Emergency Department Triage Process Improvement

Tessa Williams
Western Michigan University, tessawilliam01@yahoo.com

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EMERGENCY DEPARTMENT TRIAGE PROCESS IMPROVEMENT
Denise Azcui, Meghan Burt, and Tessa Williams
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Abstract

This senior design project was completed at Ascension Borgess Hospital located in Kalamazoo, Michigan. The mission of Ascension Borgess Hospital is to provide patient centered care. In 2018, 562 patients left the Emergency Department (ED) without being seen, which is a large safety risk for the patients and hospital. Based on this, as well as other obstacles, this project focused on meeting the mission of Ascension Borgess by improving key ED metrics that impact patient centered care. In order to meet that mission, this study aims to improve patient experience, safety and quality of the care provided, profitability for the hospital, and staff satisfaction. This will be accomplished by reducing the number of patients that leave without being seen, reducing the total patient length of stay, and reducing the ineffective use of staff.

Discrete-event simulation software, ProModel, was used to test changes in the ED without disrupting the current system. The current state model was created in ProModel through observations, data collection, and provided hospital databases. The locations, entities (patients), arrival cycles of the entities, processing code, resources (staff), and path networks were created in the current state model. Patients that enter the ED are assigned an acuity level during the triage process which is based upon the severity of the patient's symptoms as well as the number of resources they could potentially occupy from the hospital. The acuity scale ranges from 1 to 5, 1 being high severity and 5 being nonurgent symptoms. The current state model was verified using visual testing and stress testing, and then it was validated using paired sample t-tests on key outcomes.

Four outputs from each simulation model were analyzed in order to measure the three metrics from the project objectives which were the number of patients that leave without being seen (LWBS), the average patient length of stay (LOS), and the inefficient use of staff. The four metrics that were analyzed for each model were: the number of patients that leave without being seen, the average patient length of stay, the percent of time a patient was blocked in the system, and the resource underutilization.

After the current state model was created, four different models were tested against the current state model. The first model created was vertical care, which focuses on patients with acuity level four and five meaning that their symptoms are nonurgent and can be treated in a vertical chair. After they receive treatment, they wait in a results pending area. This helps reduce cleaning cost and utilizes less resources from the hospital. The results from this model showed no changes from the current state metrics.

The second model created focused on check-in and triage changes. This model utilized two triage locations to reduce registered nurses (RN) from doing non-registered nurse related activities. Model two was able to reduce the number of patients that left without being seen by 13% and the percent of time a patient was blocked in the system by 16%.

The third model tested was a proposed lobby layout. This layout was created by essential ED staff that implemented new components into the lobby. Those components were four triage bays, minimal waiting area, two kiosks for digital registration, a separate location for heart attack testing, and a results pending area. The results of this study showed a reduction in LWBS by 22% and a percent of time a patient was blocked by 20%. Based on the simulation outputs and systematic layout planning (SLP), a revised lobby layout was created. This layout reduced the number of triage bays to three and the number of EKG curtain locations to one. The results from this output were promising with a reduction in the number LWBS and percent blocked by 37% and 22%, respectively.
Finally, the fourth model which added an admit holding unit was created and tested. This model added a waiting area for patients being admitted into the hospital for further treatment which created more ED bed availability. The outputs from this model were the most significant as the reduction in LWBS was 69% and the percent blocked was reduced by 40%.

The models were compared through two methods: statistical analysis and a cost analysis. The statistical analysis used ANOVA testing, specifically a Tukey-Kramer test, to determine if the outputs produced were statically different from the current state model. Model 3 showed the most statistically different results for almost every acuity. Additionally, this analysis showed statistically different metrics in model 4 for patients with acuity 1, 2, and 3. This is expected as only patients with more severe symptoms are typically admitted into the hospital. Next a cost analysis was performed which looked at resource usage cost as well as return on investment (ROI) and payback period. Model 4 was the best according to the cost and investment analysis. Model 4 was significantly lower than the other three models for yearly patient resource usage cost by about one million dollars. The return on investment for model 4 was the highest at 63% and had the lowest payback period at 1.7 years.

Based on the results of the study, two short-term recommendations were made. The first was to implement model four, the admit holding unit, as it showed the greatest improvements to the system and cost metrics. Additionally, model two was recommended to be implemented due to its small initial investment of under $74,000. The results of this model were positive for such a small change and investment. Finally, the long-term recommendation was to implement model 3, the proposed lobby layout. This is due to the systems metric benefits and ROI of 30%. The results of model four were very significant to the system and drastically different than the analysis on the other models. This showed that the underlying issue was due to admission blockages throughout the hospital. Therefore, it is recommended to complete a root-case analysis on the admissions issues throughout the entire hospital as implementing model 4 is a surface solution. To complete this, the entire hospital would need to be modeled as patients leaving the ED can move to any department throughout Ascension Borgess.

Finally, the proposed lobby layout and the admit holding unit were combined and a simulation was created. This simulation representing 0ppo These overall recommendations accomplished two of the three metrics: the number of patients that leave without being seen and the patient length of stay. Overall, this study was able to improve patient experience, safety and quality of the care provided, and profitability of the hospital.
Introduction

Background

The senior design study was completed at Ascension Borgess Hospital located on 1521 Gull Rd, Kalamazoo, MI 49048. Ascension Borgess Hospital was founded in 1889 and is a catholic hospital. The hospital is “nationally recognized for specialty services in cardiovascular, pulmonary, orthopedic, bariatric, stroke, rehabilitation and spine care, among others” (Ascension Borgess Hospital). Additionally, they are a regional emergency and trauma center as well as a behavioral health crisis center. Ascension Borgess is a 392 bed community hospital with around 3,200 associated employees. Their mission and values are centered around putting the person at the center of care, specifically with the “Just Say Yes” policy that aims to say yes to every and all patients that walk through the doors.

Within Ascension Borgess, this study will focus on the emergency department, specifically the triage process. The emergency department provided 24-hour care for all types of patients, injuries, and illnesses. Due to the location and subject of this study, the industry sponsors are Larry Carpenter and Raechel Rowland. Larry and Raechel are both part of the performance excellence team at Ascension Borgess. Additionally, the academic advisors are Dr. Tycho Fredericks and Dr. Steven Butt.

Ascension Borgess Emergency Department and Acuity Levels

The goal of the Emergency Department (ED) is to process as many patients as possible with a correct diagnosis and treatment, and get them to a stable condition to either be discharged or move to another place in the hospital for further treatment. The patient flow in an emergency department is as follows. Patients arrive to the ED either as a walk-in or via ambulance. Walk-in patients must register and check-in with the nurse running the front desk. The patients are then asked to wait in the lobby until a triage nurse is available to triage the patient. Once the triage process, or patient evaluation is complete, they will be either placed in a room or sent back to the lobby to wait. The amount of time a patient will wait in the lobby during this step is dependent on the patient’s severity (acuity) of injury or illness as well as availability of resources and rooms at the given time. This process has many steps that leave the patients waiting. The nurses have to juggle this process with the patients arriving via ambulance. For the ambulance arrivals, the EMT’s will call in to the nurse at the desk and provide the information of the incoming patient. Based on their specific acuity, the nurse can assign them a bed before they arrive, allowing the EMT’s to take them directly to that space. The patient flowchart can be shown in Figure 1 below.

![Emergency Department Patient Flowchart](Figure 1 - Emergency Department Patient Flowchart)
In order to run the most effective system and process for both the patients and hospital, the Emergency Department must aim to quickly care for the patients that are the most severe and need immediate attention while letting the less severe patients wait to be seen. At Ascension Borgess Medical Center, a triage process is used to correctly care for the severe patients that come to the ED and aims to prioritize patients based on a triage acuity level. As the patients enter the Emergency Department, either by ambulance or walk-in, the triage nurse performs a quick assessment and assigns the patient a triage acuity level which indicates how urgent a patient must be seen. The Emergency Severity Index (ESI) is used to evaluate a patient’s acuity level. This is a five-level triage algorithm that evaluates the patient’s severity along with the number of resources the patient requires. The acuity scale ranges from 1 to 5, with 1 being the most severe and 5 being non-urgent. If the patient is severe and should not wait to see a doctor, they receive an acuity level of 1 or 2. An acuity level of 3 through 5 is then determined by the number of resources used by each patient. For example, a patient with poison ivy will receive an acuity of 5 while a patient with chest pain will receive an acuity of 2. The image in Figure 2 outlines the Emergency Severity Index process for the evaluation of acuity levels at Ascension Borgess.

Figure 2 - Emergency Severity Index Conceptual Algorithm

Based on the acuity of each patient, the appropriate room assignment will be placed. Within the ED, there are 4 trauma rooms designated for patients with an acuity of 1. For patients with an acuity of 2 or 3, there are 25 standard rooms available for care. Lastly, there are 10 fast track rooms available for patients with an acuity of 4 or 5. Additionally, Ascension Borgess is a behavioral mental health institute, there are eight rooms reserved for patients showing signs of mental illnesses. Behavior mental health (BMH) patients usually have an acuity type of 2 or 3. It is the responsibility of the triage nurse at the front desk to assign the patients that arrive via walk-in or ambulance.

Although the triage process sounds easy in theory, to simply assign a patient an acuity level and have the doctor diagnose their problem, is not simple in practice. There are many factors that affect the efficiency of the triage process that can occur both before and after the triage evaluation is completed. Some of those factors deal with the resources available at the
given time a patient enters the ED, such as the availability of rooms, the number of nurses and doctors working, and incoming calls of the ambulance arriving with traumas. Other factors that could affect triage efficiency are the layout and flow of the Emergency Department. This includes the layout and size of the waiting room, the flow of the waiting room, the flow between the rooms, the flow of the beds, as well as the flow of the psychiatric unit within the ED.

Project Objectives

At Ascension Borgess Hospital, their mission is having patients at the center of their care. They are focused on their patients and making sure they receive the adequate care they need. There are several factors that go into creating a patient centered care hospital, and more specifically a patient centered care Emergency Department. The first and most important factor for the ED is creating a positive patient experience. Patient experience is dependent upon several aspects such as the amount of time a patient waits to be seen by a doctor, if they feel that their care was satisfactory, the environment of the ED, the total amount of time a patient’s stay in the ED is, the attitude of the staff, and many other aspects. A patient experience is also dependent on the individual, their acuity level, and their experiences at other hospitals. In order for Ascension Borgess to increase patients experience there are several factors that need to be considered and it is important to look at the process as a whole.

The second factor that allows for a patient centered care ED is to create safe and quality care. This means that the doctors are able to make the correct diagnosis, the patients are able to receive the appropriate treatment, the patients are not waiting too long to be seen so that their conditions are not worsening with time, the privacy of the patients is kept, and the patients are handled with care while moving throughout the system. The third factor is increase profitability for the hospital. This means to efficiently and efficiently allocate funds that aim to be driven towards either patient experience or safety and quality. In order to keep the focus on the patient, the ED does need to function as a business and look for ways to make sure they are making profit to give back to the people of Kalamazoo. The last factor is staff satisfaction. A big part of a patient’s experience in the ED is how they feel the staff interacts with them while they receive their care. Therefore, it is important to make sure the doctors, nurses, and other administrative clerks feel satisfied at work.

This project aims to improve the four objectives discussed above: patient experience, safety and quality of the care provided, profitability for the hospital, and staff satisfaction. In order to improve these objective, three key metrics will aim to be reduced. The first metric is reduced the number of patients that leave the hospital without being seen and receiving the care they need (LWBS). This is one of the biggest safety risks for the patients and hospitals. Within the last year, 562 patients left without being seen. Ideally, this number should be zero as all patients should be cared for in an adequate amount of time. A potential reason for these patients leaving could be due to the amount of time patients must wait to see a doctor. Therefore, the second metric that will aimed to be reduced is the amount of time a patients spend in the system or length of stay (LOS). This should improve on the patient experience as patients are not waiting as long to receive treatment, their conditions will not worsen with time, and the hospital will be able to increase profit as they will be able to see the same amount of patients in the same amount of time. The last metric that will aimed to be reduced is ineffective use of staff. The ED wants to make sure that each member is performing at the top of their license and being as efficient as possible.
Problem Statement

Efficiency in a hospital Emergency Department is crucial to a patient's treatment outcomes. At Ascension Borgess Hospital, this project aims to improve the efficiency of the emergency department by improving patient experience, the safety and quality of the care provided, profitability for the hospital, and staff satisfaction. This will be accomplished by reducing the number of patients that leave without being seen, reducing the total patient length of stay, and reducing the ineffective use of staff.

Methodology and Literature Review

The first step of the study was to create and analyze different processes to improve the efficiency of the Emergency Department. However, this problem is a national issue as more hospitals nowadays are looking to apply lean manufacturing techniques to the medical setting. Many experiments and studies have already been created that analyzed different processes aiming to reduce overcrowding in the emergency department. In a journal published by Robert Derlet and John Richards in 2000, the most common causes of overcrowding in the ED are: increased complexity and acuity of patients, overall increase in patient volume, lack of beds for patients admitted to the hospitals, delays in service provided by radiology, laboratory, and ancillary services, and shortage of nursing staff as well as administrative/clerical support staff. With these given causes, the major effects of overcrowding are as follows: public safety at risk, prolonged pain and suffering, long waits and dissatisfaction of patients, violence, and miscommunications due to increased volumes (Derlet & Richards, 2000).

An increased complexity and acuity of patients as well as an overall increase in patient volumes were considered in processes moving forward. The big areas of concern were:

- Delays in service provided by radiology, laboratory, and ancillary services
- Shortage of nursing staff as well as administrative/clerical support staff
- Lack of bed for patients admitted to the hospitals

It was determined that these common causes will be further investigated for potential solutions that could be applied to Ascension Borgess Hospital Emergency Department.

