COMPUTER SIMULATION AND SIX-SIGMA TOOLS APPLIED TO PROCESS IMPROVEMENT IN AN EMERGENCY DEPARTMENT

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Abstract

Simulation modeling was used along with Six Sigma techniques to address issues of length of stay and patient satisfaction in an emergency department. Goals of the project were to increase the quality of care, decrease the time in the ED for patients, and increase patient satisfaction.

Investigators worked with hospital staff of an emergency department to implement a Six Sigma process improvement strategy focused on patient length of stay, patient satisfaction, and cost savings. ProModel computer simulation software was used to test alternatives in process change prior to implementation. DMAIC methodology identified several improvement projects targeted at inefficient or ineffective ED processes. Results have shown a dramatic reduction in LOS, improvements in patient satisfaction, and cost savings.

The Central Texas Medical Center (CTMC) is a 113-bed acute-care general hospital, and is one of 37 hospitals in ten states operated by the Adventist Health System (AHS). Their mission is to provide physical, mental, and spiritual services in efforts to build a healthier community. They are committed to working with the community to reduce the incidence of disease, morbidity, mortality, accidents, and injuries (About Us, 2003). Fifty-seven percent of inpatient admissions come through the emergency department. The emergency department sees approximately 32,000 annual admissions each year.

In an effort to become more efficient, effective, and adaptable at meeting community and business needs, the hospital agreed to allow their Emergency Department (ED) to be the focus of a Six Sigma Process Improvement and Computer Simulation study. The goal of the project is to use Six Sigma methodology – specifically the Define, Measure, Analyze, Improve, and Control (DMAIC) improvement format – to reengineer key processes within the emergency department. Furthermore, the hospital wanted to address the dissatisfaction of patients who encounter long waiting times in the ED process. Concurrently, the hospital would like to address the frequency and sources of mistakes; and improve upon the general quality level of care given to their patients. The efficacy of the improvements would be measured by the extent to which the Six Sigma methodology helped to improve the quality of care while reducing patients’ length of stay (LOS) and process errors. The key process inputs identified as “process improvement targets” are as follows – equipment and supplies, diagnostic results, the patient chart, materials, personnel, and doctor communication.

The following discussion will introduce a healthcare case study to demonstrate the effectiveness of an integrated process improvement roadmap in improving quality, cost and speed in a hospital emergency department.

Introduction

A 1999 congressionally chartered report by the Institute of Medicine found that anywhere from 44,000 to 98,000 patients die every year from preventable medical errors made in hospitals (Factsheet, 2003). Alarmingly, these numbers do not include harm from mistakes made in outpatient settings (About Us, 2003). Contrast these numbers to the numbers of deaths due to other causes: motor vehicle accidents (43,458), breast cancer (42,292), and AIDS (16,516). A 1991 Harvard Medical Practice Study reported that 4% of New York state hospital patients suffered iatrogenic injuries that prolonged their stay or resulted in measurable disability. Alarmingly, 14% of these
injuries were fatal. Based on these incidence rates, and if extrapolated to the entire U.S. population, 180,000 people would die each year due to iatrogenic injury. This equates to approximately three jumbo jet crashes every 2 days (Leape, 1994). Obviously, the cost in terms of lives is substantial. Medical errors can be defined as the failure of a planned action to be completed as intended or the use of a wrong plan to achieve an aim (Institute of Medicine, To Err is Human, 1999). The most common types of errors are adverse drug reactions and improper transfusions, surgical injuries and wrong-site surgeries, suicides, restraint-related injuries and deaths, burns, falls, pressure ulcers, and mistaken patient identities. The highest error rates with serious consequences are most likely to occur in intensive care units, operating rooms, and emergency departments (Institute of Medicine, To Err is Human, 1999). And, there are many other hidden costs that are not as readily measurable – lost personal income, years of potential life lost, disability, longer rehabilitation, and increased insurance premiums – which contribute to the burden placed on society. These costs have been estimated to be between $17 billion and $29 billion per year in hospitals nationwide (Institute of Medicine, To Err is Human, 1999).

