Impact of MAINTENANCE FUNCTION on Plant Safety

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This study was conducted to determine whether a correlation exists between maintenance audit score and injury frequency. A maintenance audit was conducted at 28 manufacturing plants located in Alabama (although analysis is based only on the data from the 25 plants that provided complete results). Data from each plant's OSHA 200 log were also collected. The Spearman rank correlation analysis was conducted for individual components as well as the aggregate relationship between maintenance score and plant injury indices. The study showed an inverse relationship of moderate strength between injury frequency index and maintenance audit score (rho=-0.336). This finding supports the hypothesis that better maintenance (as represented by higher audit score) is associated with lower injury frequency. However, due to the limitations of this study, a more-extensive and precise examination of verifiable maintenance activities and injury circumstances is needed. Ultimately, development and use of a high-quality instrument for evaluating maintenance function will help employers improve plant maintenance and enhance safety in the workplace.

Some three decades after passage of the OSH Act of 1970, occupational injuries remain at a high level. In 1996, an estimated 3.9 million disabling injuries and 4,800 deaths occurred, with an estimated cost of $121 billion (NSC 48, 49, 51).

Efforts to reduce injury in the workplace have historically focused on production operations. However, due to increasing automation, the impact of maintenance activities on plant safety may also be of concern. Automation has introduced complex, costly machinery to the work environment, while decreasing the role of production workers. For example, through machine coupling, a production department can assign multiple production machines (such as lathes and screw machines) to a single operator.

However, as machines become more complex, the need for more-skilled maintenance workers grows. New machines are capital-intensive; therefore, the cost of machine downtime is high. As a result, ensuring the quality of maintenance has become a major component of the plant safety program.

Maintenance work may significantly increase the likelihood of work injuries across many industries, including manufacturing (BLS *Bulletin 2115*; Sorock, et al 439+). In 1989, OSHA promulgated the Lockout/Tagout Standard. The agency estimated that its implementation would prevent 122 fatalities, 2,840 lost-workday injuries and 31,900 non-lost-workday injuries per year due to accidents involving equipment maintenance or repair (*Federal Register* 36644).

To support these estimates, OSHA cited a Bureau of Labor Statistics survey of 883 workers injured while cleaning, unjamming or performing other non-operating tasks on machines, equipment or electrical systems. According to this study, 74 percent of the accidents occurred in manufacturing industries; moving machine parts were the cause of 88 percent of injuries. The occupational distribution of injured workers were operators, 45 percent; craft and kindred workers, 24 percent; and mechanics and repairers, 10 percent (*Federal Register* 36648).

OSHA also reviewed 83 fatality investigations conducted between 1974 and 1980. Of these deaths, 25 percent were attributed to lack of adherence to safe work procedures, and 60 percent were caused by failure to properly de-energize machines or equipment before performing maintenance (*Federal Register* 36649). Agitators, mixers, rolls and rollers, conveyors, augers, saws and hoists were involved in 63 percent of the fatalities (*Federal Register* 33650).

Unpublished empirical evidence from an automotive component plant in Alabama showed that maintenance workers