1. Delays in Services Provided by ED

The ED provides several services that require patients to wait a significant amount of time in their respective room. The time waiting in these room means that new patients entering the ED must wait a longer amount of time to receive the care they need. This process creates a lot of overcrowding issues in the emergency room as patients are in hospital beds longer than need be. After researching and investigating this issue, the concept of vertical care was found (Coppa, 2018). Vertical care is designed for patients with non-urgent symptoms that can remain in an upright chair position. Once the treatment is received, they then wait in a “results pending” area for diagnosis, further treatment, and discharge. There are many significant benefits of vertical care. The first is that it allows for patients that do not have as severe of injuries to be placed in a chair instead of a bed, allowing for more patients to be seen at one time. Another is that the results pending area allows for multiple nurses to monitor the patients, freeing up resources to be used on more severe patients. Vertical care implementation allows for the
diagnostic tests to be ordered earlier in the process. This will potentially speed up some of the blockage that is creating overcrowding in the Emergency Department (Nakamura). Lastly, vertical can reduce cleaning cost and time. Instead of nurses having to clean the entire room, they can simply clean a vertical chair.

In a study published by Stanford Medicine, it was found that implementation of vertical care increased the number of patients able to be seen from 10 to 20 due to the space availability. Additionally, the average length of stay for patients decreased from 384 minutes to 270 minutes (Coppa, 2018). This study shows the success of vertical care and the benefits of implementing this process into the current ED staff. Therefore, this will be the first method explored in this study.

2. Shortage of Staff

The second biggest issue for overcrowding in the Emergency Department was having a shortage of nursing staff as well as administrative and clerical support staff. Due to the scope of this project, it was determined that the best approach for developing a solution would be to talk directly with the hospital staff at Ascension Borgess Hospital. They currently already struggle with staffing in the ED and it is difficult for the charge nurse to be fully staffed. After asking several of the nurses, it was found that more often than not they are understaffed. This leads to a lot of confusion and exhaustion for the nurses working in the ED. The scope of this project was focused more on the triage process instead of the back rooms of the ED. Therefore, solutions to the staffing issues will be directed more towards the front triage process.

After completing several questionnaires and speaking with the triage nurses, several conclusions were made in regard to making improvements on the shortage of staff. The first method that was analyzed is the addition of two patient care assistants (PCAs). The PCAs allow the nurses to function at the top of their license by taking care of the part of the registration process, assisting the nurses where needed, and running patients to different locations throughout the hospital. The addition of PCAs has been implemented in the current system, and this study aimed to validate the productivity and utilization of those assistants.

The second conclusion that was made was on the use of fast track one and two. In the current system, fast track one and two are used for triage only if an EKG is needed. However, these rooms can be better utilized for triage purposes as they provided the necessary privacy and space to complete the triage. This will remove the current cluster in the triage in registration area.

3. Lack of Beds for Admitted Patients

The final issue on the overcrowding of the Emergency Department has to deal with the lack of beds available for admitted patients. From research and speaking with the hospital staff at Ascension Borgess, one of the main blockages in the ED is caused by beds not being available throughout the hospital floors. This leaves the patients in the ED, that need to be admitted, stuck in their current ED rooms until a bed becomes available. This could take several days which means that new patients coming into the hospital must wait even longer to get an available bed. A feasible solution to this problem could be found in a holding area for admitted patients. “A holding area is described as a place to temporarily hold ED patients that already have a disposition (admission, transfer, OR, discharge) but cannot be accommodated due to a lack of inpatient beds, or availability, or discharge issues such as locating a responsible caretaker”
Therefore, an admit observation unit would be utilized as a holding area for patients that have maximized their care in the ED and are waiting to receive further treatment.

In a study conducted by Chalfin in 2007, it was found that an admitted observation unit would not benefit patients that are in critical condition (Chalfin, 2007). Therefore, patients being admitted into the ICU will not be included in this method. One of the biggest factors to consider for this method was the cost of implementing an admit holding area. In a study completed in 2017, it was found that the total personnel costs per patient bed-hour for holding a patient in the ED was $58.20, whereas holding a patient in an admission holding unit would be $10.40 (Schreyer, 2017). This can be seen in the Figure 3 below. These respective costs indicate that money could be saved in the long run if chosen to be implemented.

Figure 3 – Personnel Cost Per Patient Bed-Hour

Proposed Layout

The final area that will be investigated further is on a proposed lobby layout. A lobby layout was created by essential ED staff that looks to implement new key components that are not currently in their layout. The layout focused on four new key additions. The first addition is to increase the number of triage points, a minimized waiting area, a separate area for EKG, and lastly implementation of kiosks.

Finalized Models

Based on the research conducted above, this study will focus on analyzing four main models and comparing them against the base scenario (current state of ED). Each model will need to be evaluated for efficiency, wait times, and the number of patients that leave without being seen. In summary the four models can be outlined below:

1. Vertical Care
2. Check-in and Triage Changes
3. Proposed Lobby Layout
4. Admit Observation Unit
Procedure

Once a problem statement was defined and a literature review was completed, general methodology for potential ways to solve the problem were found. These methodologies were narrowed down to four different models that could be used to solve the problems specified in the ED. Due to the nature of the ED and the difficult implementation of some of the models, a new way for testing out these different models needed to be found. A large factor in this was that small changes to the hospital processes could have negative effects on patient quality of care. For this reason, different models were tested was using discrete simulation software. The software chosen was ProModel. A description of the software, which includes the reasoning for its use in this study can be read in the as follows: “ProModel is a discrete-event simulation technology that is used to plan, design and improve new or existing manufacturing, logistics and other operational systems. It empowers you to accurately represent real-world processes, including their inherent variability and interdependencies, in order to conduct predictive analysis on potential changes. Optimize your system around your key performance indicators” (ProModel). The first step in using this software was to collect the data needed to simulate the current state of the hospital emergency department. This was done using several different methods which will be discussed in the following section.

Data Collection

Observation

Several methods were used to collect data for this study. The process of data collection started by spending a significant amount of time observing the current state of the ED. Notes on perceived “pain points” for staff and patients throughout this time were collected. Brainstorming was done after each observation session, which led to more research and questions for the academic and industry sponsors.

Questionnaires

Questionnaires were created for the nurses and other hospital staff to further narrow down the scope of the project and root cause the problems in the ED which are patient wait times, patients leaving without being seen, and staff utilization. Several questionnaires were made. A copy of the questionnaire questions seen in table 1 can be found in Appendix A. From the responses to this questionnaire a summary table was created as can be seen below in table 1.

<table>
<thead>
<tr>
<th>Question</th>
<th>Nurse 1</th>
<th>Nurse 2</th>
<th>Nurse 3</th>
<th>Nurse 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>How long have you been a nurse working in triage here?</td>
<td>3 years</td>
<td>3 years</td>
<td>15 years</td>
<td>6 years</td>
</tr>
<tr>
<td>Question</td>
<td>Clinicals</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Have you worked in triage at any other hospitals? (if so ask for best practices)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>How long do patients wait to be triaged after check-in?</td>
<td>Under 10 min usually but 30-40 min when busy</td>
<td>10 minutes</td>
<td>A few minutes: 2-5 min</td>
<td>With no wait-less than 5 min</td>
</tr>
<tr>
<td>How long does it take to triage a patient?</td>
<td>3-5 Minutes but 5-7 for EKG</td>
<td>2 minutes</td>
<td>5 min on average but EKG is 10 min</td>
<td>2 minutes but EKG takes 10</td>
</tr>
<tr>
<td>At your busiest times how many patients are waiting to be seen?</td>
<td>10</td>
<td>5-25</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Does the acuity of a patient effect triage times or is it a standard process?</td>
<td>Standard</td>
<td>Standard but may wait longer based on staff availability</td>
<td>Higher Acuity comes back faster</td>
<td>Same questions for everyone but higher acuity gets in quicker</td>
</tr>
<tr>
<td>What is the biggest issue/bottleneck for getting patients to a bed?</td>
<td>Moving patients into beds upstairs and staffing</td>
<td>Staffing levels - too few people at busy times and bad layout</td>
<td>Dr.s wait on patients and see less than they can</td>
<td>The ED is always understaffed</td>
</tr>
<tr>
<td>Where do you think the biggest improvement could occur in the ED?</td>
<td>Fast Track, Discharge/waiting on results, Staffing</td>
<td>Physical layout, triage process</td>
<td>More staffing, not enough for close rooms</td>
<td>Can’t get bed and staffing from other areas of hospital</td>
</tr>
</tbody>
</table>

Table 1 - Triage Nurse Questionnaire Summary

Time Studies

After the observation and questionnaires, preliminary time studies were conducted. These studies were meant to gain a better understanding of the ED processes and bottlenecks, as well as a general understand of the timing for patient care. Furthermore, they were used to validate a hospital database which was the main method of data for the creation of simulation models. An example time study which was taken on all patient processing for the front lobby will be outlined
in this section. First, the process was broken down into elements, which were as follows in table 2.

<table>
<thead>
<tr>
<th>Time Study Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element 1</strong></td>
</tr>
<tr>
<td>Door to Check-in</td>
</tr>
</tbody>
</table>

Table 2 - Preliminary Lobby Time Study Elements

After elements were found for the study the number of required observations was found using the following equation:

$$n = \left(\frac{Z \cdot S}{a \cdot \bar{x}}\right)^2$$

Where,

- $n$ = number of observations
- $Z$ = desired statistical confidence
- $S$ = observed standard deviation in time required to complete the task element
- $a$ = desired accuracy or precision
- $\bar{x}$ = the mean observed time to complete the task

The $z$-value used was 1.44, which is an 85% confidence level. This confidence level was chosen due to the fact that these time studies were not going to be used as a data source in the project, but only as means to validate hospital databases. Therefore, only generalizations of the processing times were needed in order to identify outliers in the databases, as well as to confirm all of the other times were reasonable. The desired accuracy was set at 15%. The observed mean and standard deviation were found for each element based on initial observations. These calculations, which can be found in Appendix B are summarized below in table 3.

<table>
<thead>
<tr>
<th>Element: Calculated Number of Observations</th>
<th>11</th>
<th>14</th>
<th>11</th>
<th>14</th>
<th>7</th>
</tr>
</thead>
</table>

Table 3 - Preliminary Lobby Time Study Number of Observations

The highest number of observations required was 14 for both elements 2 and 4, so this was the number of observations taken for this initial time study. However, due to time constraints and not being able to see each part of the emergency department at once for further time studies, it was decided to only use this time study for verification of hospital data and not for use in the actual models. The results from this time study can be seen below in table 4.
<table>
<thead>
<tr>
<th>Patient</th>
<th>Door</th>
<th>Check-in</th>
<th>Sit Down</th>
<th>Triage</th>
<th>Return</th>
<th>Bed</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0:03</td>
<td>1:31</td>
<td>12:55</td>
<td>19:36</td>
<td>1:43:11</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1:20</td>
<td>1:26</td>
<td>3:25</td>
<td>4:53</td>
<td>35:42</td>
<td>47:08</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>11:26</td>
<td>11:28</td>
<td>13:06</td>
<td>29:56</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>14:42</td>
<td>15:51</td>
<td>17:35</td>
<td>35:15</td>
<td>38:31</td>
<td>58:47</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>18:07</td>
<td>18:40</td>
<td>21:15</td>
<td>38:57</td>
<td>43:03</td>
<td>1:00:23</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>24:49</td>
<td>24:59</td>
<td>26:27</td>
<td>47:12</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>30:24</td>
<td>30:26</td>
<td>32:49</td>
<td>55:10</td>
<td>1:02:16</td>
<td>1:44:50</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1:04:16</td>
<td>1:04:18</td>
<td>1:05:56</td>
<td>1:06:32</td>
<td>-</td>
<td>1:15:18</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1:12:57</td>
<td>1:13:32</td>
<td>1:14:38</td>
<td>1:17:18</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1:40:01</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Patient LWBS</td>
</tr>
</tbody>
</table>

*0:00 = 2:09 pm  *25 people asked to go back as visitors

Table 4 - Preliminary Lobby Time Study Example

The time studies taken were used to validate this hospital data which will be discussed in the following section. They were also used to gain a more thorough understanding of the ED processes by breaking the process down into elements.
Hospital Database

The final method for data collection was retrieving data from the hospital's ED patient database. The other methods for data collection discussed above were used to gather information for the models that was not given in the hospital databases. This includes observation, questionnaires, and collection time data. Furthermore, some information was found through research. Altogether, the hospital database was the most heavily used source of data throughout this study. This data was extracted in an Excel® spreadsheet, therefore the biggest tools that were used for data mining were pivot tables.

Base Model

After the needed data was collected, a base model was created as a representation of the current state of the ED. Several different elements went into the creation of this model which included: Locations, Entities, Arrivals, Processing, Resources, Path Networks, and Background Graphics. Each of these parts of the model will be discussed in detail in the following sections.

Locations

The first portion of the model to be defined were locations. A layout was created using AutoCAD drawing software which included all locations of the ED. An image showing each of the three main locations can be seen in the following figure 4.

![Figure 4 - ProModel Locations](image-url)
As can be seen in the figure above there are three main locations for the base model. Each of these three main locations have several more locations defined within them in the model. The total number of locations within these three main locations are summarized below:

- Total number of locations in the lobby: 11
- Total number of locations in triage: 4
- Total number of locations in rooms area: 47

The lobby area includes room for patients to wait, ques for check in, room for patients to wait in chairs to be seen, and general space for movement and furniture. The second location is the check-in and triage area which is for staff use. Patients also use this area when they are being seen by staff. The final area of the model is the main ED, which includes different types of patient rooms. A patient who is assigned an acuity of 1 will most likely be placed in a trauma room, an acuity of 2 or 3 will be placed in a standard room and an acuity of 4 or 5 will go to a fast track room. There are also rooms meant for behavior mental health, which contain the resources needed for any patient receiving mental health care.

