Continuous Safety Sampling Methodology

Rolando Quintana
Anil Nair

The University of Texas at El Paso, USA

This research introduces a proactive methodology for accident prevention, called Continuous Safety Sampling Methodology, by utilizing the principles of work sampling and control charting. Sampling is performed to observe the occurrence of conditions that may become hazardous in a given system. These conditions, known as dendritics, may become hazards and could result in an accident or occupational disease. Continuous Safety Sampling Methodology performs a random sampling for the occurrence of these dendritics. The collected data are then used to generate a control chart. Based on the pattern of the control chart, a system "under control" is not disturbed whereas a system "out of control" is investigated for potential conditions becoming hazardous. Appropriate steps are then taken to eliminate or control these conditions to maintain a desired safe system.

1. INTRODUCTION

The Department of Labor reports that in 1990 the U.S. workforce experienced approximately 6.8 million job-related injuries and illnesses with approximately 60 million workdays lost (Bureau of Labor Statistics, 1992). A recent study by the Rand Corporation estimates that the direct costs of work accidents were $83,000 million for 1989 and that workers' compensation premiums cost the American industry more than $60 billion annually (Hensler, 1991).

This research emphasizes the need to look at the concept of industrial safety from a proactive rather than reactive view. The focus is on the limitations of the existing safety practices, which is elucidated by the statistics pertaining to the number of accidents and injuries, and the productivity loss in terms of direct and indirect costs still occurring in the industrial world.

The occurrence of an injury invariably results from a completed sequence of factors—the last one of these being the accident itself. The accident, in turn, is invariably caused or permitted by a mechanical or physical hazard (Heinrich, Peterson, & Roos, 1979).

Knowledge of the factors in the accident sequence guides and assists in selecting a point of attack in accident prevention. It permits simplification without sacrifice of
effectiveness and allows opportunity for the application of general educational plans, with a more complete knowledge of exactly what should be done and why it should be done. In short, the factors in the accident sequence constitute an index of the kind of information the accident preventionist must deal with to work efficiently. Figure 1 provides a flow chart for an accident sequence, a development of an idea advocated by Heinrich in 1950 (Heinrich et al., 1979).

Here is a chain of circumstances and events that tie in with one another in a systematic fashion. If the conditions becoming hazardous are identified, the hazard can be eliminated or at least controlled by applying the proper engineering or administrative controls, or both. This ultimately preempts the occurrence of accidents and the possibility of injury. These conditions becoming hazardous are known as the “dendritics” of a given system. Safety programs are usually established piecemeal, based on an after-the-fact philosophy of accident prevention (Roland & Moriarty, 1983). When an accident occurs, an investigation is conducted to determine the causes. Accident causes are then reviewed and discussed to determine what must be done to prevent similar accidents. As a result of the accident occurring, the workplace may be modified in order to prevent or minimize its re-occurrence.

In the industrial environment, safety may be defined as recognition of reasonable risks, whereas an accident is an unplanned and undesirable event that interrupts planned activity (Marshall, 1982). When a person is unable to cope with an unexpected situation, it may lead to an accident. However, accidents do not happen unless a hazard exists (Marshall, 1982). Moreover, by definition, a hazard is a condition or changing set of circumstances that presents a potential for injury, illness, or property damage (Firenze, 1978). This definition carries with it two significant points. First, a condition does not have to exist at the moment to be classified as a hazard. When the total hazard is being evaluated, potentially hazardous conditions must be considered. Second, hazards may result not only from
independent failure of workplace components but also from one workplace component acting upon or influencing another. Thus, the existence of a hazard can be seen as a series of stochastic and dependent events (Firenze, 1978).

An objective of safety engineering is to keep the workplace reasonably free of physical and health hazards but the stochastic nature of hazards and the cost of eliminating them makes a 100% safe environment impractical. Although theoretically possible, because most hazards can be identified and removed, injurious occurrences are repeated despite knowledge of their causes or the availability of recommended controls (Orn, 1980).

Safety engineering, as a concept and practice, has been in transition since its beginning. Within the boundaries of safety engineering's emerging abilities exists a capacity for more than simply the detection of causative relationships and the design of practical controls. To quote Grimaldi (1980), "Many (injurious) events, almost nine out of ten that occur in work places..., can be predicted." The implication is clear that knowledge exists which, if used, would stem the vast majority of injurious events. The most effective methods for accident prevention are analogous with the methods for the control of quality, cost, and quantity of production (Heinrich et al., 1979).

