University of Michigan Health System (UMHS)

An Analysis of Current State Workflow, Workloads, and Error Rates in UMHS Inpatient Pharmacies

Final Report

Industrial and Operations Engineering 481: Practicum in Hospital Systems

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Executive Summary

The University of Michigan Health System (UMHS) inpatient pharmacy manager believes that patient safety could be increased by improving IV preparation workflow in UMHS pharmacies. The team of industrial engineering students was tasked with evaluating the current state of the intravenous (IV) drug preparation process in UMHS inpatient pharmacies in order to evaluate ways to improve workflow and patient safety. The current state assessment done by the team assessed three major areas of the current state of the pharmacies with regard to IV preparations:

1. Workflow, in terms of the sequence of process steps to prepare IVs
2. Workloads, in terms of IV order volumes
3. Error rates, in terms of IV preparations needing rework

The team particularly emphasized issues of workload and workflow that could affect error occurrence in IV preparation procedures. The team worked closely with the pharmacy manager in the analysis of six UMHS pharmacies. Included in the study were the following pharmacies:

- IV clean room on floor B2 of University Hospital (UH),
- Floors 5, 6 and 8 pharmacies in UH
- 4th floor pharmacy in Cardiovascular Center (CVC)
- 5th floor pharmacy in Mott Children’s Hospital (MCH)

Methodologies and Findings

The team performed the following tasks to assess the current state of UMHS pharmacies:

- Interviewed pharmacy staff and directly observed IV preparation workflows
- Timed IV preparations of three IV types (piggybacks, large volumes, and syringes)
- Obtained and analyzed data from UMHS’s WORx® network on pharmacy workloads
- Collected data for a week-long period to determine pharmacy error-rates

Observations and Interviews: From the initial observations of pharmacy processes and interviews with pharmacy staff, the team made the following assessments:

- Work procedures are not standardized (i.e. workflow steps vary between technicians)
- IV supplies and drug product locations vary between pharmacies
- Workspaces are small and ventilated hoods where IVs are prepared can become crowded
- Workloads within and between pharmacies are uneven
- Technicians waste time on non-value added activities such as in the Mott pharmacy where technicians often wait for pharmacists to check over their orders

Figure 1 shows a high-level flowchart of IV preparation procedures. The process that the team examined begins with the technicians receiving order labels that print in the pharmacies and ends with the technicians taking finished products to the countertops where they are checked over by
pharmacists before being dispensed to patients. Appendix A shows a detailed process map of IV order preparations.

![Flowchart of the basic IV preparation process](image)

**Figure 1: A high-level flowchart of the basic IV preparation process**

**Preparation Timing Data:** The team collected and analyzed data on IV preparation times to find the average filling times for IV orders. IV preparations were timed from the moment the needles were attached to the syringes used for filling orders until the labels were placed on finished IV products. The team also noted whether the IVs were piggybacks (< 250 ml), large volumes (≥ 250 ml), or syringes. Figure 2 shows the team’s findings for IV preparation times:

![Average IV preparation times by IV type](image)

**Figure 2: Average IV preparation times by IV type**  
*Source: Team data collection on IV timing*

Overall, IV orders take approximately 76 seconds to prepare on average. IVs containing drugs requiring reconstitution take longer to fill with an average preparation time of 212 seconds to fill.

**Workload Analysis:** The team’s analysis of workloads (based on data obtained from the hospital’s WORx® network) showed that the six pharmacies analyzed prepared an estimated 900,000 IVs in 2009. The team found that IV order volumes vary considerably between months. Additionally, weekday IV order volumes tend to be higher than IV order volumes on weekends.
On average, approximately 2,443 IV orders are filled per day in all six pharmacies. Finally, approximately 23% of IV preparations are large bags, 43% are piggyback IVs, and 34% are syringes.

**Error Rate Determination:** For a week long period in March 2010, registered pharmacists (RPh) were asked to mark-off all IV items requiring rework during their routine checks of IV orders leaving the pharmacies. The data were then compared to workload data obtained from the WORx® network to obtain error rates. Table 1 summarizes the findings of this study:

<table>
<thead>
<tr>
<th></th>
<th>5MCH</th>
<th>B2</th>
<th>6UH</th>
<th>5UH</th>
<th>8UH</th>
<th>4CVC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total IV Orders</strong></td>
<td>8555</td>
<td>5953</td>
<td>4149</td>
<td>2612</td>
<td>1046</td>
<td>1624</td>
</tr>
<tr>
<td><strong>RPh Reported Errors</strong></td>
<td>22</td>
<td>14</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Accuracy Rate</strong></td>
<td>99.743%</td>
<td>99.765%</td>
<td>99.855%</td>
<td>99.923%</td>
<td>99.904%</td>
<td>99.938%</td>
</tr>
<tr>
<td><strong>Error Rate</strong></td>
<td>0.257%</td>
<td>0.235%</td>
<td>0.145%</td>
<td>0.077%</td>
<td>0.096%</td>
<td>0.062%</td>
</tr>
<tr>
<td><strong>Estimated Yearly IV Orders</strong></td>
<td>375,929</td>
<td>184,161</td>
<td>144,171</td>
<td>91,229</td>
<td>51,793</td>
<td>48,373</td>
</tr>
<tr>
<td><strong>Estimated Annual Errors</strong></td>
<td>967</td>
<td>433</td>
<td>208</td>
<td>70</td>
<td>50</td>
<td>30</td>
</tr>
</tbody>
</table>

The errors reported in Table 1 are only those errors that the pharmacists caught and recorded. Therefore, the numbers reported above are low-end estimates for actual error occurrences during the week of data collection. While the technicians’ accuracy rates in filling IVs exceed 99 percent in all pharmacies, hundreds of IV preparation errors per year are still expected to occur in UMHS pharmacies.

**Recommendation: The Possibility of Implementing IV Safety Technology**
The team examined the feasibility of implementing an IV safety and workflow technology called DoseEdge™ that could potentially mitigate IV preparation related errors in UMHS pharmacies. The DoseEdge™ system could provide the following benefits for improving IV preparation workflow and patient safety:

- Reduce medication errors through use of automatic drug verification (barcode checking)
- Provide automatic computations of doses and dilutions needed
- Allow for inspection of dose preparation from remote computers
- Prevent waste by reducing the occurrence of lost and missed doses

The process maps in Appendices M and N show the IV preparation workflow before and after DoseEdge™ implementation.

**Conclusions**
The information given in this report can be helpful to pharmacy leadership to understand the current state of IV preparations in UMHS pharmacies and therefore make informed management decisions with this information. Furthermore, the information in this report can be used to assess the feasibility of implementing new IV safety and workflow technology such as DoseEdge™ in UMHS pharmacies.
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Introduction and Project Description

The University of Michigan Health System (UMHS) inpatient pharmacy manager believes that by improving the workflow in UMHS inpatient pharmacies, IV related rework can be decreased and patient safety increased. The pharmacy manager has therefore asked the team of Industrial and Operations Engineering undergraduate seniors at the University of Michigan to examine the workflow of intravenous (IV) drug preparation in the inpatient pharmacies of the UMHS’s Main Campus. The team was asked to observe and analyze IV preparation procedures to document the current state of the UMHS inpatient pharmacies, with specific emphasis on determining ways to reduce errors in IV preparations.

In January through April of 2010, the team observed and analyzed the current system for IV product preparation in UMHS inpatient pharmacies to find areas for improvement. The team reviewed, documented, and diagramed current workflows and workloads in UMHS main campus pharmacies. The team measured IV preparation times, assessed pharmacy workloads, drew current state workflow diagrams, and approximated IV preparation error rates. Based on its analyses, the team has assessed the current state of the pharmacy and developed recommendations to reduce the number of IV preparation errors. The purpose of this report is to document the methods used to assess the current state of the UMHS inpatient pharmacies, present the key findings, and make recommendations that pharmacy leadership could use to reduce errors in IV preparations.

Background

The pharmacies located in the University Hospital (UH), Cardiovascular Center (CVC) and Mott Children’s Hospital on the UMHS main campus dispense (on average) over 17,000 IV products weekly to patients within the hospital.1 The sole responsibility of preparing the IV products for patient use belongs to the hospital pharmacies. Pharmacies receive IV medication orders electronically from doctors and nurses throughout the hospital, typically through the hospital’s computerized WORx® system. Pharmacists verify that the medications and doses requested are appropriate for the patients. Technicians then prepare the IV products by selecting the drugs and IV fluids based on the order information given to them by the pharmacists.

