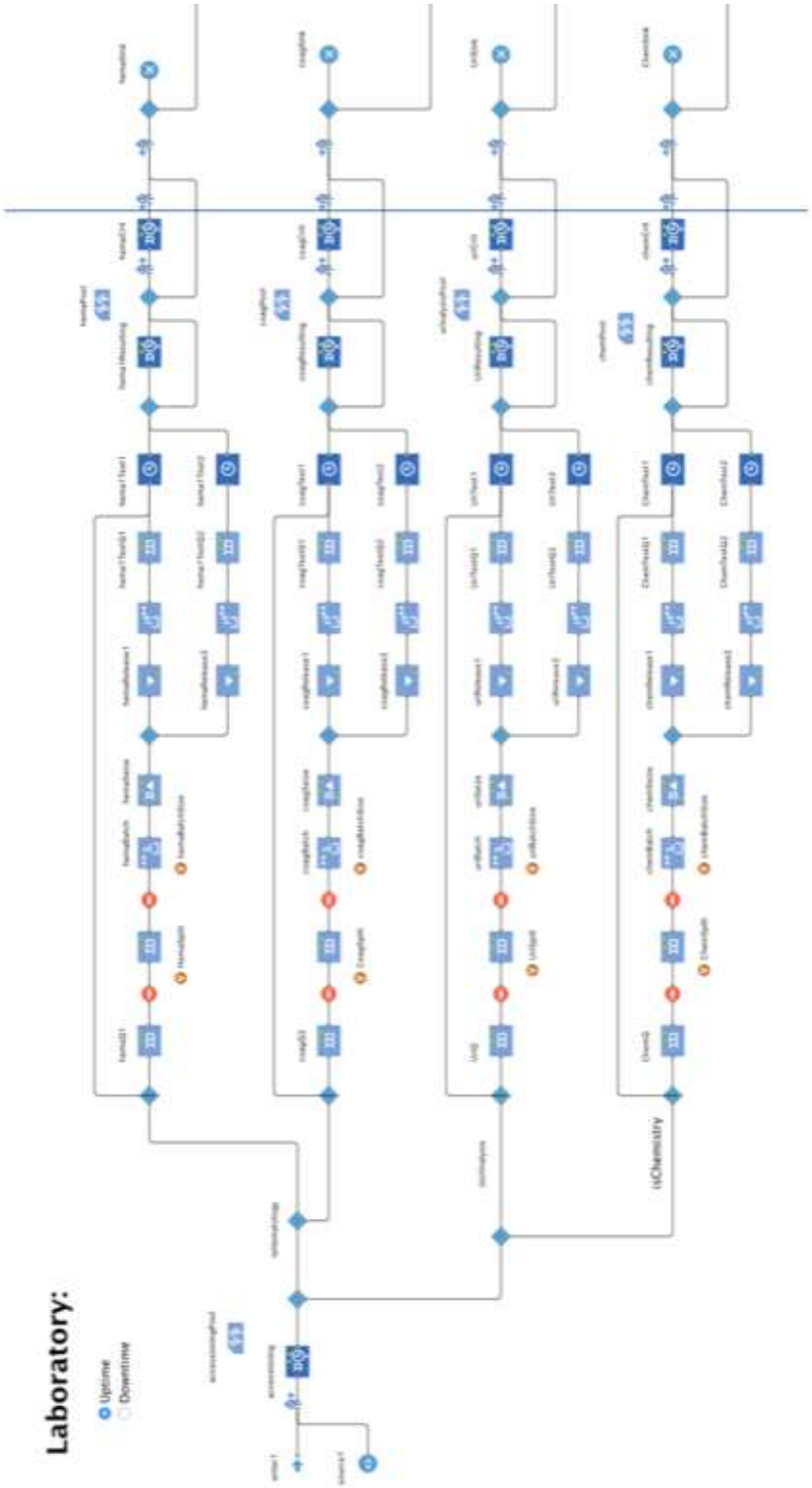
Appendix C.2 – Clinical Laboratory Simulation Model



APPENDIX D: SIMULATION ANALYSIS DETAILED RESULTS

Appendix D.1 – Limited Testing Menu Experiments

Appendix D.1.1 – Door to Doc Time

Method

Null hypothesis H_0: All means are equal
Alternative hypothesis H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	2916675765	486112628	19479.90	*
Error	10493	261848317	24955		
Total	10499	3178524082			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
157.970	91.76%	91.76%	91.75%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	1417.97	236.733	(1409.98, 1425.97)
Downtime Limited Menu 10%	1500	1161.35	203.789	(1153.36, 1169.35)
Downtime Limited Menu 20%	1500	898.758	210.041	(890.763, 906.753)
Downtime Limited Menu 30%	1500	357.681	176.192	(349.686, 365.677)
Downtime Limited Menu 40%	1500	81.9738	26.9753	(73.9787, 89.9690)
Downtime Limited Menu 50%	1500	78.1597	26.3372	(70.1645, 86.1549)
Downtime Limited Menu 75%	1500	76.6128	22.9752	(68.6176, 84.6080)

Pooled StDev = 157.970

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Downtime 7 day	1500	1417.97	A
Downtime Limited Menu 10%	1500	1161.35	B
Downtime Limited Menu 20%	1500	898.758	C
Downtime Limited Menu 30%	1500	357.681	D
Downtime Limited Menu 40%	1500	81.9738	E
Downtime Limited Menu 50%	1500	78.1597	E
Downtime Limited Menu 75%	1500	76.6128	E

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-256.620	5.768	(-273.629, -239.612)	-44.49	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-519.214	5.768	(-536.223, -502.206)	-90.01	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1060.29	5.768	(-1077.30, -1043.28)	-183.81	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-1336.00	5.768	(-1353.01, -1318.99)	-231.61	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-1339.81	5.768	(-1356.82, -1322.80)	-232.27	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1341.36	5.768	(-1358.37, -1324.35)	-232.54	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	-262.594	5.768	(-279.603, -245.586)	-45.52	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	-803.671	5.768	(-820.679, -786.662)	-139.33	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	-1079.38	5.768	(-1096.39, -1062.37)	-187.12	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-1083.19	5.768	(-1100.20, -1066.18)	-187.79	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-1084.74	5.768	(-1101.75, -1067.73)	-188.05	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	-541.077	5.768	(-558.085, -524.068)	-93.80	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	-816.784	5.768	(-833.793, -799.776)	-141.60	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-820.599	5.768	(-837.607, -803.590)	-142.26	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-822.145	5.768	(-839.154, -805.137)	-142.53	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-275.708	5.768	(-292.716, -258.699)	-47.80	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-279.522	5.768	(-296.530, -262.513)	-48.46	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-281.069	5.768	(-298.077, -264.060)	-48.73	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-3.814	5.768	(-20.823, 13.194)	-0.66	0.9946
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-5.361	5.768	(-22.370, 11.647)	-0.93	0.9679
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-1.547	5.768	(-18.555, 15.462)	-0.27	1.0000

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

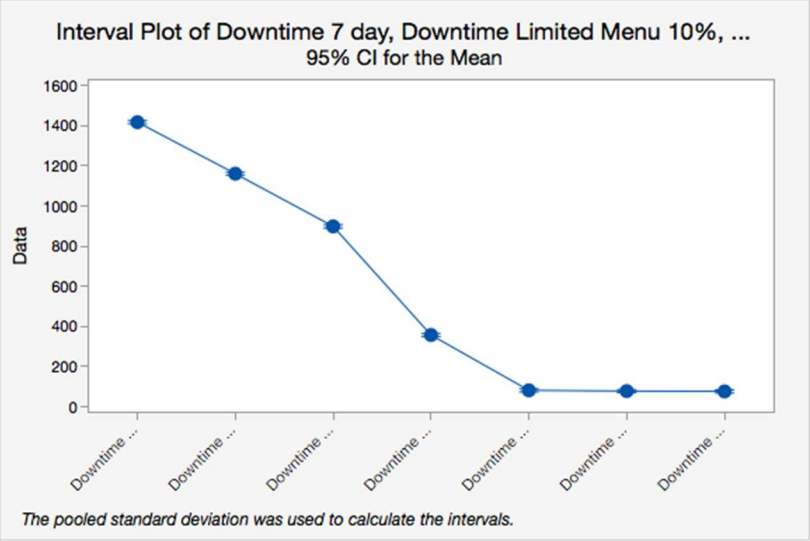
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	1417.97	A
Downtime Limited Menu 10%	1500	1161.35	
Downtime Limited Menu 20%	1500	898.758	
Downtime Limited Menu 30%	1500	357.681	
Downtime Limited Menu 40%	1500	81.9738	
Downtime Limited Menu 50%	1500	78.1597	
Downtime Limited Menu 75%	1500	76.6128	

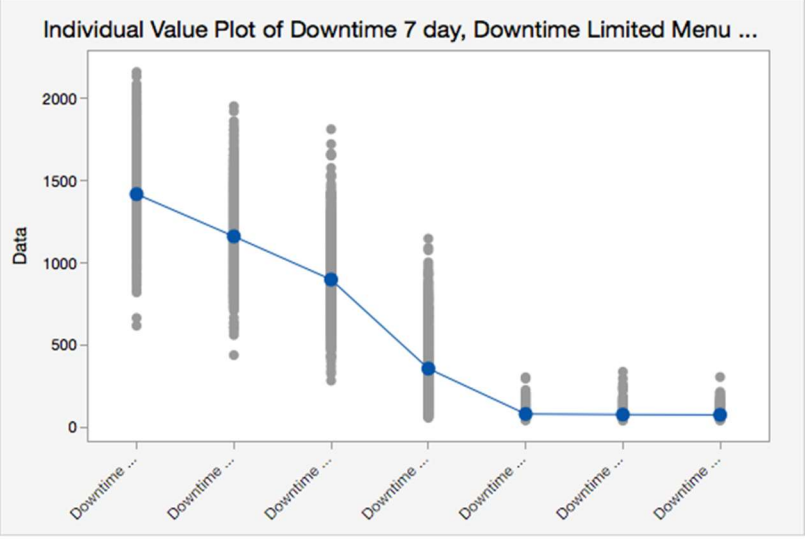
Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-256.620	5.768	(-271.427, -241.813)	-44.49	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-519.214	5.768	(-534.021, -504.407)	-90.01	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1060.29	5.768	(-1075.10, -1045.48)	-183.81	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-1336.00	5.768	(-1350.81, -1321.19)	-231.61	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-1339.81	5.768	(-1354.62, -1325.01)	-232.27	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1341.36	5.768	(-1356.17, -1326.55)	-232.54	<0.0001

Individual confidence level = 98.97%





Appendix D.1.2 – Total Treatment Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	3452953002	575492167	21600.10	*
Error	10493	279565296	26643		
Total	10499	3732518298			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
163.227	92.51%	92.51%	92.50%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	1731.50	247.070	(1723.24, 1739.76)
Downtime Limited Menu 10%	1500	1448.71	208.590	(1440.45, 1456.97)
Downtime Limited Menu 20%	1500	1184.52	206.366	(1176.26, 1192.78)
Downtime Limited Menu 30%	1500	638.183	182.163	(629.922, 646.444)
Downtime Limited Menu 40%	1500	283.222	46.762	(274.960, 291.483)
Downtime Limited Menu 50%	1500	265.425	45.897	(257.164, 273.687)
Downtime Limited Menu 75%	1500	258.794	43.404	(250.533, 267.056)

Pooled StDev = 163.227

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Downtime 7 day	1500	1731.50	A
Downtime Limited Menu 10%	1500	1448.71	B
Downtime Limited Menu 20%	1500	1184.52	C
Downtime Limited Menu 30%	1500	638.183	D
Downtime Limited Menu 40%	1500	283.222	E
Downtime Limited Menu 50%	1500	265.425	F

Downtime Limited Menu 75%	1500	258.794	F

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-282.794	5.960	(-300.369, -265.220)	-47.45	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-546.982	5.960	(-564.556, -529.407)	-91.77	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1093.32	5.960	(-1110.89, -1075.74)	-183.44	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-1448.28	5.960	(-1465.85, -1430.71)	-242.99	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-1466.08	5.960	(-1483.65, -1448.50)	-245.98	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1472.71	5.960	(-1490.28, -1455.13)	-247.09	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	-264.187	5.960	(-281.762, -246.613)	-44.33	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	-810.524	5.960	(-828.099, -792.950)	-135.99	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	-1165.49	5.960	(-1183.06, -1147.91)	-195.54	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-1183.28	5.960	(-1200.86, -1165.71)	-198.53	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-1189.91	5.960	(-1207.49, -1172.34)	-199.64	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	-546.337	5.960	(-563.911, -528.763)	-91.66	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	-901.298	5.960	(-918.873, -883.724)	-151.22	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-919.095	5.960	(-936.669, -901.520)	-154.21	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-925.725	5.960	(-943.300, -908.151)	-155.32	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-354.961	5.960	(-372.536, -337.387)	-59.56	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-372.758	5.960	(-390.332, -355.183)	-62.54	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-379.388	5.960	(-396.963, -361.814)	-63.65	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-17.796	5.960	(-35.371, -0.222)	-2.99	0.0448
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-24.427	5.960	(-42.002, -6.853)	-4.10	0.0008
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-6.631	5.960	(-24.205, 10.944)	-1.11	0.9245

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

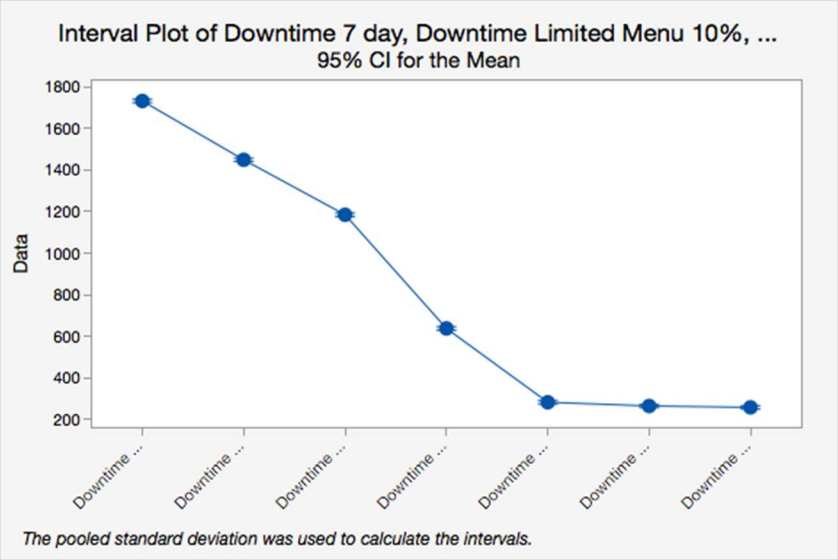
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	1731.50	A
Downtime Limited Menu 10%	1500	1448.71	
Downtime Limited Menu 20%	1500	1184.52	
Downtime Limited Menu 30%	1500	638.183	
Downtime Limited Menu 40%	1500	283.222	
Downtime Limited Menu 50%	1500	265.425	
Downtime Limited Menu 75%	1500	258.794	

