

Using the TapRoot® System for Process Safety Incident Investigation and Root Cause Analysis

Background

TapRoot® System is a process and techniques to investigate, analyze and develop corrective actions to solve problems. The process and tools are completely described in the *TapRoot® Book*¹.

The TapRoot® System has been used since 1991 for the investigation of process safety incidents. A limited survey conducted in 2001 by the Center for Chemical Process Safety showed that it was one of the most used root cause analysis systems by its members. The TapRoot® System also has broad use in a variety of other industries including:

- healthcare,
- transportation,
- aerospace,
- manufacturing,
- telecommunications,
- utilities,
- oil exploration and production,
- pulp and paper, and
- construction.

These industries use TapRoot® to:

- improve process safety,
- improve industrial safety,
- improve product and service quality,
- reduce operations and maintenance errors, and
- increase service and equipment reliability.

Success stories achieved using TapRoot® can be found at www.taproot.com in the Success Stories section.

The TapRoot® System (process and tools) was not developed from a fault tree nor is it used like a checklist. Instead, the TapRoot® System combines both inductive and deductive techniques for systematic investigation of the fixable root causes of problems. The system can be used either *reactively* (as in the example provided in this appendix) to prevent the recurrence of events or *proactively* to find ways to improve performance before a major process safety accident occurs.

The TapRoot® System also goes well beyond the simple technique of "asking why" or the standard techniques of cause and effect (sometimes known as fishbone diagrams) or fault tree diagrams. The TapRoot® System has embedded intelligence so that the system helps investigators find root causes that they may not have previously had the knowledge to identify. As Albert Einstein said: *"It's impossible to solve significant problems using the same level of knowledge that created them."*

The embedded intelligence allows the TapRoot® System to be used by people in the field to investigate everyday problems and yet robust enough for even the most complex major process safety accident investigation.

Unlike other common root cause techniques, the TapRoot® System is an investigation system. This means the tools and techniques in the TapRoot® System are used in all phases of an investigation - from initial planning through the collection of information and root cause analysis to the development of corrective actions and the presentation of an investigation to management or other interested parties. The system is supported by patent pending TapRoot® Software that makes presenting information easy and logical and provides a trendable incident/root cause database and corrective action management database.

To train individuals to effectively use the techniques there are public and on-site courses (a 2-day course for basic users and a 5-day course for expert users / team leaders). There is also an annual conference for advanced topics, continuing learning, and refresher training.

Example Analysis Using TapRoot®

The following is an example of the use of the system to analyze an environmental accident (fish kill) at a process plant. The event has been de-identified and is not intended to represent an actual event at any particular process plant.

Also to shorten and simplify this appendix, the information collection portion of the investigation will not be shown. Rather the use of TapRoot® will only be demonstrated for root cause analysis of problems and the development of corrective actions.

Also, because this is a fairly simple incident, only the standard TapRoot® System techniques will be shown: SnapCharT® and the Root Cause Tree®. If readers are interested in the other four optional techniques (Equipfactor®, Safeguards Analysis, Change Analysis, and Critical Human Action Profile), they can read about them in the *TapRoot® Book*¹.

Finally, to shorten the presentation further, only the development of corrective actions for a single causal factor (of the four identified) will be presented.

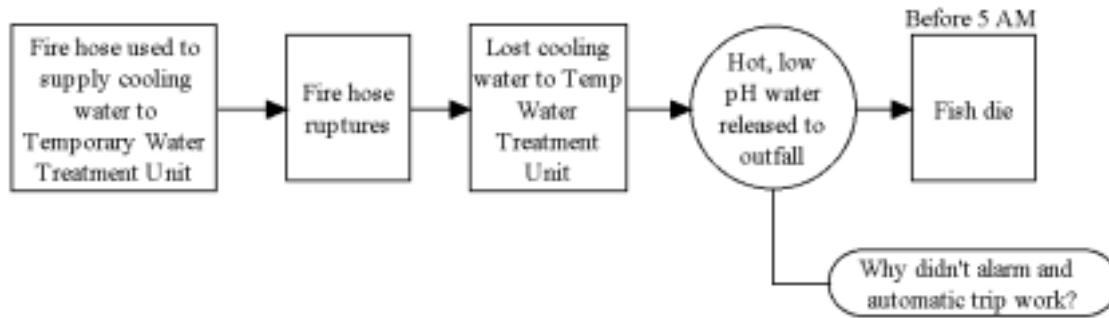


Figure 1*****: Initial Incident SnapCharT®

Initial Incident Description

During a normal night shift at a process plant, fish were killed when a temporary (temp) water treatment unit overheated and released hot, low pH water to one of the plant's outfalls.