The formal methods of hazard analysis, categorized as inductive and deductive (National Safety Council, 1992), are limited in their effectiveness as they only come into the picture once an accident has taken place. They are like a post-mortem report that identifies what happened and how it happened. They do not provide real time information on whether the conditions in a system are becoming hazardous, which may finally lead to an accident, an injury, or an occupational disease. Present safety methodologies basically provide feedback on hazards after accidents have happened. However, what is required is a concept that indicates that the system under consideration is becoming hazardous. This information would facilitate to check and eliminate the hazard before accidents can happen.

This research espouses one such concept, namely, Continuous Safety Sampling Methodology (CSSM), which studies the system for occurrence of conditions becoming hazardous and takes steps to eliminate these conditions when their occurrence crosses certain preset limits or when they show an unnatural pattern. The concepts underlying this proactive approach to industrial safety are derived from work sampling and control chart theories. These theories emphasize a cost effective way of keeping a continuous check on the safety status of the system under consideration. CSSM involves a planned, systematically organized, and before-the-fact process characterized as the identify-analyze-control method of safety. The emphasis is placed on an acceptable safety level designed into the system prior to actual production or operation of the system. CSSM requires timely identification and evaluation of the conditions becoming hazardous—before losses occur. A policing and inspection approach aimed at enforcement of safety and health standards cannot generate effective preventive measures because it is episodic, external, and coercive rather than sustained, internal, and self-governed, and often arbitrary and indifferent rather than relevant and motivated. In essence, CSSM is concerned with determining and maintaining a preset degree of safety, within the constraints of operational effectiveness, time, cost, and other applicable interfaces to safety that can be
achieved throughout the life cycle of the system. The premise here is that continuous improvement is very much valid for the discipline of safety engineering, as has been shown in the field of quality.

To demonstrate the potential use of CSSM, an industrial setting was selected, involving the cumulative trauma disorders (CTD) commonly associated with the frequent use of computer workstations. The growth in the area of information technology and computer workstations, or video display terminals (VDTs) has resulted in a metamorphosis of a traditional office desk job. It is not uncommon for a VDT operator to work for hours without interruption. The operators’ movements are restricted, attention is concentrated on the screen, and the hands are linked to the keyboard. These tasks require a constantly high degree of attention and interruptions are rare. Hence, it is not surprising that these operators show a frequent occurrence of CTD.

To validate the hypothesis of Continuous Safety Sampling Methodology, the office desk job in the health care industry was selected. As part of the scope, the dendritics and the methodology for developing them for cumulative trauma disorder among VDT operators will be described.

2. METHODOLOGY

In CSSM, the safety status of a system is evaluated using dendritics, the core conditions leading to hazards in any given system. The effectiveness of CSSM depends on the identification of these dendritics for performing the sampling study of a given system. A schematic of CSSM is provided in Figure 2.

![Figure 2. Schematic of Continuous Safety Sampling Methodology.](image-url)
As seen in Figure 2, the steps taken for the creation of CSSM are
1. The dendritic elements are constructed.
2. A random sampling scheme is developed.
3. Samples are used to construct a safety control chart.
4. The control chart observations are tested for “out of control” conditions.
5. If an out of control condition is detected, appropriate action is taken.

Each of these steps will be briefly discussed.

2.1. Dendritic Construction

The fundamental issue in the implementation of continuous safety sampling is the identification of the core conditions leading to hazards in any given system. These core conditions can be termed as dendritics of a particular class of hazards, which if present may lead to a hazardous condition, which ultimately can result in an accident. An example of dendritics, in the case of a fire hazard, would be the presence of substances helping combustion which may lead to a fire hazard and can finally result in a fire.

To develop the dendritics for a system, an analysis of the system must be performed using the preliminary hazard analysis (PHA). A PHA provides an initial risk assessment of a system, identifies safety critical areas, evaluates hazards, and identifies the safety design criteria to be used (Grimaldi & Simonds, 1989). CSSM will dynamically monitor the state of the system with respect to dendritics developed from this initial risk assessment. The PHA effort should, thus, commence during the initial phases of system development, or in the case of a fully operational system, at the initiation of a safety evaluation.

A preliminary hazard analysis provides an initial risk assessment of a system. Then a Pareto analysis can be performed to list the dendritics based on hazard severity, hazard probability, risks, and operational constraints. Pareto analysis is a technique for prioritizing types or sources of problems (Dean & Evans, 1994). It separates the “vital few” from the “trivial many” and provides help in selecting directions for improvement.