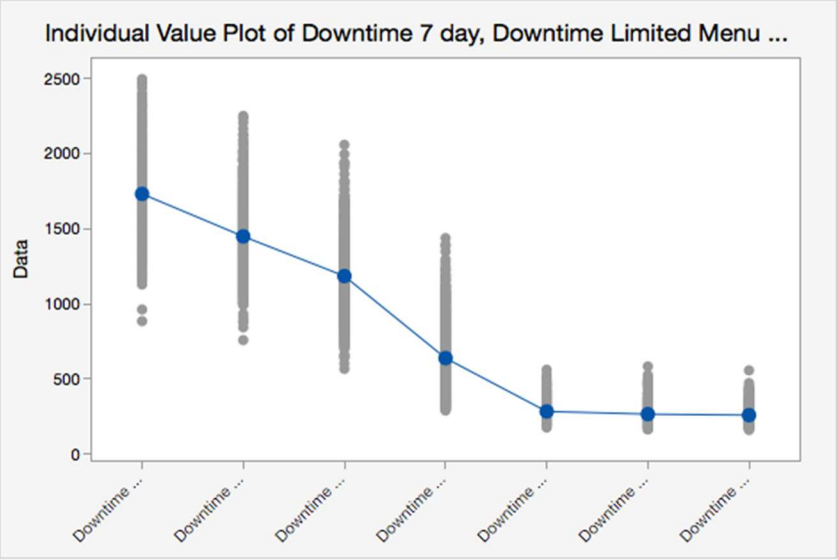
Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-282.794	5.960	(-298.094, -267.494)	-47.45	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-546.982	5.960	(-562.281, -531.682)	-91.77	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1093.32	5.960	(-1108.62, -1078.02)	-183.44	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-1448.28	5.960	(-1463.58, -1432.98)	-242.99	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-1466.08	5.960	(-1481.38, -1450.78)	-245.98	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1472.71	5.960	(-1488.01, -1457.41)	-247.09	<0.0001

Individual confidence level = 98.97%


Interval Plot of Downtime 7 day, Downtime Limited Menu 10%, ...
95% CI for the Mean
Data
1800
1600
1400
1200
1000
800
600
400
200
Downtime ...
Downtime ...
Downtime ...
Downtime ...
Downtime ...
Downtime ...
Downtime ...
The pooled standard deviation was used to calculate the intervals.


Individual Value Plot of Downtime 7 day, Downtime Limited Menu ...
Data
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2000
1500
1000
500
0
Downtime ...
Downtime ...
Downtime ...
Downtime ...
Downtime ...
Downtime ...
Downtime ...

Appendix D.1.3 – Lab Throughput

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	5527827266	921304544	154904.64	*
Error	10493	62407741	5948		
Total	10499	5590235007			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
77.1204	98.88%	98.88%	98.88%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	4529.40	67.031	(4525.50, 4533.30)
Downtime Limited Menu 10%	1500	4605.34	69.445	(4601.44, 4609.25)
Downtime Limited Menu 20%	1500	4730.76	74.680	(4726.85, 4734.66)
Downtime Limited Menu 30%	1500	4895.27	81.478	(4891.37, 4899.18)
Downtime Limited Menu 40%	1500	4802.33	80.605	(4798.42, 4806.23)
Downtime Limited Menu 50%	1500	4196.70	87.605	(4192.80, 4200.61)
Downtime Limited Menu 75%	1500	2641.85	77.003	(2637.95, 2645.76)

Pooled StDev = 77.1204

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Downtime Limited Menu 30%	1500	4895.27	A
Downtime Limited Menu 40%	1500	4802.33	B
Downtime Limited Menu 20%	1500	4730.76	C
Downtime Limited Menu 10%	1500	4605.34	D
Downtime 7 day	1500	4529.40	E
Downtime Limited Menu 50%	1500	4196.70	F

Downtime Limited Menu 75%	1500	2641.85	G

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	75.945	2.816	(67.641, 84.248)	26.97	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	201.358	2.816	(193.055, 209.661)	71.50	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	365.873	2.816	(357.569, 374.176)	129.92	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	272.925	2.816	(264.622, 281.229)	96.92	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-332.697	2.816	(-341.001, -324.394)	-118.14	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1887.55	2.816	(-1895.85, -1879.24)	-670.28	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	125.413	2.816	(117.110, 133.717)	44.54	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	289.928	2.816	(281.625, 298.231)	102.96	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	196.981	2.816	(188.677, 205.284)	69.95	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-408.642	2.816	(-416.945, -400.339)	-145.11	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-1963.49	2.816	(-1971.80, -1955.19)	-697.25	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	164.515	2.816	(156.211, 172.818)	58.42	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	71.567	2.816	(63.264, 79.871)	25.41	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-534.055	2.816	(-542.359, -525.752)	-189.65	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-2088.91	2.816	(-2097.21, -2080.60)	-741.79	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-92.947	2.816	(-101.251, -84.644)	-33.01	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-698.570	2.816	(-706.873, -690.267)	-248.07	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-2253.42	2.816	(-2261.72, -2245.12)	-800.21	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-605.623	2.816	(-613.926, -597.319)	-215.06	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-2160.47	2.816	(-2168.78, -2152.17)	-767.20	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-1554.85	2.816	(-1563.15, -1546.55)	-552.14	<0.0001

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

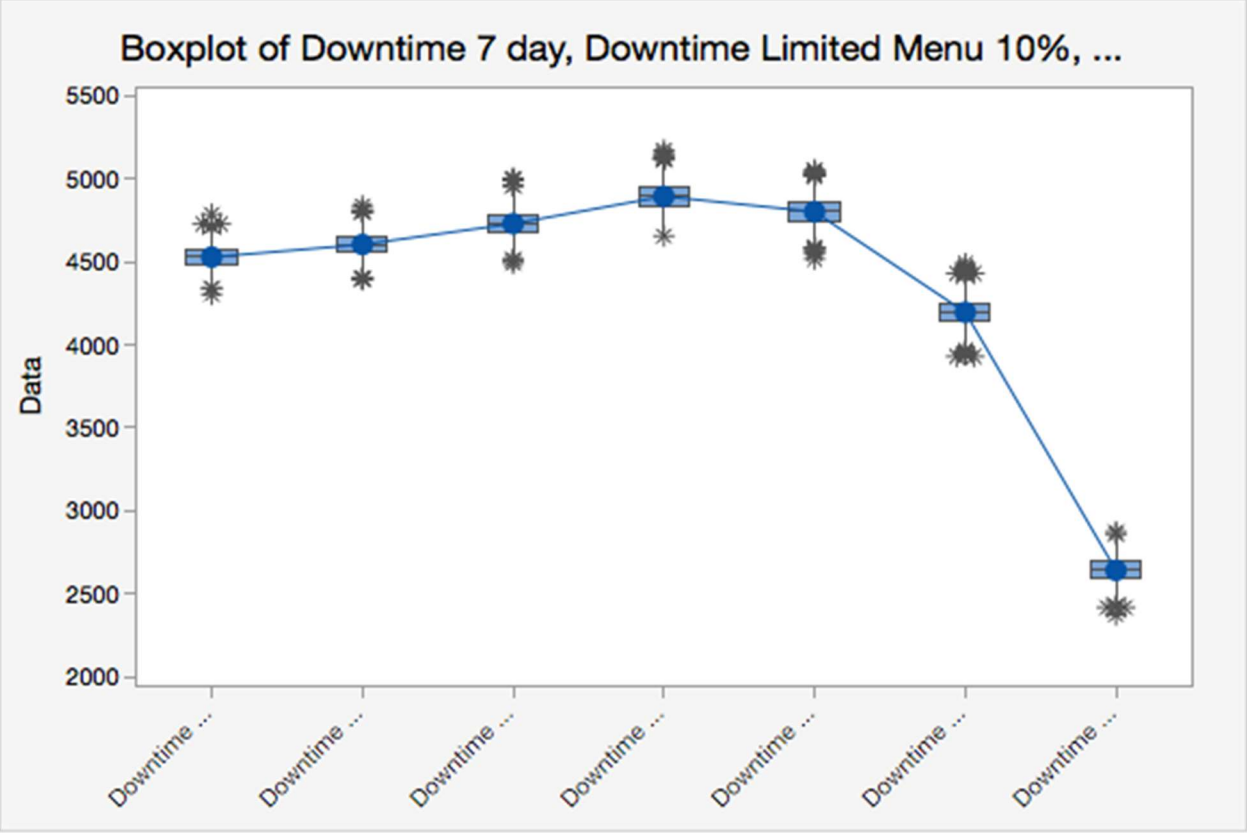
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	4529.40	A
Downtime Limited Menu 30%	1500	4895.27	
Downtime Limited Menu 40%	1500	4802.33	
Downtime Limited Menu 20%	1500	4730.76	
Downtime Limited Menu 10%	1500	4605.34	
Downtime Limited Menu 50%	1500	4196.70	
Downtime Limited Menu 75%	1500	2641.85	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	75.945	2.816	(68.716, 83.173)	26.97	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	201.358	2.816	(194.129, 208.587)	71.50	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	365.873	2.816	(358.644, 373.101)	129.92	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	272.925	2.816	(265.697, 280.154)	96.92	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-332.697	2.816	(-339.926, -325.469)	-118.14	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1887.55	2.816	(-1894.78, -1880.32)	-670.28	<0.0001

Individual confidence level = 98.97%



Appendix D.1.4 – Reporting of Critical Results within 15 min

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	392738	65456.4	9292.07	*
Error	10493	73916	7.0		
Total	10499	466654			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.65412	84.16%	84.15%	84.14%

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.65412	84.16%	84.15%	84.14%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	78.7837	2.88726	(78.6493, 78.9180)
Downtime Limited Menu 10%	1500	78.9751	2.84120	(78.8407, 79.1094)
Downtime Limited Menu 20%	1500	79.5430	2.72558	(79.4087, 79.6774)
Downtime Limited Menu 30%	1500	80.2931	2.74411	(80.1587, 80.4274)
Downtime Limited Menu 40%	1500	81.5565	2.71470	(81.4222, 81.6908)
Downtime Limited Menu 50%	1500	83.7241	2.83600	(83.5898, 83.8584)
Downtime Limited Menu 75%	1500	97.3543	1.59064	(97.2200, 97.4887)

Pooled StDev = 2.65412

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	0.19141	0.09691	(-0.09436, 0.47718)	1.98	0.4307
Downtime Limited Menu 20%-Downtime 7 day	0.75939	0.09691	(0.47363, 1.04516)	7.84	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	1.50942	0.09691	(1.22365, 1.79519)	15.57	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	2.77283	0.09691	(2.48707, 3.05860)	28.61	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	4.94046	0.09691	(4.65469, 5.22622)	50.98	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	18.5707	0.09691	(18.2849, 18.8564)	191.62	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	0.56798	0.09691	(0.28222, 0.85375)	5.86	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	1.31801	0.09691	(1.03225, 1.60378)	13.60	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	2.58142	0.09691	(2.29566, 2.86719)	26.64	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	4.74905	0.09691	(4.46328, 5.03481)	49.00	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	18.3793	0.09691	(18.0935, 18.6650)	189.64	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	0.75003	0.09691	(0.46426, 1.03579)	7.74	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	2.01344	0.09691	(1.72768, 2.29921)	20.78	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	4.18107	0.09691	(3.89530, 4.46683)	43.14	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	17.8113	0.09691	(17.5255, 18.0970)	183.78	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	1.26341	0.09691	(0.97765, 1.54918)	13.04	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	3.43104	0.09691	(3.14527, 3.71680)	35.40	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	17.0612	0.09691	(16.7755, 17.3470)	176.04	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	2.16762	0.09691	(1.88186, 2.45339)	22.37	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 40%	15.7978	0.09691	(15.5121, 16.0836)	163.01	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 50%	13.6302	0.09691	(13.3444, 13.9160)	140.64	<0.0001

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

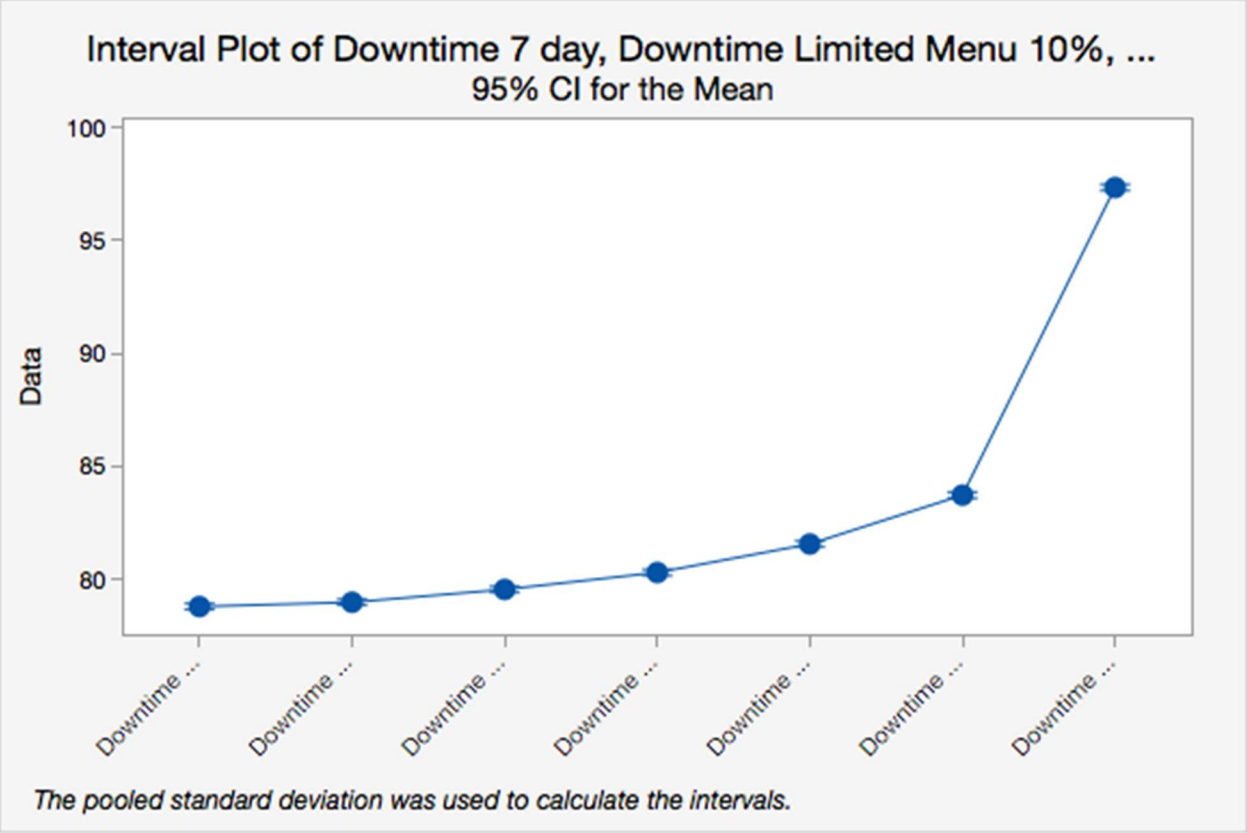
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	78.7837	A
Downtime Limited Menu 75%	1500	97.3543	
Downtime Limited Menu 50%	1500	83.7241	
Downtime Limited Menu 40%	1500	81.5565	
Downtime Limited Menu 30%	1500	80.2931	
Downtime Limited Menu 20%	1500	79.5430	
Downtime Limited Menu 10%	1500	78.9751	A

