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A KNOWLEDGE-BASED EXPERT SYSTEM FOR SILICATE GLASS PLANT MAINTENANCE

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ABSTRACT

A Knowledge-Based Expert System (KBES) which will aid diagnosis of plant faults within Silicate Glass Plant domain was developed. Knowledge was elicited using a combination of techniques (protocol-generation, teach and teach back, protocol analysis techniques) and root cause failure analysis was used to identify primary cause of fault as they were presented by the domain experts. The elicited knowledge were structured and coded in form of rules using C Language Integrated Production System 'CLIPS SHELL'. The KBES developed comprised a main system and four sub-systems with utility files. Performance evaluation was carried out on the KBES for consistency and exactness. Field tests were conducted and the data acquired were analyzed using some maintenance parameters. Results obtained when the KBES was used in the plant's faults diagnosis compared with when it was not used showed that with expert system in use, an average reduction in plant downtime of 36.62% was obtained for field test carried out. Also, 24.28% and 34.03% were obtained for average increase in Plant Availability and Total Plant Maintenance Productivity respectively.

Keywords: Silicate Glass Plant, Knowledge Based Expert System, Maintenance, CLIPS Shell

INTRODUCTION

Realizing the increasing needs by enterprises to cut-down on process flow time from initiation to finish has resulted in various techniques which eliminated unproductive time. An important element in any enterprise, either service or manufacturing, which could lead to unproductive time, is maintenance. Facility maintenance is important to ensure that facilities are kept in proper operational conditions, yet it takes away some productive time. In other to keep this unproductive time minimal, since it cannot be totally eliminated, there is need to keep the time lag between fault manifestation and corrective maintenance activities as minimum as possible.

Excessive downtime remains a problem for many organizations, particularly those using complex capital intensive manufacturing processes. To reduce this, many use computerized management systems to support various aspects of their maintenance activities including breakdown diagnosis (Davies and Greenough, 2005). Al-Taani (2005) affirmed that his expert system developed for car failure diagnosis indicated that a full expert system will be practical and can be extremely useful in providing consistent car failure detection. Peter's (2006) results showed that Expert System made diagnoses similar to those of the experienced mechanics for a given number of selected test cases. This demonstrated successful implementation of Expert System.

Expert System

An expert system is a system that employs human knowledge stored in a computer to solve problems that usually require human expertise. Well designed systems imitate the reasoning process of experts to solve specific problems. Such systems can be used by non experts to improve their problem solving capabilities (Adewunmi, 2008).

Adejuyigbe (2002) defined expert (knowledge-based) system as a category of artificial intelligence program that makes use of information gathered from previous projects and are created using a programming language or a shell. Expert Systems are computer programs tailored towards modeling the human experts' methods of reasoning about problems solutions. They are developed to solve problem similar to the way human experts will solve the particular problems. The modern expert systems are domain specific, they solve problem in a defined domain. This has made expert systems not being able to reason beyond their knowledge base.

The work of Newell and Simon (1972) showed that much of the human problem-solving (cognitive) could be expressed as IF-THEN production rules. The duo regarded knowledge as modular i.e. each rule corresponding to a small module of knowledge called "*chunk*" (Noran, 2005).

Plant Maintenance

Equipment maintenance within a manufacturing facility is a vital activity that has impacted installed capacity, runtime, and safety (Emerson, 2009).

Plant maintenance usually refers to the methods, strategies, and practices used to keep an industrial factory running efficiently (Strasser, 2012). Plant maintenance can include, but not limited to, regular checks of equipment to make sure they are functioning properly, cleaning garbage bins and toilets, and use of appropriate tools and materials. The general aim of plant maintenance is to create a productive working environment that is also safe for workers (Strasser, 2012). Excessive downtime remains a problem for many organizations, particularly those using complex capital intensive manufacturing processes. To counter this, many use computerized management systems to support various aspects of their maintenance activities including breakdown diagnosis (Davies and Greenough, 2005).

As a result of the persistently high down time duration for the plant (Silicate Glass Plant) belonging to factory X, a method (knowledge-based expert system) that will reduce plant down time was suggested, developed and evaluated. The expert system assists Silicate Glass Plant Maintenance personnel in diagnosing fault efficiently and in due time as it was developed using experiences of experts in the plant.

MATERIALS AND METHODS

The materials used for the purpose of this work are root-cause analysis sheets, personal computer (PC), machine maintenance history card and CLIPS Shell (C Language Integrated Production System).

Root-cause analysis sheets were used to structure the problems in other that the root cause of each fault was indentified. Consequently, it aided formulating the rules for the knowledge base of the expert system. The elicited knowledge was formulated into production rules using CLIPS Shell (C Language Production System). The CLIPS Shell runs in Windows environment installed on personal computer (PC).