Current Procedures

This project examined the workflow for IV preparation starting from when the label containing IV order information prints in the pharmacy. After collecting all the items needed for the IV preparation, the technician measures the dosage of the drug and injects it into the IV fluid. Then, as a safety precaution, the technician removes and draws back the syringe to indicate the amount

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1 According to hospital data on inpatient IV records for February, June and November of 2009
of drug dispensed so that the pharmacist can verify the dosages and dispense the products to the various patient units within the hospital. Part of this project has been to determine the error rate associated with this method since no previous studies have been performed at UMHS to determine error occurrence frequencies. A study in five U.S. hospitals shows error rates for IV preparation as high as 9%\(^2\), indicating the need for UMHS to measure error rates in its own pharmacies. Improving accuracy in product preparation can result in lower costs due to fewer wasted products and rework, as well as improved safety for patients. For the purposes of this study, errors were defined as cases where IV orders need to be redone if found defective by the pharmacists who double-check the IV orders before they leave the pharmacies.

Until this project was done, there existed no previous estimates of how many IV preparation errors occur annually within the UMHS inpatient pharmacies. Therefore, the team was asked to estimate error occurrences, analyze the IV product preparation workflow, and assess the IV filling procedures to reduce rework costs and increase safety.

Based on preliminary observations, the team observed the following things concerning the UMHS pharmacies:

**Small Space Constraints**

Team members observed that workspaces in UMHS pharmacies are often too small for current needs given the number of materials being stored in each pharmacy, as well as the considerable space needed for IV preparation equipment (IVs are prepared in laminar flow hoods that generally measure around 6 x 1.5 feet). Therefore the space must be used effectively, since pharmacy workers note that items can be confused and mixed up in cluttered spaces.

**Non-Standardized Work Procedures**

Non-standardized work procedures may be a factor in IV error rates; the team observed that different workers use slightly different procedures for filling IV orders. Standardized work procedures are commonly implemented in manufacturing operations to reduce errors and allow for continuous improvement of workflow processes\(^3\).

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\(^3\) See Professor Jeffrey Liker’s book *The Toyota Way* for a detailed description of how and why standardized work procedures have helped reduce defects and improve quality in automobile manufacturing (and manufacturing in general). Professor Liker, a University of Michigan College of Engineering faculty member, is currently involved in research on how to apply principles of quality in manufacturing to the healthcare industry.
Uneven Workloads Within and Between Pharmacies

From observations of the IV filling procedures, team members noticed that workloads are uneven within and between pharmacies. For example, the pharmacy on the 5th floor of UH may have a very high workload at a given time, while the pharmacy on the 6th floor of UH could have a light workload at the same time. Furthermore, workloads are not distributed evenly throughout the day, so that some time periods are far busier than others. As a result, pharmacy technicians hurry to fill IV orders at some times, potentially leading to errors since they must do the same work in less time, while the technicians have little work to do at other times.

Key Issues

The following primary issues drove the need for this project:

- Current IV filling procedures are prone to human error, potentially due to small workspaces where items can easily be mixed up and non-standardized work procedures
- Uneven workloads mean that technicians and pharmacists are overworked at times, as reported by technicians and observed by the team, possibly leading to further errors
- Basic metrics and data were needed for the current process to determine actual error rates
- Pharmacy leaders were interested in determining effective ways to mitigate errors

Goals and Objectives

To determine the frequency of errors and assess ways to reduce their occurrence by improving the current workloads and workflow of the IV preparations in UMHS pharmacies, the team completed the following tasks:

- Performed studies to determine current IV preparation workloads in UMHS pharmacies during various time periods throughout a typical week
- Observed IV preparations in UMHS pharmacies to document and time the procedures currently being practiced by pharmacy technicians to fill IV orders
- Performed a study to obtain an approximate error rate of the pharmacy technicians in regard to IV preparations, with errors being defined as items needing rework
- Researched potential ways to improve workflow and lower error rates

With this information, the team developed a list of key findings concerning:

- Error rates in IV product preparation
- Workflow considerations for the IV order filling process
- Workload considerations concerning work volumes in hospital pharmacies
- Feasibility of implementing new technology in order to mitigate errors
Project Scope

The project’s scope included only the processes of preparing and reconstituting drug doses for use in patient IVs. The project focused on the areas and activities of UMHS main campus pharmacies dedicated to IV preparation and error-checking by technicians and pharmacists. The team examined IV related activities in the following six UMHS main campus pharmacies:

- The IV clean room on floor B2 of UH (B2)
- Floor 5 of UH (5UH)
- Floor 6 of UH (6UH)
- Floor 8 of UH (8UH)
- CVC pharmacy (4CVC)
- Mott Children’s Hospital pharmacy (5MCH)

The team did not analyze any portions of the IV preparation process that occur outside of the UMHS pharmacies. Furthermore, the team did not look at the process of receiving and verifying orders for IV preparation requests and the team therefore assumed that all orders received by pharmacy technicians to be filled were of the correct dosages and types for patient needs. Error rates were measured based solely on errors that occurred after technicians received orders.

Omnicell orders were not included in this project.

The Cancer Center pharmacy was not analyzed in this project since the process for filling cancer treatment IVs (mostly chemotherapy related) is significantly different from the processes of IV preparation in other pharmacies. The IV preparation times for chemotherapy drugs tend to be far higher than for other IV preparations. The chemotherapy IV preparations taking place in the Mott and UH Floor 8 pharmacies were not analyzed for preparation timing and workflow purposes for the same reason.

Project Approaches and Findings

The project’s approaches can be divided into the following four major categories:

- Initial observations and technician interviews
- Workflow and timing analysis
- Workload analysis
- Error rate determination

The sections below discuss the team’s methodologies as well as the findings from the various activities performed for this project. The information is organized according to the four categories above.
**Initial Observations and Technician Interviews**

After an initial meeting with the project clients to discuss their concerns about IV preparations as well as the project scope and requirements, the team observed IV preparation procedures in UMHS pharmacies.

**Methods: Observations and Interviews**

For one week in early February, each team member spent approximately 4-5 hours directly observing the procedures for IV preparations, informally interviewing technicians, and getting acquainted with the layouts and activities of the hospital pharmacies.

The team also interviewed a pharmacy technician who works at all UMHS pharmacy locations. The interviewee helped the team to identify and document general pharmacy steps and procedures for filling IV orders. The data from this interview were used to construct the flowcharts discussed below in the “Workflow and Timing Analysis” section.

**Findings: Observations and Interviews**

From these initial observations and interviews, the team gained a better understanding of pharmacy procedures, making further data collection and analysis possible.

**Process Flow:** The team observed that the process for filling IV’s is generally linear, with several steps that change between pharmacies. In particular, the process is modified for the Mott pharmacy since an additional safety check is performed there. While the process flow changes slightly for special circumstances (e.g. a phone call in the middle of filling an order, a forgotten step, or a mistake that is realized in the middle of filling an order), the same basic steps are followed in almost all cases. See the high-level flowchart in Figure 1.

![Figure 1: A high-level flowchart of the basic IV preparation process](image)

For a more detailed flowchart of these steps, see Appendix A. The team noted from their observations that different technicians’ procedures varied dramatically within the steps described
in the flowchart, since no rigidly defined standardized procedures for filling IV orders in the UMHS pharmacies exist.

Physical Setups: The team observed that IV preparation areas are often too small for current needs. IV orders are typically prepared in laminar flow hoods measuring 6 x 1.5 feet and preparation materials for many IV orders are often placed in the hoods at the same time. As a result, IV preparation areas are often cramped, with IV orders placed in close proximity to each other, which may lead to confusion or errors by technicians and pharmacists. Additionally, the locations of drugs, IV solutions, and other items vary between pharmacies, making it difficult for pharmacy technicians to work in pharmacies whose layouts they are not used to. In addition, printers that print IV labels are located in different areas in different pharmacies. In some pharmacies, such as Mott, the printers are located right next to the work areas, meaning that technicians do not waste time walking to grab order printouts; in other pharmacies, the printers are located at varying distances from the IV hoods, meaning that technicians occasionally waste time walking to grab IV order labels.

Standardized Procedures: Finally, workers do not always have or follow standardized work procedures to fill IV orders. For example, in preparing batches, some workers simply use the same syringe to fill several IV preparations of the same type. This use of one syringe to fill several preparations may create problems for checking items since pharmacists only have one syringe to look over for a batch, rather than one for each item; with only one syringe to check over for an entire order, pharmacists are able to do fewer individual checks and may be less likely to find preparation errors. As another example, technicians often prepare IVs for common IV preparations ahead of time and then attach a label to them when an order label arrives for the IV type prepared. Rigidly defined standardized procedures do not appear to be in place to address the above examples.