An investigation that included a contractor representative (contract personnel were operating the temporary water treatment unit) was conducted using the TapRoot® System. The investigation found a sequence of events shown on a SnapCharT® in Figure 1*****).

Results of Additional Investigation

After considerable investigation including:

- interviews with all contract operators and their supervisor,
- discussions with the temporary water treatment unit vendor's engineers,
- interviews with plant personnel at the process plant unit,
- interviews with procurement personnel, and
- interviews with operations management,

a more detailed SnapCharT® (Figure 2*****)) with causal factors (indicated by black triangles) was developed.

Each of the four causal factors (a causal factor includes all of the information attached to it in the SnapCharT®) was analyzed for its specific root causes and generic causes using the Root Cause Tree® and Root Cause Tree® Dictionary (the Root Cause Tree® and Root Cause Tree® Dictionary come with the *TapRoot® Book*). The following is an analysis of one of these causal factors (contract operator falls asleep).

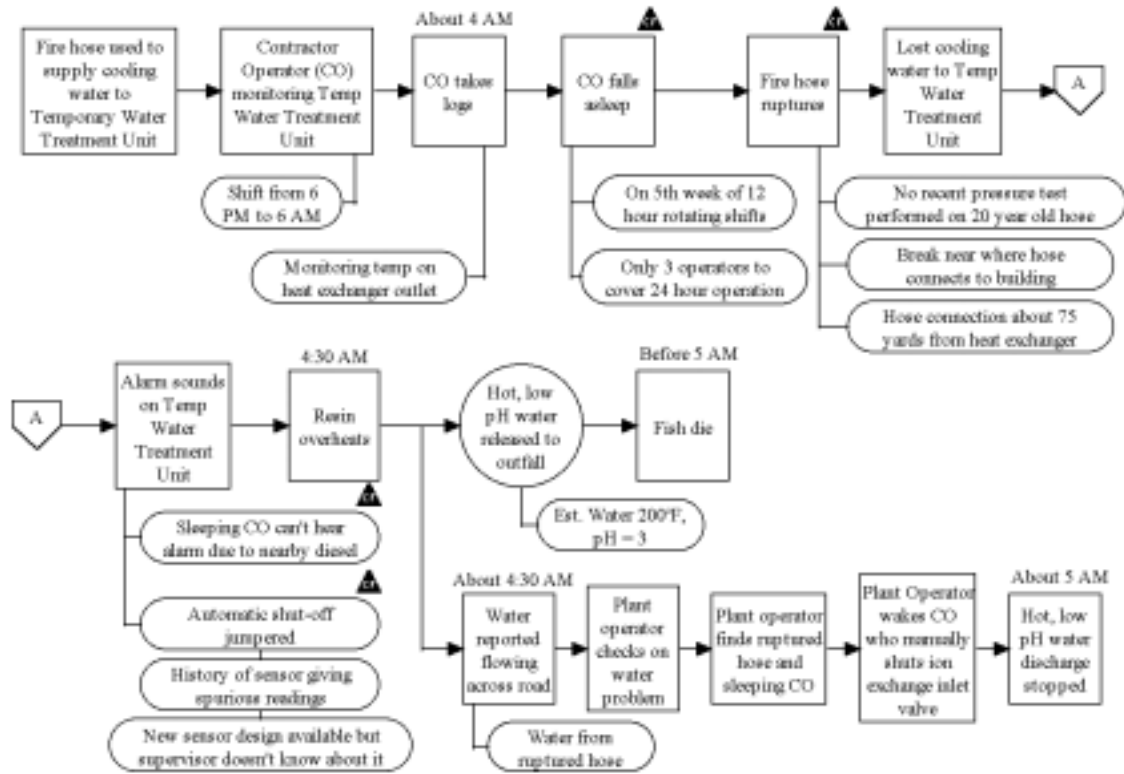


Figure 2*****: Complete SnapCharT® for Fish Kill Incident

Analyzing a Causal Factor

A causal factor is an event or condition that, if eliminated or modified, would have stopped the progression of the incident or made the consequences significantly less severe.