Expert System Development

In developing the expert system, the following were steps taken:

a. Identification of the problem;
b. Problem investigation/analysis;
c. Solution Derivation;
d. Structuring and codification of problems & solution into rules (forming a knowledge base);
e. Validation and verification of developed expert system;
f. Evaluation of developed expert system;
g. Deployment of expert system; and
h. Consistent update and evaluation of knowledge base.

The problem identified in this case is that of high plant down time duration and the goal is to cut down on the plant down time duration resulting from sudden plant failures. For each of the faults covered, root cause analysis (RCA) was carried out which revealed the basic causes of failures. Experts who have been maintaining the plant were engaged in structured interviews for the process of carrying out the RCA and techniques used in the interview process are; protocol generation, teach-and-teach back and protocol analysis.

At the end of the elicitation process, the knowledge gathered was structured into production rules and coded using CLIPS (C Language Integrated Production System) Shell. Production rules are of the form as shown below:

IF A *THEN* B
IF A *and* B *THEN* C.

The *IF* part of the rule is called the **antecedence** while the *THEN* part is called the **consequence**.

A typical rule of such as developed is given in Figure 1 below. For the purpose of this work, three categories of rules were developed, namely, **F**aults **D**etection **R**ules (Figure 1), **S**ymptoms **Q**uestion **R**ules (Figure 2) and **S**ymptoms **C**heck **R**ules (Figure 3).

```
(defrule silicate-diss-faulty1
?hsw<-(silicate dissolving hoist stop working)
?lsps<-(limit switch position shifted)
?co<-(controller not operating)
?lsf<-(limit switch fail)
=>
(printout t"FAULT DETECTED: The adjusting screw is slack."crlf)
(printout t"RECOMMENDATION: Carry out regular check on adjusting screw i.e
every shift."crlf)
(continueK"Press 'K' from your keyboard to continue."))
```

Fig. 1 Fault Detection Rule in *Silicate Glass Dissolver* subsystem

```
(defrule sd-fault-1-quest
?sd1<-(symptom s1)
=>
(retract ?sd1)
(if(respond "Did the silicate dissolving hoist stop working(yes/no)?")
 then (assert(silicate dissolving hoist stop working)
          (symptom s2))
 else(assert(symptom s5))))
```

Figure 2. Symptoms Questions Rules in *Silicate Glass Dissolver* subsystem

```
(defrule checks-facs16
?c16<-(checks facs16)
(brake coil for silicate dissolving hoist burnt)
(plunger going fully into coil slot)
(not(moving arm stiff))
=>
(retract ?c16)
(printout t"FAULT DETECTED: You seem not to have a full knowledge of the symptoms of the uniden-
tified problem. Anyway, I think the likely problem is that the brake coil is drawing excessive cur-
rent."crlf)
(printout t"RECOMMENDATION: Service the entire brake unit, replace worn parts and check coil cur-
rent regularly."crlf)
(continueK"Press 'K' from your keyboard to continue."))
```

Figure 3. Check Rule in *Silicate Glass Dissolver* subsystem

Architecture of the Expert System (ES)

Silicate Glass Plant ES developed covers four sub-assemblies of the entire plant. To this end, the ES comprises the main system which can also be called the welcome page, combustion blower sub-system, silicate glass dissolver sub-system, slat conveyor sub-system and water jacket screw feeder sub-system.

There are four other utility files created, which enable any user to utilize the individual sub-system from the main system.

Verification and Validation of the Expert System

The expert system was verified by checking for internal inconsistencies in the expert system.

The validation was carried out in two phases. The first was laboratory validation which involved the use of test cases to measure the performance of the expert system in an environment different from the actual environment of application (artificial environment). The second was field validation which was carried out by the domain experts and the end users in the real environment for which the expert system was developed. The following are reasons for verification and validation of the expert system:

a. ensure that the expert system is able to provide consistent solution to same problem.
b. measure the level of reliability of the expert system.
c. ascertain its suitability to the end user.
d. detect misrepresented knowledge or conflicting knowledge.