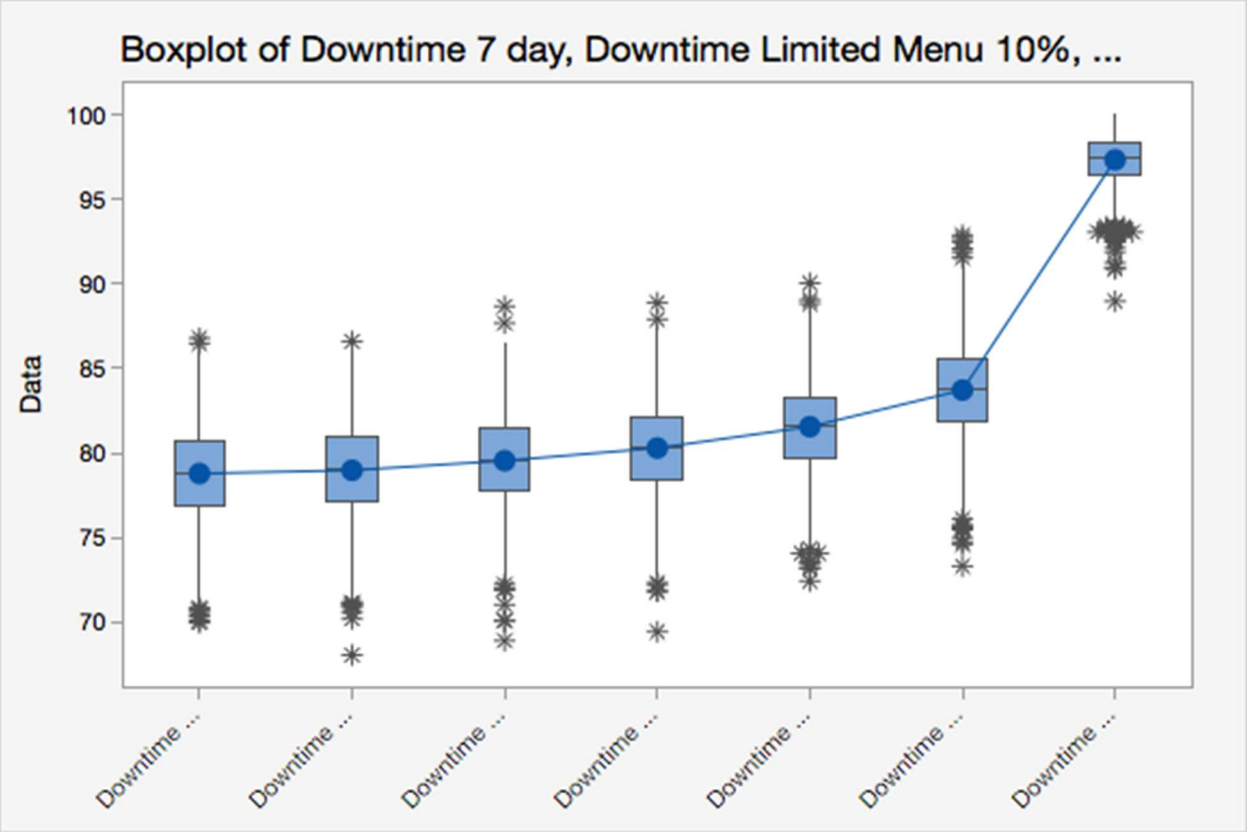
Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	0.19141	0.09691	(-0.05737, 0.44019)	1.98	0.2011
Downtime Limited Menu 20%-Downtime 7 day	0.75939	0.09691	(0.51062, 1.00817)	7.84	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	1.50942	0.09691	(1.26064, 1.75820)	15.57	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	2.77283	0.09691	(2.52406, 3.02161)	28.61	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	4.94046	0.09691	(4.69168, 5.18923)	50.98	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	18.5707	0.09691	(18.3219, 18.8194)	191.62	<0.0001

Individual confidence level = 98.97%




Boxplot of Downtime 7 day, Downtime Limited Menu 10%, ...
Data
100
95
90
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80
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Downtime ...
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Appendix D.1.5 – Chemistry Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	19776907207	3296151201	257347.51	*
Error	10493	134396152	12808		
Total	10499	19911303359			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
113.173	99.33%	99.32%	99.32%

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
113.173	99.33%	99.32%	99.32%

Grouping Information Using the Fisher LSD Method and 95% Confidence

Factor	N	Mean	Grouping
Downtime 7 day	1500	3637.57	A
Downtime Limited Menu 10%	1500	2953.84	B
Downtime Limited Menu 20%	1500	2130.80	C
Downtime Limited Menu 30%	1500	1176.89	D
Downtime Limited Menu 40%	1500	170.421	E
Downtime Limited Menu 50%	1500	64.1435	F
Downtime Limited Menu 75%	1500	21.1395	G

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-683.728	4.133	(-691.828, -675.627)	-165.45	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-1506.77	4.133	(-1514.87, -1498.67)	-364.61	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-2460.68	4.133	(-2468.78, -2452.58)	-595.45	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-3467.14	4.133	(-3475.25, -3459.04)	-838.99	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-3573.42	4.133	(-3581.52, -3565.32)	-864.71	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-3616.43	4.133	(-3624.53, -3608.33)	-875.12	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	-823.042	4.133	(-831.143, -814.942)	-199.16	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	-1776.95	4.133	(-1785.05, -1768.85)	-429.99	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	-2783.42	4.133	(-2791.52, -2775.32)	-673.54	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-2889.69	4.133	(-2897.79, -2881.59)	-699.26	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-2932.70	4.133	(-2940.80, -2924.60)	-709.67	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	-953.908	4.133	(-962.008, -945.807)	-230.83	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	-1960.37	4.133	(-1968.48, -1952.27)	-474.38	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-2066.65	4.133	(-2074.75, -2058.55)	-500.10	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-2109.66	4.133	(-2117.76, -2101.56)	-510.50	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-1006.47	4.133	(-1014.568, -998.367)	-243.55	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-1112.74	4.133	(-1120.84, -1104.64)	-269.27	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-1155.75	4.133	(-1163.85, -1147.65)	-279.67	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-106.277	4.133	(-114.378, -98.177)	-25.72	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-149.281	4.133	(-157.382, -141.181)	-36.12	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-43.004	4.133	(-51.105, -34.904)	-10.41	<0.0001

Simultaneous confidence level = 55.97%

Grouping Information Using the Dunnett Method and 95% Confidence

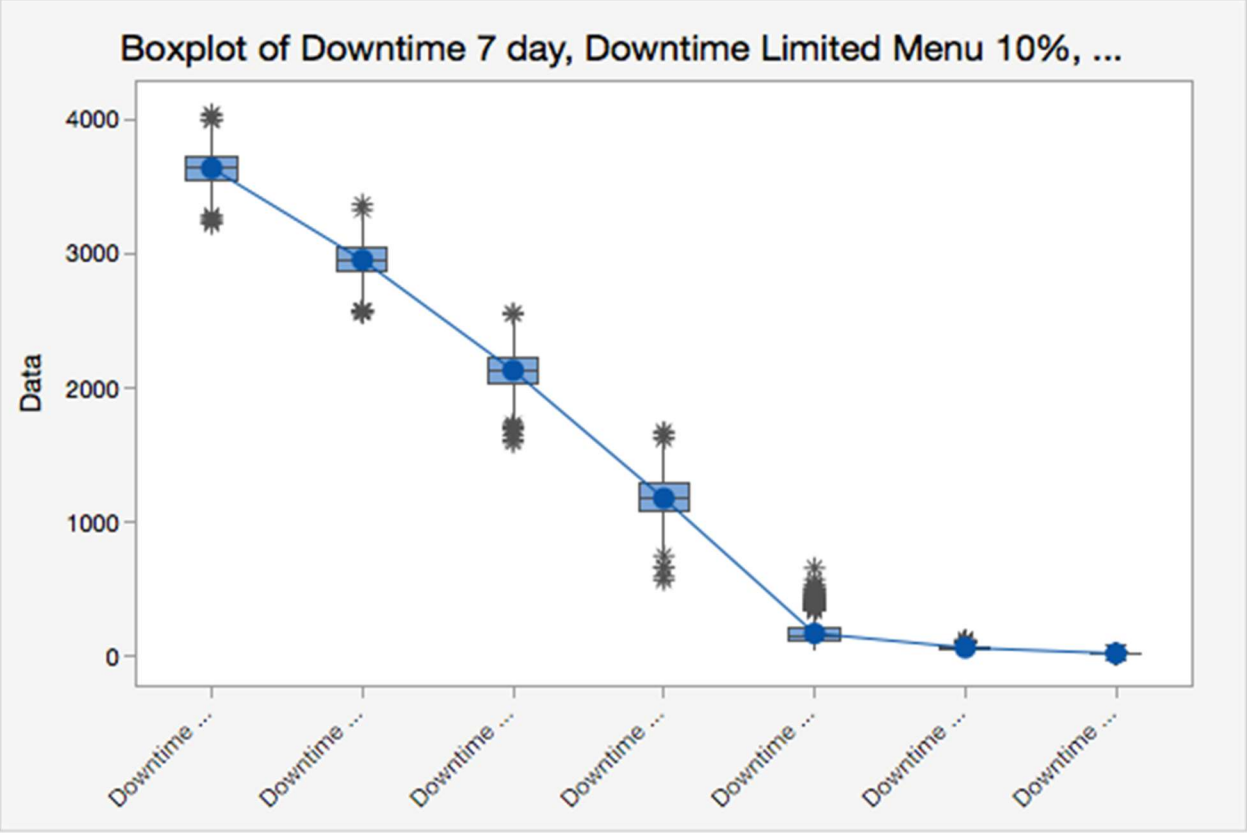
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	3637.57	A
Downtime Limited Menu 10%	1500	2953.84	
Downtime Limited Menu 20%	1500	2130.80	
Downtime Limited Menu 30%	1500	1176.89	
Downtime Limited Menu 40%	1500	170.421	
Downtime Limited Menu 50%	1500	64.1435	
Downtime Limited Menu 75%	1500	21.1395	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-683.728	4.133	(-694.336, -673.120)	-165.45	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-1506.77	4.133	(-1517.38, -1496.16)	-364.61	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-2460.68	4.133	(-2471.29, -2450.07)	-595.45	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-3467.14	4.133	(-3477.75, -3456.54)	-838.99	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-3573.42	4.133	(-3584.03, -3562.81)	-864.71	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-3616.43	4.133	(-3627.03, -3605.82)	-875.12	<0.0001

Individual confidence level = 98.97%



Appendix D.1.6 – Coagulation Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	6216347670	1036057945	143949.17	*
Error	10493	75522188	7197		
Total	10499	6291869858			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
84.8374	98.80%	98.80%	98.80%

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
84.8374	98.80%	98.80%	98.80%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	2041.41	116.368	(2037.12, 2045.70)
Downtime Limited Menu 10%	1500	1565.23	110.995	(1560.94, 1569.53)
Downtime Limited Menu 20%	1500	982.188	113.868	(977.894, 986.482)
Downtime Limited Menu 30%	1500	298.795	107.484	(294.502, 303.089)
Downtime Limited Menu 40%	1500	28.7682	0.87897	(24.4744, 33.0619)
Downtime Limited Menu 50%	1500	27.7872	0.72122	(23.4934, 32.0810)
Downtime Limited Menu 75%	1500	26.2695	0.39952	(21.9757, 30.5633)

Pooled StDev = 84.8374

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Downtime 7 day	1500	2041.41	A
Downtime Limited Menu 10%	1500	1565.23	B

Downtime Limited Menu 20%	1500	982.188		C	
Downtime Limited Menu 30%	1500	298.795			D
Downtime Limited Menu 40%	1500	28.7682			E
Downtime Limited Menu 50%	1500	27.7872			E
Downtime Limited Menu 75%	1500	26.2695			E

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-476.177	3.098	(-485.311, -467.043)	-153.71	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-1059.22	3.098	(-1068.36, -1050.09)	-341.92	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1742.61	3.098	(-1751.75, -1733.48)	-562.53	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-2012.64	3.098	(-2021.78, -2003.51)	-649.70	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-2013.62	3.098	(-2022.76, -2004.49)	-650.01	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-2015.14	3.098	(-2024.28, -2006.01)	-650.50	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	-583.045	3.098	(-592.179, -573.911)	-188.21	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	-1266.44	3.098	(-1275.57, -1257.30)	-408.82	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	-1536.47	3.098	(-1545.60, -1527.33)	-495.98	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-1537.45	3.098	(-1546.58, -1528.31)	-496.30	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-1538.96	3.098	(-1548.10, -1529.83)	-496.79	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	-683.393	3.098	(-692.527, -674.258)	-220.60	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	-953.420	3.098	(-962.554, -944.286)	-307.77	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-954.401	3.098	(-963.535, -945.267)	-308.09	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-955.919	3.098	(-965.053, -946.784)	-308.58	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-270.027	3.098	(-279.162, -260.893)	-87.17	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-271.008	3.098	(-280.143, -261.874)	-87.48	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-272.526	3.098	(-281.660, -263.392)	-87.97	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-0.981	3.098	(-10.115, 8.153)	-0.32	0.9999
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-2.499	3.098	(-11.633, 6.636)	-0.81	0.9844
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-1.518	3.098	(-10.652, 7.617)	-0.49	0.9990