**Entities**

The second portion of building the model was defining entities. In the ED model, the entities are the hospital patients. The entities were broken down into five different categories based on their acuity. As discussed in the introduction, the percentage of each type of acuity was broken up based on a year and a half of hospital records. This breakdown can be seen in the following image and was used in the model as the percentage breakdown of total patients to acuity level as can be seen in figure 5.

![Figure 5 - Percent of Each Acuity in ED](image)

Next, the quantity of each type of entity was found using Stat::Fit in ProModel. The aim was to find distributions for the quantity of patients in the system, which could then be
entered into the model. The outputs for each type of entity (each patient acuity level) were found as follows in figure 6.

Figure 6 - Quantity Distributions for Each Acuity Level

These distributions were entered into ProModel as the quantities for each acuity for 1 through 5. After finding the amount of each type of patient, the cycles for which they arrived was determined. This will be discussed in detail in the next section.

**Arrivals**

For the arrivals of the model entities trends were found using a year and a half of hospital data. This was done for daily, weekly, and monthly trend. After these trends were found, the length of the arrival cycles could be determined. The graph of the daily trends found for the arrival of patients (regardless of acuity) can be seen in the following figure 7.
As can be seen in the figure above, there is an obvious trend from hour to hour in the daily trend of patient arrivals. From midnight to late morning there is an expected dip in patients. From early morning to midday there is a drastic increase in patients and then a steady number of patients until nighttime. At night, it can again be seen that the number of patients once again tapers off to start the cycle again. The second trend that was observed in the weekly trend. This can be seen in the following figure 8.

Once again, there is a definite trend from day to day in the weekly cycle of patient arrivals. It can be seen in the figure above that there is a decrease in patient arrivals on Saturday and Sunday, then a spike on Monday. From there, a relatively similar number of patients can be seen on Tuesday through Friday, which a slight decline each day. The next trend that was observed was the monthly trend. This can be seen in the following figure 9.
As can be seen in the figure above, there is a small amount of trend from month to month for patient arrivals. While some months fluctuate slightly lower than average or slightly higher than average, it can be seen that there is a relatively small amount of trend from month to month. Due to this observation in trend, month to month data was not included in arrival cycles. A weekly arrival cycle was deemed to capture all of the trend necessary for the scope of this project. Therefore, a week was broken up into 168 hours in order to find the arrival cycles necessary for this model. This can be seen in the following figure 10.
Due to the nature of the model, it was found that entering a 168-hour arrival cycle was difficult to enter into the simulation. For this reason, it was decided that the arrival cycles needed to be broken up into 4-hour time blocks. This can be seen in the following figure 11.

As can be seen in the figure above, the arrival cycle in 40, 5-hour time blocks follow the exact same trend as the previous 168-hour arrival cycle. However, it was much more manageable for entering into the model, so it was used for the final ProModel.

Processing

Once the locations, entities (types of patients), entity quantities, and entity arrival cycles were defined in the model, processing could be done. The processing of the model accounts for all of the movement of the patients and hospital staff, as well as the processing (patient care) that takes place. Some of the things that the processing accounts for in this model is patient care time, patient attributes such as acuity, heart conditions, if they are behavior mental health patients, if they are admitted versus discharge, and if they are a flight risk. Furthermore, the processing accounts for staff movement and priority for the patients they see, as well as room placements. The majority of the coding used for processing of the model was put into macros in the model. These macros can be seen in Appendix C. One of the metrics used in processing was the average length of stay of patients. This was found using the average of a year and a half of data containing information on over 73,000 patients in that time. The average length of stay found can be seen in the following figure 12.
The average length of stay of patients was further broken down based on if they were admitted or discharged. First, the number of admitted versus discharged patients needed to be found. This can be seen in the following figure 13.

As can be seen in the figure above, there are less than 1% of admits for acuity level 4 and 5. Most of the admitted patients are acuity level 1 at 85%. As can be seen, 50% of acuity level 2 and 25% of acuity level 3 are also admitted. Next, the times for length of stay were found for each acuity based on the attribute of being admitted or discharged. This can be seen in figure 14.
It can be seen that there is a significantly larger length of stay for patients that are admitted, particularly for the acuity level of 4 and 5. These times could then be used as the processing time in the model for the patients to be seen by a doctor and take up a room resource. Due to the nature of the mental health section of the ED, this process was repeated for the behavior mental health section of the hospital. As can be seen in the following figure 15.

As can be seen in the above figure, there are different trends for the behavioral mental health patients for the time they spend in their ED bed. Patients that are discharged spend more time in the room when they are behavioral mental health patients. This is due to the fact that the mental health patients need more monitoring before being discharged. Another thing that was added into the processing of the model was patients that leave without being seen. In the model, patients were given a “flight risk” based on the percentage of the population who will leave after waiting too long. A pie chart of the percent of total patients that leave without being seen based on acuity can be seen in the following figure 16.
If a patient who was assigned as a “flight risk” waits for too long, the model exits them out of the system as a patient who has left without being seen. The details of this processing can be seen in the process code provided in Appendix C.

**Resources**

The next thing that was defined in the model was the model resources. There were three different types of resources defined in the model which are all triage staff. These are triage nurses, patient care assistants (PCA) and registration workers. The times these staff take to complete tasks were found using observation, questionnaires, and time studies. Any other doctors or nurse is the system were modeled as processing time, not actual resources. For example, if a doctor sees a patient for 15 minutes, the patient will need to stay in their room for that 15 minutes to get the care they need, and the model will increment the cost of utilizing that “resource” without it being defined in the model as an actual resource. This is done based on averages of how many doctors or nurses that patient needs with their acuity level, as well as the costs associated with all of those staff. When changes to the base model are made, the number of resources and cost of resources will be tested and compared as potential solutions to some of the problems being tackled.

**Path Networks**

Once the resources were defined in the model, a path for them to follow as created. This path was used for the resources to travel and move patients from the lobby, to triage, and back to the rooms within the ED. The main path network for resources can be seen in the following figure 17.
Other smaller path networks were also included in the model, however, the main path network can be seen in the figure above and gives an overall understanding of the path network in the ProModel.

**Background Graphics**

Finally, graphics were added into the model for representations of locations, entities (patients), and resources (hospital staff). When run, the model shows all of the graphics moving over the different locations. This visual effect can be used as a high-level verification on the processing and movement of the entities and resources within the model. Therefore, the background graphics were used for visual verification. Furthermore, statistical verification took place. This will be discussed in the following section.

**Verification and Validation of Base Model**

Upon the completion of the base simulation model validation and verification was completed. Verification was done first, which is testing that the model runs as intended. This was done using two different methods, the first being visual verification and the second being stress testing. After this, validation was completed which is testing that the model is an accurate
representation of the real world. This was done using a paired two sample t-test of key outputs of the simulation model.

**Visual Verification**

Visual verification was done by watching the model background graphics and making sure everything was running as intended. Any red flags from watching the model were addressed and changed in the simulation processing code or other inputs. This was done in several iterations until everything was running smoothly and all elements of the model were acting in a similar way to the real world.

**Stress Testing**

The second method used for verification of the model, which is making sure the model runs as intended, was stress testing. This was done in order to ensure that the model would be able to handle stressful environments without crashing or giving unreasonable outputs. The stress test performed was running the model for an 8-year amount of time and checking the outputs for reasonableness. The following figure 18 and figure 19 shows the outputs for the 8-year model run next to the 1-year run which was the bases for comparing the models created.

![Figure 18 - 8 Year Simulation Outputs: LWBS, Admit, Discharge](image)

![Figure 19 - 8 Year Simulation Outputs: LOS, Blocked, Resource](image)

It can be seen that the model outputs for the 8-year simulation run were in fact reasonable. For the first metrics of patients who left without being seen (LWBS), the 1-year run gave an output of 562 patients, where the yearly average for the 8-year run was 592. This is an acceptable number. The same was true for the number of admitted and discharged patients, where the 1-year run verses the 8-year yearly average for admits was 12,568 verses 12,574. Furthermore, the discharge numbers were 35,639 for the 1-year run and 35,786 for the yearly average of the 8-year run. This was again very similar and gave indication of a positive stress test output. Next, the average length of stay was compared (LOS) and showed 295 minutes for both outputs. The same was true or the percent patients blocked with both numbers stay around 4.9 percent. Finally, total resource underutilization was compared and showed 77.38 percent for the 1-year run, and 75.73% for the 8-year run. These values were all deemed acceptable, and therefore the model passed a stress test of 8 years.
Paired Sample T-Tests

Next, validation was completed which was testing that the model is an accurate representation of the real world. This was done using a paired two sample t-test of key outputs of the simulation model verses real world statistics. These outputs were total patient outputs, admitted verses discharged patients, average length of stay, and the number of patients who left without being seen. In order to do the t-test, real world values and values found from the simulation model outputs were used. The first of the key metrics was the total patient output. The numbers from real world statistics verses the simulation model output can be seen in figure 20.

<table>
<thead>
<tr>
<th>Acuity</th>
<th>Raw</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Resuscitation</td>
<td>1007</td>
<td>863</td>
</tr>
<tr>
<td>2- Emergent</td>
<td>20391</td>
<td>20301</td>
</tr>
<tr>
<td>3- Urgent</td>
<td>31752</td>
<td>32166</td>
</tr>
<tr>
<td>4- Less Urgent</td>
<td>18037</td>
<td>18013</td>
</tr>
<tr>
<td>5- Non-Urgent</td>
<td>1805</td>
<td>1668</td>
</tr>
</tbody>
</table>

Figure 20 – Real World Statistics and Simulation Outputs for Total Patients

Next, a paired sample t-test was performed on these two sets of data and the following output was found as can be seen in figure 21.

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>t-Test: Paired Two Sample for Means</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>14598.4</td>
<td>14602.2</td>
</tr>
<tr>
<td>Variance</td>
<td>172005354</td>
<td>177164024</td>
</tr>
<tr>
<td>Observations</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-0.036</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.486</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>2.132</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.973</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.776</td>
<td></td>
</tr>
</tbody>
</table>

Figure 21 – t-Test for Total Patients

When analyzing the output from the paired sample t-test it can be seen that the two-tail P value is greater than the alpha used of 0.05, therefore it can be determined that there is no statistically significant different between the means of the raw and simulated data. This t-test was repeated for all of the key metrics discussed, and it was found for all of the key metrics that the
two-tail P value was greater than the alpha used of 0.05. A summary table can be seen in figure 22 for all of these key metrics.

![Paired Sample T-Test Results]

Figure 22 – Paired Sample t-Test Results

All of the raw verses simulated outputs for these key metrics can be found in Appendix D along with their corresponding t-Test outputs. Upon the successful completion of the paired sample t-Tests for all of the key metrics discussed, it was concluded that the base simulation model was validated and verified. This means that the model was running as intended and was an accurate representation of the real-world Ascension Borgess emergency department.

Output Metrics of Simulation Base Model

After the current state model was completed and validated, the models were then analyzed for specific outputs. The outputs of the simulation model that were chosen to be analyzed correspond with the key metrics in the project objective. Those three metrics were the number of patients that left without being seen for all acuity levels, the total length of stay for all acuity levels, and ineffective use of staff. In order to compare models that will aim to reduce these metrics, the same four metrics from the simulation outputs will be compared. The first simulation output that will be analyzed is the total number of patients that left without being seen in one year (LWBS). The second output is the average total length of stay (LOS) for each acuity level. The third output is the percentage of time that patients spend blocked in the system, this means that they are waiting at any location. The final output that will be analyzed is the average resource underutilization. This underutilization percentage accounts for the time that the staff is doing tasks that are not at the top of their license. For example, when nurses are handling patients and doing RN duties, this accounts for resource utilization. However, when they are completing task such as registration, that an administrative clerk can do, this is considered underutilization. The current state base simulation model metrics can be seen in figure 23 below.
Changes from Current State Model

Once a base simulation model was created, new models were created and then compared to the base (current state of the ED) using the simulation output metrics. Later on in the study statistical analysis and cost analysis were used to compare the models further. The four different models created were based on the methodology and literature review and aim to reduce the 3 target metrics discussed while meeting the mission of Accession Borgess to provide patient centered care.

Model 1: Vertical Care

Introduction

The simulation model created for vertical care looked to address the key ED challenges of delays in service to patients as well as shortage of hospital staff. Vertical care is designed for acuity levels of 4 and 5 and is meant to get them through the ED system faster with less delays while using less resources. This is done using horizontal bed that looks similar to a chair, rather than the traditional vertical bed. The reason for this is because a horizontal, or upright, position for these patients with non-urgent needs saves room. Patients can simply be divided by a curtain rather than taking up an entire ED room. This can be seen in the following figure 24.
One of the greatest benefits to this model is the fact that it reduces cleaning costs, as hospital staff only need to wipe off a chair rather than the alternative of waiting for a cleaning crew to clean an entire ED room. The final aspect of vertical care is the results pending area. This area is meant as a hub for patients while they are waiting on their test results and creates more room for new patients to move into care areas.

**Changes in Simulation Model**

To make the adaption to vertical care in the simulation model the first step was to change the layout. In AutoCAD, the layout was altered so that fast track rooms three, four and five became the vertical area. Once placed into simulation, these previous locations had to altered and added to in order to create the 6-chair vertical care area. A location was also added in the lobby for results pending. The initial layout, altered layout and ProModel appearance can be seen in figure 25 below.