Evaluation of the Expert System

The expert system was subjected to real life test by the end user and the time taken by a maintenance personnel (end user) performing plant faults diagnosis, to bringing the plant back to full operational condition using the expert system was recorded. The time recorded previously for same fault solution without the use of expert system was also obtained from existing factory's maintenance records. Both data were analyzed to obtain Down Time Index (DTI), Plant Availability (PA), Direct Maintenance Cost (DMC), Total Plant Maintenance Productivity (TPMP) and Total Maintenance Cost (TMC).

$$DTI=\frac{\text{Down time}}{\text{Planned Time}} \times 100 \quad \text{2.1}$$

$$PA=\frac{\text{Planned time} - \text{Down time}}{\text{Planned Time}} \times 100 \quad \text{2.2}$$

$$DMC=\text{Cost of Spare} + \text{Material Cost} + \text{Maintenance ManHour Cost} \quad \text{2.3}$$

$$TPMP=\frac{\text{Plant Output in the given Period}}{\text{Total Maintenance Cost in the given Period}} \quad \text{2.4}$$

$$TMC=\text{Direct Maintenance Cost} + \text{Cost Due to Production Loss} \quad \text{2.5}$$

RESULTS AND DISCUSSION

The welcome page of the developed expert system is given in Figure 4. The welcome page gives few introductory statements to the user(s). A continuation of the welcome page is the list of available sub-systems.

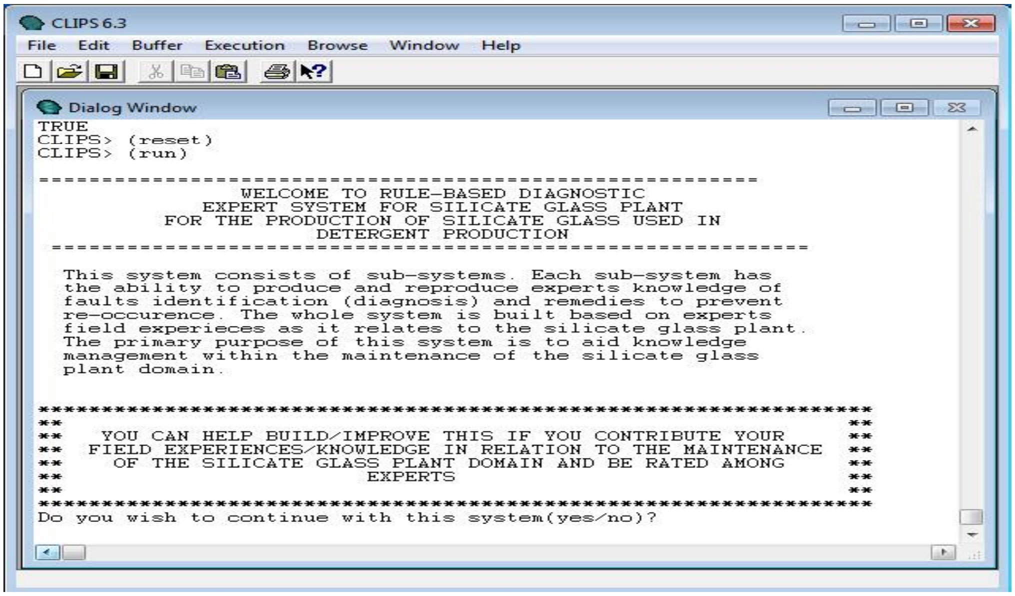

Fig. 4 Main System's Welcome Page

The validation of the system showed true representation of the domain experts' knowledge. The validation results (see Figure 5 for one) gave the exact solution to the problems cases (test cases) used, as presented by the domain experts.

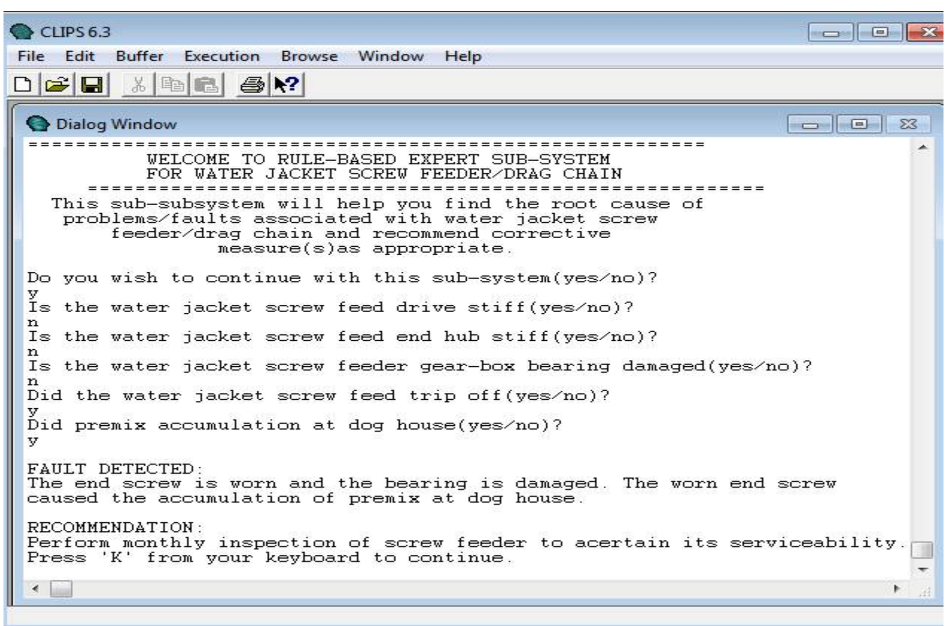

Fig.5 Validation of Test Case

Field test showed that a considerable reduction in plant down time was achieved when the expert system was employed in fault diagnosis (see Table 1). In Tables 1, 3, 4, 5 and 6 are the DTI, PA, DMC, TPMP and TMC before and after use of expert system in fault diagnosis. Increase was obtained for PA and TPMP. Likewise, decrease was obtained for DTI, DMC and TMC.

