

Evaluation of implementation an Integrated Safety and Preventive Maintenance System for Improving of Safety Indexes

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ABSTRACT

Accident analysis shows that one of the main reasons for accidents is non-integration of maintenance units with safety. Merging these two processes through an integrated system can reduce and or eliminate accidents, diseases, and environmental pollution. These issues lead to improvement in organizational performance, as well. The aim of this study is to design and establish an integrated system for obtaining the aforementioned goal. Integration was carried out at Nirou Moharreke Machine Tools Company via Structured System Analysis & Design Method (SSADM). In order to measure the effectiveness of the system, selected indexes were compared using statistical methods prior and after system establishment. Results show that the accident severity index reduced from 135.46 in 2010, to 43.85 in 2012. Moreover, system effectiveness improved equipment reliability and availability (e.g. reliability of the Pfeiffer Milling machine ($P(t > 50)$) increased from 0.89 in 2010, to 0.9 in 2012. This system by forecasting various failures, and planning and designing the required operations for preventing occurrence of these failures, plays an important role in improving safety conditions of equipment, and increasing organizational performance, and is capable of presenting an excellent accident prevention program.

Key words: Safety, Preventive Maintenance, Integrated system, Structured System Analysis and Design Method (SSADM)

INTRODUCTION

One of the unpleasant consequences of industrialization is a rise in the number of job accidents. This high number of accidents has become a major concern for both developing and developed countries, as the World Health Organization considers them as an epidemic phenomenon in the general health field. Obviously accidents are costly for both societies and industries, therefore should be prevented as much as possible.

A brief literature review indicates that there is a close relationship between maintenance and occurrence of major accident. This leads to development of a new tendency toward considering the risk as a planning criterion for maintenance measures. Using a hybrid approach of the maintenance and safety, some authors proposed a suitable meaning for optimization of the factories' potentials. They believe that safety and maintenance are not strictly interactive functions and factors. Table 1 indicates a literature review in this field of study [3].

Table 1: literature review of the safety and Maintenance field of study

Author	Literature review	Year
Kelly <i>et al.</i>	Investigate the systematic approach of the safety in maintenance; the paper evaluates safety aspects in maintenance in Defense Ministry of the UK [4]	2001
Farrington <i>et al.</i>	Investigate safety culture in maintenance of railroad; in this paper the problems of the insecure behavior and effect of safety in maintenance of the railroad is discussed [5]	2005
Eti <i>et al.</i>	Discuss the reliable integration and availability of the equipment; they performed risk assessment in the maintenance unit. The results was an improvement in activities of the AFAM fossil fuel Plant in Britain [6]	2006
Herrera <i>et al.</i>	Study safety of airline transportation and maintenance based on the main organization changes; this paper investigates the effects of simultaneous organization changes on management system of the safety and maintenance in airline study of Norway [7].	2009
Oingfent <i>et al.</i>	Consider development and application of the maintenance of the equipment and its integration with management system; the paper simultaneously studies the attitude change in the maintenance and safety and reliability of the equipment from the traditional to the modern approach in China's industry [8].	2011
Atak <i>et al.</i>	Study safety culture in Airplane Maintenance Organization; this is a case study on safety culture in maintenance unit of the planes which is conducted based on document analysis [9].	2011

Qingfeng *et al.* (2011) indicates that lack of appropriate planning in maintenance and fix process are among the most important causes of accidents, that can lead to occurrence of an unpredicted failure in the equipment and consequently irreversible accidents and costs for both the firm and beneficiaries; where this cost is independent from the economic costs imposed to the firms due to stopping the production [8].

In this regard, some petrochemical industries have successfully reduced their costs down to 50 % through applying some programs for simultaneous improvement of the safety and accessibility to the equipment [10]. Thus, integration of these two processes with a whole system can lower the likelihood of accident occurrences, illnesses, and environmental pollutions. Consequently, these factors lead to an improvement in organization performance [8, 11]. The purpose of this study is to design and establish an Integrated Safety and Preventive Maintenance System for Improving Safety Indexes at the Nirou Moharreke Machine Tools Company.