To analyze the causal factor - contract operator falls asleep - the investigator started at the top of the TapRoot® Root Cause Tree® (Figure 3*****, the complete Root Cause Tree® is available in the *TapRoot® Book*¹) and worked down the tree through a process of selection and elimination. The investigator thus asks and answers questions to identify the specific root causes for the causal factor.

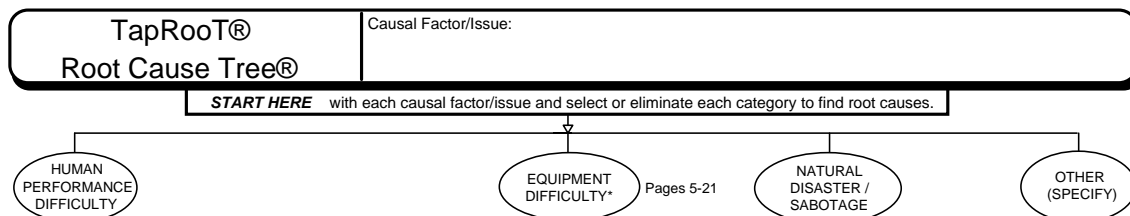


Figure 3*****: Top of TapRoot® Root Cause Tree®

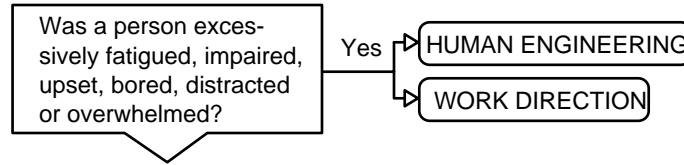


Figure 4*****: First of the 15 Questions in the Human Performance Troubleshooting Guide

In this case, the causal factor (contract operator falls asleep) was identified as a Human Performance Difficulty (one of the four major problem categories at the top of the Root Cause Tree®) and the other three categories were eliminated.

When the investigator identified a Human Performance Difficulty, they were guided to a set of 15 questions (part of the tree's embedded intelligence) called the Human Performance Troubleshooting Guide. The first of the 15 questions of the guide is shown in Figure 4*****. This troubleshooting guide helped the investigator identify which of the seven human performance related Basic Cause Categories to investigate further. The seven categories are:

- Procedures
- Communications
- Work Direction
- Training
- Management System
- Quality Control
- Human Engineering

Each category indicated by a "Yes" answer to the questions in the Human Performance Troubleshooting Guide was investigated further to see if it could be eliminated or if one or more Near-Root Causes and related Root Causes contributed to the problem (and thereby helped "cause" the incident). One of the seven Basic Cause Categories (Human Engineering) is shown in Figure 5****.

In the Fish Kill incident the first of the 15 questions, shown in Figure 4*****, was answered "Yes" because the contract operator was thought to be both fatigued and bored. When the rest of the 15 questions were answered the following Basic Cause Categories were indicated for more investigation:

- Human Engineering
- Work Direction
- Management System
- Procedures

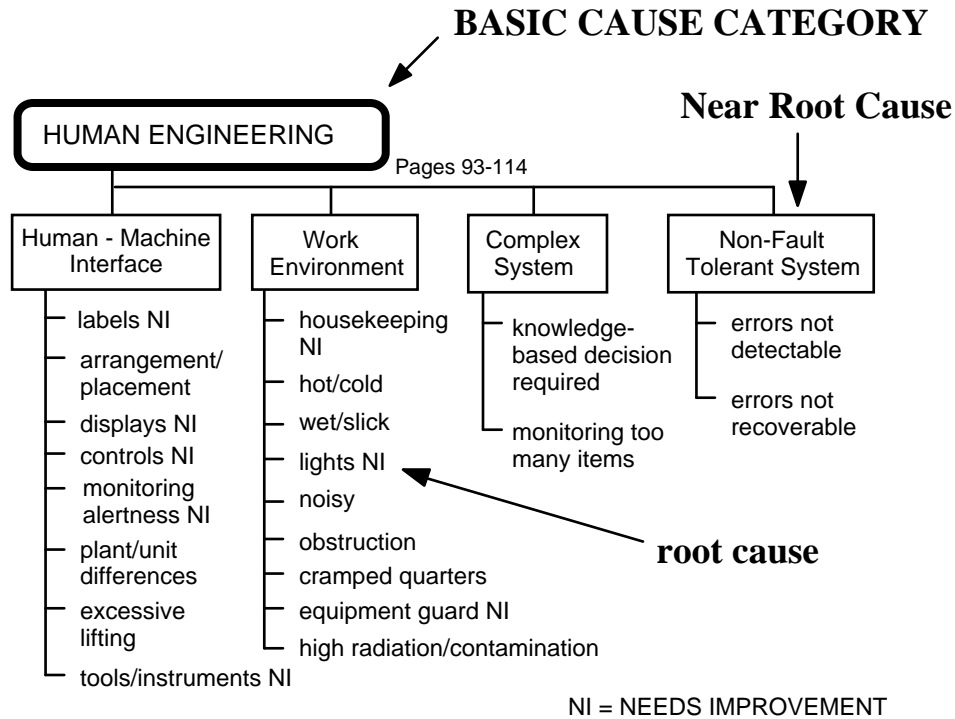


Figure: 5*****: Human Engineering Basic Cause Category

The completed analysis of one of these categories (Human Engineering) is shown in Figure 6*****.

When this causal factor was analyzed using the rest of the applicable Basic Cause Categories (not shown here - Work Direction, Procedures, Management System) the following root causes and generic causes were identified:

1. Monitoring alertness needs improvement.
2. Shift scheduling needs improvement.
3. Selection of fatigued worker.
4. The "no sleeping on the job" policy needs to have a practical way to make it so that people can comply with it.

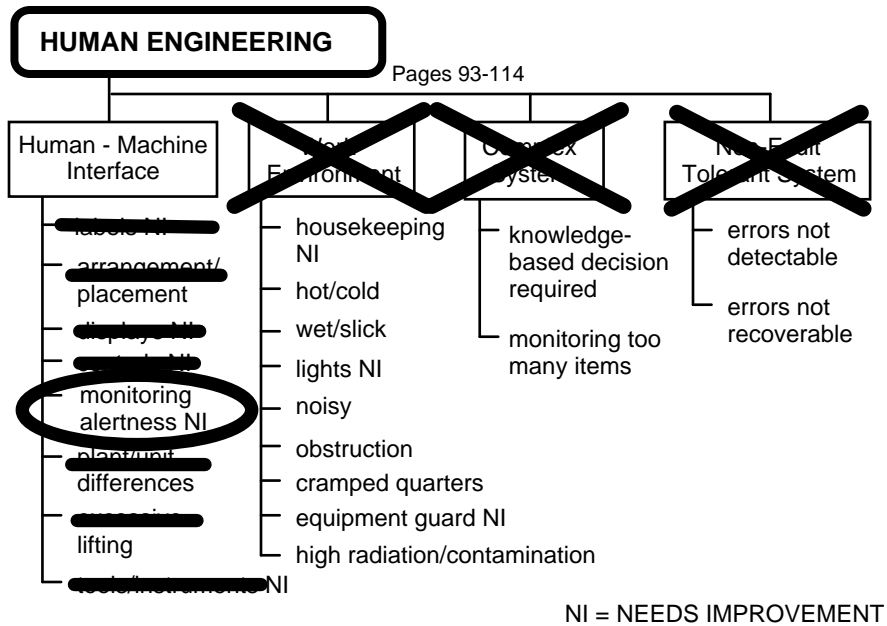


Figure 6*****: Analysis of One Basic Cause Category

Developing Corrective Actions

Once the causes for all of the causal factors were identified, the investigator used the Corrective Action Helper® module of the TapRooT® Software to help develop the corrective actions for each of the root causes. This module of the software helps investigators:

1. Verify that they are addressing the real causes of the incident.
2. Develop corrective actions to fix the specific cause of the problem.
3. Develop corrective actions for the generic (or systemic) cause (if applicable) for the problem.
4. Develop additional implementing actions needed to make the corrective actions successful.
5. Find references to study the problem in detail and learn more about potential strategies to eliminate the problem.

The following is an example of the guidance provided by the Corrective Action Helper® module of the TapRooT® Software for one of the root causes (Monitoring Alertness Needs Improvement) that was identified for the Fish Kill Incident:

Check:

You have decided that the problem was related to loss of performance over time while monitoring. (The job was too boring.)