As the ranks of the unemployed/uninsured swell and the health care workforce becomes smaller in proportion to those seeking care the system swoons under the load. An ABC World News Tonight Report recently stated that there are now approximately 43.6 million uninsured and 46 million underinsured citizens in the United States (ABC World News Tonight, 2003). One out of ten children is uninsured and 59 percent of individuals are unsure that they can pay for health insurance in the future. Because of the skyrocketing costs of healthcare families now pay 49 percent more for health care than they did in the year 2000. A piece of this cost is attributed to a 13.9 percent increase in insurance premiums. So, Americans now spend 15.2 percent of our GNP on health care, or about $1.6 trillion. Thus, emergency rooms have become the primary source of health care for many Americans. Couple this with the potentially devastating effects of terrorism attacks or an epidemic outbreak of diseases, like SARS, the system may reach a breaking point.

A visit to virtually any hospital emergency waiting room exposes the fact that our emergency departments are becoming increasingly crowded. The Centers for Disease Control and Prevention (CDC) reported in June 2003 that over the last decade emergency room trips increased approximately 20 percent - from 89.8 million visits in 1992 to 107.5 million in 2001 (Jones, 2003). To make matters worse the CDC also reported that the number of emergency rooms dropped by 15 percent. Another study completed by the American Hospital Association indicated that 62 percent of hospitals feel that they are operating at or over their capacity. When the study considered only Level I Trauma Centers and larger, 300-plus bed hospitals the percentage jumps to 90 percent. And, the General Accounting Office reported that 66 percent of emergency departments diverted incoming ambulances in 2001 (Pexton, 2003). In addition, 1 out of every 10 hospitals reported being on diversion status more than 20 percent of the year (Jones, 2003). These numbers are alarming to the strategic managers of our nation’s healthcare system. It has become apparent to many stakeholders, both within and outside the health care industry, that reengineering some of the key processes would go a long way in enabling health care organizations to be more efficient, effective, and adaptable.

Six Sigma process improvement techniques can help improve health care. The following case study demonstrates their effectiveness in a health care emergency department environment.

**Define Phase**

**Preparation for Project Team Members**

The Six Sigma portion of the study required the inclusion of CTMC’s own employees in quality improvement efforts. The Six Sigma philosophies integrate quality into the day-to-day activities of every employee. Thus, in order to implement a lasting business culture of quality it is important that the leaders of any organization support the strategies and vision behind Six Sigma projects. An initial meeting was held on in which the methodologies and goals of Six Sigma and Simulation were introduced to CTMC’s executive leaders. The scope and potential need for resources were discussed. The leaders agreed to embark on a cooperative effort - between the hospital, the university, and SBTI - to make quality improvements within the Emergency Department.

**Initial Six Sigma Project Team meeting**

The initial Six Sigma Project Team meeting yielded the following results:

- Financial measurements to be included in the Project Charter:
  - Revenue per ED patient.
  - Length of Stay (LOS)
- The identification of the “voice of the customer (VOC)” and the “voice of the business (VOB)”:
> VOC – the decision was to use the results of the Gallup Organization’s telephone survey and the internal CTMC telephone survey to capture customers’ satisfaction levels.
> VOB – internal project leaders concluded that this would envelope two goals of the business – increasing quality care (especially in regards to reducing the number and sources of errors) and lowering patient admission times.

- Sub departmental sources for the internal project team members – at least one representative from each sub department would participate in all future Six Sigma Project Team improvement activities:
  - Laboratory
  - Radiology
  - Registration
  - Respiratory
  - Therapy/Cardiology
  - Emergency Room Department
  - Materials

In addition, in this first meeting a Murphy’s Analysis was conducted to identify “defects” in the current Emergency Department processes. The Murphy’s Analysis is a negative brainstorming technique used by the process improvement team to collectively explore known problems with the current process. The ideas generated in this exercise have an added benefit of exposing problems that are unknown to other areas or sub-departments of the Emergency Department staff. This exercise helps orient all the team members to the full spectrum of problems faced by team. Subsequent Six Sigma tools help to focus process improvement efforts only on the most glaring process problems. These further tools facilitate the alignment of improvement efforts with strategic business needs or goals. The 6 Ms technique was employed within the Murphy’s Analysis; each defect was categorized into one of the 6 M categories:

- Man
- Machine
- Mother Nature
- Materials
- Method

- Measurement

**The VOC – Gallup Survey Results**

A review of the Gallup Organization’s telephone survey of customers from Central Texas Medical Center provides the “voice of the customer (VOC)” in regards to satisfaction levels. The patient ranks their experience at the hospital on a four-point Likert scale: 4 = Very Satisfied, 3 = Satisfied, 2 = Somewhat Dissatisfied, 1 = Very Dissatisfied. Descriptive statistics are computed for each quarter and presented in the survey results. The historical records reviewed comprised four quarters worth of data spanning from Q3 2002 (July – September) through Q2 2003 (April – June). The survey focused on four major areas of measurement: Patient Loyalty, Overall Evaluation, People, and Speed and Efficiency. The lowest mean in each of the four quarters reviewed was “Wait Time” which is a subcategory of the major area labeled Speed and Efficiency.

The mean Wait Time scores in each of the four previous quarters were 2.73, 2.97, 2.90, and 2.95. Also, only 27 % of patients reported “Very Satisfied” scores in regards to Wait Time. When patients were asked where unsatisfactory delays occurred, 81 % of all the patients identified the delay before being taken to a treatment room. And, 56 % of all the patients identified the delay before being treated by a physician as unsatisfactory.

In addition, the major category of Speed and Efficiency showed a mean that was below the mean for all hospitals in the Gallup Healthcare Database. This data point led to the reduction of patient waiting time as a prime opportunity for improvement efforts. The Gallup surveys suggest that a reduction in the mean waiting time and an improvement in the speed and efficiency of the operations would benefit the hospital, customers, and the community.

**Metrics Identified**

Metrics identified by the Six Sigma Project Team were:

1. Average Length of Stay – goal to see a 5% reduction
2. Triage to ED Bed - goal to reduce turnaround time by 20 minutes
3. Left Without Being Seen – goal to reduce to under 2 %
4. Patient Satisfaction – goal to increase Gallup scores in overall satisfaction, wait time, helpful and courteous staff, ED efficiency, and speed of service.
**Measurement Phase**

*Process Description*

The Six Sigma Project Team was developed to include both internal and external membership. This team met regularly to carry out the Six Sigma process improvement methodology. The team listed five major process steps for emergency department patients:

1. Patient presents to Triage
2. Patient presents to Registration
3. Management (initial health care administered by nurse)
4. Treatment (course of primary care administered by physician)
5. Disposition of patient

*Process Map*

The five major steps in the ED process serve as the backbone for the construction of a SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) map. This Project Team meeting included additional Project Team members consisting of CTMC stakeholders representing the major internal suppliers and customers to emergency department processes. The Project Team members built a SIPOC map by focusing on the top 5 or 6 high level steps in the Emergency Department processes. These top-level processes would be listed in sequential order and be described by action verbs. Then, the team members would list the Inputs to each process – what goes into the process - and list the Outputs to each process – what comes out of the process. The Inputs and Outputs to the SIPOC map were to take into consideration both the internal and external customers and the descriptions of each item was to be listed as nouns. In addition, three to five sub-processes were listed under each major Process step. The sub-processes list what happens within each process step. The ED Process Map is shown in Appendix I. Finally, the Process steps, Inputs, and Outputs would be used to create the next tool in the Six Sigma methodology – the Cause and Effect Matrix (C & E Matrix).

*Cause and Effects Matrix*

The C & E Matrix tool is used to prioritize where to focus improvement efforts. It is built in an Excel table format with the major Process Steps and their respective Inputs listed in rows. The team reviews the Outputs from the SIPOC map and rephrases the Outputs as measurable requirements. These are then listed across the top of the table as column headers. Each measurable requirement is also assigned an output rating score. Each Output was scored on a scale of one to ten. Higher scores meant that the requirement was of prime importance to the customer or the business. Thus, the voice of the customer and the voice of the business help to guide the Project Team in formulating the requirement ratings. Next, the team assigns correlation scores between each of the Process Inputs and each Output requirement. The scores assigned could have only one of four levels:

- 0 = No Correlation
- 1 = The process input is slightly correlated to the output requirement.
- 3 = The process input is moderately correlated to the output requirement.
- 9 = The process input has a strong correlation with the output requirement.