MATERIAL AND METHODS

The present study is local, descriptive, retrospective work conducted to investigate and compare indexes of safety and maintenance both prior to and after implementation of the integrated safety, maintenance system and evaluation of the partial effect of the system. The required data were gathered by means of observation and interviews. The archived documents of the firm were studied, as well. The gathered data were analyzed using

SPSS software package. Besides, different parts of the firm, such as registration and archive units, were considered as the research environment. This study was conducted in the following 7 steps:

First, after being familiar with the system and accurate detection of its elements, a number of safety and maintenance indexes were determined, measured, and analyzed to clarify the partial effect of system implementation by these indexes. There are a large number of methods for determination of the partial effect of the safety programs, each of them had a specific value in the specific occasions. Regarding the limitations of the studied firm in this work, a set of safety and maintenance indexes were selected to determine efficacy of the model. The safety indexes of this study are accident frequency rate (AFR), accident severity rate (ASR), and incident rate (IR); chosen through study of the scientific contexts. Besides, owing to the fact that reliability and safety are measured using a set of predefined parameters such as reliability, availability, mean time to failure, etc., in this work 12 statistical indexes were applied to determine simultaneous efficacy of the system on safety and maintenance unit. The indexes are as follows: rate of failure, reliability, unreliability, availability, unavailability, failure probability, mean time to failure (MTTF), mean time to repair (MTTR), mean time between failures (MTBF), mean time to fail safely (MTTFS), mean time to fail dangerously (MTTFD) and number of dangerous failures. Steps 2 to 6 are allocated to integration, analysis, and design of the system based on structured system analysis design method (SSADM). Figure 1 presents flow diagram of these steps.

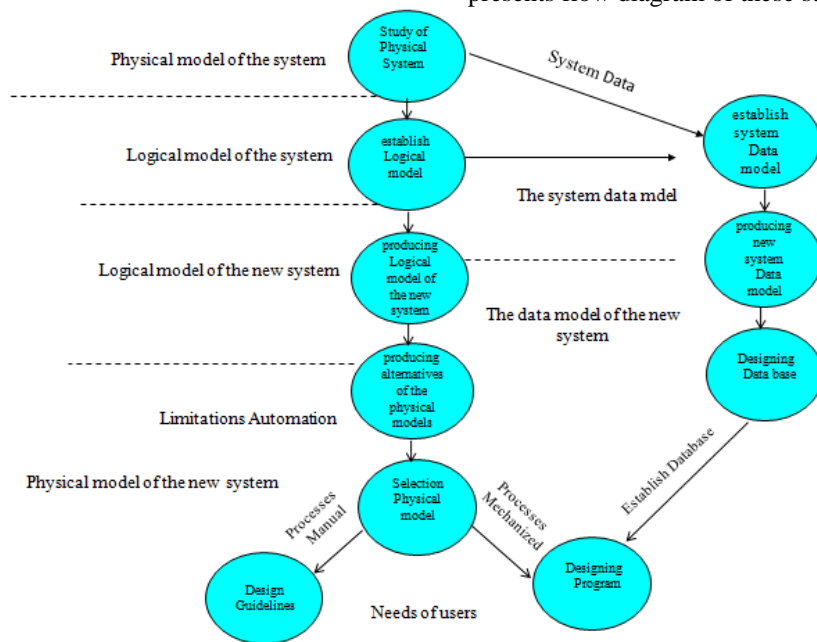


Fig. 1: Flow diagram of the study

SSADM was developed in the late 1970's by three researchers: Demarco, Gane, and Sarsson. This method is a member of the developed information system methods family which is applied as the most important analysis and design method for information systems in England. Similar to many other structured system methods, this method implements an information system in the form of an engineering project, so it can be considered as a data-oriented methodology. Here, the logical structure of the system data and their internal relationships are modeled. For completed logic design of the data, SSADM applies two techniques, i.e., "logic data organization" and "relational data analysis", and then combine their results. Logic data organization is a top-down approach where the smallest information component is accurately analyzed to generate a complete and flexible data organization [12-16].