Ideas:

1. You should consider recommending the following options: (Order does not indicate preference.)
 - a. Provide an alarm to alert the worker and relieve the boredom of monitoring.
 - b. Provide an automated monitoring and response system to replace human monitoring and response. **NOTE:** this will probably leave the worker in supervisory control. You will need to consider ways to keep the worker informed as to what the automation is doing and to clearly indicate why it is doing it. You should also consider ways to keep the workers involved in the process so that they maintain their situational awareness and maintain their manual control proficiency.
 - c. Rotate the person monitoring more frequently. (Experiment to find out how long they can monitor reliably and then rotate people so that they only monitor for less than that time.)
 - d. Redesign the job to provide other tasks that don't compete with the monitoring task to keep the person alert and involved. (For example, playing the radio while driving.) **Do not** provide tasks that compete for the same resource. (For example, reading a book while driving.)
 - e. Provide false signals to keep the worker involved. However, you should also consider that people may ignore real signals if they become accustomed to receiving only false signals.
 - f. Consult the workers to see if they have ideas that would make the task more interesting without conflicting with the monitoring requirements.
2. Fatigue can also combine with monitoring alertness problems. Consider training supervisors to understand that fatigued personnel should not be assigned to tasks that require a high degree of monitoring alertness.
3. Also, consider testing individuals for their alertness before assigning them to a monitoring task.
4. Once changes have been approved, consider training the workers about the changes and their intended impact.

Ideas for Generic Problems:

1. If monitoring alertness is a generic problem, consider recommending a review of the jobs to redesign them and add more active tasks.

References:

For more information about vigilance and monitoring alertness, consider reading:

The Psychology of Vigilance by D. R. Davies and R. Parasuraman, 1981.
Published by Academic Press, New York.

Engineering Psychology & Human Performance by C. D. Wickens, 1992.
Published by Harper-Collins, New York.

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Because the practices of a contractor were involved, the corrective actions had to be negotiated in consultation with the contractor. When the suggestions of this Corrective Action Helper® module were reviewed with the other modules for the rest of the root causes, the following corrective actions were recommended to improve performance:

CAUSAL FACTOR: Contract Operator Falls Asleep

Root and Generic Causes:

1. Monitoring alertness needs improvement.
2. Shift scheduling needs improvement.
3. Selection of fatigued worker.
4. The "no sleeping on the job" policy needs to have a practical way to make it so that people can comply with it.

Corrective Actions for Root Causes (these address issues specific to this incident):

1. Move diesel driven compressor away from temporary water treatment unit so that the alarm on the unit can be heard. (Cause 1)
2. Remove the jumpers and place the automatic trip feature back in service. (Cause 1)
3. Require the contractor to provide at least 4 contract operators working rotating shifts so that overtime is reduced and so that no operator monitors the temporary water treatment unit for more than 8 hours. (Causes 1 and 2)
4. Recommend to the contractor that if other contract operators are available on site that people be rotated through monitoring tasks to increase alertness. (Causes 1 and 4)

Corrective Actions for Generic Causes (These corrective actions were developed to correct generic - sometimes called systemic - problems that were identified in this investigation.):

5. In association with the Human Resources and Contracts Departments, develop guidance for plant and contract personnel on acceptable overtime scheduling and monitoring duration. This should include the maximum number of hours to be worked in a 24, 48, 72, and 120 hour period. It should also provide guidance for shift scheduling (shift rotation) and requirements for approval for exceptions to the maximum hours policy. It should also include suggested monitoring durations and monitoring rotation ideas. (Causes 2, 3, & 4)
6. Develop guidance for supervisor oversight of employees and contractors. This guidance should include company expectations for supervisors to