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

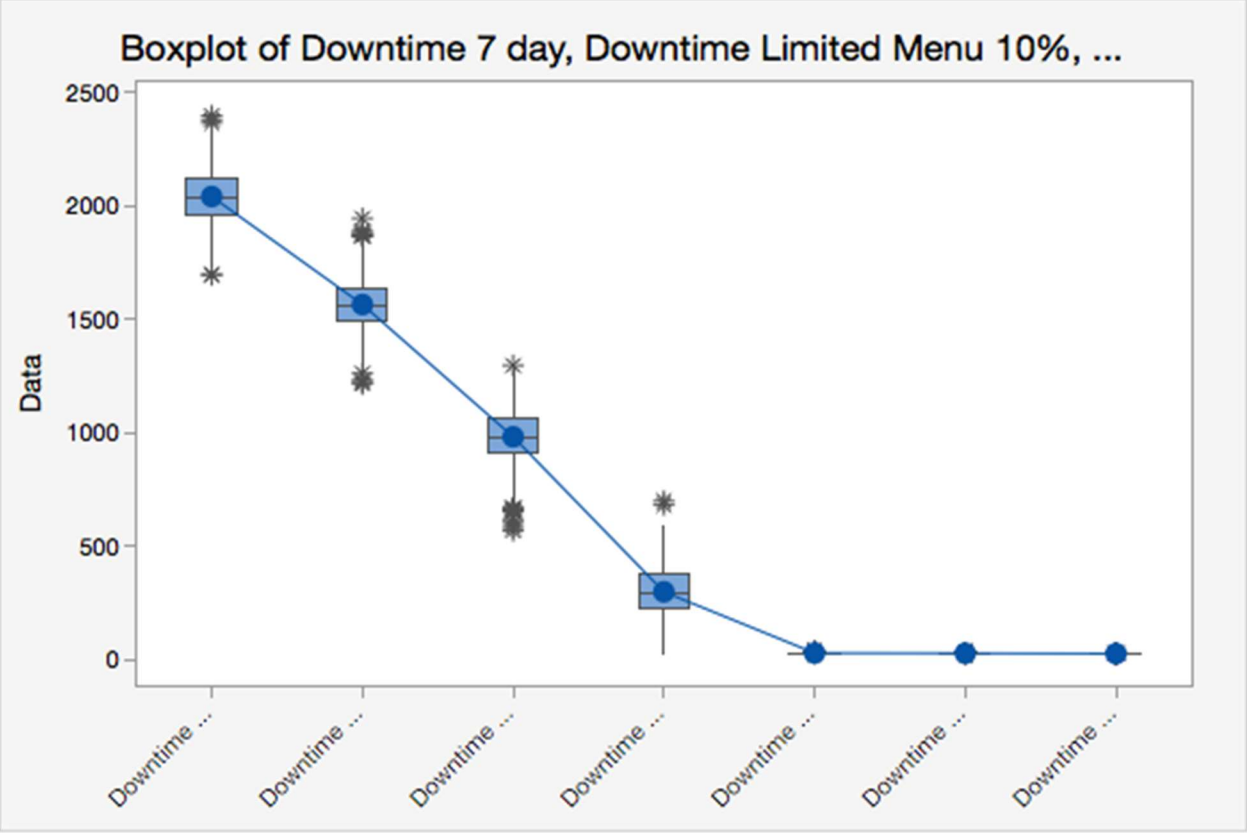
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	2041.41	A
Downtime Limited Menu 10%	1500	1565.23	
Downtime Limited Menu 20%	1500	982.188	
Downtime Limited Menu 30%	1500	298.795	
Downtime Limited Menu 40%	1500	28.7682	
Downtime Limited Menu 50%	1500	27.7872	
Downtime Limited Menu 75%	1500	26.2695	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-476.177	3.098	(-484.129, -468.225)	-153.71	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-1059.22	3.098	(-1067.17, -1051.27)	-341.92	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1742.61	3.098	(-1750.57, -1734.66)	-562.53	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-2012.64	3.098	(-2020.59, -2004.69)	-649.70	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-2013.62	3.098	(-2021.58, -2005.67)	-650.01	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-2015.14	3.098	(-2023.09, -2007.19)	-650.50	<0.0001

Individual confidence level = 98.97%



Appendix D.1.7 – Hematology Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	11159052129	1859842022	179737.10	*
Error	10493	108577038	10348		
Total	10499	11267629168			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
101.723	99.04%	99.04%	99.04%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	2724.59	127.031	(2719.44, 2729.74)
Downtime Limited Menu 10%	1500	2090.07	128.374	(2084.92, 2095.22)
Downtime Limited Menu 20%	1500	1327.12	135.485	(1321.97, 1332.27)
Downtime Limited Menu 30%	1500	436.676	146.484	(431.527, 441.824)
Downtime Limited Menu 40%	1500	23.9279	1.21596	(18.7795, 29.0762)
Downtime Limited Menu 50%	1500	22.1636	0.95339	(17.0152, 27.3120)
Downtime Limited Menu 75%	1500	19.2860	0.358403	(14.1377, 24.4344)

Pooled StDev = 101.723

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping				
Downtime 7 day	1500	2724.59	A				
Downtime Limited Menu 10%	1500	2090.07		B			
Downtime Limited Menu 20%	1500	1327.12			C		
Downtime Limited Menu 30%	1500	436.676				D	
Downtime Limited Menu 40%	1500	23.9279					E
Downtime Limited Menu 50%	1500	22.1636					E

Downtime Limited Menu 75%	1500	19.2860	E

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-634.518	3.714	(-645.470, -623.565)	-170.83	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-1397.47	3.714	(-1408.43, -1386.52)	-376.23	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-2287.91	3.714	(-2298.87, -2276.96)	-615.96	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-2700.66	3.714	(-2711.61, -2689.71)	-727.08	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-2702.43	3.714	(-2713.38, -2691.47)	-727.55	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-2705.30	3.714	(-2716.26, -2694.35)	-728.33	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	-762.955	3.714	(-773.908, -752.003)	-205.40	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	-1653.40	3.714	(-1664.35, -1642.44)	-445.13	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	-2066.14	3.714	(-2077.10, -2055.19)	-556.25	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-2067.91	3.714	(-2078.86, -2056.96)	-556.73	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-2070.79	3.714	(-2081.74, -2059.83)	-557.50	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	-890.442	3.714	(-901.394, -879.489)	-239.73	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	-1303.19	3.714	(-1314.14, -1292.24)	-350.85	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-1304.95	3.714	(-1315.91, -1294.00)	-351.32	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-1307.83	3.714	(-1318.78, -1296.88)	-352.10	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-412.748	3.714	(-423.700, -401.795)	-111.12	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-414.512	3.714	(-425.464, -403.560)	-111.60	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-417.390	3.714	(-428.342, -406.437)	-112.37	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-1.764	3.714	(-12.717, 9.188)	-0.47	0.9992
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-4.642	3.714	(-15.594, 6.311)	-1.25	0.8745
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-2.878	3.714	(-13.830, 8.075)	-0.77	0.9874

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

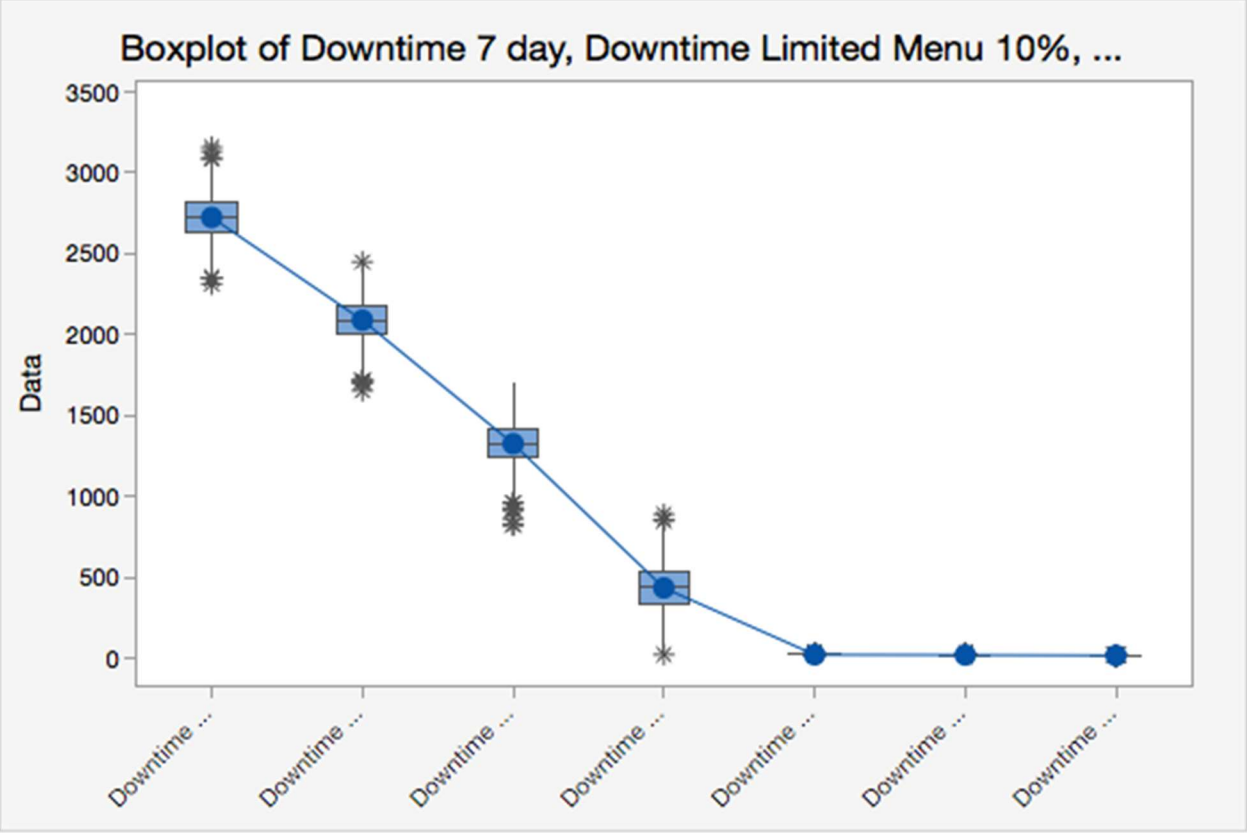
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	2724.59	A
Downtime Limited Menu 10%	1500	2090.07	
Downtime Limited Menu 20%	1500	1327.12	
Downtime Limited Menu 30%	1500	436.676	
Downtime Limited Menu 40%	1500	23.9279	
Downtime Limited Menu 50%	1500	22.1636	
Downtime Limited Menu 75%	1500	19.2860	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-634.518	3.714	(-644.052, -624.983)	-170.83	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-1397.47	3.714	(-1407.01, -1387.94)	-376.23	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-2287.91	3.714	(-2297.45, -2278.38)	-615.96	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-2700.66	3.714	(-2710.20, -2691.13)	-727.08	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-2702.43	3.714	(-2711.96, -2692.89)	-727.55	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-2705.30	3.714	(-2714.84, -2695.77)	-728.33	<0.0001

Individual confidence level = 98.97%



Appendix D.1.8 – Urinalysis Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	7	Downtime 7 day, Downtime Limited Menu 10%, Downtime Limited Menu 20%, Downtime Limited Menu 30%, Downtime Limited Menu 40%, Downtime Limited Menu 50%, Downtime Limited Menu 75%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	6	2900832799	483472133	119674.35	*
Error	10493	42390648	4040		
Total	10499	2943223447			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
63.5602	98.56%	98.56%	98.56%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	1424.81	95.205	(1421.60, 1428.03)
Downtime Limited Menu 10%	1500	1067.53	88.680	(1064.32, 1070.75)
Downtime Limited Menu 20%	1500	660.376	78.818	(657.159, 663.593)
Downtime Limited Menu 30%	1500	217.190	71.666	(213.973, 220.406)
Downtime Limited Menu 40%	1500	35.8552	1.20686	(32.6383, 39.0721)
Downtime Limited Menu 50%	1500	34.5887	0.99070	(31.3718, 37.8056)
Downtime Limited Menu 75%	1500	32.1482	0.59665	(28.9313, 35.3651)

Pooled StDev = 63.5602

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping				
Downtime 7 day	1500	1424.81	A				
Downtime Limited Menu 10%	1500	1067.53		B			
Downtime Limited Menu 20%	1500	660.376			C		
Downtime Limited Menu 30%	1500	217.190				D	
Downtime Limited Menu 40%	1500	35.8552					E
Downtime Limited Menu 50%	1500	34.5887					E

Downtime Limited Menu 75%	1500	32.1482	E

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-357.281	2.321	(-364.124, -350.437)	-153.94	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-764.437	2.321	(-771.280, -757.593)	-329.37	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1207.62	2.321	(-1214.47, -1200.78)	-520.33	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-1388.96	2.321	(-1395.80, -1382.11)	-598.46	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-1390.22	2.321	(-1397.07, -1383.38)	-599.00	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1392.66	2.321	(-1399.51, -1385.82)	-600.06	<0.0001
Downtime Limited Menu 20%-Downtime Limited Menu 10%	-407.156	2.321	(-414.000, -400.313)	-175.43	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 10%	-850.342	2.321	(-857.186, -843.499)	-366.39	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 10%	-1031.68	2.321	(-1038.52, -1024.83)	-444.52	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 10%	-1032.94	2.321	(-1039.79, -1026.10)	-445.06	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 10%	-1035.38	2.321	(-1042.23, -1028.54)	-446.11	<0.0001
Downtime Limited Menu 30%-Downtime Limited Menu 20%	-443.186	2.321	(-450.030, -436.343)	-190.96	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 20%	-624.521	2.321	(-631.364, -617.677)	-269.09	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 20%	-625.787	2.321	(-632.631, -618.944)	-269.63	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 20%	-628.228	2.321	(-635.071, -621.384)	-270.68	<0.0001
Downtime Limited Menu 40%-Downtime Limited Menu 30%	-181.334	2.321	(-188.178, -174.491)	-78.13	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 30%	-182.601	2.321	(-189.444, -175.757)	-78.68	<0.0001
Downtime Limited Menu 75%-Downtime Limited Menu 30%	-185.041	2.321	(-191.885, -178.198)	-79.73	<0.0001
Downtime Limited Menu 50%-Downtime Limited Menu 40%	-1.267	2.321	(-8.110, 5.577)	-0.55	0.9981
Downtime Limited Menu 75%-Downtime Limited Menu 40%	-3.707	2.321	(-10.550, 3.136)	-1.60	0.6842
Downtime Limited Menu 75%-Downtime Limited Menu 50%	-2.440	2.321	(-9.284, 4.403)	-1.05	0.9418