Workflow and Timing Analysis

The team gathered IV preparation timing data between February 15, 2010 and March 10, 2010. These data were used in conjunction with observational data to document the workflow for IV preparation in UMHS inpatient pharmacies.

Methods: Workflow and Timing Analysis

To collect timing data, the team members observed technicians in the various pharmacies and measured the times to fill IV preparations using stopwatches. In total, roughly 20 team hours were spent observing pharmacies for workflow documentation and timing purposes. To ensure uniform timing methods, the team, in conjunction with the Pharmacy Manager, defined the start and end points of the IV preparation process as follows:

Start: The moment a needle was attached to the product preparation syringe
End: The moment the label was placed onto the IV product.

For each observed IV preparation, the team also noted whether the drug required reconstitution, any irregularities (which most commonly consisted of noting if items were batched together and if so, the number batched together), and which type of IV was being prepared. For purposes of the timing data, the IVs were classified into three types as follows:

- Small IV Piggyback Pouches ($< 250$ ml)
- Large IV Bags ($\geq 250$ ml)
- Syringes

A copy of the Timing Data Collection Sheet used by the team is found in Appendix B.

Pharmacy technicians often prepare multiple IVs of the same type in batches to speed up the process (e.g. A technician prepares three of the same product to be given to a single patient three times throughout the day). However, for the purposes of analyzing the data accurately, the team counted each of these preparation batches as a single data point, with the time noted as the total batch preparation time divided by the number of IV products in the batch. For example, if a technician prepared 10 identical IVs at the same time (usually by lining up the IV materials and filling them one after the other) over a period of 10 minutes, the data collected was counted as a single data point with a time of 60 seconds. Analyzing the data in this way prevented the batched IV orders from artificially lowering the variability of preparation times.

Because IVs are prepared somewhat sporadically in UMHS pharmacies (as shown in the “Workload Analysis” section below), the team members often arrived at specific pharmacies and found that no IVs were being prepared at those times. If this was the case, team members simply searched for pharmacies that were currently preparing IVs. No data were collected at the pharmacy on floor 8 of UH because team members simply arrived to collect data at that pharmacy at the wrong times during the timing data collection period. However, the team believes that it collected enough data from other pharmacies for the data to be useful in determining approximate timing measures for the various IV preparations. (Note: At the time of timing data collections, the team did not have access to data on workload information as discussed in the “Workload Analysis” section below. Therefore, the team did not know when the best times were to arrive to specific pharmacies for timing data collection.)

**Findings: Workflow and Timing Analysis**

The team observed a total of 185 IV preparations. For purposes of analysis, 121 total data points were analyzed since batched preparations were counted as one data point each, as described above. The overall average time to prepare the IVs was 76 seconds. Small IV piggyback pouches were the most commonly observed type of IV preparation; Table 1 shows the respective sample sizes broken down by IV type:
Table 1: Number of observations by IV order type

<table>
<thead>
<tr>
<th>Number of Observations:</th>
<th>Piggybacks</th>
<th>Syringes</th>
<th>Large Bags</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>74</td>
<td>27</td>
<td>20</td>
</tr>
</tbody>
</table>

(Source: IV preparation data collected from the team’s observations in UMHS pharmacies)

Table 2 illustrates the number of observations taken at each satellite pharmacy.

Table 2: Number of observations at each satellite pharmacy

<table>
<thead>
<tr>
<th>Number of Observations:</th>
<th>B2</th>
<th>UH5</th>
<th>UH6</th>
<th>CVC</th>
<th>Mott</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24</td>
<td>42</td>
<td>22</td>
<td>14</td>
<td>19</td>
</tr>
</tbody>
</table>

(Source: IV preparation data collected from the team’s observations in UMHS pharmacies)

Average Preparation Times: Figure 2 illustrates the average preparation times by IV type. 11 of the 121 observations shown in Figure 2 required reconstitution. Of the 11, 9 of the reconstituted IVs were Piggybacks and the other 2 were Large IV Bags. Reconstituted IVs took an average of 212 seconds to prepare, with a standard deviation of 131 seconds. As the large standard deviation indicates, reconstitution times vary greatly depending on the medication type and the preparing technician. As reconstitutions take significantly longer to prepare (on average 212 seconds) than IVs not requiring reconstitution (on average 63 seconds), the team also analyzed the data with the reconstituted preparations removed. Figure 3 illustrates the average IV preparation times by IV type, excluding reconstituted IVs.
As seen in Figure 2, the overall average time for preparing individual IVs was 76 seconds. Large IV bags take significantly longer to prepare than syringes and piggybacks.

![Figure 3: Average IV preparation times by IV type, excluding reconstituted IV orders](Source: IV preparation data collected from the team’s observations in UMHS pharmacies)

When the effects of reconstitutions are excluded, a comparison of Figure 3 to Figure 2 shows that average preparation times drop considerably, especially for large IV bag preparations. Table 3 below shows the average IV preparation times by IV type with their respective standard deviations and coefficients of variation, again excluding reconstituted IVs:

**Table 3: Means, standard deviations, and coefficients of variation of IV preparations by type, excluding reconstitutions**

<table>
<thead>
<tr>
<th>IV Type</th>
<th>Mean Preparation Time</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation (Standard Deviation / Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piggyback Pouch</td>
<td>56 Seconds</td>
<td>39 Seconds</td>
<td>0.70</td>
</tr>
<tr>
<td>Large IV Bag</td>
<td>77 Seconds</td>
<td>41 Seconds</td>
<td>0.53</td>
</tr>
<tr>
<td>Syringe</td>
<td>67 Seconds</td>
<td>86 Seconds</td>
<td>1.28</td>
</tr>
</tbody>
</table>

The high coefficients of variation in the IV preparation process indicate that variation is significant. For detailed statistical summary charts showing the distributions of IV preparation times (reconstituted preparations not included), see Appendix C. These graphical depictions of IV preparation times for each IV type show that most IV orders are prepared within predictable
time periods near the median preparation times. However, several IV orders within each IV type take far longer to prepare, which significantly increases preparation time variability.  

**Reasons for Variance in Preparation Times:** The large variances observed in the timing data can be attributed to several factors:

- Non-standard procedures for preparing IVs. Each technician performs the process a little differently, introducing variation in the preparation times.
- Different types of IVs (piggybacks, large volumes, and syringes) take different amounts of time to prepare.
- IVs prepared in batches (Identical preparations prepared at the same time) take slightly shorter to prepare per preparation.
- Occasionally, technicians are interrupted in the middle of preparing an IV (e.g. taking a phone call, searching for a writing implement).

**Preparations in Batches:** While collecting data on IV preparation times, the team logged 16 batches being prepared. In this context, a batch constitutes IV preparations in which multiple products are prepared simultaneously with the same medication. For example, if three identical IV order labels print in the pharmacy at the same time, technicians commonly prepare all of the orders simultaneously, rather than sequentially. Often, one syringe drawback is all that the pharmacist can verify from the entire order, although that syringe was most likely used for multiple IV preparations.

For batches, timing data were also collected from the point the needle was attached to the first syringe until the last label was placed on the respective IV products. To evaluate unit preparation times, the total time for batch preparation was divided by \( n \), the batch size.

Figure 4 illustrates that preparing IV products in batches is faster per unit preparation when compared to the average time to prepare an individual IV product. As batch sizes increase, unit preparation times tend to decrease.
Preparing IVs in batches is typically faster than preparing IVs individually; however, preparation accuracy and patient safety are more important than timing, and batching IV preparations in the pharmacies may introduce safety concerns. The team believes that a safety concern is introduced since pharmacists cannot verify the amount of drug injected into each IV individually, only the batch as a whole, making the detection of errors more difficult.

**Process Map Flowcharts:** Team members each spent around 10 hours in UMHS pharmacies observing, timing, and documenting IV preparations. The team observed that methods for filling IV orders can vary significantly between technicians and for different products. The team compiled information obtained from observations, interviews, and timing data collection and analysis to construct the current process flowchart shown in Appendix A. While the process flow may change slightly for special circumstances (e.g. a phone call in the middle of filling an order, a forgotten step, or a mistake that is realized in the middle of filling an order), the basic steps shown in the flowchart are accurate for the majority of cases observed by the team. Nonetheless, the team noted that different staff members’ procedures often vary within the steps described in the flowchart, since no rigidly defined standardized procedures for filling IV orders in the UMHS pharmacies exist. The team also observed that for the Mott pharmacy, considerable time was wasted when the technicians waited for pharmacists to walk to the preparation area to check dosages before technicians were allowed to fill IVs.
Workload Analysis

The team analyzed the technicians’ IV preparation workloads by analyzing data on IV orders available from the UMHS computer system. These data were used to determine information about pharmacy workflow, including:

- Work volumes at various pharmacy locations
- Variability of work volumes by time
- IV order types at each pharmacy

Methods: Workload Analysis

The team received data from the UMHS’s WORx® network, which is used to process IV orders in the hospital. The data contained information on the drugs ordered, such as what times the IV orders were printed out in the individual pharmacies, the order types (large bag, piggyback or syringe), and the pharmacist who entered the order into the system. Because hundreds of thousands of IV orders were to be analyzed, the team underwent several iterations of having data pulled from the system until the team members determined that all (or nearly all) relevant data were obtained. The final data that the team analyzed were given to the team in the form of a text file (.txt) containing 625,974 rows of data and 25 columns containing information on each IV order. The data were then uploaded into Microsoft Excel 2007 (which allows for data sheets containing just over one million rows of data) for further analysis.