- observe employees on a periodic basis to help detect fitness for duty issues including fatigue. (Cause 3 & 4)
7. Create training for supervisors (and a training module to be provided to contractors) to communicate the requirements and techniques for supervisory oversight of employees and contractors to detect fitness for duty (including fatigue) issues and to communicate any new guidance on overtime scheduling and monitoring limitations developed in Corrective Action 4. (Causes 3 & 4)
 8. Add the training developed above to the standard class for new supervisors. (Causes 3 & 4)
 9. Conduct training created in Corrective Action 6 for current operations, maintenance, and engineering supervisors. Document training in the plant's training records. (Causes 3 & 4)
 10. Supply the supervisory training developed in Corrective Action 6 to current contractor representatives as a good practice. Suggest that contractors have at least one representative observe one of the on-site training classes conducted for company supervisors. (Causes 3 & 4)
 11. Require some minimum contractor supervisory observations (developed in Corrective Action 5) of contract operators and mechanics as part of future contracts. Include this requirement in the standard contract terminology and in new buyer training. (Causes 3 & 4)
 12. Develop training for Operations and Maintenance Personnel (and a training module to be provided to contractors) about fitness for duty and their responsibility to report fitness for duty problems (for example, fatigue) to their supervisor. This training should include sleep, dietary, and life factors to improve their alertness. (Causes 1, 3, & 4)

The remaining three causal factors:

- Fire hose ruptures
- Automatic shut-off jumpered
- Contract operator can't hear alarm due to noise

would also be analyzed using the process described above and appropriate corrective actions would then be developed. Some of these corrective actions might overlap with the corrective actions for the first causal factor (for example, Corrective Action 2 would also be applicable for correcting at least part of the causes for the "Automatic Shut Off Jumpered" causal factor. Therefore, once all causal factors have been analyzed, the corrective actions would be reviewed to see if any duplication exists or if any more efficient ways might be developed to address problems.

Also, the corrective actions would be reviewed to ensure they were sufficient. In some cases additional safeguards could be recommended to add more defense in depth to the system or to recommend the complete removal of hazards that present too great of a risk.

Also, the corrective actions would be reviewed to ensure they were specific, measurable, that someone was accountable (no responsible people were listed here), reasonable, timely (no due dates were listed here and no interim corrective actions were provided for long term projects), effective, and reviewed for unanticipated consequences.

Before final approval by management of the corrective actions, the corrective actions could also be prioritized by use of a risk ranking matrix or other prioritization tool based on the risk being addressed, the benefit and cost of a particular corrective action.

Finally, all lessons learned that could be applicable to other company sites would be referred to the corporate lessons learned clearing house.

Also, as time passed and data was accumulated, data from the root causes would be reviewed using Pareto Charts to detect potential areas for generic improvements and also reviewed using Process Behavior Charts (either rate charts or interval charts depending on the trends to be observed) to detect negative trends or verify that improvement has occurred. More information about these advanced trending techniques are available in the *TapRoot® Book*¹.

Comparison of Results

A real incident similar to the Fish Kill incident was reported in an industry trade magazine. The magazine reported that the contract operator had been fired because they had violated the company's no sleeping policy. Compare the "fire the contract operator" corrective action and its effectiveness with the corrective actions presented above.

Firing the contract operator:

1. Is easy.
2. Provides an example to others that they need to be alert.
3. Is consistent with the company policy.
4. Seems effective in that no other operators are found sleeping for several weeks after the contract operator is fired.

However, what factors were missed and left uncorrected that could contribute to future incidents?

1. No actions were taken to improve the equipment reliability (either the reliability of the fire hose or of the automatic shutoff and alarm).
2. No effective corrective actions were taken to improve monitoring alertness. At best, only a temporary improvement in alertness was achieved. In fact, the results of spot audits could be non-representative because operators may be "covering" for each other to ensure that no one else gets fired.
3. After a contract operator is fired, other operators will view future investigations with suspicion and will be less likely to be fully cooperative. For example, would

an operator admit that they had nodded off? Would another operator "tell" on a fellow operator if he or she found the other operator sleeping? Or would they just "handle it on-shift" and not tell anyone? Would covering up mistakes get in the way of effective learning from mistakes?

Even though:

- Root cause analysis using TapRoot® and developing corrective actions is more difficult than blaming those involved, and
- TapRoot® suggests more thorough and potentially more difficult to implement corrective actions than the easy "fire the contractor" answer,

If the problem really needs to be solved to improve process safety, industrial safety, quality, or productivity, then good root cause analysis and implementing effective corrective actions can be worthwhile.

References

1. Mark Paradies and Linda Unger. *TapRoot® - The System for Root Cause Analysis, Problem Investigation, and Proactive Improvement*, Copyright 2000 by System Improvements, Inc., Knoxville, Tennessee.

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