TABLE 1 Plant Characteristics

PLANT NO.	SIC CODE	INDUSTRY TYPE	TOTAL NO. OF WORKERS	IFR/100 WORKERS	LWDCI	AUDIT RATING	BLS IFR
1	3523	Farm Machinery Mfg.	82	15.2	4.9	183	11.8
4	2015	Poultry Processing	126	4.8	2.8	127	11.5
5	3084	Plastics-Fabrication	112	9.8	5.4	157	10.2
7	3321	Ferrous Foundry	86	5.7	0.0	88	23.5
8	3721	Gear Mfg.	58	36.6	9.9	173	5.4
9	3441	Sheet Metal Fabrication	125	3.5	0.0	92	16.3
11	3339	Smelting of Metals	66	20.4	8.0	193	N/A
14	2511	Wood Furniture	52	24.0	13.4	117	9.7
15	3564	Industrial Fans	72	21.5	21.5	131	10.7
16	3321	Iron Foundries	390	10.8	6.7	155	23.5
17	3634	Electric Housewares	28	25.0	0.0	119	9.2
18	3324	Steel Foundries	45	70.0	42.2	115	11.0
19	3523	Farm Machinery	126	12.0	2.4	234	11.8
20	3599	Industrial Machinery	11	60.0	45.0	173	10.0
22	3844	X-Ray Apparatus	20	5.0	2.5	141	3.0
24	3469	Metal Stampings	72	10.4	2.1	52	15.5
25	2679	Converted Paper	45	10.0	6.7	113	9.8
26	3089	Plastics Products	57	11.6	1.8	95	12.0
27	3442	Metal Doors, Frames	127	23.6	9.9	199	13.5
28	3443	Fabricated Plate Work	42	23.8	8.3	117	14.0
29	3429	Hardware	131	20.6	14.9	154	10.0
31	3086	Plastics Foam Products	127	5.1	2.0	212	12.4
32	312	Steel Works	147	45.9	6.1	41	12.2
33	2431	Millwork	68	30.9	18.4	150	13.2
37	3559	Special Machinery	227	23.5	17.0	183	9.0

TABLE 2 Program Components

MAINTENANCE COMPONENT	NO. OF CHECK ITEMS
A. Systems and Procedures	6
B. Maintenance Information Systems	5
C. Initiation and Authorization of Work	4
D. Maintenance Operation	8
E. Planning, Scheduling and Follow-Up	5
F. Procurement & Storage of Parts	6
G. Budgeting , Backlog, Maintenance Ratios	5
H. Maintainability	4
I. Training, Hiring & Employment	4
J. Safety	3
Total No. of Check Items	50

suffered 14 percent of injuries in the plant. When the number of maintenance workers was compared to the number of production operators, it was discovered that maintenance workers were involved in a disproportionately high number of accidents (Batson, et al 7). In a study conducted in New Jersey, the number of maintenance mechanics involved in finger amputations that required hospitalization was also disproportionately high (Sorock, et al 439+).

The nature of maintenance work exposes those who perform it to greater hazards. In most cases, machine guards and other safety devices must be removed to properly execute the tasks; yet, if procedures are not followed, machines may not be in zero energy state or locked/tagged out. Work in confined spaces can also pose significant hazards to maintenance workers (Asfahl 236). These facts justify the statement, "Safety training to maintenance [personnel] has to go well beyond the training given other workers" (Levitt).

The approach of autonomous maintenance by production operators, as a part of the total productive maintenance (TPM), relies on operators to perform routine maintenance (Levitt). This practice increases the possibility of maintenance-related accidents, however, because production operators are less-skilled in maintenance activities. Furthermore, operators may injure their hands when working with malfunctioning equipment that has not been adequately maintained (Hertz and Emmett 28, 36, 41).

In many cases, no safety standards are in place to cover maintenance work nor is any priority assigned to this work. In many small and mid-sized plants, maintenance work orders are executed only when time permits. Traditionally, the mission of maintenance has been to support the production effort. This was achieved by focusing on machines and production systems. Businesses now focus on the entire production process—and on people as well as hardware.

To date, few published studies have assessed the impact of maintenance on plant safety. The reasons for this may be lack of management priority, lack of sophisticated analytical tools and non-availability of knowledgeable researchers. In addition, no standard tool exists to assess the quality of maintenance practices in a plant.

Levitt suggested an approach to evaluate the quality of a plant maintenance program. He grouped check questions that may be useful in evaluating the quality of maintenance activities into 10 categories. This study attempted to determine the relative importance of those 10 maintenance components. A correlational analysis between maintenance audit score and the injury frequency, and lost-workday case incidents (LWDCI) of all production and maintenance workers was also performed.

STUDY METHOD

Plant Characteristics

The plants selected were small to mid-size manufacturing facilities. Within the manufacturing classification, the plants known to the Safe State Agency of Alabama were approached and asked to participate (voluntarily).