Finally, the sub-scores for each Process Input are calculated by cross-multiplying the respective rating of importance to the customer and the correlation score for each cell in the Process Input row. Each of the sub-scores are added together to yield a total score for the Process Input. The highest total score identifies those Process Inputs that are the most important in explaining the variation in the Process Outputs. The results of the C & E Matrix are shown in Appendix II. The most important Process Inputs become the input to the Failure Modes and Effects Analysis (FMEA) tool.

*Summary of Six Sigma Measurement Phase*

The Murphy’s Analysis, SIPOC map, C & E matrix, and the current ED process procedures become the inputs for the analysis phase of the Six Sigma methodology. A review of the C & E matrix shows that the following process steps/inputs are direct inputs into the Failure Modes and Effects Analysis tool in the analysis phase:

- Patient presents to Triage – Equipment and Supplies.
- Patient presents to registration – Chart
- Treatment – Diagnostic results
- Treatment – Materials

*Computer Simulation*

ProModel’s MedModel computer simulation software requires the user to gather data in order to build an “as-is” model of the emergency room processes. The researchers used several methods in order to gather this data – interviews, tabulation of historical records, direct observations, and physical measurements of facility layout. Interviews and historical records were used to generate the details for the entities (patients) and the resources (the doctors, nurses, and sundry technicians). The Emergency Department’s ER Logbook contained historical
records that were useful in describing the patient and the frequencies with which they required certain hospital resources and services. The data collected were analyzed to yield patient arrival times, patient acuity levels, lengths of stays at certain points in the process, and total length of patient stay. It was found that the best fitting distribution for patient arrivals was of the Inverse Gaussian typology. Interviews with key hospital stakeholders were used to gather information regarding the processing of patients, the staffing levels, and the shift strategies employed. All of this information provides the detail required to build a valid model that accurately reflects the “real-world” system.

Analysis Phase

FMEA

The next step in the DMAIC process was the construction of the Failure Modes and Effects Analysis (FMEA). The FMEA is the primary tool for risk assessment. The inputs include the results from the Murphy’s Analysis, SIPOC, and the C & E Matrix. The outputs yield a list of defects to be improved, a prioritized list of actions to improve processes, and the basis for a control plan. Each of the critical Process Inputs identified in the C & E Matrix are transferred to the FMEA – each Process Input serving as a row header in the FMEA spreadsheet. The team described the Failure Mode – “what can go wrong with the input?” and the Potential Failure Effects – “what is the effect on the outputs?”. The team assigned a Severity Level score (1 – 10, with a score of 10 representing the most severe impact) for each Process Input. Next, the team described and listed the Potential Causes of the Failure Mode. And, the team would assigned an Occurrence score (1 – 10, with a score of 10 representing a very likely occurrence) for each Potential Cause of the Failure Mode. Next, the Current Controls were discussed by the team and entered into the FMEA. The team then assigned a Detection score (1 – 10, with a score of 10 representing the case where the detection of the cause or failure would never occur). Finally, a Risk Priority Number (RPN) was calculated by multiplying the Severity, Occurrence, and Detection scores together for each Process Input row. The FMEA, the portion completed up to this point in the project, is shown in Appendix III. The RPN is the output of the FMEA and serves to prioritize process improvement actions. High RPN scores are the basis for a process control plan. The FMEA is best constructed with full participation of the Project Team.

Inputs identified in the C & E matrix were transferred to the FMEA – each Process Input serves as a row header in the FMEA. The team then described the Failure Mode – “what can go wrong with the input?” and the Potential Failure Effects – “what is the effect on represent prime opportunities for improvement efforts. The Process Inputs identified in the FMEA serve as the focus for the Improve and Control stages of the Six Sigma DMAIC methodology.

Direct Observations – Length of Stay in ED

A proportionally stratified random sampling plan was designed to directly observe emergency department patients. Detailed data was captured on times for each stage of treatment for 61 ED patients. Additionally, ED log data was analyzed for over 1000 ED patients. Data analyzed included lab turnaround, radiology turnaround, number of visits to patient by nurses and physician, specimens unacceptable, times for final instructions, and discharge times. Table 1 shows the descriptive analysis of length of stay.