Individual confidence level = 99.68%

Grouping Information Using the Dunnett Method and 95% Confidence

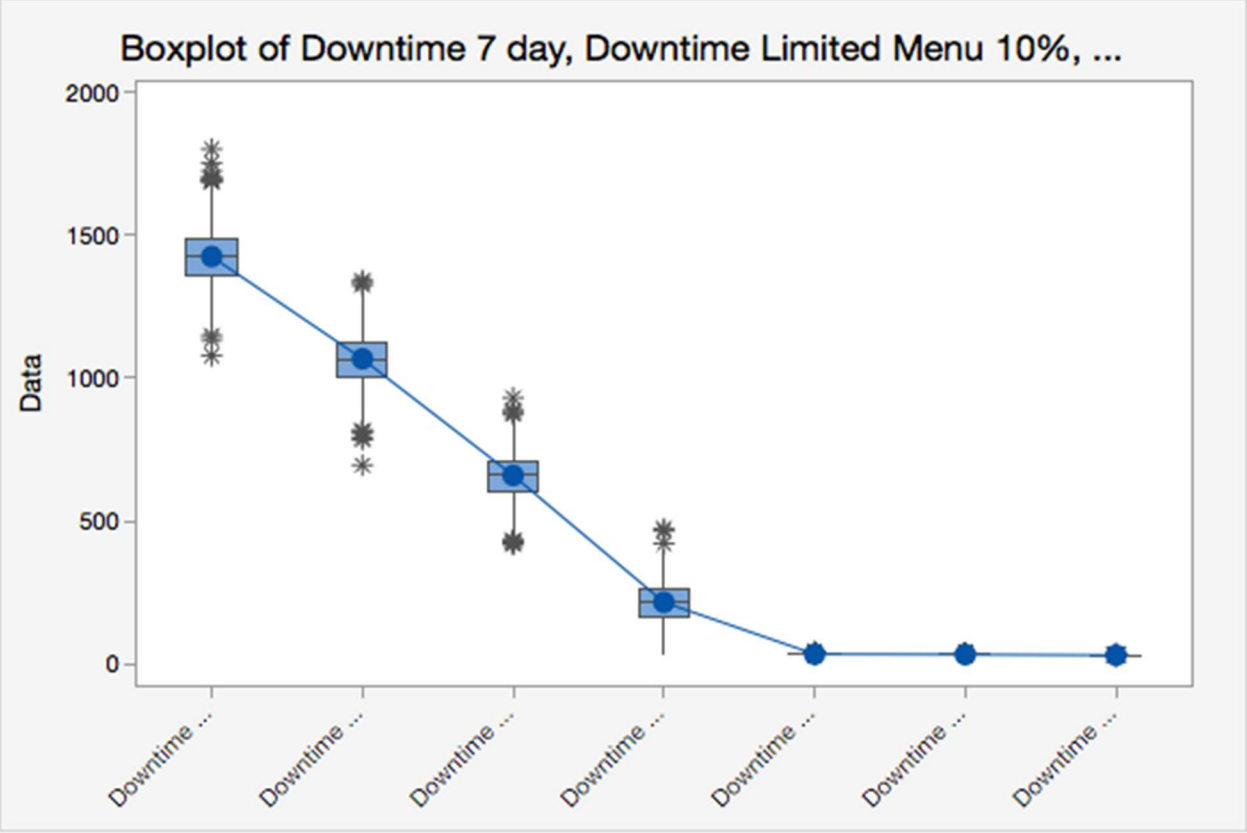
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	1424.81	A
Downtime Limited Menu 10%	1500	1067.53	
Downtime Limited Menu 20%	1500	660.376	
Downtime Limited Menu 30%	1500	217.190	
Downtime Limited Menu 40%	1500	35.8552	
Downtime Limited Menu 50%	1500	34.5887	
Downtime Limited Menu 75%	1500	32.1482	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime Limited Menu 10%-Downtime 7 day	-357.281	2.321	(-363.238, -351.323)	-153.94	<0.0001
Downtime Limited Menu 20%-Downtime 7 day	-764.437	2.321	(-770.394, -758.479)	-329.37	<0.0001
Downtime Limited Menu 30%-Downtime 7 day	-1207.62	2.321	(-1213.58, -1201.67)	-520.33	<0.0001
Downtime Limited Menu 40%-Downtime 7 day	-1388.96	2.321	(-1394.92, -1383.00)	-598.46	<0.0001
Downtime Limited Menu 50%-Downtime 7 day	-1390.22	2.321	(-1396.18, -1384.27)	-599.00	<0.0001
Downtime Limited Menu 75%-Downtime 7 day	-1392.66	2.321	(-1398.62, -1386.71)	-600.06	<0.0001

Individual confidence level = 98.97%



Appendix D.2 – Additional Staffing Experiments

Appendix D.2.1 – Door To Doc Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, Downtime +1 staff, Downtime +2 staff, Downtime +3 staff, Downtime +4 staff

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	3198893477	799723369	35395.60	*
Error	7495	169341020	22594		
Total	7499	3368234497			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
150.313	94.97%	94.97%	94.97%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	1417.97	236.733	(1410.36, 1425.58)
Downtime +1 staff	1500	1418.60	232.097	(1410.99, 1426.21)
Downtime +2 staff	1500	89.8191	36.4015	(82.2112, 97.4271)
Downtime +3 staff	1500	89.5088	34.5018	(81.9009, 97.1168)
Downtime +4 staff	1500	76.3328	23.2982	(68.7249, 83.9408)

Pooled StDev = 150.313

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping	
Downtime +1 staff	1500	1418.60	A	
Downtime 7 day	1500	1417.97	A	
Downtime +2 staff	1500	89.8191		B
Downtime +3 staff	1500	89.5088		B
Downtime +4 staff	1500	76.3328		B

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	0.627	5.489	(-14.354, 15.608)	0.11	1.0000
Downtime +2 staff-Downtime 7 day	-1328.15	5.489	(-1343.13, -1313.17)	-241.98	<0.0001
Downtime +3 staff-Downtime 7 day	-1328.46	5.489	(-1343.44, -1313.48)	-242.04	<0.0001
Downtime +4 staff-Downtime 7 day	-1341.64	5.489	(-1356.62, -1326.66)	-244.44	<0.0001
Downtime +2 staff-Downtime +1 staff	-1328.78	5.489	(-1343.76, -1313.80)	-242.10	<0.0001
Downtime +3 staff-Downtime +1 staff	-1329.09	5.489	(-1344.07, -1314.11)	-242.15	<0.0001
Downtime +4 staff-Downtime +1 staff	-1342.27	5.489	(-1357.25, -1327.29)	-244.55	<0.0001
Downtime +3 staff-Downtime +2 staff	-0.310	5.489	(-15.291, 14.671)	-0.06	1.0000
Downtime +4 staff-Downtime +2 staff	-13.486	5.489	(-28.467, 1.495)	-2.46	0.1006
Downtime +4 staff-Downtime +3 staff	-13.176	5.489	(-28.157, 1.805)	-2.40	0.1151

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

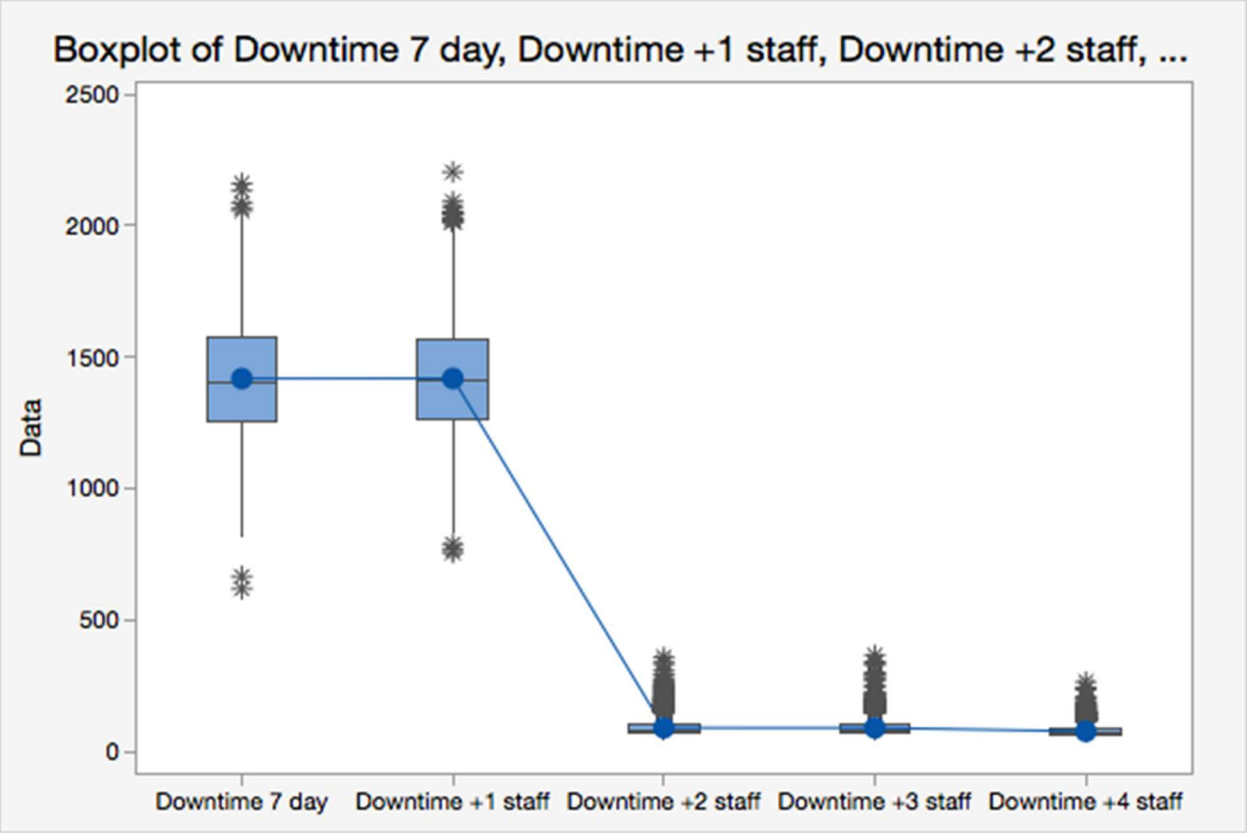
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	1417.97	A
Downtime +1 staff	1500	1418.60	A
Downtime +2 staff	1500	89.8191	
Downtime +3 staff	1500	89.5088	
Downtime +4 staff	1500	76.3328	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	0.627	5.489	(-12.775, 14.029)	0.11	0.9999
Downtime +2 staff-Downtime 7 day	-1328.15	5.489	(-1341.56, -1314.75)	-241.98	<0.0001
Downtime +3 staff-Downtime 7 day	-1328.46	5.489	(-1341.87, -1315.06)	-242.04	<0.0001
Downtime +4 staff-Downtime 7 day	-1341.64	5.489	(-1355.04, -1328.24)	-244.44	<0.0001

Individual confidence level = 98.54%



Appendix D.2.2 – Total Treatment Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, Downtime +1 staff, Downtime +2 staff, Downtime +3 staff, Downtime +4 staff

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	3742353795	935588449	36731.97	*
Error	7495	190902803	25471		
Total	7499	3933256599			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
159.595	95.15%	95.14%	95.14%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	1731.50	247.070	(1723.42, 1739.58)
Downtime +1 staff	1500	1732.44	241.847	(1724.36, 1740.51)
Downtime +2 staff	1500	304.851	56.207	(296.774, 312.929)
Downtime +3 staff	1500	304.428	54.243	(296.350, 312.506)
Downtime +4 staff	1500	261.970	41.454	(253.892, 270.048)

Pooled StDev = 159.595

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
Downtime +1 staff	1500	1732.44	A		
Downtime 7 day	1500	1731.50	A		
Downtime +2 staff	1500	304.851		B	
Downtime +3 staff	1500	304.428		B	
Downtime +4 staff	1500	261.970			C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	0.935	5.828	(-14.971, 16.841)	0.16	0.9999
Downtime +2 staff-Downtime 7 day	-1426.65	5.828	(-1442.56, -1410.74)	-244.81	<0.0001
Downtime +3 staff-Downtime 7 day	-1427.07	5.828	(-1442.98, -1411.17)	-244.88	<0.0001
Downtime +4 staff-Downtime 7 day	-1469.53	5.828	(-1485.44, -1453.63)	-252.17	<0.0001
Downtime +2 staff-Downtime +1 staff	-1427.58	5.828	(-1443.49, -1411.68)	-244.97	<0.0001
Downtime +3 staff-Downtime +1 staff	-1428.01	5.828	(-1443.91, -1412.10)	-245.04	<0.0001
Downtime +4 staff-Downtime +1 staff	-1470.47	5.828	(-1486.37, -1454.56)	-252.33	<0.0001
Downtime +3 staff-Downtime +2 staff	-0.424	5.828	(-16.330, 15.482)	-0.07	1.0000
Downtime +4 staff-Downtime +2 staff	-42.882	5.828	(-58.788, -26.976)	-7.36	<0.0001
Downtime +4 staff-Downtime +3 staff	-42.458	5.828	(-58.364, -26.552)	-7.29	<0.0001