As noted, of the 28 plants that participated, three were excluded due to incomplete or inaccurate data recording. The total number of workers at each facility ranged from 10 to 390, with an average of 100 workers per plant. Maintenance workers composed about six percent of the total number of workers.

Although the plants audited were in the manufacturing industry, they covered a broad range of operations (SIC range 2015 to 3844).

- Five belonged to major SIC group 35 and included industrial and commercial machinery and computer equipment manufacturing plants.
- Five belonged to major SIC group 34 and included fabricated metal products except machinery and transportation equipment manufacturing plants.
- Four belonged to major SIC group 33 and included primary metal industries.
- Three belonged to major SIC group 30 and included rubber and miscellaneous plastic products.
- The remaining eight plants represented diverse groups of industries.

Plant characteristics were primarily descriptive in nature about: 1) type of industry; 2) number of workers; 3) injury frequency rate (IFR); 4) lost-workday case incidents (LWDCI); 5) maintenance audit scores; and 6) Bureau of Labor Statistics (BLS) data on national injury frequency rate. Injury frequency rates for each plant were compared to published national rates (BLS *Report 913*). According to the results, 16 of 24 plants had a higher-than-average injury frequency rate compared to national averages; one plant had no published national rate available for comparison. Table 1 provides a summary of these characteristics.

Measures of Maintenance Function

Table 2 lists the 10 components of maintenance function, as well as the number of check items for each component. Each item received an audit score ranging from 1 (strongly disagree) to 5 (strongly agree); a score of 0 (not applicable) is also possible. Each questionnaire listed these factors and a total of 50 questions.

Six safety consultants affiliated with the University of Alabama and experienced in industrial safety practices conducted the audits. (These consultants were familiar with plants involved, as they provide inspection service to them on a regular basis). To collect data, the consultants observed maintenance activities and interviewed plant supervisory personnel. They used the maintenance checklist to determine a score in each plant. The auditors also collected OSHA 200 log injury information and recorded it on an appropriate evaluation form.

As noted, a score of 5 indicates strong agreement, while a score of 1 indicates minimal agreement; a response of 0 indicates that the statement is not applicable to a specific process. A maximum possible score of 250 (5 x 50) indicates a perfect program. Audit scores were calculated as a summary of all scores for each component of maintenance; therefore, no adjustment was needed for "not applicable" responses.

Measures of Injury Outcome

The basis of computing the injury indexes generally followed OSHA practice of using the injury record in the OSHA 200 log. This basis is accepted in industry as a standard procedure; most U.S. industries are required to enter all recordable injuries and illnesses on this form on an annual basis.

The two indexes used for assessing injury frequency rate (IFR) and lost workday incidence (LWDCI) are given below:

Injury Frequency Rate:

$$IFR = \frac{\text{No. of all recordable cases}}{\text{No. of workers}} \times 100$$

cases/100 workers/year

Lost Workday Incidence Case Rate:

$$LWDCI = \frac{\text{Lost workday cases}}{\text{No. of workers}} \times 100$$

cases/100 workers/year

This study covered injury cases in 1997 and 1998 and calculated an average for the two years. The computation procedure assumed that each worker completed each work-year and could be injured more than once during the study time period. Injury data included all recordable injuries involving all plant workers—both production and maintenance.

The numerators of rates was restricted to OSHA recordables, which means onsite injuries only, most of which could be related to maintenance functions (for example, falls could be related to housekeeping, forklift crashes to poor maintenance).

The denominator of rates was the full-time equivalent (FTE) number of workers. While workhours is a more-accurate basis for computing injury and severity indexes, some facilities did not maintain accurate workhour data. These plants record OSHA data using FTE workers (e.g., two workers, 0.5 day each=1 FTE worker, 1 FTE= 2,000 workhours). This alternate recordkeeping procedure is approved by OSHA (March 1998). To be consistent, this procedure was used to compute audit score indexes for all participating plants.