<table>
<thead>
<tr>
<th>System</th>
<th>Hazard Type</th>
<th>Hazard</th>
<th>Symptoms</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDT operators in the health care industry</td>
<td>Carpal Tunnel Syndrome, a musculoskeletal disorder</td>
<td>The result of compression of the median nerve and the radial artery in the carpal tunnel in the wrist</td>
<td>Pain in the wrist, Enervated wrist, Loss of motor control of the arm, Tingling sensation at the tip of the fingers</td>
<td>Repetitious nature of the job, Improper (constraint) wrist posture while performing the job, The duration and the intensity of force applied to carry out the job</td>
</tr>
</tbody>
</table>
Thus, the dendrites form the basis for performing continuous safety sampling to evaluate whether the system is becoming hazardous, so that preemptive actions can be taken to avoid accidents. This characteristic of CSSM makes it a generic tool which can be applied to control any kind of safety hazard.

As a “proof of principle,” the system comprising the VDT health care operators mentioned above was analyzed and the preliminary hazard analysis results are given in Table 1.

From the results of Table 1, the dendrites used in this research were constructed and are shown in Table 2. These dendrites are the elements to be sampled.

<table>
<thead>
<tr>
<th>No.</th>
<th>Dendritic Element Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Pinching of the wrists by supporting them at a sharp edge</td>
</tr>
<tr>
<td>2.</td>
<td>The extension position of the wrists</td>
</tr>
<tr>
<td>3.</td>
<td>The flexion position of the wrists</td>
</tr>
<tr>
<td>4.</td>
<td>The radial deviation of the wrists</td>
</tr>
<tr>
<td>5.</td>
<td>The ulnar deviation of the wrists</td>
</tr>
<tr>
<td>6.</td>
<td>No dendrites present</td>
</tr>
</tbody>
</table>

### 2.2. Random Sampling Scheme

CSSM is a concept of providing safety condition information in a statistically verifiable and economically viable manner by using the principles of work sampling and control charts. The basic hypothesis is that a random sample of a sufficiently large size, as in work sampling, reflects the state of the system being observed. Further, the plotting of the attribute, namely, the existence or potential for a hazard, could indicate whether the system is safe or not, similar to the use of $p$-charts to perform quality control in industry.

The sampling feature makes CSSM a cost-effective tool in analyzing a system for safe conditions. The sampling can be performed in conjunction with other routine job functions, without additional allocation of resources. The safety sampling observations are made with a pre-assigned degree of reliability, resulting in a more meaningful technique with those not conversant with such data collection methods.

### 2.3. Control Chart

Control charts can be an effective means to help safety professionals identify current problem areas and for predicting future problem areas or areas that are going out of control. By providing information regarding the tendency of a system, the control charts in CSSM indicate when systems tend to become hazardous, facilitating the implementation of corrective steps to prevent hazardous conditions getting out of control and resulting in accidents.

Control charts are of two kinds: (a) charts for variables, in which quality is described quantitatively in terms of dimensions, weights, or other characteristics, and
(b) charts for attributes, in which inspection is visual or by go-no-go gauges, with the product classified as either good or bad. The $p$-chart is the proper chart to use for category proportions, being used to plot percentages in successive samples (Feigenbaum, 1991).

A $p$-chart is constructed by plotting the daily value of $\bar{p}$ against the date. The $\bar{p}$ is the daily weighted average of all the proportion of non-conforming observations (dendritics). The average or $\bar{p}$ are given by the following formula (Juran, 1951):

$$UCL = \bar{p} + 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}, \quad LCL = \bar{p} - 3 \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where $UCL$—Upper control limit, $LCL$—Lower control limit, $\bar{p}$—Average weighted proportion of non-conforming observations, $n$—Number of observations at each sampling session.

The control chart performs a very essential function in CSSM, by identifying the time period during which the conditions in a given system are tending to become hazardous.

### 2.4. Testing Control Chart

A thorough discussion of the tests involved in determining the numerous ways in which lack of control may be manifested is given by Grant and Leavenworth (1988). Juran (1980) suggests the use of a few simple rules to detect an out of control condition when

1. a single point falls outside the $3\sigma$ limits,
2. two out of three successive points fall outside the zone of $2\sigma$,
3. four out of five successive points fall outside the zone of $2\sigma$,
4. eight successive points fall on one side of the center line.