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

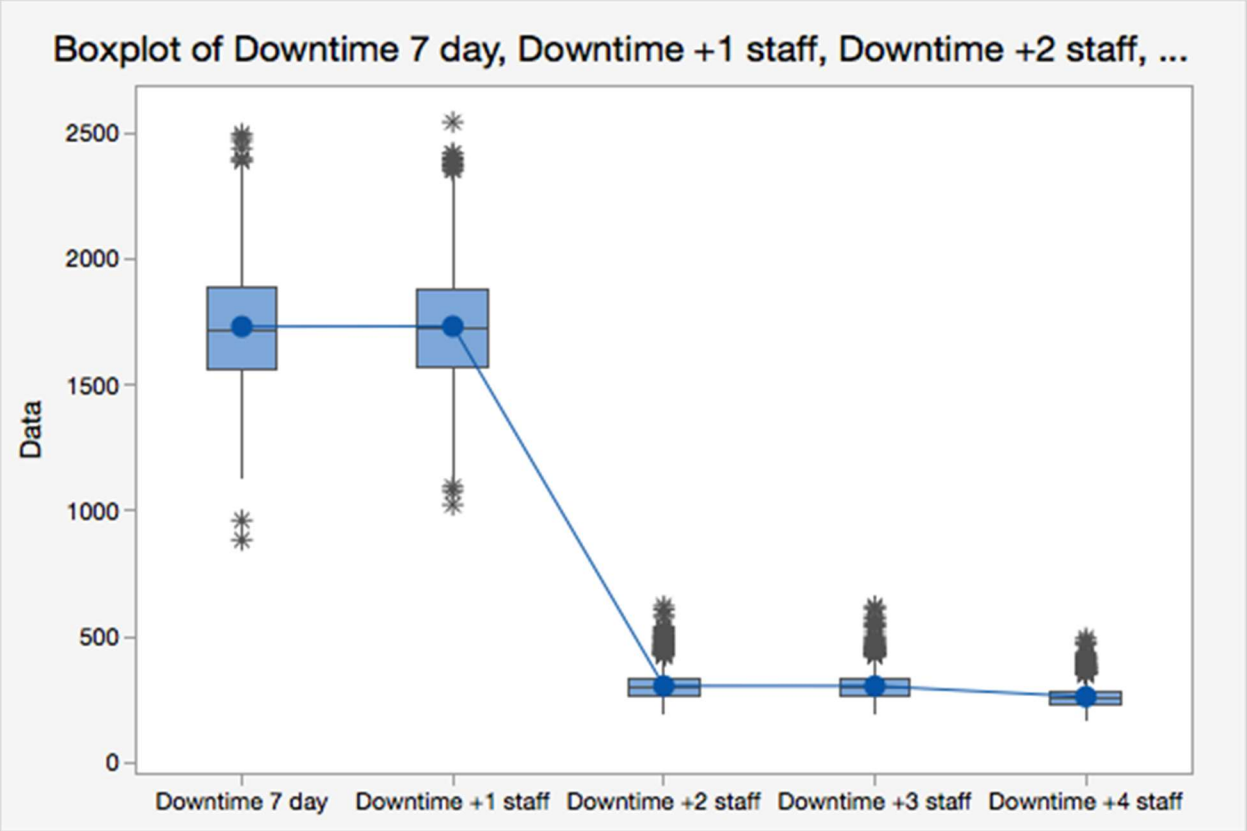
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	1731.50	A
Downtime +1 staff	1500	1732.44	A
Downtime +2 staff	1500	304.851	
Downtime +3 staff	1500	304.428	
Downtime +4 staff	1500	261.970	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	0.935	5.828	(-13.295, 15.165)	0.16	0.9995
Downtime +2 staff-Downtime 7 day	-1426.65	5.828	(-1440.88, -1412.42)	-244.81	<0.0001
Downtime +3 staff-Downtime 7 day	-1427.07	5.828	(-1441.30, -1412.84)	-244.88	<0.0001
Downtime +4 staff-Downtime 7 day	-1469.53	5.828	(-1483.76, -1455.30)	-252.17	<0.0001

Individual confidence level = 98.54%



Appendix D.2.3 – Laboratory Throughput

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, Downtime +1 staff, Downtime +2 staff, Downtime +3 staff, Downtime +4 staff

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	13006041164	3251510291	547851.93	*
Error	7495	44482950	5935		
Total	7499	13050524114			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
77.0391	99.66%	99.66%	99.66%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	4529.40	67.031	(4525.50, 4533.30)
Downtime +1 staff	1500	4525.21	66.923	(4521.31, 4529.11)
Downtime +2 staff	1500	7165.92	74.301	(7162.02, 7169.82)
Downtime +3 staff	1500	7165.75	74.292	(7161.85, 7169.65)
Downtime +4 staff	1500	7308.11	98.302	(7304.21, 7312.00)

Pooled StDev = 77.0391

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
Downtime +4 staff	1500	7308.11	A		
Downtime +2 staff	1500	7165.92		B	
Downtime +3 staff	1500	7165.75		B	
Downtime 7 day	1500	4529.40			C
Downtime +1 staff	1500	4525.21			C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	-4.187	2.813	(-11.865, 3.491)	-1.49	0.5700
Downtime +2 staff-Downtime 7 day	2636.52	2.813	(2628.84, 2644.19)	937.24	<0.0001
Downtime +3 staff-Downtime 7 day	2636.35	2.813	(2628.67, 2644.02)	937.18	<0.0001
Downtime +4 staff-Downtime 7 day	2778.71	2.813	(2771.03, 2786.38)	987.78	<0.0001
Downtime +2 staff-Downtime +1 staff	2640.70	2.813	(2633.03, 2648.38)	938.73	<0.0001
Downtime +3 staff-Downtime +1 staff	2640.53	2.813	(2632.86, 2648.21)	938.67	<0.0001
Downtime +4 staff-Downtime +1 staff	2782.89	2.813	(2775.21, 2790.57)	989.27	<0.0001
Downtime +3 staff-Downtime +2 staff	-0.169	2.813	(-7.847, 7.509)	-0.06	1.0000
Downtime +4 staff-Downtime +2 staff	142.189	2.813	(134.511, 149.867)	50.55	<0.0001
Downtime +4 staff-Downtime +3 staff	142.359	2.813	(134.681, 150.037)	50.61	<0.0001

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

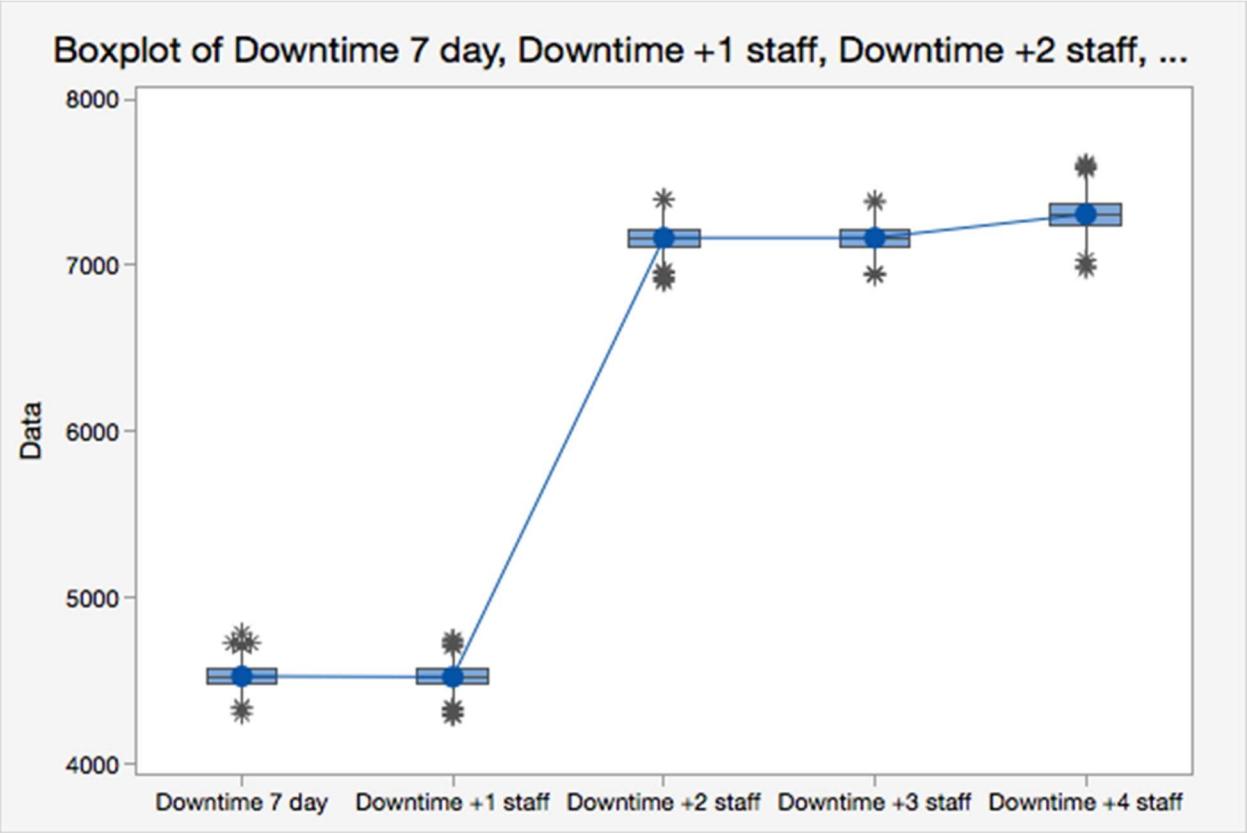
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	4529.40	A
Downtime +4 staff	1500	7308.11	
Downtime +2 staff	1500	7165.92	
Downtime +3 staff	1500	7165.75	
Downtime +1 staff	1500	4525.21	A

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	-4.187	2.813	(-11.056, 2.682)	-1.49	0.3747
Downtime +2 staff-Downtime 7 day	2636.52	2.813	(2629.65, 2643.38)	937.24	<0.0001
Downtime +3 staff-Downtime 7 day	2636.35	2.813	(2629.48, 2643.22)	937.18	<0.0001
Downtime +4 staff-Downtime 7 day	2778.71	2.813	(2771.84, 2785.57)	987.78	<0.0001

Individual confidence level = 98.54%



Appendix D.2.4 – Critical Reporting within 15 minutes

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, Downtime +1 staff, Downtime +2 staff, Downtime +3 staff, downtime +4 staff

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	366258	91564.6	18356.68	*
Error	7495	37386	5.0		
Total	7499	403644			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.23340	90.74%	90.73%	90.73%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	78.7837	2.88726	(78.6706, 78.8967)
Downtime +1 staff	1500	78.8797	2.83785	(78.7667, 78.9928)
Downtime +2 staff	1500	91.7376	1.82516	(91.6246, 91.8506)
Downtime +3 staff	1500	91.8145	1.80680	(91.7015, 91.9276)
downtime +4 staff	1500	95.0896	1.39821	(94.9765, 95.2026)

Pooled StDev = 2.23340

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
downtime +4 staff	1500	95.0896	A		
Downtime +3 staff	1500	91.8145		B	
Downtime +2 staff	1500	91.7376		B	
Downtime +1 staff	1500	78.8797			C
Downtime 7 day	1500	78.7837			C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	0.09607	0.08155	(-0.12652, 0.31866)	1.18	0.7641
Downtime +2 staff-Downtime 7 day	12.9539	0.08155	(12.7313, 13.1765)	158.84	<0.0001
Downtime +3 staff-Downtime 7 day	13.0309	0.08155	(12.8083, 13.2535)	159.79	<0.0001
downtime +4 staff-Downtime 7 day	16.3059	0.08155	(16.0833, 16.5285)	199.94	<0.0001
Downtime +2 staff-Downtime +1 staff	12.8579	0.08155	(12.6353, 13.0805)	157.66	<0.0001
Downtime +3 staff-Downtime +1 staff	12.9348	0.08155	(12.7122, 13.1574)	158.61	<0.0001
downtime +4 staff-Downtime +1 staff	16.2098	0.08155	(15.9872, 16.4324)	198.77	<0.0001
Downtime +3 staff-Downtime +2 staff	0.07696	0.08155	(-0.14564, 0.29955)	0.94	0.8798
downtime +4 staff-Downtime +2 staff	3.35196	0.08155	(3.12937, 3.57455)	41.10	<0.0001
downtime +4 staff-Downtime +3 staff	3.27501	0.08155	(3.05242, 3.49760)	40.16	<0.0001

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

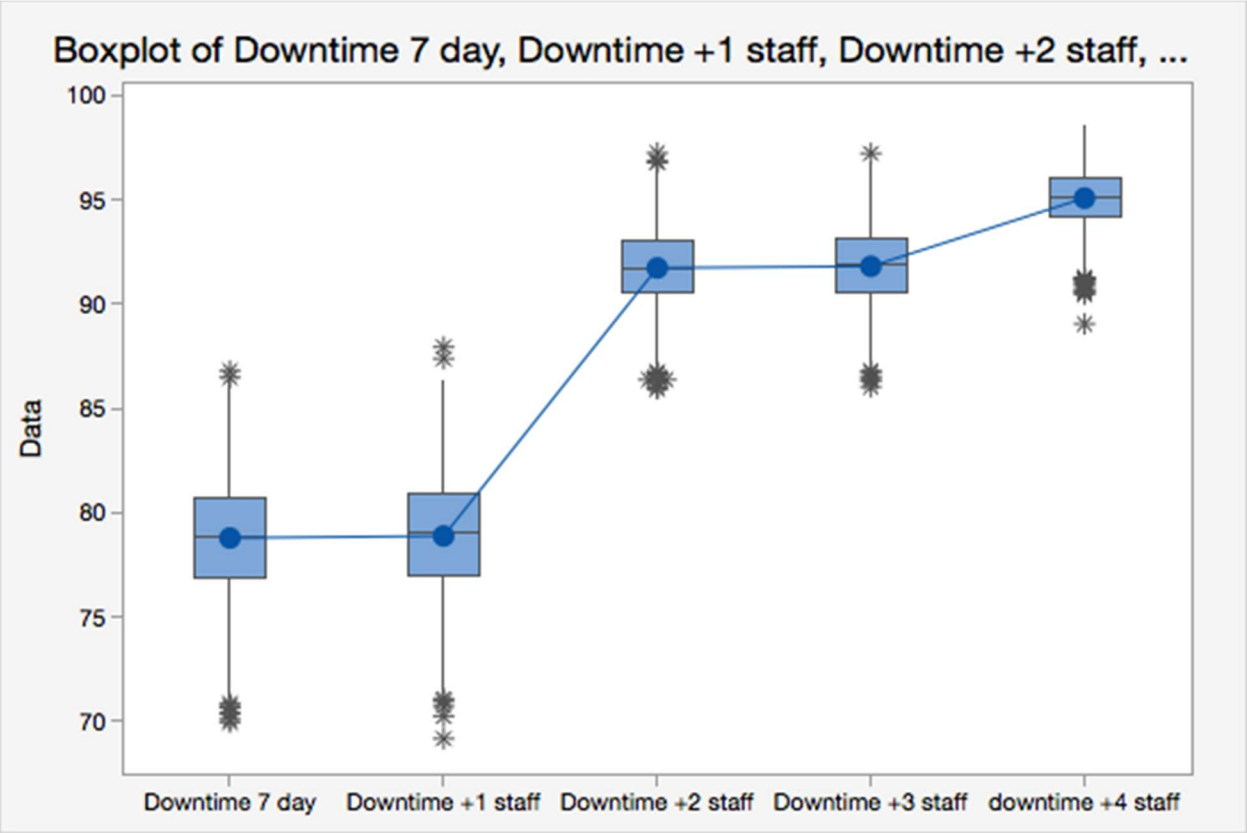
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	78.7837	A
downtime +4 staff	1500	95.0896	
Downtime +3 staff	1500	91.8145	
Downtime +2 staff	1500	91.7376	
Downtime +1 staff	1500	78.8797	A