Removing Data Points: The team filtered the data to obtain only the relevant information for workload analysis, so that the following items were removed:

- All data points from months other than February, June, and October 2009. These three months were chosen since they are spread out throughout the year and the team decided, in conjunction with the pharmacy manager, that these months would likely yield an accurate depiction of typical pharmacy workloads.
- All duplicate data points. When several medicines go into one IV order, the duplicate items were deleted so that each IV order was represented as one data point in the final data analyzed.
- All data points containing screw-on medicines or other pre-prepared products that are labeled, but not otherwise prepared in hospital pharmacies.
- All data points listed as going to the operating room pharmacy (ORRX) since this pharmacy was not included within the scope of this project.

After removing these data points, the data file to be analyzed contained 194,748 rows.

Additionally, the column in the data file labeled “Dispense Unit Quantity” indicated the number of orders represented by each line of the filtered data. For most IV orders, this column contained a value of 1. However, when this column contained a higher value, it indicated that several
identical IV preparations were ordered.

**Data Modifications and Assumptions:** The data were modified in two additional ways as follows:

- Several dozen rows contained dispense unit quantities that appeared to be artificially high (as high as 37), which the pharmacy manager and computer network specialist assumed to be input errors into the system. The team and the pharmacy manager therefore decided that any value in this column above 4 would be treated as an input error and changed to 1. The only exception to this rule was that IV orders for Continuous Renal Replacement Therapy (CRRT) solutions were changed to dispense quantities of 4 if the dispense quantity values were more than 4.

- As noted previously, the data contained a column indicating the user or pharmacist who entered each order into the system. Approximately 50% of the total IV orders were classified as having the user value “Worxuser”, which indicated that these IV orders were “batch time” orders to be filled at designated times for each pharmacy. The data were sifted through manually and the team determined which Worxuser data points were to be counted for each pharmacy based on matching up the print times and pharmacy locations to set times that each pharmacy is supposed to receive a batch. The set times for batches were obtained from the pharmacy manager and are listed in Appendix D. This step was necessary, since the original data did not contain orders to be processed in the IV clean room on floor B2 of UH. In general, “batch time” IV orders are printed out either in the IV clean room or the various satellite pharmacies; orders filled in the clean room can have longer expiration dates since they are less likely to become contaminated. The clean room generally only works at specified times, dealing with high volumes and filling batches of identical orders. All IV orders, Worxuser or not, that are attributed in the WORx® data to the Mott Children’s Hospital pharmacy are filled in that pharmacy and were analyzed as such.

The final data contained 218,393 separate IV orders that were analyzed. The data were analyzed using mostly Microsoft Excel 2007 and the Minitab statistical software suite for verification purposes where needed.

**Two Additional Modifications:** When analyzing the data for day-by-day trends, two major discrepancies were noted. On June 14, 2009 (a Sunday), the WORx® system was temporarily shut down for maintenance. As a result, the data show an unusual trend on these dates, with a higher than normal number of IV orders being filled on June 13 and a lower than normal number being filled on June 14. This first discrepancy is most likely because orders were printed early to be filled the next day since pharmacists knew that the system would be down. To prevent this oddity from skewing the overall data results, the orders for these two days were averaged together. Appendix E compares this data before and after this modification. The second chart in Appendix E shows smoother lines around these dates, as should be expected.
An additional odd trend was noted with the data on October 1, 2009 where IV order volumes are unusually high. Data were collected for September 2009 to see if the end of that month showed any trends that would explain why the order volumes should be so high on the first of October; however, no conclusive reason was found to explain this oddity in the data. Therefore, the October 1st data were deleted for certain analyses, as described in the next paragraph. See Appendix F for a comparison of the unmodified and unmodified data.

The modified data were used to determine accurate daily, weekly and monthly numbers and percentages as described in the “findings” section below. The team felt that data analyses that do not compare daily, weekly, or monthly volumes were not affected by these anomalies; therefore, analyses of IV order types by pharmacy, by time of day, etc., were analyzed using the data without these two modifications made.

**Findings: Workload Analysis**
The data were analyzed to determine workflow in the various pharmacies. All statistics, unless otherwise noted, come from the analysis of the WORx® data.

**Locations:** Figure 5 shows the percentage of IV orders filled in each pharmacy for the data analyzed.

![Figure 5: Percentages of IV orders filled in each inpatient pharmacy shows that the Mott Children’s Hospital pharmacy fills the most IV orders.](image)

(Source: WORx® network data from February, June, and October 2009)

Figure 5 above shows that the Mott Children Hospital pharmacy fills far more IV orders than any
other pharmacy. The IV order volumes for the pharmacy on the 6th floor of UH are higher than the pharmacies on the 5th and 8th floors of UH since the 6th floor pharmacy is the only pharmacy besides Mott that is open between midnight and 7 am. Therefore, any non-batched IV orders received during this time period were attributed either to 6UH or 5MCH.

Table 4 below shows the total numbers of IV orders analyzed for each pharmacy in descending order from left to right:

Table 4: Total number of IV orders for the six pharmacies in February, June, and October 2009

<table>
<thead>
<tr>
<th></th>
<th>5MCH</th>
<th>B2</th>
<th>6UH</th>
<th>5UH</th>
<th>8UH</th>
<th>4CVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total IV Orders:</td>
<td>91,665</td>
<td>44,905</td>
<td>35,154</td>
<td>22,245</td>
<td>12,629</td>
<td>11,795</td>
</tr>
</tbody>
</table>

(Source: WORx® network data from February, June, and October 2009)

About 11,795 IV orders over the time period analyzed came from the CVC pharmacy. As described later, the order volumes analyzed from the CVC appear to be lower than they are in reality (see “CVC Discrepancies” subsection).

**Batch vs. non-batch:** Based on the schedule of batch jobs provided by the pharmacy manager, the team sorted and classified the data based on IV orders that were batched and non-batched in each pharmacy. Figure 6 below shows the percentage of batched items prepared in each pharmacy. (Batched items are those classified as Worxuser.) In the chart below, the data are sorted out by items *actually prepared in each pharmacy*, meaning that items prepared in the IV clean room, but that are delivered to other areas, are counted as B2 prepared IVs. For example, batch items in 5UH refer to those items prepared in the 5UH pharmacy during its daily batch at 6:42 am. However, items prepared in the B2 IV clean room during the B2 batch times listed in Appendix D are counted as B2 items, even if they are eventually delivered to the 5th floor of UH.
Figure 6: Percentages of batched vs. non-batch IV orders for each pharmacy. The pharmacies on the 5th and 6th floors of UH only receive a small percentage of their orders from batches. (Source: WORx® network data from February, June, and October 2009)

Figure 6 shows that the pharmacies on the 5th and 6th floors of UH receive only small percentages of their orders as batches. Other pharmacies receive higher amounts of batch orders, while the IV clean room on floor B2 of UH only processes batch orders.

**Daily orders in February, September, and October 2009**: The team analyzed the data by monthly, weekly, and daily time periods. The data presented here have been modified as described in “Methods” above.

Appendix G shows charts of the daily IV orders by month (with modifications as described above). The charts show significant day-to-day variation in IV order volumes per pharmacy. Hospital-wide daily IV orders for the period analyzed varied between 1,761 and 2,868 IV orders per day, with an average of 2,443 orders per day. Appendix H shows statistical process control charts of the daily IV order volumes over each of the three months analyzed. The control charts verify that the IV order volumes have considerable day-to-day variability.

Figure 7 below shows the average number of IV order volumes by day of the week; Figure 7 shows that IV order volumes remain steady during the week (Average: 2,535), but drop off somewhat on weekends (Average: 2,210).
Figure 7: Average IV orders on each day of the week for February, June and October 2009. Orders are relatively steady throughout the work week, but drop off somewhat on weekends.
(Source: WORx® network data from February, June, and October 2009)

Figure 8 below shows the average daily IV order volumes for each of the three months studied. February was the least busy month analyzed, followed by June, and then October.