![Figure 25 – Vertical Care Layout Change](image)

Once the layout was completed changes to processing had to be made. Vertical care processing was added for acuity 4 and 5, as these are the acuity levels that have the lowest severity and are the best candidates for this change. The processing was created to allow a patient to move to vertical care in one of two case, either 1. there was a free bed in vertical care or 2. there was a shorter que for the vertical care than for a fast track room. Once a patient had moved to the vertical care the process differed by acuity. Data was found for the time spend waiting and being treated by a doctor for acuity 4 and 5. This was found to be a total of 29.74 minutes for acuity 4 and 44.91 minutes for acuity 5. After this time, the patient moved to the result pending area to wait out the rest of their time. This made it so the patients were in the system for the same amount of time, but they only occupied a room for a fraction of the time.

**Outputs**

After model one was created, the simulation was run for one year. The same four metrics were analyzed in comparison to the current state model. The outputs and comparison can be seen in figure 26 below. The model one outputs were compared to the current state model and the percentage of change can also be seen below.
Model 1 outputs were very surprising as change from the current state was expected. There was zero change from the current state. These changes are insignificant and vertical care was not able to make an impact on the system.

Model 2: Check-in and Triage Changes

Introduction

For the second simulation model, check-in and triage changes, the key ED challenge of a shortage of staff was addressed. For this model, the biggest objective was to rely on the expertise of nurses and check in staff. The was done first by heavy observations of the current check-in and triage processes, along with questions to the triage nurses and check in clerks. After this initial data collection, more formal questionnaires were created and used to gather information (see data collation section on questionnaires). It was discovered from nurses that had been working at the hospital for longer periods of time that several different check-in and triage methods had been tried over the years. It was found that the majority of the nurses preferred having two triage locations where the triage nurses focus only on the patient care. With this model there was full-time use of a registration clerk and the nurses did not have to worry about check in activity. The nurses liked that fact that they could be focused on tasks that were using their nursing license to its fullest and not doing activities that a check in clerk could do.

Changes in Simulation Model

The adaption of the simulation to include the check-in and triage changes required slight changes to the triage processing, and resource paths. For this model, there were no location changes, only change in the resource placement. A snapshot from ProModel of the layout for model 2 can be seen in figure 27 below.
For the processing of this method, instead of going to the single triage bay, patients moved to fast track room 1 or 2 depending on which was first available. If a patient moved to fast track room 1, now triage bay one they were assisted by triage nurse 1, while in room two they were assisted by triage nurse two. After this all processing continued in the same way as the current state.

**Outputs**

After model two was created, the simulation was run for one year. The same four metrics were analyzed in comparison to the current state model. The outputs and comparison can be seen in figure 28 below. The model two outputs were compared to the current state model and the percentage of change can also be seen below.

<table>
<thead>
<tr>
<th>Check-in &amp; Triage Changes</th>
<th>Current State</th>
<th>Model 2 Outputs</th>
<th>Change From Current State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>491</td>
<td>13%</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>295</td>
<td>0%</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>4.11</td>
<td>16%</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>83.73</td>
<td>1%</td>
</tr>
</tbody>
</table>

Check-in and triage changes were able to produce positive changes for three of the metrics. The biggest change was in the percent of time blocked. Model 2 reduced the percent blocked by 16%. The number of patients that left without being seen was reduced by 13%. Lastly, the resource underutilization only decreased by 1%. It was expected that the check-in and triage changes would have a stronger impact on the resource underutilization. However, this is
not the case due to how the simulation modeled the staff and the definition of resource underutilization. Overall, this model produced promising outputs considering only small changes were made to the system.

Model 3: Proposed Lobby Layout

Iteration One Introduction

The third model, proposed lobby layout, was looking into the key ED challenges of delays in service and shortages of staff. The first layout modeled was created by essential ED staff that looked to implement new components into the lobby layout that are not currently there. This first layout was modeled exactly as it was created and the outputs were compared to the base model. The key changes from the base model in the lobby layout is 4 triage bays instead of 1 which eliminates the need for large waiting areas. A results pending area as discussed in the vertical care model. Moving the EKG (which was formerly done in the triage bays) to a separate curtained area to improve process flow of the triage bays. Finally, adding two digital registration kiosks, which was estimated to reduce the cost of patient check in by $7 per patient. However, after analysis of the model outputs and using systematic layout planning, a second iteration of the lobby layout was modeled and tested which will be discussed later.

Changes in Simulation Model

The proposed lobby layout required a complete reconfiguration of the lobby and had new processing for the entirety of the triage process. The first step of this process was to adjust and add locations. Added to the simulation was an arrival point, registration areas to represent the two kiosks, additional triage locations to cover all four triage bays, several curtain areas for EKG use, a results pending area and finally, an additional fast track location, fast track zero, in the area that was previously used for triage and check-in. This layout is shown in figure 29 below.

![Figure 29 – Proposed Lobby Layout](image)

These location changes came with many processing changes. The first change was in the way registration was handled. Patients had the choice to use either the registration kiosks or be registered in triage. For the purpose of this simulation, and to stress the system, only 25% of patients used the kiosks, all others were registered by a mobile registration clerk once they were seated in a triage bay. Patients were pulled to the triage bay on a first come first served basis, proceeding to the first available bay. Once they were seated in a triage location and registered,
the process followed the typical triage process, where behavior mental health or heart patients were identified. The one difference from the prior triage procedure was that patients who had heart attack symptoms were taken to a separate curtain area for the EKG instead of remaining in triage.

**Outputs**

After model three was created, the simulation was run for one year. The same four metrics were analyzed in comparison to the current state model. The outputs and comparison can be seen in figure 30 below. The model three outputs were compared to the current state model and the percentage of change can also be seen below.

<table>
<thead>
<tr>
<th>Proposed Lobby Layout</th>
<th>Current State</th>
<th>Model 3 Outputs</th>
<th>Change From Current State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>437</td>
<td>22%</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>298</td>
<td>-1%</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>3.91</td>
<td>20%</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>92.27</td>
<td>-9%</td>
</tr>
</tbody>
</table>

Figure 30 – Model 3 Simulation Outputs

The proposed lobby layout produced positive outputs for the number of patients that left without being seen and the percent of time blocked which was 22% and 20%, respectively. This is a much larger reduction in comparison to model 2. However, the resource underutilization and length of stay did increase, which was a surprising result.

Since this lobby was created by essential ED staff, this study decided to investigate other simulation outputs to see if there were areas of improvements that could be made. Figure 31 below shows the percent of time each of the four triage bays as well as the EKG curtains were in operation or idle.

Figure 31 – Percent of Time Locations are in Operation
It can be seen that triage bay 4 (Tb 4) was never in operation. Therefore, it was not essential to the system and simply wasted space. It could be removed from the layout as only three triage bays were needed. The second observation from the figure is that curtain 2 and 3 were not needed in the system. The output shows that they were not in observation and could be removed from the system as only one curtain for EKGs are needed.

**Iteration Two Introduction: Facilities Layout**

After an analysis of the model outputs from the lobby layout iteration one, it was concluded that facilities layout, specifically systematic layout planning (SLP) could be used to improve the layout. SLP along with the reduction of unused locations according to the model outputs were the basis of the second iteration of model 3. The locations that were found to not be needed from the simulation outputs were one of the triage bays along with two of the EKG curtain areas. Once these locations were chosen to be eliminated, SLP could be done. The first step was to figure out the traffic flow of the lobby area. Each time there was movement from one location to another, the numbers in the following chart increased by 1 for every person. This organized using a from-to chart and can be seen in the following figure 32.

<table>
<thead>
<tr>
<th>Arrive</th>
<th>Reg</th>
<th>Wait for Tb</th>
<th>Tb 1</th>
<th>Tb 2</th>
<th>Tb 3</th>
<th>Curtain</th>
<th>Wait for High Ac</th>
<th>Wait for FT</th>
<th>Wait for BMH</th>
<th>High Ac</th>
<th>Ft</th>
<th>BMH</th>
</tr>
</thead>
<tbody>
<tr>
<td>12,093</td>
<td>120</td>
<td>25,890</td>
<td>7,777</td>
<td>2,223</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reg</td>
<td>8722</td>
<td>2622</td>
<td>748</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wait for Tb</td>
<td>87</td>
<td>26</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tb 1</td>
<td></td>
<td>4,969</td>
<td>11,117</td>
<td>397</td>
<td>164</td>
<td>5,447</td>
<td>8,938</td>
<td>3,129</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tb 2</td>
<td></td>
<td>1,454</td>
<td>3,342</td>
<td>119</td>
<td>49</td>
<td>1,637</td>
<td>2,686</td>
<td>941</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tb 3</td>
<td></td>
<td>427</td>
<td>955</td>
<td>34</td>
<td>14</td>
<td>468</td>
<td>768</td>
<td>269</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curtain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6890</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wait for High Ac</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15,415</td>
<td></td>
</tr>
<tr>
<td>Wait for FT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>551</td>
<td></td>
</tr>
<tr>
<td>Wait for BMH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>227</td>
<td></td>
</tr>
<tr>
<td>High Ac</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ft</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 32 - From-To chart

After the from-to chart was created, assignments for the importance of each location being near another location were created. This was done using a scale of A, E, I, O, U and X where the meaning of each letter can be seen in the following figure 33.

<table>
<thead>
<tr>
<th>A</th>
<th>Absolute</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Extremely Important</td>
</tr>
<tr>
<td>I</td>
<td>Important</td>
</tr>
<tr>
<td>O</td>
<td>Ordinary Importance</td>
</tr>
<tr>
<td>U</td>
<td>Unimportant</td>
</tr>
</tbody>
</table>

Figure 33 – Relationship Diagram Scale Abbreviations
Each of these letters were assigned to an amount of movement, where A = 10,000 people moving between a location, and so on. This can be seen in the following figure 34.

![Figure 34 – Relationship Diagram Scale Number Assignments](image)

These number assignments were used to create a relationship diagram. The purpose of this diagram is to show which locations are essential to have in close approximation and which locations do not need to be near to each other. This can be seen in figure 35.

![Figure 35 - Relationship Diagram](image)

From this relationship diagram a lobby layout could be created by placing locations based on how close they needed to be to other locations. The final lobby layout created using this process of SLP and the iteration one model outputs can be seen in the following figure 36.

![Figure 36](image)
This layout was once again placed into a simulation model, where the entire ED layout including the final lobby layout can be seen in figure 37. The main changes from the layout created by essential ED staff is 3 triage bays (as opposed to 4), 1 curtain area for EKG’s (as opposed to 3), and more waiting area for families. The waiting area for families was placed into the layout based on asking nurses their opinion on the layout, and getting feedback that minimal waiting areas would be problematic for situations where many friends and family members were waiting in the ED.
The second iteration of the lobby layout was also created in a simulation model and the metrics were compared to the base simulation model. This will be discussed in the following sections.

Changes in Simulation Model

Several alterations had to be made from the proposed layout to create the revised layout in ProModel. These including moving several existing locations as well as removing one triage bay, two curtain areas and the existence of fast track zero. This created the layout shown in figure 38 below.

![Figure 38 – Revised Lobby Layout](image)

The processing for this model had to be altered to adjust for the location removal, but all other processing remained the same as the previous version.

Outputs

After the revised lobby layout was created, the simulation was run for one year. The same four metrics were analyzed in comparison to the current state model. The outputs and comparison can be seen in figure 39 below. The model outputs were compared to the current state model and the percentage of change can also be seen below.

<table>
<thead>
<tr>
<th>Revised Lobby Layout</th>
<th>Current State</th>
<th>Revised Lobby Layout</th>
<th>Change From Current State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>352</td>
<td>37%</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>295</td>
<td>0%</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>3.85</td>
<td>22%</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>91.81</td>
<td>-8%</td>
</tr>
</tbody>
</table>

![Figure 39 – Revised Lobby Layout Simulation Outputs](image)
The revised lobby layout was able to make significant improvements to the system metrics. The number of patients that left without being seen was reduced from 562 to 352. Additionally, the layout was able to reduce the percent of time blocked by 22%. These metrics showed improvements from the original proposed lobby layout. This showed that the changes made and created from the simulation outputs and facilities layout techniques were beneficial to the system.

**Model 4: Admit Holding Unit**

**Introduction**

The final simulation model created was for an admit holding unit. This unit would change the process flow of admitted patients so that they could go to a holding unit if they were not able to immediately be admitted into the hospital. This change to the ED process flow can be seen in the following figure 40.

![Figure 40 – Admission Holding Unit Process Flow](image)

The purpose of the admit holding unit is that patients do not wait in ED beds. The reason for this, as discussed in the literate section is that the personnel cost per patient bed-hour are much higher for an ED bed rather than a holding unit. Just moving a patient from an ED bed to a holding unit reduces the personnel costs per patient bed-hour by about $47 per patient (Schreyer, 2017). The reason for this is that one nurse can monitor several patients in a holding unit. In the following figure 41, an admit holding unit in Singapore can be seen.
In this admission holding unit, the nurse is able to do the paperwork needed for patients to be admitted onto a hospital floor. This paperwork is time consuming and often is one of the blockages for patients not being admitted more quickly (Hermes, 2017). The final aspect of the admit holding unit the fact that it cannot be modeled with intensive care unit (ICU) patients. In a study conducted by Chalfin in 2007, it was found that an admitted observation unit would not benefit patients that are in critical condition (Chalfin, 2007). Therefore, patients being admitted into the ICU will not be included in this method.

Changes in Simulation Model

This simulation change required a deep look into the processing code, as the physical layout remained relatively unchanged. For this model, an admit holding location was created in a location outside of the main layout, to represent its location elsewhere in the model. This location was set to hold 8 people, creating an 8-bed holding unit. Once this location had been created the code had to be amended to move people to this location. The admissions holding unit was programmed to take in acuities one, two and three. For these acuities, it was found how long the actual care took pace, versus the time they spend waiting for admission. The base care time was performed, then if there was a free bed in the holding unit, patients would be moved there on a first come first serve basis. Once reaching the admit hold area, patients would wait the rest of their time until a bed in the hospital was available and they were admitted. If there was not a spot available in the admission holding unit, patients would wait in their ED bed, until either there was a spot, or they timed out and were directly admitted. The only exception to this rule were the top 20% of acuity 1 and 2 patients, who were considered to be ICU patients. These individuals were kept in their ED bed until they were directly admitted to the floor.
Outputs

After model four was created, the simulation was run for one year. The same four metrics were analyzed in comparison to the current state model. The outputs and comparison can be seen in figure 42 below. The model four outputs were compared to the current state model and the percentage of change can also be seen below.