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Downtime +1 staff-Downtime 7 day	0.09607	0.08155	(-0.10307, 0.29520)	1.18	0.5832
Downtime +2 staff-Downtime 7 day	12.9539	0.08155	(12.7548, 13.1531)	158.84	<0.0001
Downtime +3 staff-Downtime 7 day	13.0309	0.08155	(12.8318, 13.2300)	159.79	<0.0001
downtime +4 staff-Downtime 7 day	16.3059	0.08155	(16.1068, 16.5050)	199.94	<0.0001

Individual confidence level = 98.54%



Appendix D.2.5 – Chemistry Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, staff+1 TAT, staff+2 TAT, staff+3 TAT, staff+4 TAT

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	20085157828	5021289457	322074.78	*
Error	7495	116850393	15590		
Total	7499	20202008221			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
124.862	99.42%	99.42%	99.42%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	3637.57	129.399	(3631.25, 3643.89)
staff+1 TAT	1500	3673.96	131.536	(3667.64, 3680.28)
staff+2 TAT	1500	444.392	145.636	(438.072, 450.712)
staff+3 TAT	1500	440.304	148.157	(433.984, 446.624)
staff+4 TAT	1500	92.2049	27.3159	(85.8851, 98.5247)

Pooled StDev = 124.862

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
staff+1 TAT	1500	3673.96	A		
Downtime 7 day	1500	3637.57		B	
staff+2 TAT	1500	444.392			C
staff+3 TAT	1500	440.304			C
staff+4 TAT	1500	92.2049			D

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	36.392	4.559	(23.947, 48.836)	7.98	<0.0001
staff+2 TAT-Downtime 7 day	-3193.17	4.559	(-3205.62, -3180.73)	-700.36	<0.0001
staff+3 TAT-Downtime 7 day	-3197.26	4.559	(-3209.71, -3184.82)	-701.26	<0.0001
staff+4 TAT-Downtime 7 day	-3545.36	4.559	(-3557.81, -3532.92)	-777.61	<0.0001
staff+2 TAT-staff+1 TAT	-3229.57	4.559	(-3242.01, -3217.12)	-708.35	<0.0001
staff+3 TAT-staff+1 TAT	-3233.65	4.559	(-3246.10, -3221.21)	-709.24	<0.0001
staff+4 TAT-staff+1 TAT	-3581.75	4.559	(-3594.20, -3569.31)	-785.59	<0.0001
staff+3 TAT-staff+2 TAT	-4.088	4.559	(-16.532, 8.356)	-0.90	0.8983
staff+4 TAT-staff+2 TAT	-352.187	4.559	(-364.631, -339.743)	-77.25	<0.0001
staff+4 TAT-staff+3 TAT	-348.099	4.559	(-360.543, -335.655)	-76.35	<0.0001

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

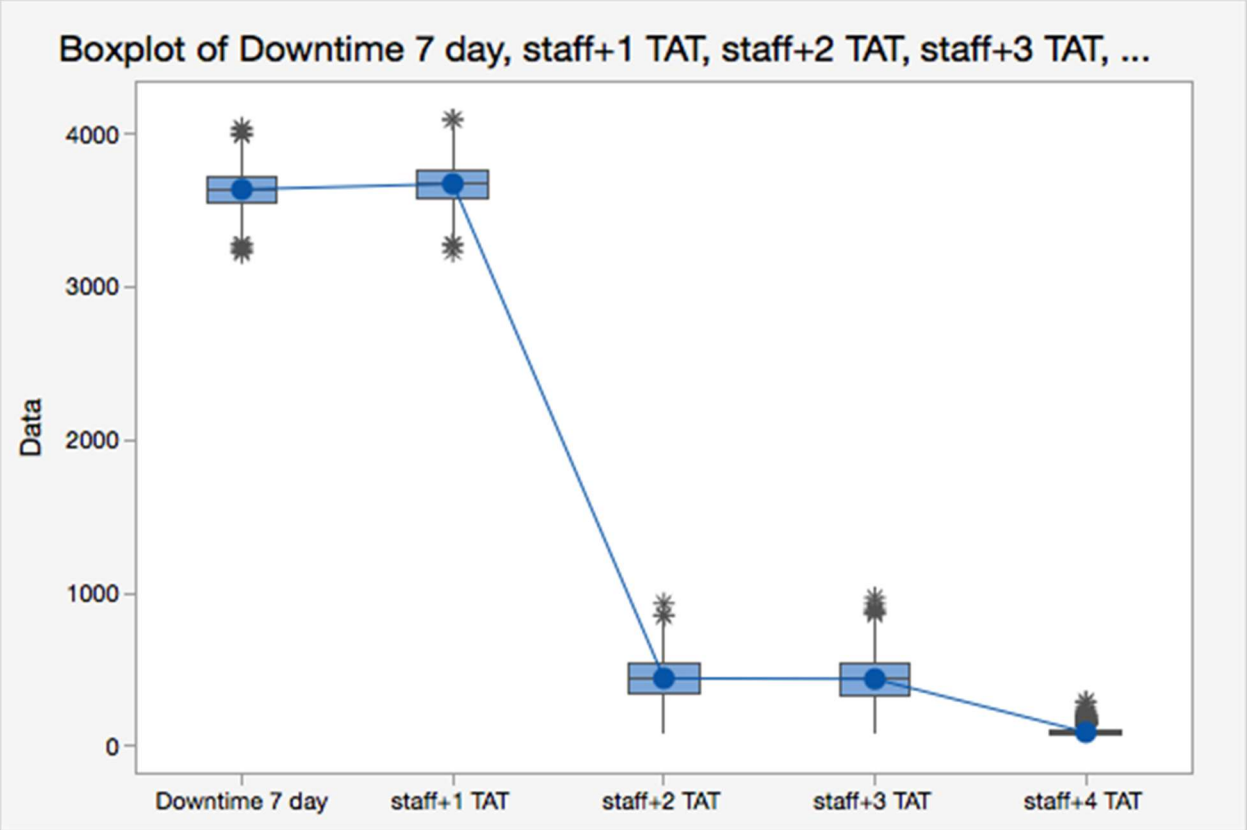
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	3637.57	A
staff+1 TAT	1500	3673.96	
staff+2 TAT	1500	444.392	
staff+3 TAT	1500	440.304	
staff+4 TAT	1500	92.2049	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	36.392	4.559	(25.259, 47.525)	7.98	<0.0001
staff+2 TAT-Downtime 7 day	-3193.17	4.559	(-3204.31, -3182.04)	-700.36	<0.0001
staff+3 TAT-Downtime 7 day	-3197.26	4.559	(-3208.39, -3186.13)	-701.26	<0.0001
staff+4 TAT-Downtime 7 day	-3545.36	4.559	(-3556.49, -3534.23)	-777.61	<0.0001

Individual confidence level = 98.54%



Appendix D.2.6 – Coagulation Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, staff+1 TAT, staff+2 TAT, staff+3 TAT, staff+4 TAT

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	6984093115	1746023279	303542.65	*
Error	7495	43112375	5752		
Total	7499	7027205490			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
75.8429	99.39%	99.39%	99.39%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	2041.41	116.368	(2037.57, 2045.25)
staff+1 TAT	1500	2066.92	113.491	(2063.08, 2070.76)
staff+2 TAT	1500	89.3577	32.9456	(85.5190, 93.1965)
staff+3 TAT	1500	88.7934	35.2246	(84.9546, 92.6321)
staff+4 TAT	1500	75.2746	3.58665	(71.4358, 79.1133)

Pooled StDev = 75.8429

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
staff+1 TAT	1500	2066.92	A		
Downtime 7 day	1500	2041.41		B	
staff+2 TAT	1500	89.3577			C
staff+3 TAT	1500	88.7934			C

staff+4 TAT	1500	75.2746	D

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	25.508	2.769	(17.949, 33.067)	9.21	<0.0001
staff+2 TAT-Downtime 7 day	-1952.05	2.769	(-1959.61, -1944.49)	-704.87	<0.0001
staff+3 TAT-Downtime 7 day	-1952.62	2.769	(-1960.18, -1945.06)	-705.07	<0.0001
staff+4 TAT-Downtime 7 day	-1966.14	2.769	(-1973.69, -1958.58)	-709.95	<0.0001
staff+2 TAT-staff+1 TAT	-1977.56	2.769	(-1985.12, -1970.00)	-714.08	<0.0001
staff+3 TAT-staff+1 TAT	-1978.12	2.769	(-1985.68, -1970.57)	-714.28	<0.0001
staff+4 TAT-staff+1 TAT	-1991.64	2.769	(-1999.20, -1984.08)	-719.16	<0.0001
staff+3 TAT-staff+2 TAT	-0.564	2.769	(-8.123, 6.995)	-0.20	0.9996
staff+4 TAT-staff+2 TAT	-14.083	2.769	(-21.642, -6.524)	-5.09	<0.0001
staff+4 TAT-staff+3 TAT	-13.519	2.769	(-21.078, -5.960)	-4.88	<0.0001

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

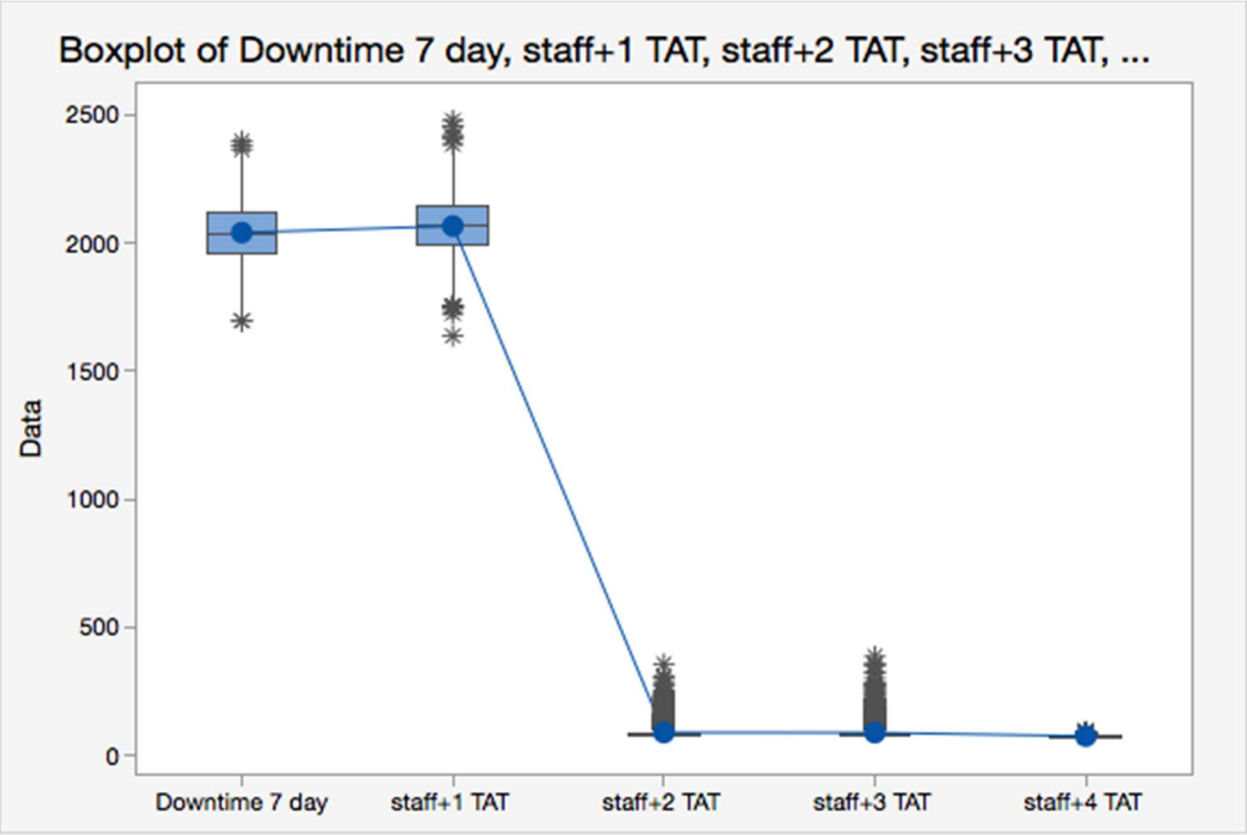
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	2041.41	A
staff+1 TAT	1500	2066.92	
staff+2 TAT	1500	89.3577	
staff+3 TAT	1500	88.7934	
staff+4 TAT	1500	75.2746	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	25.508	2.769	(18.745, 32.270)	9.21	<0.0001
staff+2 TAT-Downtime 7 day	-1952.05	2.769	(-1958.82, -1945.29)	-704.87	<0.0001
staff+3 TAT-Downtime 7 day	-1952.62	2.769	(-1959.38, -1945.85)	-705.07	<0.0001
staff+4 TAT-Downtime 7 day	-1966.14	2.769	(-1972.90, -1959.37)	-709.95	<0.0001

Individual confidence level = 98.54%



Appendix D.2.7 – Hematology Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, staff+1 TAT, staff+2 TAT, staff+3 TAT, staff+4 TAT