Figure 8: Average daily IV order volumes for all pharmacies in each month. February is the least busy month analyzed (Average: 2,277 orders/day), followed by June (Average: 2,454 orders/day), and then October (Average: 2,588 orders/day).
(Source: WORx® network data from February, June, and October 2009)
Average number of IV orders hourly: The team also determined how many IV orders are filled each hour, on average, in each pharmacy. Figure 9 shows a summary graph of IV orders per hour in each pharmacy.

![Average IV order volumes for each hour of the day. The large spikes tend to indicate batch times during those hours.](image)

(Source: WORx® network data from February, June, and October 2009)

Appendix I contains more graphs showing hourly variation, with each pharmacy displayed separately. The hourly variation graphs tend to show spikes at certain hours that are caused by the printing of batches during those hours.

Combining the 5th and 6th floor pharmacies in UH: The pharmacy manager has considered combining the 5UH and 6UH pharmacies, so the team has provided charts showing combined workloads for these two pharmacies in Appendix J. Because the workload in the 5UH pharmacy is relatively smooth (on average) throughout the day, the average workload from the combination of these two pharmacies mirrors the variability of the 6UH pharmacy, but with a steady addition of IV preparations throughout the day.

The advantage of combining these two pharmacies would be to reduce order volume variability. At times, the 6UH pharmacy has a heavy workload, while the workload is light or even non-existent in the 5UH pharmacy (or vice versa). The combination of these pharmacies would level the overall workloads. However, the major drawback of combining these pharmacies is that workloads would occasionally be too high for individual technicians working in the existing areas (unless additional IV preparation areas and staff were added to the combined pharmacy).
Furthermore, the comparison data have not been analyzed in depth in this report, but the two pharmacies do appear to see different IV order types, which might be an obstacle to combining them. These potential drawbacks are worth studying further before considering combining the two pharmacies.

**Types of Orders:** The team determined the IV order types (i.e. large bags, piggybacks or syringes) made in each pharmacy, as shown in Figure 10.

![Graph showing IV order types for each pharmacy.](source)

*Figure 10: IV order types for each pharmacy, shown as percentages. Piggybacks are the most common type of preparation in all UH pharmacies. The Mott pharmacy shows a large percentage of syringes.*

(Source: WORx® network data from February, June, and October 2009)

**CVC Discrepancies:** As shown in Figure 10 above, the data showed a remarkably low percentage of syringes prepared in the CVC pharmacy; staff in the CVC pharmacy note that far more syringes are actually prepared there (one pharmacist estimated that 80% of CVC pharmacy orders are syringes). The team was unable to account for these missing orders since a hospital computer network specialist was unable to find these orders after multiple attempts. The pharmacy department should analyze the reason why these syringe orders do not appear in the WORx® system in order to gain a better understanding of operations in the CVC pharmacy and to verify that they are being tracked properly for billing purposes (the WORx® system is used to track billing information for IVs).
Error Rate Determination

Error rates are a concern in any pharmacy since errors can result in costly rework and are also a potential safety concern. After understanding the process of preparing IV products in the University Hospital, CVC and Mott Children’s Hospital, the team approximated IV preparation error rates to quantify them before attempting to recommend how errors could be addressed.

The UMHS adopts a double checking procedure when preparing IVs. After pharmacy technicians prepare the IV products, licensed pharmacists double check the dilutions, hang by dates, drug types, and so on, before allowing the IVs to be dispensed to patients. IV preparations in the Mott pharmacy undergo an additional pharmacist check of syringe contents before they are injected into a final preparation. Additionally, the concentrations of high-risk medications in the Mott pharmacy are verified using a technology called ValiMed™ just before the high-risk medications are dispensed to patients.

Medical research shows that medical personnel find about 95% of all clearly visible and identifiable mistakes when checking the work of others4,5. The benefit of double checks can be demonstrated by multiplying this 5% error rate and the rate in which errors occur with the task itself (the checking error rate multiplied by the task error rate). For example, if a pharmacy dispensing error rate is 5% (based on research findings), and a double check occurs before medications are dispensed, then the actual chance of a dispensing error reaching the patient is 5% of 5%, or only 0.25%. Research also points out that the effectiveness of double check systems depends on training staff to carry them out properly – as an independent cognitive task, not a superficial routine task6. Fewer well-placed double checks are far more effective than an overabundance of superficial and routine double checks.7

Methods: Error Rate Determination

The team observed the inpatient pharmacies and noted behaviors, routines, and physical setups that could increase error rates. During the observations, the team members also informally interviewed technicians and pharmacists by inquiring about safety procedures and safety concerns. These observations and informal interviews were used to determine potential root-causes of errors.

7 “The virtues of independent double checks – they really are worth your time!” by the Institute of Safe Medication Practices. Available at: http://www.ismp.org/Newsletters/acuteCare/articles/20030306.asp
The team ran a study from March 4, 2010 to March 11, 2010 to approximate IV preparation error rates. For the purposes of this study, errors were counted every time an item needing rework was detected by pharmacists in their routine checks. Error rate sheets were placed in each satellite pharmacy and an email was sent to all pharmacists asking them to record any rework that was required during that period onto the sheets. The sheets were printed on bright orange paper and were placed on the counters where the IVs are checked in each pharmacy. A copy of the sheets is shown in Appendix K. No names were collected on these sheets to remove all identifiers and eliminate concerns that might worry pharmacists and technicians and therefore prevent them from properly recording the data.

To approximate error rates, the team also determined the total number of IV orders prepared during the collection week to compare the number of reworked items (preparation errors) to total throughput volumes in each pharmacy. Data were collected from the hospital’s WORx® system regarding all IV orders occurring during the week of the pharmacists’ data collection. The format of the data was identical to the format of the data obtained for the workflow analysis described in the previous section. The error rate data were modified by a different team member than the workload data; however, the team members checked their methods against each other to verify that their sorting and deletion methods produced similar, if not identical results.

**Findings: Error Rate Determination**

After collecting the data on total errors and total throughput for the data collection week, the team brainstormed to determine causes of errors in each pharmacy.

**Findings from Observations and Informal Interviews:** Definitively determining the root causes of IV preparation errors is almost impossible since it is difficult to run controlled experiments to assess the factors that may lead to preparation errors in UMHS pharmacies. However, based on their experiences with industrial engineering and their common sense, the team members were able to assess several possible causes of IV preparation errors. From observations in the inpatient pharmacies, the team noticed the following issues that may increase error rates:

- Work areas in the IV preparation hoods are small (Roughly 1.5 x 6 feet)
- Multiple drugs and IV products are in the hood at the same time
- Drug amounts are calculated mentally by the technicians
- Drawback-of-syringe method is error prone because it relies on memory
- Drawn back syringes are prone to be mixed up in the cluttered checking areas
- Work procedures are often not standardized

The drawing back of syringe method should be revamped to remove the element of memory. According to the team’s informal interviews with the pharmacy technicians, there are occasions that the technicians forget the amount of drug put into the IV solution. Therefore, for the drawback procedure, the technicians recalculate dosages and assume that the dosages calculated
earlier were the same; however, recalculated dosages are not guaranteed to be the same as actual dispensed dosages.

Multiple IV products are often prepared in the small hood area at the same time, so that the hood countertops become visibly cluttered. The cluttered hoods and close proximity of orders can cause drugs to be confused with each other, resulting in errors. The work areas where pharmacists verify that orders were filled and labeled correctly are often cluttered as well, which again may contribute to mix-ups of IV products.

Several pharmacists mentioned that they are generally more confident in the work of experienced pharmacy technicians; therefore, they may not scrutinize experienced technicians’ work as carefully. If pharmacists are careful to check over all orders carefully, even the orders prepared by experienced technicians, error rates may be lowered. Also, the team observed that pharmacists tended to check items quicker when more products needed to be checked, so the variability in the workload might have an effect on the error rate (higher workloads mean that more orders at a time will need to be checked).

**Approximations of Error Rates:** Table 5 below shows the team’s findings for error rates in all pharmacies.

<table>
<thead>
<tr>
<th>IV Preparations</th>
<th>4CVC</th>
<th>5MCH</th>
<th>5UH</th>
<th>6UH</th>
<th>8UH</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Error Count</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1624</td>
<td>1</td>
<td>22</td>
<td>2</td>
<td>6</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td><strong>Error Rate (%)</strong></td>
<td>0.06158%</td>
<td>0.25716%</td>
<td>0.07657%</td>
<td>0.14461%</td>
<td>0.09560%</td>
<td>0.23518%</td>
</tr>
</tbody>
</table>

Source: Error rate data collected by the team from March 4 through March 11, 2010

As Table 5 shows, error rates were highest in the Mott and B2 pharmacies. The team assumes that the higher error rate in Mott is a result of more errors being caught due to stricter checking procedures and tighter specification limits for children’s IV products. In the B2 pharmacy, where only batch IVs are produced, the team assumes that the error rate is high because a whole batch gets thrown out when an error is discovered on one product within that batch. The team could not determine why 6UH showed a higher error rate than the other UH pharmacies on floors 5 and 8; however, the higher error rate may simply have been due to chance. Otherwise, the error rates for CVC, 5UH and 8UH are comparable to one another.