In this research SSADM was applied for assigning a completely clear objective and domain at each step for achieving the desired output. The expected output in this methodology involves the programs and databases which are applied for system implementation. In the second step, as the first step of this methodology, the inputs and outputs of the safety and maintenance system was detected through evaluation of the system elements, study of the documents, interviews with the experts, and system history analysis. Then, to determine the relationship type between safety and maintenance system, physical data flow diagram (what does the system? How the tasks are performed? Who and when perform the tasks?) of the safety and maintenance was plotted. In the third step, as the second step of this methodology, the physical data diagram of the present system was converted to the logic data diagram (what does the system?) to analyze status of the physical data flow diagram (DFD) of the safety and maintenance process and evaluate the soundness or wrongness of the performance in the system. In step 4, as the third step of this methodology, in order to design a new system, the analyzed logic data flow diagram was converted to the new logic data flow diagram of the system (what systems is allowed to do (do's and not do's). To do so, it is required to add the new relationships and processes to the logic data flow diagram of the present system or remove their unnecessary relationships and processes. In step 5, as the fourth step of this methodology, physical data flow diagram of the new system was plotted based on the new logic data flow diagram. In this step the considered firm was chosen based on the defined requirements in a gradual manner and were converted to physical requirements. In other words, the logic DFD of the new system was converted to the desired physical DFD; i.e., they were modeled based on logic diagrams (the ones required by the new system), the physical models (how do satisfy

these requirements) were modeled. This was done for instant development of an integrated safety and maintenance system in the studied firm. The 6 step, as the fifth step of this methodology, was performed to determine the boundaries between human and machineries in the form of a system; i.e., new and conventional duties of each safety and maintenance units were defined. A database was created for the zones placed in machinery boundary and their data modeling was organized and documented. In this step, the system was completed and a proper guideline was defined through implementation program including conversion programming of the new system instead of the old one. The new system was implanted in the form of management information system (MIS) in "Nirou Moharreke Machine Tools Inc." and monitored for 6 months. Then, in step 7, as the sixth step of SSADM, after 6 months, the indexes mentioned in step 1 were measured again and their changes induced by the mentioned intervention were evaluated using the statistical Wilcoxon test. It should be noticed that the mentioned system was implemented for 6 months and after passing another 6 month period these indexes were monitored again.

RESULTS

The findings of this work include two parts. First, the findings about safety indexes are analyzed and in the second part, findings of the common indexes of the safety and maintenance are investigated.

Safety index findings before and after system implantation

Tables 2 and 3 show safety indexes before and after system implantation. As shown in the tables, in the year before system implantation 25 accidents have been occurred as AFR was 13.77, severity rate, 135.46, and incident rate, 238.10. In the years after system implantation these values are as: number of accidents (N.A): 13; AFR: 7.13; severity rate: 43.85; incident rate: 126.21. Statistical expression of these indexes is prepared using the Wilcoxon statistical test (table 4). The statistical analysis indicates that AFR, severity rate, and incident rate have $p\text{-value} \leq 0.05$; hence, it can be inferred that system implementation significantly improved each of these safety indexes in the studied firm. On the other hand, the results of Wilcoxon test (table 4) imply that the changes of incident rate are not statistically significant ($p\text{-value} \geq 0.05$).

Findings of the common safety, maintenance indexes before and after system implantation

Another group of the findings are those of common safety, maintenance indexes, as shown in tables 4 and 5. It should be noted that these indexes were obtained based on failure log sheet of 9 important machines of the studied firm with specific working hours by failure distribution function. The results are shown in tables 5 and 6. The statistical

expressions of these indexes are introduced using the Wilcoxon test in table 7. The statistical analysis indicates that the indexes including failure rate, reliability, unreliability, availability, unavailability, failure probability mean time to failure, mean time to repair, mean time between failures, mean time to fail dangerously, and number of dangerous failures had p-value ≤ 0.05 . Therefore, through comparing

these indexes before and after system implementation it was observed that system implementation can improve these indexes. The results of statistical tests about one of the indexes indicated that p-value of the mean time to fail safely (MTTFS) is not statistically significant (p-value ≥ 0.05).

Table 2: Safety index findings before system implantation (2010)

Months Index	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Total
<i>N.A</i>	3	2	4	2	2	1	2	3	2	2	0	2	25
<i>AFR</i>	20.28	13.17	26.48	13.18	12.91	6.48	13.2	20.4	12.92	13.2	0	13.26	13.77
<i>days lost</i>	9	9	29	9	13	35	3	14	13	5	0	107	246
<i>ASR</i>	60.83	59.25	191.98	59.29	83.94	226.81	19.8	95.21	83.99	33	0	709.17	135.46
<i>IR</i>	28.57	19.05	38.1	19.05	19.05	9.52	19.05	28.57	19.05	19.05	0	19.05	238.1

Table 3: Safety index findings after system implantation (2012)