STATISTICAL ANALYSIS

Correlation Analysis of Plant Maintenance & Safety

Since the sample size was less than 30 and the nature of distribution was unknown, the researchers conducted the Spearman rank order non-parametric test for the direction of expected results—that a higher maintenance audit score is associated with lower accident/injury rates. Analysis was conducted to reveal the relative effect of each maintenance component audited on IFR and LWDCI. The goal was to determine the relative importance of each component on plant safety.

FIGURE 1 Audit Scores - SIC 35

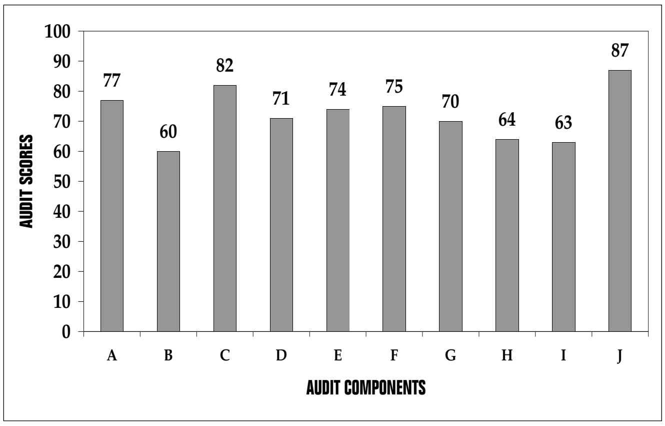


FIGURE 2 Audit Scores - SIC 34

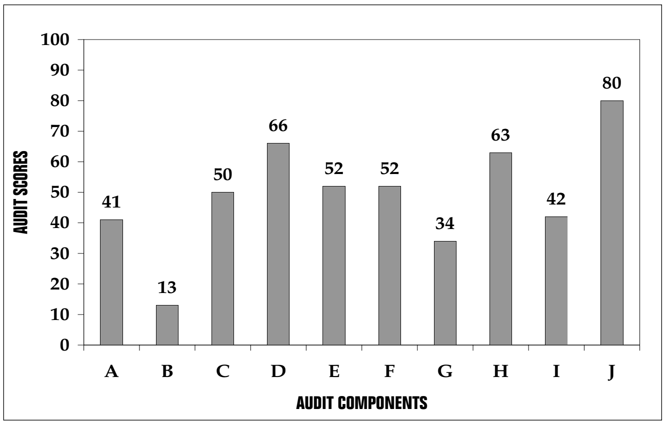
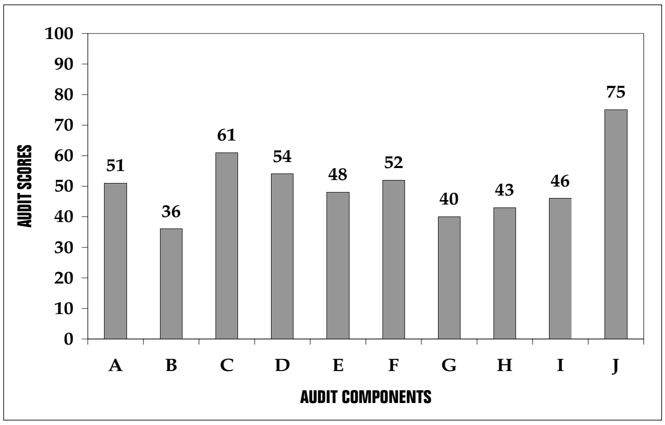


FIGURE 3 Audit Scores - SIC 33



RESULTS

IFR varied from 1.52 to 70 cases/100 workers/year, while LWDCI ranged from 0.00 to 45 cases/100 workers/year. The audit rating varied from 41 to 212; the low score reflected a poor score in all components at a particular steel plant (plant no. 32). A plastic foam product plant secured the highest score; it was a modern plant with planned maintenance activities.

The major SIC group 35 presented high maintenance scores in most areas except in 1) maintenance information system; 2) maintainability; and 3) training, hiring and employment components (Figure 1).

The major SIC group 34 had an average maintenance score, but scores were particularly low in 1) maintenance information system; 2) budgeting, backlog and maintenance ratios; and 3) training, hiring and employment areas (Figure 2).