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	12566584934	3141646233	422463.31	*
Error	7495	55736529	7436		
Total	7499	12622321463			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
86.2351	99.56%	99.56%	99.56%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	2724.59	127.031	(2720.23, 2728.95)
staff+1 TAT	1500	2757.57	127.596	(2753.20, 2761.93)
staff+2 TAT	1500	106.020	46.948	(101.656, 110.385)
staff+3 TAT	1500	105.514	49.507	(101.150, 109.879)
staff+4 TAT	1500	85.3663	10.4763	(81.0016, 89.7310)

Pooled StDev = 86.2351

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
staff+1 TAT	1500	2757.57	A		
Downtime 7 day	1500	2724.59		B	
staff+2 TAT	1500	106.020			C
staff+3 TAT	1500	105.514			C

staff+4 TAT	1500	85.3663	D

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	32.976	3.149	(24.382, 41.571)	10.47	<0.0001
staff+2 TAT-Downtime 7 day	-2618.57	3.149	(-2627.16, -2609.98)	-831.59	<0.0001
staff+3 TAT-Downtime 7 day	-2619.08	3.149	(-2627.67, -2610.48)	-831.75	<0.0001
staff+4 TAT-Downtime 7 day	-2639.22	3.149	(-2647.82, -2630.63)	-838.15	<0.0001
staff+2 TAT-staff+1 TAT	-2651.55	3.149	(-2660.14, -2642.95)	-842.07	<0.0001
staff+3 TAT-staff+1 TAT	-2652.05	3.149	(-2660.65, -2643.46)	-842.23	<0.0001
staff+4 TAT-staff+1 TAT	-2672.20	3.149	(-2680.79, -2663.61)	-848.62	<0.0001
staff+3 TAT-staff+2 TAT	-0.506	3.149	(-9.101, 8.089)	-0.16	0.9999
staff+4 TAT-staff+2 TAT	-20.654	3.149	(-29.249, -12.059)	-6.56	<0.0001
staff+4 TAT-staff+3 TAT	-20.148	3.149	(-28.743, -11.554)	-6.40	<0.0001

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

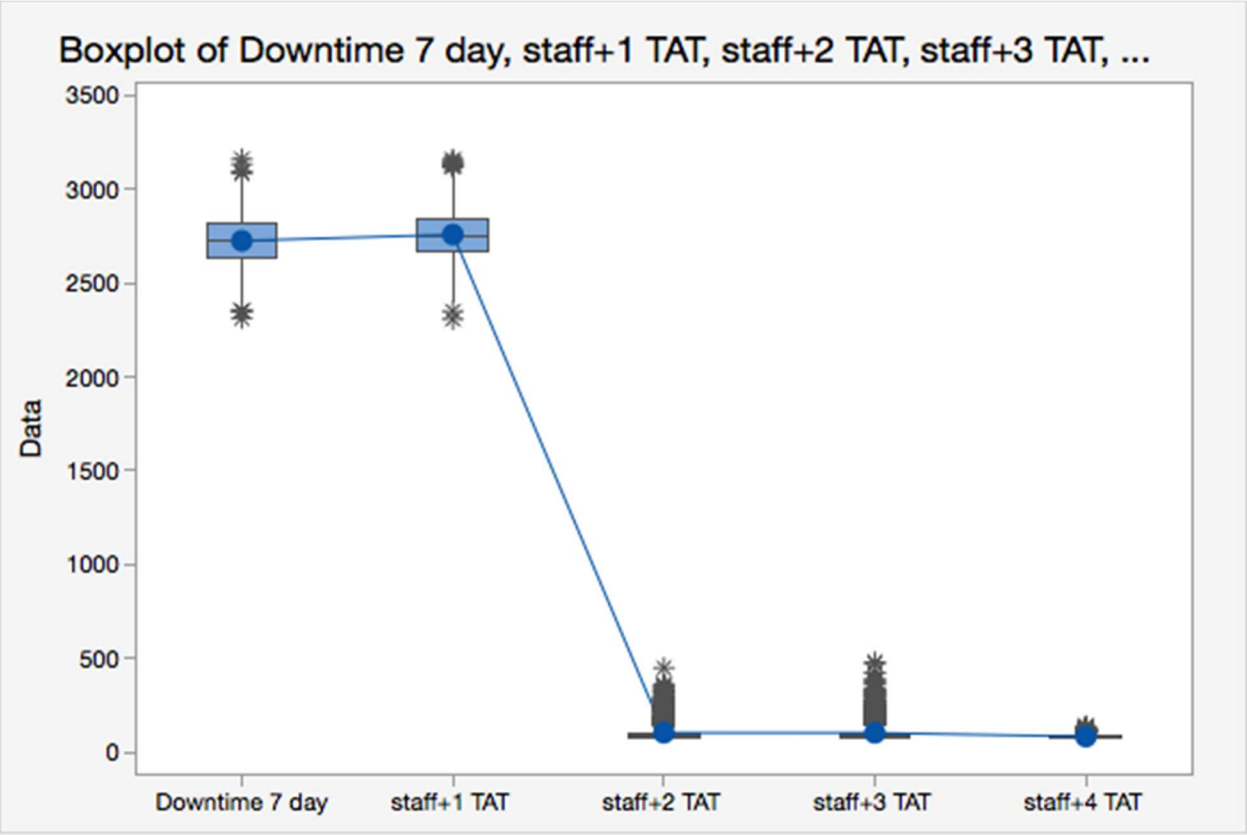
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	2724.59	A
staff+1 TAT	1500	2757.57	
staff+2 TAT	1500	106.020	
staff+3 TAT	1500	105.514	
staff+4 TAT	1500	85.3663	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	32.976	3.149	(25.287, 40.665)	10.47	<0.0001
staff+2 TAT-Downtime 7 day	-2618.57	3.149	(-2626.26, -2610.88)	-831.59	<0.0001
staff+3 TAT-Downtime 7 day	-2619.08	3.149	(-2626.76, -2611.39)	-831.75	<0.0001
staff+4 TAT-Downtime 7 day	-2639.22	3.149	(-2646.91, -2631.53)	-838.15	<0.0001

Individual confidence level = 98.54%



Appendix D.2.8 – Urinalysis Turnaround Time

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	Downtime 7 day, staff+1 TAT, staff+2 TAT, staff+3 TAT, staff+4 TAT

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	3298346322	824586580	216767.69	*
Error	7495	28511059	3804		
Total	7499	3326857380			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
61.6767	99.14%	99.14%	99.14%

Means

Factor	N	Mean	StDev	95% CI
Downtime 7 day	1500	1424.81	95.205	(1421.69, 1427.93)
staff+1 TAT	1500	1459.24	94.280	(1456.11, 1462.36)
staff+2 TAT	1500	91.8476	22.0021	(88.7259, 94.9693)
staff+3 TAT	1500	91.2554	23.9101	(88.1337, 94.3771)
staff+4 TAT	1500	82.5654	3.40831	(79.4437, 85.6871)

Pooled StDev = 61.6767

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
staff+1 TAT	1500	1459.24	A		
Downtime 7 day	1500	1424.81		B	
staff+2 TAT	1500	91.8476			C
staff+3 TAT	1500	91.2554			C

staff+4 TAT	1500	82.5654	D

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	34.423	2.252	(28.276, 40.570)	15.28	<0.0001
staff+2 TAT-Downtime 7 day	-1332.97	2.252	(-1339.11, -1326.82)	-591.87	<0.0001
staff+3 TAT-Downtime 7 day	-1333.56	2.252	(-1339.70, -1327.41)	-592.14	<0.0001
staff+4 TAT-Downtime 7 day	-1342.25	2.252	(-1348.39, -1336.10)	-595.99	<0.0001
staff+2 TAT-staff+1 TAT	-1367.39	2.252	(-1373.54, -1361.24)	-607.16	<0.0001
staff+3 TAT-staff+1 TAT	-1367.98	2.252	(-1374.13, -1361.83)	-607.42	<0.0001
staff+4 TAT-staff+1 TAT	-1376.67	2.252	(-1382.82, -1370.52)	-611.28	<0.0001
staff+3 TAT-staff+2 TAT	-0.592	2.252	(-6.739, 5.555)	-0.26	0.9990
staff+4 TAT-staff+2 TAT	-9.282	2.252	(-15.429, -3.135)	-4.12	0.0004
staff+4 TAT-staff+3 TAT	-8.690	2.252	(-14.837, -2.543)	-3.86	0.0011

Individual confidence level = 99.36%

Grouping Information Using the Dunnett Method and 95% Confidence

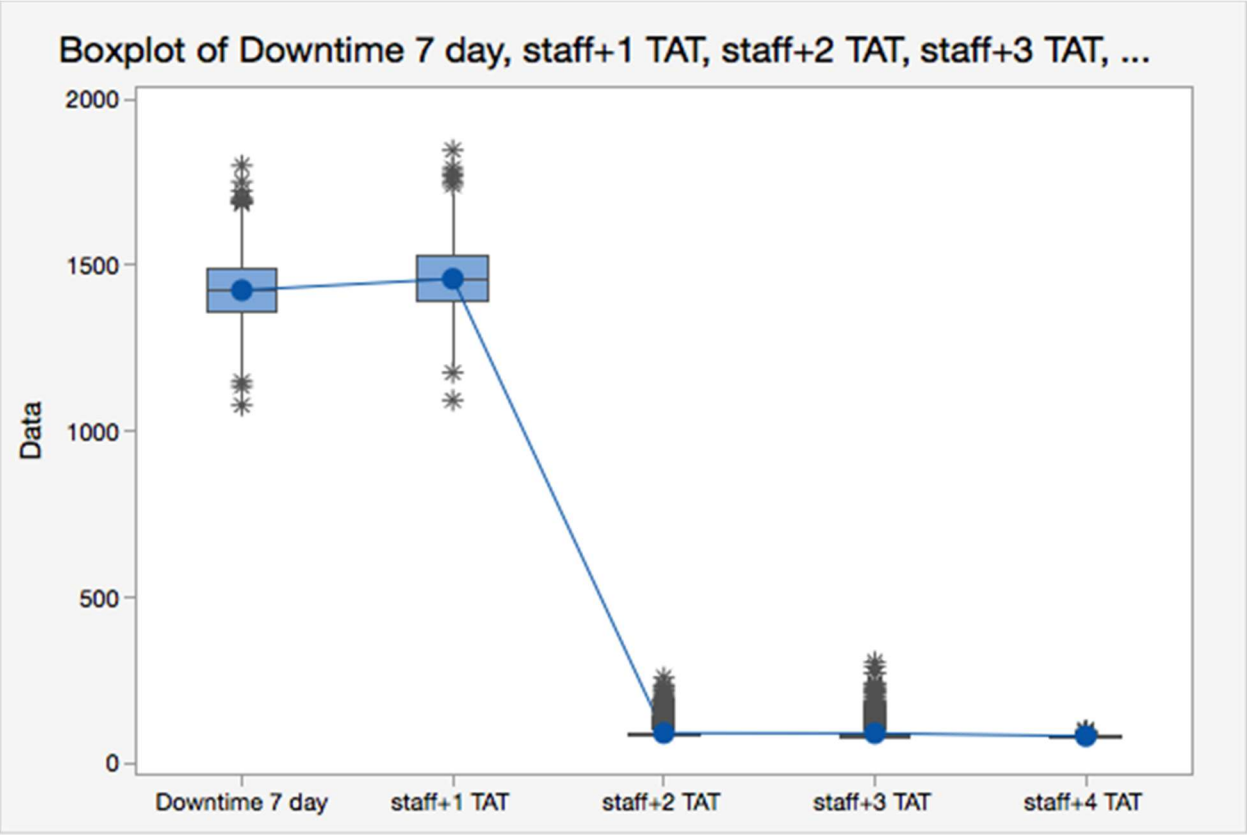
Factor	N	Mean	Grouping
Downtime 7 day (control)	1500	1424.81	A
staff+1 TAT	1500	1459.24	
staff+2 TAT	1500	91.8476	
staff+3 TAT	1500	91.2554	
staff+4 TAT	1500	82.5654	

Means not labeled with the letter A are significantly different from the control level mean.

Dunnett Simultaneous Tests for Level Mean - Control Mean

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
staff+1 TAT-Downtime 7 day	34.423	2.252	(28.924, 39.922)	15.28	<0.0001
staff+2 TAT-Downtime 7 day	-1332.97	2.252	(-1338.46, -1327.47)	-591.87	<0.0001
staff+3 TAT-Downtime 7 day	-1333.56	2.252	(-1339.06, -1328.06)	-592.14	<0.0001
staff+4 TAT-Downtime 7 day	-1342.25	2.252	(-1347.75, -1336.75)	-595.99	<0.0001

Individual confidence level = 98.54%



Appendix D.2.9 – Support Staff Time to Report Results

Method

Null hypothesis	H_0: All means are equal
Alternative hypothesis	H_1: At least one mean is different

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4	Report+1, Report+2, Report+3, Report+4

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	373.519	124.506	1333.52	*
Error	5996	559.828	0.093		
Total	5999	933.348			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.305560	40.02%	39.99%	39.94%

Means

Factor	N	Mean	StDev	95% CI
Report+1	1500	36.3064	0.326117	(36.2909, 36.3218)
Report+2	1500	36.4728	0.302024	(36.4574, 36.4883)
Report+3	1500	35.8982	0.292487	(35.8828, 35.9137)
Report+4	1500	35.9113	0.300580	(35.8958, 35.9268)

Pooled StDev = 0.305560

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping		
Report+2	1500	36.4728	A		
Report+1	1500	36.3064		B	
Report+4	1500	35.9113			C
Report+3	1500	35.8982			C

Means that do not share a letter are significantly different.

Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Report+2-Report+1	0.16646	0.01116	(0.13782, 0.19510)	14.92	<0.0001
Report+3-Report+1	-0.40815	0.01116	(-0.43679, -0.37951)	-36.58	<0.0001
Report+4-Report+1	-0.39507	0.01116	(-0.42371, -0.36643)	-35.41	<0.0001
Report+3-Report+2	-0.57462	0.01116	(-0.60326, -0.54598)	-51.50	<0.0001
Report+4-Report+2	-0.56153	0.01116	(-0.59017, -0.53289)	-50.33	<0.0001
Report+4-Report+3	0.01308	0.01116	(-0.01555, 0.04172)	1.17	0.6441

Individual confidence level = 98.97%