<table>
<thead>
<tr>
<th>Admit Holding Unit</th>
<th>Current State</th>
<th>Model 4 Outputs</th>
<th>Change From Current State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>175</td>
<td>69%</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>289</td>
<td>2%</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>2.93</td>
<td>40%</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>84.97</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 42 – Model 4 Simulation Outputs

The admit holding unit created the most promising results. The most significant of all four models was a 69% reduction in the number of patients that left without being seen. Additionally, the percent of time patients were blocked in the system was reduced by 40%. The length of stay and resource underutilization showed almost no change from the current system. These results were the most promising and drastic to the system.

Comparing Output Metrics of 4 Models

All four models were compared to the current state model. A summary of the raw number outputs for each model can be seen in figure 43 below.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Current State</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Revised Lobby Layout</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>562</td>
<td>491</td>
<td>437</td>
<td>352</td>
<td>175</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>294</td>
<td>295</td>
<td>298</td>
<td>295</td>
<td>289</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>4.94</td>
<td>4.11</td>
<td>3.91</td>
<td>3.85</td>
<td>2.93</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>84.94</td>
<td>83.73</td>
<td>92.27</td>
<td>91.81</td>
<td>84.97</td>
</tr>
</tbody>
</table>

Figure 43 – Comparison Simulation Outputs
Additionally, the percentage of change from each model from the current state model can be seen in figure 44 below.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Current State</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Revised Lobby Layout</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>0%</td>
<td>13%</td>
<td>22%</td>
<td>37%</td>
<td>69%</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>0%</td>
<td>0%</td>
<td>-1%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>0%</td>
<td>16%</td>
<td>20%</td>
<td>22%</td>
<td>40%</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>0%</td>
<td>1%</td>
<td>-9%</td>
<td>-8%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 44 – Comparison Percent Change From Simulation Outputs

It can be seen from figure 43 and 44 above that model four, the admit holding unit, was able to produce the most significant results. The revised lobby layout was able to have the second biggest impact on left without being seen and the percent of time patients were blocked in the system. It can be seen that model one, vertical care, had the least impact on the system.

Results

After the completion of the base model, creation of 4 new models, and comparison of basic model statistics, more comparison methods were used in order to make conclusions on which models were worth implementing. This was done in two ways, the first being a statistical comparison and the second being a cost analysis. For the statistical comparison, an AVOVA test was used to compare the models. For cost analysis, total resource cost was compared for each of the models and an investment analysis was done.

Statistical Comparison of the Models

For a statistical comparison of the base model against the 4 new models created, an AVONA analysis was done. A Tukey-Kramer test was used to see if the base simulation model was statistically different from the 4 new models created. This was done for the left without being seen metric, the length of stay metric, and finally the percent patient blocked metric. Every acuity level for each model was compared for each metric. The results of this test can be seen in Appendix E. However, a summary of the Tukey Kramer outputs can be seen in figure 45, figure 46, and figure 47. This can be seen in the summary table as a “yes” if the output is statistically different and a “no” if it is not statistically different. The first summary table is for the left without being seen metric as seen in figure 45.
For the left without being seen metric, each of the 4 new models were compared to the base model to see if they were statistically different from the base model for each acuity level. Model 1 is the vertical care model, model 2 is the check in and triage changes, model 3 is the new lobby layout, and model 4 is the admissions holding area. It can be seen that model 1 has no statistical difference. Model 2 has a difference for acuity levels 1, 2, 4 and 5. Model 3 has statistical difference for all of the acuity levels, and model 4 only has difference for the patients with “higher” acuity levels (patients with more severe conditions). This is expected, as only patients with more severe needs will be admitted into the hospital. Next, this will be repeated for the length of stay metric as seen in figure 46.

Once again, this test was repeated for the average length of stay metric, where each of the 4 new models were compared to the base model to see if they were statistically different from the base model for each acuity level. As a reminder, Model 1 is the vertical care model, model 2 is the check in and triage changes, model 3 is the new lobby layout, and model 4 is the admissions holding area. It can be seen that model 1 only statistical difference for acuity levels 4 and 5. Model 2 has a difference for acuity level 2. Model 3 has statistical difference for acuity levels 2 and 5, and model 4 once again only has difference for the patients with “higher” acuity levels (patients with more severe conditions). Again, this is expected as only patients with more severe needs will be admitted into the hospital. Overall there was no significant trend for one model being the best on decreasing the average length of stay metric. This was finally repeated for the percent blocked metric as seen in figure 47.
Finally, the percent blocked metric was used to see if each of the 4 new models were statistically different from the base model for each acuity level. Model 1 is the vertical care model, model 2 is the check in and triage changes. Model 3 is the new lobby layout, and model 4 is the admissions holding area. It can be seen that model 1 has statistical difference for acuity 4. Model 2 has a difference for acuity levels 1, 3, 4 and 5. Model 3 has statistical difference for all of the acuity levels, and model 4 only has difference for the patients with acuity levels of 2 and 3.

Overall, from this Tukey Kramer test it can be seen that model 1 is generally not statistically different form the base model, so it is not seen as a viable model. Model 2 sees some statistical difference from the base model, and finally, model 3 and 4 see the most statistical difference from be base model. This is because model 3 is different from the base model for all acuity levels with the left without being seen metric as well as the percent blacked metric. In the same way, model 4 is statistically different for all of the acuity levels it affects (patients with “higher” acuity levels, or more severe conditions, as only patients with more severe needs will be admitted into the hospital). This is true for all of the metrics looked at in the Tukey-Kramer test for model 4 for acuity levels 1, 2 and 3, except for acuity level 1 for the percent blocked metric.

Cost Analysis

**Patient Resource Usage Cost**

Next a cost analysis was done to compare the 4 simulation models. First, the patient resource usage cost was compared. This cost accounted for resources such as hospital staff and all associated room costs. The costs placed in the model were determined according to national averages for hospital staff. The room cost per hour was found from research done by Schreyer in 2017. These costs are listed as follows:

<table>
<thead>
<tr>
<th>Resource cost per hour:</th>
</tr>
</thead>
<tbody>
<tr>
<td>RN’s - $29.37</td>
</tr>
<tr>
<td>PCA’s - $12.19</td>
</tr>
<tr>
<td>Registration Workers - $13.54</td>
</tr>
</tbody>
</table>
**Room cost per hour:**
- Trauma room - $58
- Standard Room - $58
- Fast Track - $24.80
- Vertical Care - $24.80
- Results Pending - $10.40
- Admit Holding Area - $10.40

After being placed into each of the 4 simulation models and run for a yearlong period, the ProModel software was able to find the patient resource usage cost per model. These costs were compared between models as shown in figure 48 below.

![Figure 48 - Patient Resource Usage Cost for all Models](image)

It can be seen that model 4 is significantly lower in yearly patient resource usage cost by about one million dollars. This was seen as a promising output for model 4.

**Investment Analysis**

To show the economic viability of these models, this cost analysis estimated construction costs, then using the difference in usage cost as revenue, determined the return on investment and payback years for each method. The initial investment cost estimates shown in figure 49 below pull together research done on costs associated with each method, the costs of specific resources, and hospital construction costs.
Staff costs for several of the models were found using the equation for present worth, $PV(i\%, n, PMT, F)$, where:

- $i\% = \text{interest rate} = 5\%$
- $n = \text{years} = 8$ for methods 1, 3 and 4 and 2 years for method 2
- $PMT = \text{annual salary of the worker. This was found using the national average hourly wage of $13.54 for a registration worker, and$29.37 for an RN}$.
- $F = \text{the final total, in this case zero}$.

Another assumption for this estimate was calculating the construction costs. Research by Vesely, et. al in 2016 showed that the cost for renovating a hospital was $400 per square foot. Therefore, the size of the space to be renovated was estimated and evaluated according to this cost.

Based on the investment cost, a cash flow table was created as shown in figure 50 below. For this cash flow, the yearly income was the difference in patient resource usage cost between the method and the base model.

**Figure 49 – Investment Cost Estimates**

<table>
<thead>
<tr>
<th>Method 1</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td>item</td>
<td>quantity</td>
</tr>
<tr>
<td>RN</td>
<td>1</td>
</tr>
<tr>
<td>Redliner</td>
<td>6</td>
</tr>
<tr>
<td>Construction</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 2</th>
<th>Check in and Triage Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>item</td>
<td>quantity</td>
</tr>
<tr>
<td>Reg Clerk</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 3</th>
<th>Test Layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>item</td>
<td>quantity</td>
</tr>
<tr>
<td>Kiosk</td>
<td>2</td>
</tr>
<tr>
<td>Construction</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 4</th>
<th>Admit</th>
</tr>
</thead>
<tbody>
<tr>
<td>item</td>
<td>quantity</td>
</tr>
<tr>
<td>RN</td>
<td>1</td>
</tr>
<tr>
<td>Bed Purchase</td>
<td>8</td>
</tr>
<tr>
<td>Construction</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
From these cash flow calculations, the return on investment (ROI) as well as payback years was found for each model. These calculations, as well as the initial investment estimates can be seen in the following summary table in figure 51.

![Figure 50 – Cash Flow Table](image)

From the summary of the investment analysis it can be seen that once again model 4 was the best. A higher ROI is desired as that means the return on the hospital’s initial investment will be higher. A short payback period is also desired, as that is the amount of time it will take for the hospital to have paid back its initial investment and start making money on the model. According to these standards, model 4 was seen as the best according to the investment analysis. The return on investment for model 4 was the highest at 63% and had the lowest payback period at 1.7%. Model 1 and model 3 tied for second best in the investment analysis as they both had ROI values of 30% and payback years of 3.2. Finally, model 2 also had a low value for payback years, however it had a very small return on investment value which is not desired.

**Short-Term Recommendations**

After analyzing the comparisons of the four models, recommendations were made. There are two short-term recommendations. The first short-term recommendation is to implement
model 4, the admit holding unit. This model showed the greatest benefits to the systems metrics as the number of patients that left without being seen was reduced by 69% and the percent of patients blocked in the system was reduced by 40%. Additionally, this model had the largest return on investment with 63% in 1.7 payback years. Although the initial investment was high, this model had the greatest return in the shortest amount of time. Therefore, model 4 is recommended to implement as soon as possible.

The second recommendation is to implement model 2, check-in and triage changes. The reasoning behind this recommendation is that it did show some improvements to the system with a 13% reduction in left without being seen and 16% reduction in the percent of time a patient is blocked. These results are promising considering that only a small initial investment was required. The initial investment is only above $74,000 with a 2 year payback period. This is also recommended due to the fact that it was created by the nurses, and making sure that the nurses are satisfied is important for the ED.

Long-Term Recommendations

The long-term recommendation is to implement model 3, the proposed lobby layout. The initial investment is around $282,000, which is due to the construction costs. However, the return on investment is 30% in a payback period of 3.2 years. Additionally, these ANOVA outputs showed the most statistically significant difference for almost every acuity. This model was able to reduce the number of patients that left without being seen by 37% and the percent blocked by 22%. Therefore, it is recommended for the hospital make these changes to the lobby layout to reduce ED key metrics.

It was then investigated why model 4 was able to produce such promising and significant outputs in comparison to the base model and the other four models. The reasoning was found that these significant metrics showed the underlying challenge in the emergency department is patients being admitted into the hospital for further treatment. Patients that are admitted will wait in the ED rooms for a significant amount of time which can create a major hold up in the system. The implementation of model 4 allowed those patients being admitted to wait in a separate location so new patients can receive treatment in ED. Therefore, it is recommended to complete a root-case analysis on the admissions issues throughout the entire hospital as implementing model four is a surface solution. It was recommended as a short-term recommendation, because it is a temporary fix to a larger issues within the hospital. In order to complete a root-cause analysis, the entire hospital would need to be model as patients that leave the ED can be admitted to any department throughout Ascension Borgess. This is a very large scope and not something that would be able to be completed due to the timeline of this project.

Simulation Model of Long-Term Recommendations

Using the long-term recommendations, a simulation model was created that combined the long-term recommendations. The proposed lobby layout was created in ProModel with the addition of the admit holding unit. This was done to show the outputs of the long-term recommendations and assuming the root-cause analysis was complete. Therefore, the admit holding unit will be modeled to show the effects on the ED. The finalized recommended layout can be seen in figure 52 below.
The outputs of the simulation model after running the model for one year can be shown below in figure 53.

<table>
<thead>
<tr>
<th>Long-Term Recommendations</th>
<th>Current State</th>
<th>Model 3+4</th>
<th>Change From Current State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Without Being Seen (#/yr.)</td>
<td>562</td>
<td>82</td>
<td>85%</td>
</tr>
<tr>
<td>Length of Stay (min)</td>
<td>295</td>
<td>290</td>
<td>2%</td>
</tr>
<tr>
<td>Percent of Time Blocked (%)</td>
<td>4.92</td>
<td>2.08</td>
<td>58%</td>
</tr>
<tr>
<td>Resource Underutilization (%)</td>
<td>84.96</td>
<td>91.09</td>
<td>-7%</td>
</tr>
</tbody>
</table>

In addition to the significant output metrics, implementing both the proposed lobby layout as well as the admit holding unit has a significant cost component. After a 1.8 year payback period, Ascension Borgess can save $1,268,258 from in patient resource usage cost.
Additionally, Ascension Borgess can increase its revenue by $900,000 due to the reduction of patients that leave without being seen. This is due to the assumption that the hospital makes about $2,000 per patient visit. However, this cost does not account for the public image it can create by reducing the number of patients that leave the ED without being seen.