Months Index	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Total
<i>N.A</i>	1	0	0	4	2	1	0	1	2	0	1	1	13
<i>AFR</i>	6.7	0	0	26.06	13.25	6.5	0	6.51	12.95	0	6.49	6.63	7.13
<i>days lost</i>	7	0	0	38	4	3	0	6	14	0	3	5	80
<i>ASR</i>	46.89	0	0	247.55	26.5	19.5	0	39.04	90.62	0	19.47	33.15	43.85
<i>IR</i>	9.71	0	0	38.83	19.42	9.71	0	9.71	19.42	0	9.71	9.71	126.21

Table 4: Results of the Wilcoxon test for *Safety* indexes

Index	FR- FR	SR- SR	IR – IR
Z	-2.095	-2.040	-1.337
p-value	.036	.041	.181

(AFR)compared before and after system implantation

FR- FR

(ASR)compared before and after system implantation

SR- SR

(IR)compared before and after system implantation

IR — IR

Table 5: Findings of the common safety, maintenance indexes before system implantation (2010)

Equipment	CNC milling machine (Pfeiffer)	CNC center milling machine	Grinding machine	Universal milling machine	Hydrolic press machine	Guillotine machine	Press brake machine	Decoiling machine	CNC Punching machine
Failure Distribution Function	EXP($\beta=400$)	EXP($\beta=540$)	EXP($\beta=670$)	EXP($\beta=290$)	EXP($\beta=630$)	EXP($\beta=250$)	EXP($\beta=220$)	EXP($\beta=650$)	EXP($\beta=300$)
Rate of Failure	0.0025	0.0019	0.0015	0.0034	0.0016	0.004	0.0045	0.0015	0.0033
Reliability P($t > 50$)	0.88	0.91	0.93	0.84	0.92	0.82	0.8	0.93	0.85
Availability	0.995	0.989	0.9985	0.9831	0.9937	0.9921	0.991	0.9939	0.9804
Failure Probability P($50 \leq t \leq 100$)	0.1037	0.0806	0.0667	0.1333	0.0705	0.1484	0.162	0.0686	0.13
MTTF	400	540	670	290	630	250	220	650	300
MTTR	2	6	1	5	4	2	2	4	6
MTBF	402	546	671	295	634	252	222	654	306
MTTFD	1339.59	2597.83	1771.3	1550.83	1041.14	1290.24	1071.76	1121.02	1488.14
MTTFS	487.12	577.29	1062.78	357.88	1735.23	322.56	315.22	1401.28	343.42
No. of Dangerous Failures	4	2	3	3	5	4	5	5	3

Table 6: Findings of the common safety, maintenance indexes after system implantation (2012)

Equipment	CNC milling machine (Pfeiffer)	CNC center milling machine	Grinding machine	Universal milling machine	Hydrolic press machine	Guillotine machine	Press brake machine	Decoiling machine	CNC Punching machine
Failure Distribution Function	EXP($\beta=500$)	EXP($\beta=620$)	EXP($\beta=780$)	EXP($\beta=400$)	EXP($\beta=700$)	EXP($\beta=350$)	EXP($\beta=300$)	EXP($\beta=800$)	EXP($\beta=410$)
Rate of Failure	0.002	0.0016	0.0013	0.0025	0.0014	0.0029	0.0033	0.0013	0.0024
Reliability P($t > 50$)	0.9	0.92	0.94	0.88	0.93	0.87	0.85	0.94	0.89
Availability	0.996	0.992	0.999	0.99	0.996	0.994	0.993	0.996	0.988
Failure Probability P($50 \leq t \leq 100$)	0.086	0.071	0.058	0.104	0.064	0.115	0.13	0.057	0.102
MTTF	500	620	780	400	700	350	300	800	410
MTTR	2	5	1	4	3	2	2	3	5
MTBF	502	625	781	404	703	352	302	803	415
MTTFD	1712.88	5408.98	4715.6	2312.31	2691.39	2397.66	1607.14	1705.69	5338.92
MTTFS	734.09	676.12	943.12	513.85	1076.55	479.53	401.79	1279.27	410.69
No. of Dangerous Failures	3	1	1	2	2	2	3	3	1

Table 7: Results of the Wilcoxon test for common safety, maintenance indexes

Index	L-L	K-K	J—J	I-I	H-H	G-G	F-F	E-E	D-D	C-C	B-B	A-A
Z	-2.724	-0.533	-2.666	-2.67	-2.236	-2.68	-2.666	-2.666	-2.666	-2.666	-2.666	-2.666
p-value	0.006	0.594	0.008	0.008	0.025	0.007	0.008	0.008	0.008	0.008	0.008	0.008