Importantly, the numbers in the table above are low-end estimates of actual error rates. Additional errors may have occurred that were simply not caught or were not reported by pharmacists.
**RiskPro Data:** Errors that are not caught by the pharmacists get dispensed to patient areas. Occasionally, the nurses catch errors and report them through the hospital’s RiskPro system. However, the nurses’ abilities to catch pharmacy related IV preparation errors are limited: Nurses can only catch errors that can be physically seen—wrongly colored solutions or other visual problems with the dispensed medications. Common errors like wrong-drug dispensations or incorrect dosages cannot be easily caught by nurses.

During the March 4 through March 11, 2010 study, the only reported incident that was related to IV preparations in the pharmacies occurred at the Mott Children’s Hospital Pharmacy. The error was caught by the nurse because 0.9% NaCl was dispensed for 0.45% NaCl with Heparin.

The team gathered information about Pharmacy related errors in 2009 from the RiskPro system. 59 cases of dispensing errors and 23 incorrectly prepared product errors were reported that were pharmacy related. (The team estimates that about 900,000 IV orders were prepared in the inpatient pharmacies studied in 2009). Therefore, it appears that about 82 errors were reported to the RiskPro system in 2009 or about one error every 4.5 days.

**Summary of Key Findings**

The following are observations and key findings summarizing the team’s data collection and analyses with regard to IV preparation times, workloads, and error rates.

**IV Preparation Times**
The team’s observations, data collection, and analysis of IV preparation times show that:

- The average IV preparation requires 76 seconds
- IVs requiring reconstitution take significantly longer to prepare with an average preparation time of 212 seconds
- Batching IV preparations saves time, but opens a potential avenue for error, as only one syringe drawback is checked for the entire batch

**Workload Analysis**
The team analyzed data from the hospital’s WORx® system to determine workloads in the different pharmacies. The team found estimates, based on the data collected, that about 900,000 IV orders are prepared per year in the pharmacies analyzed. The data collected showed high workload variability within and between the pharmacies. Mott Children’s Hospital pharmacy received the highest volume of IV orders hospital wide (42%). The pharmacy on floor 6 of UH received a higher amount of orders than pharmacies on floors 5UH and 6UH, most likely due to being open 24 hours a day. The data also showed that order volumes hospital-wide decrease on weekends.
Error Rates

The team calculated error rates and approximated that the pharmacy technicians are over 99.7% accurate in filling IV orders without needing rework. Table 6 summarizes the team’s findings. In addition, by matching up the workload volume data to the error approximations, the team determined the number of IV preparation errors that are estimated to be caught by pharmacists in a year; these are also shown in Table 6. The estimated yearly IV orders were obtained by finding average daily volumes for each pharmacy over the three months analyzed in 2009 and multiplying those values by 365 to determine yearly IV order volumes.

Table 6: Calculated error rates in UMHS pharmacies and expected yearly error rates

<table>
<thead>
<tr>
<th></th>
<th>5MCH</th>
<th>B2</th>
<th>6UH</th>
<th>5UH</th>
<th>8UH</th>
<th>4CVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total IV Orders</td>
<td>8555</td>
<td>5953</td>
<td>4149</td>
<td>2612</td>
<td>1046</td>
<td>1624</td>
</tr>
<tr>
<td>RPh Reported Errors</td>
<td>22</td>
<td>14</td>
<td>6</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Accuracy Rate</td>
<td>99.743%</td>
<td>99.765%</td>
<td>99.855%</td>
<td>99.923%</td>
<td>99.904%</td>
<td>99.938%</td>
</tr>
<tr>
<td>Error Rate</td>
<td>0.257%</td>
<td>0.235%</td>
<td>0.145%</td>
<td>0.077%</td>
<td>0.096%</td>
<td>0.062%</td>
</tr>
<tr>
<td>Estimated Yearly IV Orders</td>
<td>375,929</td>
<td>184,161</td>
<td>144,171</td>
<td>91,229</td>
<td>51,793</td>
<td>48,373</td>
</tr>
<tr>
<td>Estimated Annual Errors</td>
<td>967</td>
<td>433</td>
<td>208</td>
<td>70</td>
<td>50</td>
<td>30</td>
</tr>
</tbody>
</table>

Source: Error rate data collected by the team from March 4 through March 11, 2010

Recommendations

Due to time constraints, the team spent the majority of the four-month long project defining and documenting the current state of UMHS inpatient pharmacies rather than determining specific solutions to standardize and improve workflow, level workloads, and mitigate IV preparation errors. However, the team did exam the possibility of implementing an IV workflow technology called DoseEdge™, which is sold by the Baxa Corporation. DoseEdge™ shows promise as a system for improving IV preparation workflow and lessening the number of errors leaving the inpatient pharmacies. However, the DoseEdge™ technology is a costly investment and the hospital therefore wanted the team to examine its feasibility before considering purchasing the technology. The team recommends that the hospital use the information provided in this report to consider the implementation of the DoseEdge™ system or similar automated IV safety and workflow technology.

The following is a description of the DoseEdge™ system from the company’s webpage:

“DoseEdge™ is a workflow software product designed to improve safety and accuracy in the preparation of pharmacy-based IV admixtures; enable pharmacists to perform their quality assurance functions without having to waste time gowning and ungowning; drive compliance with sterile preparation regulatory steps and provide transparency to IV room operations.”
According to information on the DoseEdge™ website, the new technology could provide the following benefits for improving workflow:

- Reduce medication errors through use of automatic drug verification (barcode checking)
- Provide automatic computations of doses and dilutions needed
- Allow for inspection of dose preparation from remote computers
- Prevent waste by reducing the occurrence of lost and missed doses

A typical DoseEdge™ deployment is shown in the network diagram in Appendix L.

**DoseEdge™ Costs**

Based on an estimated 2,443 average orders per day (as determined from the workload analysis data), or roughly 900,000 orders per year, the DoseEdge™ system would cost UMHS approximately $90,000 per year given the $0.10/dose subscription model proposed by the pharmacy manager. It is not known what the initial capital investments for equipment would be. The data available in this report should serve pharmacy leadership to make informed decisions regarding the costs and benefits of implementing DoseEdge™ or similar technology, since the current workflow—which the new technology will change—has been thoroughly examined in this report. The following are several ways that this report can be used to assess the costs and benefits of DoseEdge™:

- If IV preparation timing data can be obtained from the manufacturer of DoseEdge™ or another hospital using the technology, the data can be compared to the timing data in this report to assess how IV preparation times will be affected by the new technology. The hospital can then assess the costs of the added (or saved) time for preparing IVs.
- The workload data can be used to determine IV work volumes, which affect the variable costs of operating the DoseEdge™ system. Based on the volumes of IV preparations in various pharmacies, the hospital can decide the best pharmacies to test the DoseEdge™ system on before rolling out the technology to all inpatient pharmacies.
- The error rate data can similarly be used to assess where a rollout of the new technology might begin. Perhaps the hospital would prefer to rollout the technology in the pharmacies with the highest error rates.

Additionally, the hospital might consider collecting data on pharmacist time savings with the DoseEdge™ system (since they would save time doing much of their work from remote computers rather than walking over to checking counters). Since the DoseEdge™ system...

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technology takes up physical space in pharmacies, the hospital should also assess the potential costs of physical renovations to IV preparation areas to accommodate the new hardware.

**Expected Outcomes: Future State Workflow with DoseEdge™**

The implementation of IV preparation safety, verification, and tracking technology with DoseEdge™ would be directly embedded in the current IV preparation procedure and would eliminate three steps from the current process – as illustrated in Appendix M by the steps with the dashed, diagonal lines running through them.