These overall recommendations accomplished two of the three metrics: the number of patients that leave without being seen and the patient length of stay. This study could be analyzed and further continued if the resources were modeled more accurately in the system. However, this study was able to improve patient experience, safety and quality of the care provided, and profitability of the hospital.
Works Cited


Appendix A: Questionnaires

Questions for Triage Nurses

1. How long have you been a nurse working in triage here?

2. Have you worked in triage at any other hospitals? (if so ask for best practices)

3. How long do patients wait to be triaged after check-in?
   Min:
   Max:
   Avg:

4. How long does it take to triage a patient?
   Min:
   Max:
   Avg:

5. At your busiest times how many patients are waiting to be seen?

6. Does the acuity of a patient effect triage times or is it a standard process?

7. What is the biggest issue/bottleneck for getting patients to a bed?

8. Where do you think the biggest improvement could occur in the ED?
Appendix B: Time Study Calculations

<table>
<thead>
<tr>
<th></th>
<th>z = 1.44</th>
<th>a = 0.15</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Observations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door to Check-in</td>
<td>Check-in to Sit Down</td>
<td>Sit Down to Triage</td>
</tr>
<tr>
<td>2</td>
<td>88</td>
<td>684</td>
</tr>
<tr>
<td>3</td>
<td>119</td>
<td>1406</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>869</td>
</tr>
<tr>
<td>2</td>
<td>104</td>
<td>758</td>
</tr>
<tr>
<td>Mean</td>
<td>2.750</td>
<td>127.750</td>
</tr>
<tr>
<td>Std. Dev</td>
<td>0.957</td>
<td>49.802</td>
</tr>
<tr>
<td>N</td>
<td>11</td>
<td>14</td>
</tr>
</tbody>
</table>
Appendix C: Processing Code Macros

Fast Track Processing Code

```plaintext
1 Free All
2 If Patient_Type = 4 Then
3 {
4     If Acuity > 4 then
5         {
6             Wait 107.33 min // wait time for discharged AC 4
7             Inc Exit_No
8             Inc Exit_Ac4
9             Route 1
10        }
11     Else
12         {
13             Wait 521.45 min // wait time for admitted AC 4
14             Inc Admit_Ac4
15             Route 2
16         }
17     }
18 Else
19     {
20         If Patient_Type = 5 Then
21             {
22                 Wait 81.39 min // wait time for discharged AC 5
23                 Inc Exit_No
24                 Inc Exit_Ac5
25                 Route 1
26             }
27     } // AC 3
28 {
29         If Acuity >= 76 Then // % of AC 3 that get admitted
30             {
31                 Wait 620.55 min // Ac 3 time in bed
32                 Inc Admit_Ac3
33                 Route 2
34             }
35         Else
36             {
37                 Wait 216.21 min
38                 Inc Exit_No
39                 Inc Exit_Ac3
40                 Route 1
41             }
42     }
43 }
```
High Acuity Processing Code

```plaintext
1  Free All
2  If Patient_Type = 2 then
3      {
4          If Acuity >= 50 Then /* % of AC 2 that get admitted
5              {  
6                  Wait 555.19 min // Ac 2 time in bed
7                      Inc Admit_Ac2
8                  Route 1
9              }
10         Else
11            {  
12                        Wait 341.31 min
13                        Inc Exit_No
14                        Inc Exit_Ac2
15                        Route 2
16            }
17       }
18  Else
19      {  
20          If Patient_Type = 3 Then
21              {  
22                  If Acuity >= 76 Then /* % of AC 3 that get admitted
23                      {  
24                          Wait 620.55 min // Ac 3 time in bed
25                              Inc Admit_Ac3
26                          Route 1
27                      }
28                  Else
29                    {  
30                        Wait 225.21 min
31                        Inc Exit_No
32                        Inc Exit_Ac3
33                        Route 2
34                    }
35                 }
36         Else
37            {  
38              If Acuity >= 16 Then /* % of AC 1 that get admitted
39                  {  
40                      Wait 409.29 min // Ac 1 admit dist of time in bed
41                          Inc Admit_Ac1
42                      Route 1
43                  }
44             }
45            }
46            }
47        }
48       }
49      }
50  }
```
Acuity 1 Processing Code

```plaintext
Free All
{
  If Acuity >= 16 Then // % of AC 1 that get admitted
  {
    Wait 409.29 min // Ac 1 admit dist of time in bed
    Inc Admit_Ac1
    Route 1
  }
  Else
  {
    Wait 294.23 min // discharged
    Inc Exit_No
    Inc Exit_Ac1
    Route 2
  }
}

Behavioral Mental Health Processing Code

Free All
If Patient_Type = 1 Then
{
  If Acuity >= 16 Then // % of AC 1 that get admitted
  {
    Wait 375.33 min // Ac 1 admit dist of time in bed
    Inc Admit_Ac1
    Route 1
  }
  Else
  {
    Wait 615.6 min // discharged
    Inc Exit_No
    Inc Exit_Ac1
    Route 2
  }
  Else //1
  If Patient_Type = 2 then
  {
    If Acuity >= 58 Then // % of AC 2 that get admitted
    {
      Wait 563.72 min // Ac 2 time in bed
      Inc Admit_Ac2
      Route 1
    }
    Else
    {
      Wait 452.67 min
      Inc Exit_No
      Inc Exit_Ac2
      Route 2
    }
  } Else //2
  If Patient_Type = 3 Then
  {
    If Acuity > 76 Then // % of AC 3 that get admitted
    {
      Wait 641.15 min // Ac 3 time in bed
      Inc Admit_Ac3
      Route 1
    }
  }
```

```
Processing Left Without Being Seen

```c
46 Else
47 {
48    Wait 226.2 min
49    Inc Exit_No
50    Inc Exit_Ac3
51    Route 2
52 }
53 }
54 Else
55 {
56    If Patient_Type = 4 Then
57    {
58        If Acuity > 4 then
59        {
60            Wait 151.34 min // wait time for discharge AC 4
61            Inc Exit_No
62            Inc Exit_Ac4
63            Route 2
64        }
65        Else
66        {
67            Wait 521.49 min // wait time for admitted AC 4
68            Inc Admit_Ac4
69            Route 1
70        }
71    }
72 }
73 Else
74 {
75    Wait 119.37 min // wait time for discharge AC 5
76    Inc Exit_No
77    Inc Exit_Ac5
78    Route 2
79 }
80 }
81 } //1
82 } //1
```

Processing Left Without Being Seen