Table 1. Length of Stay for ED Patients

<table>
<thead>
<tr>
<th>Acuity Level</th>
<th>Number of Patients</th>
<th>Mean Length of Stay (minutes)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor Emergency Clinic</td>
<td>504</td>
<td>101</td>
<td>52.95</td>
</tr>
<tr>
<td>Low Acuity</td>
<td>572</td>
<td>179</td>
<td>93.38</td>
</tr>
<tr>
<td>Medium Acuity</td>
<td>181</td>
<td>188</td>
<td>91.09</td>
</tr>
<tr>
<td>High Acuity</td>
<td>3</td>
<td>95</td>
<td>60.62</td>
</tr>
</tbody>
</table>

Low and Medium acuity patients were staying close to 3 hours before discharge and had the greatest variation. An examination of more detailed time measurements led to several changes and process improvements:

1. Tracking unacceptable lab specimens or lab analyses with greater than 60 minutes turnaround times.
2. Training of ED staff in blood-draw techniques to reduce unacceptable sample rate.
3. Change in cardiac related tests routinely run.
4. Posting of turnaround times for increased staff awareness.
5. Calibration of multiple lab instruments for tests to reduce turnaround times in case of instrument problems.
6. Procedure changes related to paperwork and orders for lab tests preventing labeling problems.
7. Procedure changes related to steps to add a lab or radiology order mid-way in patient visit.
8. Increased communication and interaction between lab, radiology, and ED related to problems.
9. Radiology staff wear pagers within hospital to reduce response times for ED patient needs.
10. Changes in patient registration and triage to immediately place patients into empty beds by triage nurse instead of being pulled into beds by ED staff.
11. Conversion of PCA position to RN position and change in responsibilities to free nurse for hospital admission duties.
12. ED supply closets redesigned to allow better organization, labeling, and stocking.

Checking with other hospitals, the average percentage of lab specimen analyses with unacceptable turnaround times was approximately 5 percent. After the above changes were put into place, the percentage of unacceptable turnaround times dropped to 2.5 percent.

The triage to ED bed time decreased from an average of 43 minutes to 19 minutes; a greater than 50 percent reduction in time as seen in Figure 1.

Figure 1. Triage to ED Bed Time

The Six Sigma goal of reduced variation was seen in the reduction in variation for the triage to ED bed time after the process changes were implemented.

In addition, the number of “left without being seen” patients showed a 60 percent reduction after the process changes were implemented as seen in Figure 2.

Before process changes were implemented, fifty patients commonly left per month without being seen. After the process changes were implemented, the rate dropped to approximately 20 patients per month. Given average revenue for ED patients, this conservatively means an increase in revenue for the ED of over $100,000 per year.
Prior to implementation of the process changes, the ED was ranked in the bottom quartile of its system hospitals in patient satisfaction. After the process changes, the ED was ranked in the top quartile of its system hospitals in ED patient satisfaction.

**Improvement and Control Phases**

Through the use of the tools of Six Sigma and Simulation, the hospital is making changes in their processes that will help them be a much stronger patient focused organization. The hospital has made significant changes in patient registration and triage in response to the Six Sigma Project Team.

Before the redesign, many patients entering the emergency department were faced with two windows – one for Triage and one for Registration. Many patients were incorrectly asking for medical assistance at the Registration window. The Triage window is the intended first stop for incoming customers. The hospital has walled off the window that faces the front entrance, thus making it more obvious to the patient that the first stop is at the Triage window. This decreases the amount of time wasted by the. Also, it eliminates some of the work load for the Registration personnel as they no longer need to reroute patients to the triage window.

Another improvement is to address the equipment, supplies, and materials problem in the ED. Currently, there is only one resupply room. The Material department and Emergency Department have agreed to create a cross-functional team to develop three separate resupply areas. They plan to use the 5S technique (a Japanese term and technique that is used to optimizes the effectiveness of a particular workspace: Seiri - Sort/Discard, Seiton - Arrange/Order, Seiso Clean/Inspect, Seiketsu - Standardize/Improve, Shitsuke Believe/Discipline.Sort) to improve the layout of their two existing resupply closets. They will add a third resupply area in the form of a metro rack near their Trauma rooms.