DoseEdge™ would also introduce 9 new steps into the process. Studying information provided by Baxa and the pharmacy manager, the team formed a future state process map with DoseEdge™ implementation. The full process map is found in Appendix N. With the DoseEdge™ system, orders initially appear on a computer display in an electronic queue. Orders are then printed “on-demand” with dose and concentration computations calculated by the system. Technicians then scan the label and retrieve the appropriate product, IV bag, and syringe. Next, medication vials are scanned into the DoseEdge™ system as well. If needed, drugs are then reconstituted and drawn into the syringe. At this point, with the new system, the technician takes a photo (using the mechanism provided by the DoseEdge™ system) of the medication’s vial and syringe’s actual drawback with the vial contents. Once the dose is injected into the IV bag and the label is placed on the bag (or syringe) the technician takes another photo of the prepared IV. At this point, with the barcode scan and photographic evidence, the pharmacist can remotely verify the technician’s IV preparation from any computer able to access the hospital’s secure network.

The extra steps introduced through the implementation of DoseEdge™ (barcode scanning and dose photos) are anticipated to add at most an additional 5 seconds per new step for the lab technician, based on the team’s knowledge of IV preparation procedures and the team’s understanding of the newly added steps. However, the ability for pharmacists to remotely verify IV preparations – possibly even for multiple pharmacies – introduces a significant time savings, as much time is wasted waiting for IVs to be approved by the pharmacist, especially in the Mott pharmacy.

**Conclusions**

The key findings and results from this project were used to evaluate the current state of operations in the inpatient pharmacies of UMHS. In addition, data analysis has been provided that could be used to assess the implications of DoseEdge™ or other IV workflow technology integration into the satellite pharmacies. Finally, the data collections and analyses provided in this report can be useful for decisions by pharmacy leadership to make changes in the future to the pharmacies’ workloads and workflows; for example, the information provided can be
considered in making decisions to combine different pharmacies’ operations in order to level workloads.

**Recommendations for Further Study**

The team observed a lack of consistency in terms of IV medication and bag/container storage between pharmacies. Product locations within pharmacies are not standardized; however, without further studies, the team does not know the extent to which this issue affects pharmacists’ and technicians’ performances. To determine whether product location standardization would be a beneficial change, the main functions of each pharmacy must be determined. This determination can be made by comparing each pharmacy’s volumes and types of IV products prepared. If two pharmacies have similar volumes of similar IV products, for example, standardizing IV product locations between the pharmacies might be beneficial.

The results of this *pharmacy-function* study would also provide insight into the appropriateness of rigidly standardizing IV preparation procedures and layouts between pharmacies. For example, if the UH5 pharmacy is found to prepare IVs mainly of drug “A,” and UH6 pharmacy is found to prepare mostly IVs of drug types “C, D, and E,” then standardizing layouts between pharmacies or combining those pharmacies might not be feasible. In this case, the highest frequency medications should be located nearest to the IV preparation hoods.

Regarding error rates, further studies should be considered that collect data for longer periods of time in order to assess error rates more accurately. Pharmacy leadership may also want to consider studies to determine which types of errors occur most frequently, so that special consideration can be given to preventing these common errors.

Finally, many factors affecting the cost of DoseEdge™ fell outside of the project scope and therefore, as previously noted, the team also recommends that an in-depth Return-On-Investment analysis be conducted on the implementation of DoseEdge™ to determine its full financial impact.

**Acknowledgements**

This project was arranged through a senior design project course in the department of Industrial and Operations Engineering at the University of Michigan, Ann Arbor. The team members would like to thank the clients, Dr. Phil Brummond and Dr. Bruce Chaffee at UMHS, who provided much assistance and knowledge in helping the team to collect data and analyze it properly. Additionally, the team would like to thank the course instructors, Professor Mark Van Oyen and Ph.D. candidate Brock Husby, and project coordinator Sam Clark for their assistance.
in arranging this project, as well as their guidance in the project’s implementation. Thank you as well to Mary Lind in the College of Engineering’s Technical Communications department for her tremendous assistance in providing feedback and editing all written and presentation materials.
Appendices

Appendix A: Current State Process Map

Note: The green and red dots indicate where the team’s timing process started and ended.
## Appendix B: Timing Data Collection Sheet

### IOE 481 Data Collection Sheet

**Name:** ____________________  
**Date:** ____________________  
**Time:** ____________________  
**Location:** ____________________

**Definitions:**
- **Start time:** Needle is attached to syringe  
- **End time:** Label is attached to IV bag

<table>
<thead>
<tr>
<th>Check One</th>
<th>Fill In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small IV &quot;Piggyback&quot; Pouches (&lt; 250 ml)</td>
<td>Total Time (Seconds):</td>
</tr>
<tr>
<td>Large IV Bags (&gt;= 250 ml)</td>
<td>Note any irregularities:</td>
</tr>
<tr>
<td>Syringe</td>
<td></td>
</tr>
<tr>
<td>Reconstitution (Check if yes)</td>
<td></td>
</tr>
</tbody>
</table>

Note any irregularities:
Appendix C-1: Distribution of Large Bag IV Preparation Times

Source: Team’s data collection on IV process timing

The chart below shows the distribution and basic statistics for preparation times of large bag IVs. Reconstituted orders have been excluded from the data in the chart, so that the data shows fewer abnormally high preparation times. In general, the chart shows that most preparation times fall within close range of the mean, or slightly below it, although there are significant outliers that take far longer to prepare.
Appendix C-2: Distribution of Piggyback IV Preparation Times

Source: Team’s data collection on IV process timing

The chart below shows the distribution and basic statistics for preparation times of piggyback IVs. Reconstituted orders have been excluded from the data in the chart, so that the data shows fewer abnormally high preparation times. In general, the chart shows that most preparation times fall within close range of the mean, although, like large bag preparations, there are significant outliers that take far longer to prepare.
Appendix C-3: Distribution of Syringe Preparation Times

Source: Team’s data collection on IV process timing

The chart below shows the distribution and basic statistics for preparation times of syringes. The observed preparations had no reconstituted syringe orders. In general, the chart shows that most preparation times fall within close range of the mean, although there are significant outliers that take far longer to prepare, similar to the large bag and piggyback orders.

![Chart showing distribution of syringe preparation times](image)

<table>
<thead>
<tr>
<th>Summary for Total Time (Seconds): Type = Syringe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anderson-Darling Normality Test</strong></td>
</tr>
<tr>
<td>A-Squared</td>
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<tr>
<td>P-Value &lt;</td>
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<tr>
<td>Mean</td>
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<td>StDev</td>
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<td>Variance</td>
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<td>Skewness</td>
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<td>Kurtosis</td>
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<td>N</td>
</tr>
<tr>
<td>Minimum</td>
</tr>
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<td>1st Quartile</td>
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<td>Median</td>
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<tr>
<td>3rd Quartile</td>
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<tr>
<td>Maximum</td>
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<tr>
<td>95% Confidence Interval for Mean</td>
</tr>
<tr>
<td>95% Confidence Interval for Median</td>
</tr>
<tr>
<td>95% Confidence Interval for StDev</td>
</tr>
</tbody>
</table>
Appendix D: Batch Job Times

Source: Obtained from the pharmacy manager. The batch order times were last revised on September 18, 2009. Only the batch times relevant to IV orders are listed below.

<table>
<thead>
<tr>
<th>UH CHEMO 4-9 PB Labels</th>
<th>Batch Times</th>
<th>Run at</th>
<th>Shift Responsible</th>
<th>Prints on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1100-1100</td>
<td>6:20</td>
<td>Day</td>
<td>8UH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UH 4-9 PB Labels</th>
<th>Batch Times</th>
<th>Run at</th>
<th>Shift Responsible</th>
<th>Prints on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000-1359</td>
<td>~6:20**</td>
<td>Day</td>
<td>B2 IVRM</td>
</tr>
<tr>
<td></td>
<td>1400-1759</td>
<td>9:45</td>
<td>Day</td>
<td>B2 IVRM</td>
</tr>
<tr>
<td></td>
<td>1800-2159</td>
<td>12:45</td>
<td>Day</td>
<td>B2 IVRM</td>
</tr>
<tr>
<td></td>
<td>2200-0159</td>
<td>17:45</td>
<td>Evening</td>
<td>B2 IVRM</td>
</tr>
<tr>
<td></td>
<td>0200-0559</td>
<td>20:45</td>
<td>Evening</td>
<td>B2 IVRM</td>
</tr>
<tr>
<td></td>
<td>0601-0959</td>
<td>20:55</td>
<td>Evening</td>
<td>B2 IVRM</td>
</tr>
</tbody>
</table>

** Job is run after UH CHEMO 4-9 PB job finishes

<table>
<thead>
<tr>
<th>UH CVC PB Labels</th>
<th>Batch Times</th>
<th>Run at</th>
<th>Shift Responsible</th>
<th>Prints on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000-1359</td>
<td>6:23**</td>
<td>Day</td>
<td>4CVC</td>
</tr>
<tr>
<td></td>
<td>1400-1759</td>
<td>10:25</td>
<td>Day</td>
<td>4CVC</td>
</tr>
<tr>
<td></td>
<td>1800-2159</td>
<td>13:25</td>
<td>Day</td>
<td>4CVC</td>
</tr>
<tr>
<td></td>
<td>2200-0159</td>
<td>19:50</td>
<td>Evening</td>
<td>4CVC</td>
</tr>
<tr>
<td></td>
<td>0200-0559</td>
<td>19:55</td>
<td>Evening</td>
<td>4CVC</td>
</tr>
<tr>
<td></td>
<td>0601-0959</td>
<td>21:25</td>
<td>Evening</td>
<td>4CVC</td>
</tr>
</tbody>
</table>

**The team noted that the sheet in the CVC pharmacy listed 6:55 as the first batch of the day. The Carelink® data showed that batch data was attributed to the CVC at both times. Therefore, any batch data appearing near either of these times were treated as being printed in the CVC.