SIC group 33 had a slightly lower-than-average score in most components, with particularly low scores in 1) maintenance information system; 2) budgeting, backlog and maintenance ratios; and 3) training, hiring and employment areas (Figure 3).

As these findings show, all three groups revealed a general inadequacy in maintenance information system, and training, hiring and employment functions.

According to these results, training and providing skilled manpower is most-highly correlated to plant safety.

TABLE 3 Maintenance Score vs. Safety

INDEXES	SPEARMAN CORRELATION COEFFICIENTS	P-VALUE	REMARKS
Injury Frequency Index	-0.336	0.100	Moderate inverse relation.
LWDCI Index	-0.117	0.578	Slight inverse relation.

TABLE 4 Component Analysis

	MAINTENANCE AUDIT COMPONENTS	SPEARMAN CORRELATION COEFFICIENTS (IFR)	(LWDCI)
A	Systems Procedures	-0.186	-0.033
B	Maintenance Information System	-0.220	-0.193
C	Initiation and Authorization of Work	-0.284	-0.149
D	Maintenance Operation	-0.125	0.094
E	Planning, Scheduling and Follow-Up	-0.275	0.022
F	Procurement and Storage of Parts	-0.209	0.061
G	Budgeting, Backlog and Maintenance Ratios	-0.128	-0.024
H	Maintainability	-0.365	-0.106
I	Training, Hiring and Employment	-0.541	-0.270
J	Safety	-0.063	0.127

Lost Workday Case Incidence

Spearman correlational analysis of the effect of maintenance components on LWDCI per 100 workers revealed an inverse correlation with training, hiring and employment; maintenance information system; and initiation and authorization of work. Again, training and availability of skilled workers were key factors. The other two components involved planning and implementation of maintenance activities.

Impact of Maintenance on Plant Safety

Both IFR and LWDCI revealed inverse correlation with the maintenance audit score (Table 3). These findings support the research assumption that plants with a higher maintenance audit score will have lower IFR. A larger sample collected over a longer period is needed to reveal any relation of maintenance and severity index.

Injury Frequency Rate

As Table 4 shows, all 10 components have a negative correlation (higher audit maintenance scores associated with lower LWDCI rates). According to these results, training and providing skilled manpower is most-highly correlated to plant safety. This may be relevant in this era of rapid change, which requires continuous updating of skills. The remaining three components represent planning, organizing and follow-up activities.

STUDY LIMITATIONS

1) Sample size was based on the availability of plants that agreed to participate in the study. The sample also consisted of data from non-homogeneous plants. In addition, data was complete for only 25 plants. A much-larger sample is required to reveal any pattern for this type of study.

2) Injury data were for 1997 and 1998, while the maintenance audit was conducted in early 1999. The effect of any change in the quality of maintenance between those times is not reflected in the injury data and may have affected analysis.

3) Several consultants collected data, but inter-observer reliability could not be tested. Thus, the differences in judgment may have had some effect. However, the consultants were experienced professionals skilled at performing objective evaluations.

4) This was a pilot study only. It could be useful, however, for planning a hypothesis testing study that uses power and sample size estimation software.

5) An industry-specific maintenance checklist (e.g., machinery manufacturing) would minimize the problem of non-applicable scores for individual plants and lead to more homogeneous questionnaires and more useful results.

CONCLUSIONS

The critical value of rho for α=.05 (one tailed test) and sample size of 25 is $\pm$0.336. The result in Table 4 indicated significant negative correlation between training, hiring and employment and maintainability for IFR. This pilot study did not reveal significant correlation of the other questionnaire components, but indicated a negative correlation between most maintenance components and injury rates.

As noted, a more-extensive study should be conducted to verify this observation and to explore the relationship between injury severity and maintenance. Extended study is also required to verify the effectiveness of the maintenance evaluation instrument. Once developed, a refined and externally verified maintenance instrument may help industry improve maintenance and overall safety. ■

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