At this point, the study is continuing into the Improvement and Control stages. Once a process is “improved” the team continues to measure that process. It is important to determine if the improvement had the desired effect. If the improvement in the process had the desired effect, then it is the duty of the team to put control processes in place. The control processes ensure that the process does not “slip” back into a state of uncontrollable variation.

**Conclusion**

Each hospital emergency department has its own, unique business environment and operational constraints. A non-punishing, data-oriented, process-focused approach to solving process problems is the key towards making steady organizational improvements. One of the key ideas is that process improvements should be focused on the process problems and not the people problems. Process improvements can be found in even the best of emergency departments. The necessity for these improvements are not the result of bad people but rather the result of bad processes.

This case study has shown that Six Sigma process improvement techniques can improve the quality of care in a health environment.

While many in health care say that we can never achieve the level of quality found in manufacturing and because of that, Six Sigma will not work in health care; they are missing the point. Whether we achieve manufacturing levels of quality or not is not what’s important. Rather it’s the fact that we must implement a system like Six Sigma to help us structure our process improvement efforts and move “toward” a health care system we all want to be a part of. Quality improvement must become a central part of what it means to be a health professional.

**References**

Appendix I. Emergency Department SIPOC Map

CTMC Level 1 Process Map

**Inputs**
1. Patient
2. Nurse
3. Signage/Layout
4. EMS/Modes
5. Equipment/Supplies

**Patient presents to triage**
1. Triage captures complaint and time.
2. Vital signs captured.
3. Basic treatment
4. Decision on where to go.

**Outputs**
1. Patient to registration.
2. Chart (including protocols)
3. Basic Treatment (stop bleeding, wrapping, etc.)

**Code 3 goes directly from triage to ER**

**Patient presents to registration**
1. Reg desk enters patient into A3400.
2. Reg desk checks insurance/method of payment.
3. Patient signs HIPAA, given Patient’s rights.
4. Patient given wristband.
5. Patient sent to waiting room.

**Outputs**
1. Patient to contact
2. Account Number
3. Chart to ER
4. Insurance Info (c Specialty)
5. Privacy Practices form (HIPAA)
6. Labels
7. Ambulance

**Inputs**
1. Patient to ER ted.
2. Nurse
3. Labels
4. Chart
5. Family members/friends

**Management**
1. Nurse picks up chart.
2. Initial assessment by primary nurse.
3. Initiate care (blood draw, IV)
4. Complete chart/communication
5. Chart to "Dr. to-be seen" rack.

**Outputs**
1. Diagnostic orders
2. Patient prepared for physician (comfort controls)
3. Possibly early diagnostics
4. Verbal instruction to M.D.
5. Auxiliary services notification
6. Patient communication

**Inputs**
1. Doctor contact
2. Diagnostic results
3. Equipment
4. Materials
5. Personnel
6. Old Charts
7. Code Teams if needed

**Treatment**
1. Doctor visits patient.
2. Labs are ordered.
3. Labs, diagnostics ordered.
4. Results received
5. Reassessment

**Outputs**
1. Doctor's orders
2. Continued tests/labs
3. Nurse treatment
4. Transport to radiology
5. Transport to GI Lab
6. Communication with family and friends
7. Pharmacy

**Inputs**
1. Doctor’s orders
2. EMS/Critical Air
3. Nurses and ER techs

**Disposition**
1. Decision/care completed.
2. Transportation arranged.
3. Patient moved.
4. Chart completed.
5. Charges entered.
6. Room cleaned.

**Outputs**
1. Patient instructed
2. Doctor dictation
3. Prescriptions
4. Transfer to another hospital
5. Patient discharged/morgue
6. Patient admitted to hospital/OR
## Appendix II. Cause and Effect Matrix

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Process Input</th>
<th>Rating of Importance to Customer</th>
<th>Quality Care</th>
<th>Error Reduction</th>
<th>Speed of Service</th>
<th>Total</th>
<th>Rating</th>
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### Appendix III. Failure Modes and Effects Analysis

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<th>Potential Failure Effects</th>
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<th>Potential Causes</th>
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<td>Paula in registration meets with staff if problems arise.</td>
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<td>Preventative maintenance.</td>
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