There are statistical tests that can detect possible dependencies among data points and one such test is "Runs Up and Down Test." In this test, the data points are represented as numbers in a sequence. A run is defined as a succession of similar patterns (up or down) followed by a different pattern.

### 2.5. Out of Control Action

Observations are plotted to obtain a safety control chart. If it is under control, that is, there is no significant potential for a hazard, the sampling process is continued. However, if the control chart indicates that the system is out of control, that is, there is a significant potential for a hazard that could result in an accident, then proactive action should be taken to prevent an accident. Further, dendritics can also be continuously improved by studies of the system from new perspectives.

The five steps listed in section 2.4. are used to implement CSSM for the selected case study. The system under consideration is the scheduling department at a health
care facility. The job involves receiving telephone calls from customers, loading data received into a computer (VDT) through a keyboard, and relaying the information on the screen to the caller. The system is comprised of eight independent VDT workstations, which perform exactly the same job function and represent the characteristics of the same population. Thus, when one random visit to the facility is made, it is equivalent to making eight random observations.

The various components of CSSM are summarized and listed as given below:

1. Create sampling plan, where the elements are various dendritics and no dendritics.
2. Determine sample size based on the confidence level and the desired accuracy.
3. Perform random sampling, as scheduled, providing values for $p$.
4. Create control charts ($p$-charts) based on observed samples.
5. If the control chart indicates a system under control, keep sampling. If an out of control condition is detected, the system could be approaching a hazardous situation. Investigate and take corrective action.
6. After preventive steps are taken, develop dendritics and recalculate the control limits for the control chart. Repeat steps 2 through 6 as appropriate.

3. RESULTS

For this case study a confidence level of 90% was used. Preliminary work sampling indicated that 891 samples were needed for this degree of confidence. As one visit to the health care facility resulted in 8 observations, 112 visits to the facility were made.

![Control Chart](image)

Figure 3. Control chart of dendritics of VDT operators in a health care facility. Note: UCL—Upper control limit, LCL—Lower control limit, $\bar{p}$—Average weighted proportion of non-conforming observations.
required. The schedule of the visits was randomly generated. At 3 visits per day, the sampling study was performed over 40 days. The sampling was performed in an unbiased and random manner. The control chart in Figure 3 was generated from the data collected from the sampling study.

The values of $p$ for each day, plotted on the control chart, show the following traits:

1. There are periodic runs of points above and below the mean line.
2. There is a perceptible trend of points, moving in the upward direction.

These traits constitute unnatural patterns of points and indicate assignable cause or causes operating on the process. Therefore, there is a reason to suspect that the system may be becoming hazardous with respect to Carpal Tunnel Syndrome (CTS), whose dendritics were sampled for presence or absence.

A Runs Up and Down Test was performed on these patterns. These patterns demonstrated that the data collected lacked the independence property, thus indicating the presence of assignable causes acting on the system. The presence of these causes indicates the existence of a potentially hazardous condition.

The total number of observations where dendritics were observed was 209. The total number of observations where no dendritics were observed was 683. This generated a percentage of dendritics to total observations of 23.4%. A summary of the sampling data is segregated by specific dendritic type and is presented in Table 3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Dendritic Element</th>
<th>Occurrences</th>
<th>Occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Pinching of the wrists by supporting them at a sharp edge</td>
<td>76</td>
<td>36.36</td>
</tr>
<tr>
<td>II</td>
<td>The extension position of the wrists</td>
<td>18</td>
<td>8.62</td>
</tr>
<tr>
<td>III</td>
<td>The flexion position of the wrists</td>
<td>34</td>
<td>16.27</td>
</tr>
<tr>
<td>IV</td>
<td>The radial deviation of the wrists</td>
<td>31</td>
<td>14.83</td>
</tr>
<tr>
<td>V</td>
<td>The ulnar deviation of the wrists</td>
<td>50</td>
<td>23.92</td>
</tr>
</tbody>
</table>

In the preceding section, the results from CSSM implementation indicated that there are reasons to suspect that the system may be becoming hazardous with respect to CTD. Thus, to take preventive steps, it is pertinent to identify the dendritics that occur most often. This information is provided in Table 3, identifying the dendritic element I (pinching of wrists by supporting them at a sharp edge) as the most frequently occurring dendritic. Once steps are taken to reasonably control the occurrence of dendritic I, the occurrence of the next dendritic, namely, V, should be considered for control.