```c
1   Wait_time = Clock() - Start_time
2   if LWBs > 76 Then
3     { //1
4       If Patient_Type = 2 Then
5         {
6             If Wait_time > 185 Then
7                 {
8                     Inc Exit_LWBs
9                     Inc Exit_No
10                    Inc AC_2_LWBs
11                    route 2
12                 }
13             Else route 1
14         }
15       Else
16         { //2
17             If Patient_Type = 3 Then
18             {
19                 If Wait_time > 147 Then
20                     {
21                         Inc Exit_LWBs
22                         Inc Exit_No
23                        Inc AC_3_LWBs
24                        route 2
25                     }
26                     Else route 1
27                 }
28         }
29     Else
30         { //3
31             If Patient_Type = 4 Then
32             {
33                 If Wait_time > 21 Then
34                     {
35                         Inc Exit_LWBs
36                         Inc Exit_No
37                        Inc AC_4_LWBs
38                        route 2
39                     }
40     }
41 }
```
Admit Holding

If Patient_Type = 1 Then
{ Bed_Wait = Clock() - Bed_Start
  While Bed_Wait < 409.2D Do
  { Wait 5 min
    Bed_Wait = Clock() - Bed_Start
  }
  Dec Admit_Hold
  Route 1
}
Else
{ //8
  If Patient_Type = 2 then
  { Bed_Wait = Clock() - Bed_Start
    While Bed_Wait < 555.19 Do
    { Wait 5 min
      Bed_Wait = Clock() - Bed_Start
    }
    Dec Admit_Hold
    Route 1
  }
  Else
  { //1
    If Patient_Type = 3 then
    { Bed_Wait = Clock() - Bed_Start
      While Bed_Wait < 620.55 Do
      { Wait 5 min
        Bed_Wait = Clock() - Bed_Start
      }
      Dec Admit_Hold
      Route 1
    }
    Else
    { Bed_Wait = Clock() - Bed_Start
      While Bed_Wait < 521.45 Do
      { Wait 5 min
        Bed_Wait = Clock() - Bed_Start
      }
      Dec Admit_Hold
      Route 1
    }
  } //1
} //8
Triage Bay

1. If Registered = 0 Then
2.  {
3.      Get Reg worker
4.      Wait 2 min
5.      Free All
6.  }
7. If FreeWaits(TN_L1) = 1 Then
8.  {
9.      Get TN_L1
10.  }
11. Else Get TN_L2
12. If Patient_Type = 1 Then
13.  {
14.      IF BPM < 1 then // % BPM
15.         {
16.                  Wait 3 min
17.                  Free all
18.                  Route 2 // BPM waiting
19.         }
20.      Else
21.          {
22.                  Wait 2 min
23.                  Free all
24.                  Route 4 // ac 1
25.          }
26.  }
27. Else
28.     {
29.       If Patient_Type = 2 Then
30.         {
31.            //ac2
32.            IF BPM < 10.1 Then
33.                {
34.                        Wait 3 min
35.                        Free all
36.                        Route 2
37.                }
38.            Else
39.                {
40.                        IF Acuity > 30 Then // % of people w/ heart attack symptoms
41.                            {
42.                                Free all
43.                                Get PCA
44.                                Route 5 //curtain
45.                            }
46.            Else
47.                {
48.                                Wait 2 min
49.                                Free All
50.                                Route 3 // high ac
51.                }
52.          }
53.     }
54.  }
55.  {
56.     If Patient_Type = 3 Then
57.         {
58.            IF BPM < 4.2 Then
59.                {
60.                            Wait 2 min
61.                            Free All
62.                            Route 2
63.                }
64.            Else
65.                {
66.                            Wait 2 min
67.                            Free All
68.                            Route 3 // high ac
69.                }
70.         }
71.     }
72.     {
73.       If Patient_Type = 4 Then
74.         {
75.             IF BPM < 1.4 Then
76.                 {
77.                     Wait 3 min
78.                     Free all
79.                     Route 2
80.                 }
81.             Else
{ 
  Wait 2 min 
  Free All 
  Route 1
}

} //2

} //1
## Appendix D: Raw vs. Simulated and t-Test Outputs

### Length of Stay

<table>
<thead>
<tr>
<th>Acuity</th>
<th>Raw</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Resuscitation</td>
<td>399.3757455</td>
<td>399.28</td>
</tr>
<tr>
<td>2- Emergent</td>
<td>461.7426918</td>
<td>516.73</td>
</tr>
<tr>
<td>3- Urgent</td>
<td>344.531809</td>
<td>383.9</td>
</tr>
<tr>
<td>4- Less Urgent</td>
<td>125.9389</td>
<td>116.69</td>
</tr>
<tr>
<td>5- Non-Urgent</td>
<td>116.8747922</td>
<td>89.24</td>
</tr>
</tbody>
</table>

### Length of Stay

**t-Test: Paired Two Sample for Means**

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>289.7</td>
<td>301.2</td>
</tr>
<tr>
<td>Variance</td>
<td>25330.1</td>
<td>35470.8</td>
</tr>
<tr>
<td>Observations</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>-0.743</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.249</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>2.132</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
<td>0.498</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.776</td>
<td></td>
</tr>
</tbody>
</table>

### Patients Discharged

<table>
<thead>
<tr>
<th>Acuity</th>
<th>Discharge</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Resuscitation</td>
<td>147</td>
<td>122</td>
</tr>
<tr>
<td>2- Emergent</td>
<td>10185</td>
<td>10042</td>
</tr>
<tr>
<td>3- Urgent</td>
<td>23914</td>
<td>24171</td>
</tr>
<tr>
<td>4- Less Urgent</td>
<td>17949</td>
<td>17929</td>
</tr>
<tr>
<td>5- Non-Urgent</td>
<td>1805</td>
<td>1668</td>
</tr>
</tbody>
</table>

### Patients Discharged
### t-Test: Paired Two Sample for Means

<table>
<thead>
<tr>
<th></th>
<th>Discharge</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>10800.0</td>
<td>10786.4</td>
</tr>
<tr>
<td>Variance</td>
<td>104464964.0</td>
<td>106898257.3</td>
</tr>
<tr>
<td>Observations</td>
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<td>5</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
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<td>t Critical one-tail</td>
<td>2.132</td>
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</tr>
<tr>
<td>$P(T&lt;=t)$ two-tail</td>
<td>0.860</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.776</td>
<td></td>
</tr>
</tbody>
</table>

#### Patients Admitted

<table>
<thead>
<tr>
<th>Acuity</th>
<th>Admitted</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Resuscitation</td>
<td>860</td>
<td>741</td>
</tr>
<tr>
<td>2- Emergent</td>
<td>10206</td>
<td>10259</td>
</tr>
<tr>
<td>3- Urgent</td>
<td>7838</td>
<td>7995</td>
</tr>
<tr>
<td>4- Less Urgent</td>
<td>88</td>
<td>84</td>
</tr>
<tr>
<td>5- Non-Urgent</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### t-Test: Paired Two Sample for Means

<table>
<thead>
<tr>
<th></th>
<th>Admitted</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3798.4</td>
<td>3815.8</td>
</tr>
<tr>
<td>Variance</td>
<td>23551202.8</td>
<td>24230398.7</td>
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<tr>
<td>Observations</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td></td>
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<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
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<td></td>
</tr>
<tr>
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<td>0.359</td>
<td></td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>2.132</td>
<td></td>
</tr>
<tr>
<td>$P(T&lt;=t)$ two-tail</td>
<td>0.717</td>
<td></td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.776</td>
<td></td>
</tr>
</tbody>
</table>
### LWBS

<table>
<thead>
<tr>
<th>Acuity</th>
<th>LWBS</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Resuscitation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2- Emergent</td>
<td>65</td>
<td>60</td>
</tr>
<tr>
<td>3- Urgent</td>
<td>374</td>
<td>362</td>
</tr>
<tr>
<td>4- Less Urgent</td>
<td>148</td>
<td>124</td>
</tr>
<tr>
<td>5- Non-Urgent</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

### LWBS

**t-Test: Paired Two Sample for Means**

<table>
<thead>
<tr>
<th></th>
<th>LWBS</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>120.4</td>
<td>112.5</td>
</tr>
<tr>
<td>Variance</td>
<td>23437.3</td>
<td>21785.1</td>
</tr>
<tr>
<td>Observations</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pearson Correlation</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Hypothesized Mean Difference</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>df</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>t Stat</td>
<td>1.702</td>
<td></td>
</tr>
<tr>
<td>P(T&lt;=t) one-tail</td>
<td>0.082</td>
<td>0.082</td>
</tr>
<tr>
<td>t Critical one-tail</td>
<td>2.132</td>
<td>2.132</td>
</tr>
<tr>
<td>P(T&lt;=t) two-tail</td>
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<td>0.164</td>
</tr>
<tr>
<td>t Critical two-tail</td>
<td>2.776</td>
<td>2.776</td>
</tr>
</tbody>
</table>
Appendix E: ANOVA Outputs

## LWBS ANOVA ANALYSIS

### One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

**Method**
- Null hypothesis: All means are equal
- Alternative hypothesis: Not all means are equal
- Significance level: α = 0.1

Basic variances were assumed for the analysis.

**Factor Information**
- Factor: Method
  - Levels: Value

**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error</td>
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<td>12000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>12000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Model Summary**

<table>
<thead>
<tr>
<th>S</th>
<th>R-sq</th>
<th>R-sq(adj)</th>
<th>R-sq(pred)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>82.15%</td>
<td>81.20%</td>
<td>81.20%</td>
</tr>
</tbody>
</table>

**Means**

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>StdDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>21</td>
<td>95.422</td>
<td>11.988</td>
<td>(86.67, 104.17)</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>95.985</td>
<td>6.404</td>
<td>(90.90, 104.90)</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>75.125</td>
<td>15.566</td>
<td>(65.56, 85.56)</td>
</tr>
<tr>
<td>Method 3</td>
<td>21</td>
<td>75.085</td>
<td>15.616</td>
<td>(69.50, 80.60)</td>
</tr>
<tr>
<td>Method 4</td>
<td>21</td>
<td>75.025</td>
<td>2.305</td>
<td>(75.00, 85.00)</td>
</tr>
</tbody>
</table>

**Tukey Pairwise Comparisons**

**Grouping Information Using the Tukey Method and 95% Confidence**

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>21</td>
<td>95.422</td>
<td>A</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>95.985</td>
<td>B</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>75.125</td>
<td>C</td>
</tr>
<tr>
<td>Method 3</td>
<td>21</td>
<td>75.085</td>
<td>D</td>
</tr>
<tr>
<td>Method 4</td>
<td>21</td>
<td>75.025</td>
<td></td>
</tr>
</tbody>
</table>

---

### One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

**Method**
- Null hypothesis: All means are equal
- Alternative hypothesis: Not all means are equal
- Significance level: α = 0.1

Basic variances were assumed for the analysis.

**Factor Information**
- Factor: Method
  - Levels: Value

**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>MS</th>
<th>F Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error</td>
<td>150</td>
<td>12000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>12000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Model Summary**

<table>
<thead>
<tr>
<th>S</th>
<th>R-sq</th>
<th>R-sq(adj)</th>
<th>R-sq(pred)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>83.38%</td>
<td>83.32%</td>
<td>83.32%</td>
</tr>
</tbody>
</table>

**Means**

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>StdDev</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>21</td>
<td>95.642</td>
<td>57.0</td>
<td>(54.48, 66.08)</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>95.621</td>
<td>91.3</td>
<td>(54.68, 97.94)</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>95.050</td>
<td>2.7</td>
<td>(97.36, 93.36)</td>
</tr>
<tr>
<td>Method 3</td>
<td>21</td>
<td>75.182</td>
<td>2.7</td>
<td>(97.36, 93.36)</td>
</tr>
<tr>
<td>Method 4</td>
<td>31</td>
<td>75.157</td>
<td>16.3</td>
<td>(19.51, 199.59)</td>
</tr>
</tbody>
</table>

**Tukey Pairwise Comparisons**

**Grouping Information Using the Tukey Method and 95% Confidence**

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>21</td>
<td>95.642</td>
<td>A</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>95.621</td>
<td>B</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>95.050</td>
<td>C</td>
</tr>
<tr>
<td>Method 3</td>
<td>21</td>
<td>75.182</td>
<td>D</td>
</tr>
<tr>
<td>Method 4</td>
<td>31</td>
<td>75.157</td>
<td></td>
</tr>
</tbody>
</table>
One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1
Equal variances were assumed for the analysis.

Factor Information
Factor Levels Values
Factor 3 Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value
Factor 4 2114.085 528.517 73.5 0.000
Error 150 11102.7 74.01 0.000
Total 154 222408

Model Summary
R² Adj R-sq(adj) R-sq(adj)
45.5793 88.72% 87.91% 87.42%

Means
Factor N Mean SDev 90% CI
Base 31 123.81 8.78 (121.20, 126.42)
Method 1 31 123.45 8.70 (120.66, 126.24)
Method 2 31 124.48 7.29 (119.93, 129.03)
Method 3 31 123.59 9.23 (120.14, 126.94)
Method 4 31 124.01 8.75 (121.55, 126.65)
Post Hoc = 85.7445

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence
Factor N Mean Grouping
Base 31 123.81 A
Method 1 31 123.45 A
Method 2 31 124.48 A
Method 3 31 123.59 A
Method 4 31 124.01 A

One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1
Equal variances were assumed for the analysis.

Factor Information
Factor Levels Values
Factor 3 Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value
Factor 4 2114.085 528.517 73.5 0.000
Error 150 11102.7 74.01 0.000
Total 154 222408

Model Summary
R² Adj R-sq(adj) R-sq(adj)
45.5793 88.72% 87.91% 87.42%

Means
Factor N Mean SDev 90% CI
Base 31 123.81 8.78 (121.20, 126.42)
Method 1 31 123.45 8.70 (120.66, 126.24)
Method 2 31 124.48 7.29 (119.93, 129.03)
Method 3 31 123.59 9.23 (120.14, 126.94)
Method 4 31 124.01 8.75 (121.55, 126.65)
Post Hoc = 85.7445

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence
Factor N Mean Grouping
Base 31 123.81 A
Method 1 31 123.45 A
Method 2 31 124.48 A
Method 3 31 123.59 A
Method 4 31 124.01 A

Acuity 3
Acuity 4
One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1

Equal variances were assumed for the analysis.

Factor Information
Factor Levels Values
Factor Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source OF Adj SS Adj MS F-Value P-Value
Factor 4 4004 1001.06 64.33 0.000
Error 150 2071 13.81
Total 154 6729

Model Summary
S = 3.7159 R-Sq = 69.22% R-Sq(adj) = 68.40% R-Sq(pred) = 67.15%

Means
Factor N Mean SDEv 95% CI
Base 31 16.000 4.951 (14.895, 17.105)
Method 1 31 16.032 4.970 (14.928, 17.137)
Method 2 31 7.774 3.127 (6.670, 8.878)
Method 3 31 2.806 1.682 (1.702, 3.911)
Method 4 31 16.000 4.290 (14.895, 17.105)

Mean SD of = 3.7159

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence
Factor N Mean Grouping
Method 1 21 16.032 A
Method 4 31 16.000 A
Base 21 16.000 A
Method 2 31 7.774 B
Method 3 21 2.806 C

Acuity 5
LOS ANOVA ANALYSIS

One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1
Equal variances were assumed for the analysis.

Factor Information

Factor Levels Values
Factor S Base Method 1 Method 2 Method 3 Method 4

Analysis of Variance

Source DF Adj SS Adj MS F-Value P-Value
Factor 4 202.8 50.710 6.69 0.000
Error 150 1136.5 7.577
Total 154 1339.3

Model Summary

S R-sq R-sq(adj) R-sq(adj)
2.75237 15.14% 12.86% 9.99%

Means

Factor N Mean StdDev 95% CI
Base 31 399.205 3.007 (398.187, 400.224)
Method 1 31 399.205 3.005 (398.186, 400.223)
Method 2 31 398.588 2.971 (397.770, 399.406)
Method 3 31 398.497 2.964 (397.679, 399.315)
Method 4 31 461.053 2.400 (460.137, 462.469)

Pooled SD = 2.75237

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor N Mean Grouping
Method 4 31 461.053 A
Base 31 398.205 B
Method 1 31 399.205 B
Method 3 31 398.588 B
Method 3 31 398.497 B

Acuity 1

One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1
Equal variances were assumed for the analysis.

Factor Information

Factor Levels Values
Factor S Base Method 1 Method 2 Method 3 Method 4

Analysis of Variance

Source DF Adj SS Adj MS F-Value P-Value
Factor 4 6956.7 1733.17 5.19 0.000
Error 150 503.3 3.34
Total 154 7460.0

Model Summary

S R-sq R-sq(adj) R-sq(adj)
1.83173 95.25% 95.07% 93.80%

Means

Factor N Mean StdDev 95% CI
Base 31 506.658 2.072 (506.133, 507.182)
Method 1 31 505.651 2.062 (505.166, 506.135)
Method 2 31 509.031 1.861 (508.456, 509.606)
Method 2 31 505.490 1.861 (504.914, 506.068)
Method 4 31 491.439 1.611 (490.314, 492.563)