MTTF compared before and after system implantation	G-G	Rate of failure compared before and after system implantation	A-A
MTTR compared before and after system implantation	H-H	reliability compared before and after system implantation	B-B
MTBF compared before and after system implantation	I-I	un reliability compared before and after system implantation	C-C
MTTFD compared before and after system implantation	J—J	availability compared before and after system implantation	D-D
MTTFS compared before and after system implantation	K-K	un availability compared before and after system implantation	E-E
number of dangerous failures compared before and after system implantation	L-L	failure probability compared before and after system implantation	F-F

DISCUSSION

According to tables 2 and 3, it can be observed that the safety indicators (accident frequency rate and accident severity rate) have significantly improved after system establishment. This can be due to the nature of the mentioned system. Since it is a safety management and maintenance system and its efficiency is a direct indicator of functional efficiency, appropriate design, establishment, and mechanization in the investigated company could enhance safety performance of the organization. In this regard, parameters and controlling equipment, which guarantee safety of devices, were installed and also were monitored in daily visits, showing their effectiveness for enhancing of safety indicators.

Another factor that causes reduction of safety factors in this system is existence of a written procedure for each phase of suspension stages. Suspension is not a routine operation and, at this phase, always there is a possibility of occurring safety-related problems [17]. As it was illustrated in tables 2 and 3, incident rate has improved after establishment of the system; however, this improvement has not been considered significant in statistical tests framework. This point does not question credibility of the system since other indicators have been statistically significant. It should be noted that this indicator studies changeability in labor force and its impact on other incidents. On the other hand, as it is observed in

tables 4 and 5, common indicators of safety and maintenance have significantly improved after establishment of the system. The probable reason could be that the new integrated system, due to their role in mechanical aging prevention of the, was clearly improved reliability. Since the mean time to failure and mean time to repair are indicators of reliability and availability, respectively, these indicators also improved. The failure time of parts is predicted in the new safety and maintenance system, and based upon it, these parts are formerly purchased and stored to reduce the time required to supply obsolescent elements and, as a result, improvement of mean time to repair, after system establishment. This system prevents accidental failure of equipment through prediction of device failure and preventive maintenance. Therefore, this feature improves the mean time between failures and indicator of mean time to failure. In other words, improvement of these indicators shows increment of the equipment lifetime, due to implementing safety and maintenance system and preventive maintenance. Findings suggest that the reduction of failure rate and reduction in failure time are because of proper maintenance techniques and setting boundaries for human and machine, and developing a procedure for automation, respectively. In fact, this system enhances availability by reducing failure rate and failure time.

In this system, based on the 20-80 law, the most important contributing factors in failures of devices and accidents were identified in the data center of the mentioned system and based on them modifying and preventive actions were developed in a way that 20% of the factors that caused 80% of the accidents were eliminated. This led to the significant improvement of all indicators of safety and maintenance except MTTFS. Although there was no improvement in this indicator, it should be mentioned that MTTFS is the probability of safe failure occurrence; hence, it cannot question the credibility of the system. The indicator with higher importance is MTTFD that was improved significantly. Moreover, it should be noted that integration of safety and maintenance has been performed in a number of researches. For example, Kelly *et al.* [4], in the British Ministry of Defense, Eti *et al.* [6], in Afam Thermal Plant of Britain, and Qingfeng *et al.* [8], in China industry have put forward considerable effort in this field. However, the distinguishing point of the current investigation is the method of combination of these two procedures that is performed by the efficient SSADM methodology, which is in accordance with System Development Life Cycle (SDLC). This has led to improvement of the indicators of both processes. Therefore, this survey is a novel work in the literature. Other studies have improved safety factors by similar techniques. Farshad *et al.* investigated efficiency of the management system of HSE in improvement of some safety factors. They showed that proper implementation of the HSE management system can improve safety indicators in oil companies and their sub-organizations [18]. In addition, Adl *et al.* investigated the role of safety control in improvement of the indicators. They claimed that safety control can be an affecting factor in hazard identification and accident prevention [19].

CONCLUSION

In the present study, findings of both methods have been employed to design an integrated safety system. Hence, systematic and planned control by HSE procedure was added to information flows between two units that lead to the success of this integrated system. In this regard, this system is of great importance in safety enhancement by predicting failures and designing required actions to prevent them. Furthermore, it can propose a complete plan for accident prevention.

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