The results generated by CSSM for the subject health care facility are validated by the historical records for 1995. The Log and Summary of Occupational Injuries and Illnesses for this health care facility for 1995 indicates two cases of Repetitive Trauma, which were specified as CTS in the summary provided by the department.
To ensure that an unbiased study was performed, it was confirmed with management that there were absolutely no modifications made to the office workplace from the time these injuries were recorded to the time CSSM was implemented.

4. DISCUSSION AND CONCLUSIONS

The existing accident prevention methodologies are either reactive in nature, that is, they come into picture once an accident has occurred, or proactive in nature, by attempting to prevent a recognized hazard from becoming an accident. Continuous Safety Sampling Methodology is a proactive approach to accident prevention, which controls, to a desired level, the occurrence of conditions that lead to a hazard or hazards. These conditions are called dendritics for a given class of hazards. CSSM combines the underlying principles of two specific areas of knowledge, namely, work sampling and control charts. The work sampling theory is utilized to develop a sampling plan for CSSM. The attribute sampled in the case of CSSM is the set of dendritics that are developed by a preliminary hazard analysis of a given system. Further, the control chart theory is used to treat the data collected by the sampling study for the control of dendritic occurrence within certain desired levels. This control of dendritics is achieved by plotting the proportion occurrence of dendritics, on a daily basis, within the predefined control limits. The pattern of the control charts and the location of points with respect to the control limits assist in identifying the tendency of the system.

In order to facilitate the understanding of the salient features of CSSM and for the purpose of proof of principle, the scheduling department of a health care facility was chosen to describe the implementation of CSSM. The focus was on the hazard relating to cumulative trauma disorders, namely, Carpal Tunnel Syndrome, among VDT operators in this department. The control chart generated, based on the sampling data collected over a period of two months, exhibited an out of control pattern, which means that there are reasons to suspect that the system may be becoming hazardous with respect to CTS. These conclusions were verified by the historical records of injury and illness for the given system for 1995. This demonstrated the validity for Continuous Safety Sampling Methodology.

The implementation of CSSM in the scheduling department of the health care facility provided the following conclusions:

1. The value of $p$, the proportion dendritic observed, changed very little compared to the initial estimate of the study. There were no points that fell outside the control limits during the course of CSSM sampling.

2. The control chart generated by plotting the daily values for $p$ showed runs of points both below and above the mean line, and an upward trend, indicating out of control patterns. Such patterns indicate assignable causes acting on the system, leading to the conclusion that there is reason to suspect that the system may be becoming hazardous with respect to CTS.

3. After identifying that assignable causes exist in the control charting effort, certain Total Quality Management (TQM) tools can be used to evolve a proactive
approach. One such tool is Quality Function Deployment, a methodology used to ensure that the customer's (VDT operator's) requirements are met throughout the product (VDT station) design process and in the design of the operation of the system. Another TQM tool is concurrent engineering, which emphasizes simultaneous contributions from all major functional disciplines to arrive at optimal solutions to various problems.

4. CSSM is a generic tool, with applicability to any industry, either of manufacturing or service orientation.

5. CSSM has the advantage of substantial cost reductions through its ability to statistically predict the tendency of a given system for the occurrence of particular hazards.

4.1. Implementation Concerns

Implementation concerns with CSSM are related to the development of dendritics and performing the sampling study. The problems are described in the following points:

1. The effectiveness of CSSM depends greatly on the development of dendritics. Not all the dendritics for a given class of hazards may be known. CSSM would require an experienced person to carry out the preliminary hazard analysis of the system.
2. A faulty sampling study may result in a wrong interpretation of the tendency of the system. The operators may work in an affected manner when the random observation is being taken. The sampling results thus obtained may not reflect the true tendency of the system.
3. CSSM may not be economical to implement in a system with a single operator or machine, or in a system with operators or machines located over large areas.

4.2. Recommendations for Further Study

Recommendations for areas of future research are:

1. Use of CSSM to develop a threshold limit for job rotation and job enlargement for systems prone to cumulative trauma disorder.
2. Modify CSSM to predict the occurrence of a safety hazard that has a very low probability of occurrence. This may be achieved by considering the Poisson approximation of the binomial distributions used in CSSM.
3. To derive an empirical relationship between the data collected through the implementation of CSSM and the productivity index. This would provide a tool for the management to measure the effectiveness of CSSM in terms of productivity indices.
4. To perform a statistical analysis (such as hypothesis testing) by implementing the CSSM in a sufficiently large number of facilities belonging to the same or similar industry, so as to provide statistical validation of CSSM.
REFERENCES