Pooled SD = 1.83173

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor N Mean Grouping
Method 3 31 509.469 A
Method 2 31 509.031 A
Base 31 506.658 B
Method 3 31 506.031 B
Method 4 31 491.439 C

Acuity 2
### One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null hypothesis: All means are equal</td>
</tr>
<tr>
<td>Alternative hypothesis: Not all means are equal</td>
</tr>
<tr>
<td>Significance level: α = 0.1</td>
</tr>
</tbody>
</table>

Equal variances were assumed for the analysis.

### Factor Information

**Factor Levels Values**

- **Factor**: S Base, Method 1, Method 2, Method 3, Method 4

### Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>7.982</td>
<td>1.995</td>
<td>4.46</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>150</td>
<td>696.3</td>
<td>4.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>765.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Model Summary

<table>
<thead>
<tr>
<th>S</th>
<th>R-sq</th>
<th>R-sq(adj)</th>
<th>R-sq(adj)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1123</td>
<td>0.9141</td>
<td>0.9121</td>
<td>0.9053</td>
</tr>
</tbody>
</table>

### Means

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>31</td>
<td>115.402</td>
<td>0.311</td>
<td>(115.314, 115.489)</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>115.505</td>
<td>0.253</td>
<td>(115.478, 115.530)</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>115.204</td>
<td>0.276</td>
<td>(115.177, 115.231)</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>115.411</td>
<td>0.306</td>
<td>(115.324, 115.498)</td>
</tr>
</tbody>
</table>

**Post Hoc Test**: T 0.05

### Tukey Pairwise Comparisons

<p>| Grouping Information Using the Tukey Method and 95% Confidence |
|----------------------|------------------|
| <strong>Base</strong> | <strong>Method 1</strong> | <strong>Method 2</strong> | <strong>Method 3</strong> |</p>
<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean</th>
<th>Grouping</th>
<th>Mean</th>
<th>Grouping</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.505 A</td>
<td>31</td>
<td>115.204 A</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>115.411 A</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.356 B</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>115.356 B</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.402 A</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.356 B</td>
<td>31</td>
<td>115.411 A</td>
</tr>
</tbody>
</table>

---

### One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null hypothesis: All means are equal</td>
</tr>
<tr>
<td>Alternative hypothesis: Not all means are equal</td>
</tr>
<tr>
<td>Significance level: α = 0.1</td>
</tr>
</tbody>
</table>

Equal variances were assumed for the analysis.

### Factor Information

**Factor Levels Values**

- **Factor**: S Base, Method 1, Method 2, Method 3, Method 4

### Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>11.182</td>
<td>2.790</td>
<td>3.355</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>150</td>
<td>12.34</td>
<td>0.066</td>
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</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>112.95</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Model Summary

<table>
<thead>
<tr>
<th>S</th>
<th>R-sq</th>
<th>R-sq(adj)</th>
<th>R-sq(adj)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.295644</td>
<td>98.65%</td>
<td>98.62%</td>
<td>98.78%</td>
</tr>
</tbody>
</table>

### Means

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Std Dev</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>31</td>
<td>115.402</td>
<td>0.311</td>
<td>(115.314, 115.489)</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>115.505</td>
<td>0.253</td>
<td>(115.478, 115.530)</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>115.204</td>
<td>0.276</td>
<td>(115.177, 115.231)</td>
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<tr>
<td>Method 3</td>
<td>31</td>
<td>115.411</td>
<td>0.306</td>
<td>(115.324, 115.498)</td>
</tr>
</tbody>
</table>

**Post Hoc Test**: T 0.05

### Tukey Pairwise Comparisons

<p>| Grouping Information Using the Tukey Method and 95% Confidence |
|----------------------|------------------|
| <strong>Base</strong> | <strong>Method 1</strong> | <strong>Method 2</strong> | <strong>Method 3</strong> |</p>
<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean</th>
<th>Grouping</th>
<th>Mean</th>
<th>Grouping</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.505 A</td>
<td>31</td>
<td>115.204 A</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>115.411 A</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.356 B</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>115.356 B</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.402 A</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>115.402 A</td>
<td>31</td>
<td>115.356 B</td>
<td>31</td>
<td>115.411 A</td>
</tr>
</tbody>
</table>

---

Acuity 3

Acuity 4
• One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1
Equal variances were assumed for the analysis.

Factor Information
<table>
<thead>
<tr>
<th>Factor</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>5</td>
<td>Base, Method 1, Method 2, Method 3, Method 4</td>
</tr>
</tbody>
</table>

Analysis of Variance
<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>2415.63</td>
<td>593.909</td>
<td>5.29632</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>150</td>
<td>17.12</td>
<td>0.114</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>2432.75</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model Summary
<table>
<thead>
<tr>
<th>1</th>
<th>R-sq</th>
<th>R-sq(adj)</th>
<th>R-sq(adj)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.33789</td>
<td>0.1950%</td>
<td>0.2819%</td>
</tr>
</tbody>
</table>

Means
<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>31</td>
<td>88.1760</td>
<td>0.1718</td>
<td>(88.0776, 88.2744)</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>88.461</td>
<td>0.1670</td>
<td>(88.0616, 88.0616)</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>88.095</td>
<td>0.1709</td>
<td>(88.0768, 88.1049)</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>98.190</td>
<td>0.2839</td>
<td>(98.0091, 98.2998)</td>
</tr>
<tr>
<td>Method 4</td>
<td>31</td>
<td>88.175</td>
<td>0.1713</td>
<td>(88.0741, 88.2768)</td>
</tr>
</tbody>
</table>

Post-test SD = 0.01789

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 3</td>
<td>31</td>
<td>88.1760</td>
<td>A</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>88.461</td>
<td>B</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>88.095</td>
<td>B, C</td>
</tr>
<tr>
<td>Base</td>
<td>31</td>
<td>98.190</td>
<td>C</td>
</tr>
<tr>
<td>Method 4</td>
<td>31</td>
<td>88.175</td>
<td>C</td>
</tr>
</tbody>
</table>
% Blocked ANOVA ANALYSIS

Equal variances were assumed for the analysis.

Factor Information
Factor | Levels | Values
--- | --- | ---
Factor | 5 | Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source | DF | Adj SS | Adj MS | F-Value | P-Value
--- | --- | --- | --- | --- | ---
Factor | 4 | 5.280 | 1.320 | 12.41 | 0.000
Error | 150 | 15.999 | 0.1064 | 0.000
Total | 154 | 21.235

Model Summary
R-sq | R-sq(adj) | R-sq(adj(adj))
--- | --- | ---
0.328140 | 0.328140 | 0.328140

Means
Factor | % | Mean | SD | P90 |
--- | --- | --- | --- | ---
Base | 31 | 0.7093 | 0.7092 | 0.6966 | 0.8090 |
Method 1 | 31 | 0.7057 | 0.7062 | 0.6966 | 0.8090 |
Method 2 | 31 | 0.8787 | 0.8787 | 0.8787 | 0.8787 |
Method 3 | 31 | 0.8570 | 0.8570 | 0.8570 | 0.8570 |
Method 4 | 31 | 0.5135 | 0.5135 | 0.5135 | 0.5135 |
Mean Diff = 0.328140

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence Interval
Factor | N | Mean | SD | Grouping
--- | --- | --- | --- | ---
Base | 31 | 0.7093 | 0.7092 | A
Method 1 | 31 | 0.7057 | 0.7062 | A
Method 2 | 31 | 0.8787 | 0.8787 | B
Method 3 | 31 | 0.8570 | 0.8570 | C
Method 4 | 31 | 0.5135 | 0.5135 | C

Means that do not share a letter are significantly different.

Tukey Simultaneous 95% CIs

Interval Plot of Base, Method 1, ...

One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

H0: All means are equal
H1: Not all means are equal

Significance level α = 0.1

Equal variances assumed for the analysis.

Source | DF | Adj SS | Adj MS | F-Value | P-Value
--- | --- | --- | --- | --- | ---
Factor | 4 | 5.35 | 1.3375 | 12.41 | 0.000
Error | 150 | 15.999 | 0.1064 | 0.000
Total | 154 | 21.235

Model Summary
R-sq | R-sq(adj) | R-sq(adj(adj))
--- | --- | ---
0.328140 | 0.328140 | 0.328140

Means
Factor | % | Mean | SD | P90 |
--- | --- | --- | --- | ---
Base | 31 | 0.6675 | 0.6675 | 0.6675 | 0.6675 |
Method 1 | 31 | 0.6675 | 0.6675 | 0.6675 | 0.6675 |
Method 2 | 31 | 0.6802 | 0.6802 | 0.6802 | 0.6802 |
Method 3 | 31 | 0.7085 | 0.7085 | 0.7085 | 0.7085 |
Method 4 | 31 | 0.5135 | 0.5135 | 0.5135 | 0.5135 |
Mean Diff = 0.328140

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence Interval
Factor | N | Mean | SD | Grouping
--- | --- | --- | --- | ---
Method 1 | 31 | 0.6675 | 0.6675 | A
Method 2 | 31 | 0.6802 | 0.6802 | B
Method 3 | 31 | 0.7085 | 0.7085 | C
Method 4 | 31 | 0.5135 | 0.5135 | C

Means that do not share a letter are significantly different.

Tukey Simultaneous 95% CIs

Interval Plot of Method 1, ...
One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: $\alpha = 0.1$
Equal variances were assumed for the analysis.

Factor Information
Factor Levels Values
Factor 5 Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>871.12</td>
<td>217.77</td>
<td>342.09</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>150</td>
<td>34.54</td>
<td>0.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>905.77</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Model Summary
$R^2$ adjusted $R^2$ unadjusted
0.860685 96.17% 94.07% 05.01%

Means
<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>StdDev</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>21</td>
<td>11.71</td>
<td>0.588</td>
<td>(11.568, 11.856)</td>
</tr>
<tr>
<td>Method 1</td>
<td>21</td>
<td>11.713</td>
<td>0.549</td>
<td>(11.684, 11.852)</td>
</tr>
<tr>
<td>Method 2</td>
<td>21</td>
<td>11.254</td>
<td>0.584</td>
<td>(11.002, 11.573)</td>
</tr>
<tr>
<td>Method 3</td>
<td>21</td>
<td>11.272</td>
<td>0.403</td>
<td>(11.212, 11.415)</td>
</tr>
<tr>
<td>Method 4</td>
<td>21</td>
<td>5.753</td>
<td>0.267</td>
<td>(5.434, 5.721)</td>
</tr>
</tbody>
</table>

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence
<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>StdDev</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>21</td>
<td>11.71</td>
<td>0.588</td>
<td>(11.568, 11.856)</td>
</tr>
<tr>
<td>Method 1</td>
<td>21</td>
<td>11.713</td>
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<td>(11.212, 11.415)</td>
</tr>
<tr>
<td>Method 4</td>
<td>21</td>
<td>5.753</td>
<td>0.267</td>
<td>(5.434, 5.721)</td>
</tr>
</tbody>
</table>

Acuity 3

Acuity 4
One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.05

Equal variances were assumed for the analysis.

Factor Information
Factor Levels Values
Factor 3 Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source DF Between SS Mean SS F-Value P-Value
Factor 4 555.290 49.322 4 0.0303 0.0000
Error 156 7.285 0.0464
Total 154 202.355

Model Summary
S R-sq R-sq(adj) R-sq(adj)
0.220300 0.9411 0.9322 0.9317

Means
Factor N Mean StDev 95% CI
Base 31 3.1436 0.2406 (3.0762, 3.2109)
Method 1 21 3.1223 0.2626 (3.0259, 3.2187)
Method 2 31 1.8186 0.2770 (1.7061, 2.1603)
Method 3 21 1.5721 0.1723 (1.5077, 1.6361)
Method 4 31 1.5712 0.1745 (1.5068, 1.6366)

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 4</td>
<td>31</td>
<td>3.1512</td>
<td>A</td>
</tr>
<tr>
<td>Base</td>
<td>31</td>
<td>3.1436</td>
<td>A</td>
</tr>
<tr>
<td>Method 1</td>
<td>31</td>
<td>3.1243</td>
<td>A</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>1.9194</td>
<td>B</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>1.5731</td>
<td>C</td>
</tr>
</tbody>
</table>

Acuity 5
Resource Underutilization ANOVA ANALYSIS

One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1

Equal variances were assumed for the analysis

Factor Information
Factor Levels Values
Factor 5 Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value
Factor 4 203.06 50.766 423.14 0.000
Error 150 194.8 1.295
Total 154 397.8

Model Summary
R-Sq: 91.86%
R-Sq(adj): 91.64%
R-Sq(adj): 91.31%

Means
Factor N Mean StdErr 95% CI
Base 31 18.3510 0.1021 (18.0126, 18.6893)
Method 1 31 18.3510 0.1021 (18.0126, 18.6893)
Method 2 31 8.969 0.1073 (8.5566, 9.3833)
Method 3 31 12.666 2.537 (10.507, 14.832)
Method 4 31 18.3510 0.1021 (18.0126, 18.6893)

One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

Method
Null hypothesis: All means are equal
Alternative hypothesis: Not all means are equal
Significance level: α = 0.1

Equal variances were assumed for the analysis

Factor Information
Factor Levels Values
Factor 3 Base, Method 1, Method 2, Method 3, Method 4

Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value
Factor 4 16864.9 4716.21 14056.57 0.000
Error 150 5.0 0.03
Total 154 16869.9

Model Summary
R-Sq: 99.97%
R-Sq(adj): 99.97%
R-Sq(adj): 99.97%

Means
Factor N Mean StdErr 95% CI
Base 31 16.0217 0.0150 (15.9712, 16.0721)
Method 1 31 16.0654 0.1510 (16.0096, 16.1211)
Method 2 31 16.0607 0.0203 (15.9398, 16.1815)
Method 3 31 16.0607 0.1510 (16.0096, 16.1815)
Method 4 31 16.0607 0.1510 (16.0096, 16.1815)

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence
Factor N Mean Grouping
Method 4 31 18.3510 A
Method 1 31 18.3510 A
Base 31 18.3510 A
Method 3 31 13.646 B
Method 2 31 8.8949 C

Tukey Pairwise Comparisons
Grouping Information Using the Tukey Method and 95% Confidence
Factor N Mean Grouping
Method 4 31 16.0607 A
Base 31 16.0717 A
Method 1 31 16.0654 A
Method 2 31 16.0607 A
Method 3 31 16.0607 A

Triage Nurse 1

Triage Nurse 2
### One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

**Method**
- Null hypothesis: All means are equal
- Alternative hypothesis: Not all means are equal
- Significance level: α = 0.1
  - Equal variances were assumed for the analysis.

**Factor Information**
- Factor: 5 Base, Method 1, Method 2, Method 3, Method 4

**Analysis of Variance**
<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
<td>4</td>
<td>596.6</td>
<td>149.16</td>
<td>3.54</td>
<td>0.012</td>
</tr>
<tr>
<td>Error</td>
<td>150</td>
<td>6680.0</td>
<td>44.56</td>
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</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>7285.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Model Summary**
- $\bar{R}^2$: 6.18%
- $R_{adj}^2$: 5.73%
- $R_{adj(adj)}^2$: 1.95%

**Means**
- Base: 13.3039
- Method 1: 13.3039
- Method 2: 14.2045
- Method 3: 18.16
- Method 4: 13.3039

**Tukey Pairwise Comparisons**
- Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1</td>
<td>31</td>
<td>18.7017</td>
<td>A</td>
</tr>
<tr>
<td>Method 2</td>
<td>31</td>
<td>18.2045</td>
<td>A</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>13.3039</td>
<td>B</td>
</tr>
<tr>
<td>Method 4</td>
<td>31</td>
<td>13.3039</td>
<td>B</td>
</tr>
</tbody>
</table>

---

### One-way ANOVA: Base, Method 1, Method 2, Method 3, Method 4

**Method**
- Null hypothesis: All means are equal
- Alternative hypothesis: Not all means are equal
- Significance level: α = 0.1
  - Equal variances were assumed for the analysis.

**Factor Information**
- Factor: 5 Base, Method 1, Method 2, Method 3, Method 4

**Analysis of Variance**
<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
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<td>796.7</td>
<td>197.68</td>
<td>174.12</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>150</td>
<td>1701.2</td>
<td>11.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>154</td>
<td>1944.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Model Summary**
- $\bar{R}^2$: 82.28%
- $R_{adj}^2$: 81.11%
- $R_{adj(adj)}^2$: 61.08%

**Means**
- Base: 18.7017
- Method 1: 18.7017
- Method 2: 18.2045
- Method 3: 12.978
- Method 4: 18.7017

**Tukey Pairwise Comparisons**
- Grouping Information Using the Tukey Method and 95% Confidence

<table>
<thead>
<tr>
<th>Factor</th>
<th>N</th>
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<tbody>
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<td>Method 1</td>
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<td>18.7017</td>
<td>A</td>
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<tr>
<td>Method 2</td>
<td>31</td>
<td>18.2045</td>
<td>A</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>12.978</td>
<td>B</td>
</tr>
<tr>
<td>Method 4</td>
<td>31</td>
<td>18.7017</td>
<td>A</td>
</tr>
<tr>
<td>Base</td>
<td>31</td>
<td>18.7017</td>
<td>A</td>
</tr>
<tr>
<td>Method 3</td>
<td>31</td>
<td>12.978</td>
<td>B</td>
</tr>
</tbody>
</table>

---

**PCA Registration Worker**