<table>
<thead>
<tr>
<th>UH 4 IV Labels</th>
<th>Batch Times</th>
<th>Run at</th>
<th>Shift Responsible</th>
<th>Prints on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0900-0900</td>
<td>6:52</td>
<td>Day</td>
<td>5UH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UH 5 IV Labels</th>
<th>Batch Times</th>
<th>Run at</th>
<th>Shift Responsible</th>
<th>Prints on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0900-0900</td>
<td>6:42</td>
<td>Day</td>
<td>5UH</td>
</tr>
<tr>
<td>Batch Times</td>
<td>Run at</td>
<td>Shift Responsible</td>
<td>Prints on</td>
<td></td>
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<tr>
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<td>-------------------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>UH 6 IV Labels</td>
<td>0900-0900 6:34</td>
<td>Day</td>
<td>6UH</td>
<td></td>
</tr>
<tr>
<td>UH 7 and Burn IV Labels</td>
<td>0900-0900 7:02</td>
<td>Day</td>
<td>6UH</td>
<td></td>
</tr>
<tr>
<td>UH 8A1 IV Labels</td>
<td>0900-0900 6:55</td>
<td>Day</td>
<td>8UH</td>
<td></td>
</tr>
<tr>
<td>UH 8 8B&amp;C, 9C&amp;D IV Labels</td>
<td>0900-0900 6:02</td>
<td>Day</td>
<td>8UH</td>
<td></td>
</tr>
<tr>
<td>UH CVC IV Labels</td>
<td>0900-0900 7:03</td>
<td>Day</td>
<td>4CVC</td>
<td></td>
</tr>
<tr>
<td>UH 10BS-1A IV Labels</td>
<td>1600-1600 13:55</td>
<td>Day</td>
<td>6UH</td>
<td></td>
</tr>
</tbody>
</table>
Appendix E: June 2009 Data With and Without Modifications

Source: WORx® network data from February, June, and October 2009 as sorted and analyzed by the project team.

The first chart below shows the data without June 13th and 14th averaged together. There is a noticed and unusual trend on those dates at all hospital pharmacies. The second chart shows the data smoother over after those two dates’ data were averaged together.
Appendix F: October 2009 Data With and Without Modifications

Source: WORx® network data from February, June, and October 2009 as sorted and analyzed by the project team.

The first chart below shows the workload data without the October 1st data removed. There is a noticed and unusual trend on this date, with the numbers for most pharmacies being too high, especially 5MCH and 5UH which both show significantly higher numbers than any other day in October. The second chart shows the modified chart, with the October 1st data removed.
Appendix G: February, June and October 2009 Comparison Data (With Modifications)

Source: WORx® network data from February, June, and October 2009 as sorted and analyzed by the project team.

The charts below show daily number of orders for each month. The data are separated by pharmacy. The charts show considerable day-to-day variation for orders in inpatient pharmacies.
Appendix H: Statistical Process Control Charts of Day-to-Day Order Volumes

Source: WORx® network data from February, June, and October 2009 as sorted and analyzed by the project team.

The statistical process control charts (Individual and Moving Range charts) below show the order volumes and variability for each month analyzed. Data from weekends were removed since the team found that weekend IV order volumes were significantly lower in general. Total IV order volumes hospital-wide were inputted into the control charts below, not individual pharmacies’ IV order volumes. Three sigma (σ) control limits were used for the control charts.

All three diagrams show significant variation as many points come close to the control limits on the moving range charts, although the control limits are never exceeded. The individual value charts for February and October both show out-of-control points (red dots), indicating significantly higher or lower IV order volumes than usual on those days.
Appendix H: Statistical Process Control Charts of Day-to-Day Order Volumes (Continued)

I-MR Chart of October

Individual Value

Date_2

Moving Range

Date_2
Appendix I-1: Average Hourly Workload Data for Inpatient Pharmacies
Source: WORx® network data from February, June, and October 2009 as sorted and analyzed by the project team.

The chart below shows average hourly data for each pharmacy. The large spikes in data correlate to batch times as listed in Appendix F.
Appendix I-2: Average Hourly Workload Data for 5UH Pharmacy
The chart below shows average hourly data for the 5UH pharmacy. Workload reaches a peak early in the morning and then slowly declines.

Appendix I-3: Average Hourly Workload Data for 6UH Pharmacy
The chart below shows average hourly data for the 6UH pharmacy. Workloads are high overnight with a large spike in the morning.
Appendix I-4: Average Hourly Workload Data for 8UH Pharmacy
The chart below shows average hourly data for the 8UH pharmacy. Workload shows a morning spike with relatively smooth levels of orders thereafter.

Appendix I-5: Average Hourly Workload Data for 4CVC Pharmacy
The chart below shows average hourly data for the 4CVC pharmacy. Workload appears to be far more spread out and sporadic than other pharmacies.
Appendix I-6: Average Hourly Workload Data for B2 (IV Clean Room)

Pharmacy

The chart below shows average hourly data for the B2 pharmacy. The orders come exclusively from batches and therefore show five spikes. Two batches are processed between 8 pm and 9 pm, which explains the higher spike in the chart during that time period. Occasionally, orders will be reprinted due to errors, which can lead to items printing slightly after the batch times.

Appendix I-7: Average Hourly Workload Data for Mott Pharmacy

The chart below shows average hourly data for the Mott pharmacy. Orders are highly variable by hour, with almost 50% of orders printing during batch times.
Appendix J: Combining the 5UH and 6UH Pharmacies

Source: WORx® network data from February, June, and October 2009 as sorted and analyzed by the project team.

The top chart below shows the workloads at 5UH and 6UH as they are currently. The bottom chart shows the workload with the two pharmacies combined. It must be noted, however, that considerations such as differences in the types of drugs filled in each pharmacy must be taken into account before combining these two pharmacies.
Appendix K: Pharmacist Data Collection Sheet

Collection Dates: ________________________

Instructions:
• Please mark off each IV order that needs rework after the final check before leaving the pharmacy
• Write down the drug name and check off the IV type (see definitions below)

Definitions:
**Syringe (SY)** - Any IV preparation delivered to the patient in a syringe form
**Piggyback (PB)** - Any preparation less than 250 mL
**Large Volume (LV)** - Any preparation greater than or equal to 250 mL

<table>
<thead>
<tr>
<th>#</th>
<th>Drug Name</th>
<th>SY</th>
<th>PB</th>
<th>LV</th>
<th>#</th>
<th>Drug Name</th>
<th>SY</th>
<th>PB</th>
<th>LV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>26</td>
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<td>50</td>
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</table>
Appendix L: Network Diagram of DoseEdge™ System

The following was obtained from the Baxa company’s website at www.baxa.com/doseedge/links/IntelliFlow%20FAQs.pdf
Appendix M: Current State IV Preparation Process Map Showing Steps Eliminated by DoseEdge™

Process Map of IV Preparation in University Hospital & Cardiovascular Center

- Technician receives order from printer
- Place label on counter
- Retrieve required product, bag, and syringe
- Unwrap and assemble syringe
- Reconstitute necessary drugs
- Perform dose and concentration computations or lookup
- Reconstitution necessary?
  - Yes
  - No
- Pull back syringe to amount injected
- Inject dose into IV bag
- Draw drug into syringe
- Write date on the printed label
- Stick label to IV bag
- Place IV product on counter to await Pharmacist check

Average IV Preparation Time
- Recreating reconstitution: 212 seconds
- Standard deviation: 131
- Sample size: 11

Average IV Preparation Time without reconstitution:
- 67 seconds
- Standard deviation: 55 seconds
- Sample size: 110

*IV preparation time data was collected starting at the point the needle was attached to the syringe and finishing at the time the label was attached to the bag.*