Table 1: Comparison between Maintenance Lead-Time with and without the Aid of Expert

S/N	Sub-assembly	Failure/Fault	Without ES (mins.)	With ES (mins.)
1	Variable Screw Feeder	Stiff and inoperative Screw feeder	180	115
2	Slat Conveyor	Slat Conveyor Tripped off	90	60
3	Slat Conveyor	Slat Conveyor Chain Cut1	120	85
4	Slat Conveyor	Slat Conveyor Chain Cut2	195	105
5	Combustion Blower	Combustion Blower Vibrating	300	200
6	Water Jacket Screw Feeder	Water Jacket Screw Feeder Stiff	180	110

Table 2: Down Time Indices (DTI) for Periods before Evaluation (bE) and during Evaluation(dE)

S/N	Sub-assembly	Failure/Fault	DTI bE	DTI dE
1	Variable Screw Feeder	Stiff and inoperative Screw feeder	37.50	23.96
2	Slat Conveyor	Slat Conveyor Tripped off	18.75	12.50
3	Slat Conveyor	Slat Conveyor Chain Cut1	25.00	17.71
4	Slat Conveyor	Slat Conveyor Chain Cut2	40.63	21.88
5	Combustion Blower	Combustion Blower Vibrating	62.50	41.67
6	Water Jacket Screw Feeder	Water Jacket Screw Feeder Stiff	37.50	22.92

Table 3: Plant Availability (PA) for Periods before and during Evaluation of Silicate Gas Plant Expert System

S/N	Sub-assembly	Failure/Fault	Before Evaluation	During Evaluation	% Increase in Availability
1	Variable Screw Feeder	Stiff and inoperative Screw feeder	63.0	76.0	20.64
2	Slat Conveyor	Slat Conveyor Tripped off	81.0	88.0	8.64
3	Slat Conveyor	Slat Conveyor Chain Cut1	75.0	82.0	9.33
4	Slat Conveyor	Slat Conveyor Chain Cut2	59.0	78.0	32.20
5	Combustion Blower	Combustion Blower Vibrating	38.0	58.0	52.63
6	Water Jacket Screw Feeder	Water Jacket Screw Feeder Stiff	63.0	77.0	22.22

Table 4: Direct Maintenance Cost (DMC) for Periods before Evaluation (bE) and during Evaluation (dE) of Silicate Glass Plant Expert System

S/N	Sub-assembly	Failure/Fault	DMC bE (N)	DMC dE (N)	%Decrease in DMC
1	Variable Screw Feeder	Stiff and inoperative Screw feeder	147,586.24	146,652.32	0.63
2	Slat Conveyor	Slat Conveyor Tripped off	31,293.12	30,862.08	1.38
3	Slat Conveyor	Slat Conveyor Chain Cut1	251,724.16	251,221.28	0.20
4	Slat Conveyor	Slat Conveyor Chain Cut2	25,801.76	24,508.64	5.01
5	Combustion Blower	Combustion Blower Vibrating	1,504,310.40	1,502,873.60	0.10
6	Water Jacket Screw Feeder	Water Jacket Screw Feeder Stiff	57,586.24	56,580.48	1.75

Table 5: Total Maintenance Cost (TMC) for Periods before Evaluation (bE) and during Evaluation (dE) of Silicate Glass Plant Expert System

S/N	Sub-assembly	Failure/Fault	TMC bE (N)	TMC dE (N)	%Decrease in TMC
1	Variable Screw Feeder	Stiff and inoperative Screw feeder	395,586.24	330,652.32	16.42
2	Slat Conveyor	Slat Conveyor Tripped off	159,293.12	110,862.08	30.40
3	Slat Conveyor	Slat Conveyor Chain Cut1	419,724.16	395,221.28	5.84
4	Slat Conveyor	Slat Conveyor Chain Cut2	297,801.76	192,508.64	35.36
5	Combustion Blower	Combustion Blower Vibrating	1,928,310.40	1,798,873.60	6.71
6	Water Jacket Screw Feeder	Water Jacket Screw Feeder Stiff	321,586.24	232,580.46	27.68

Table 6: Total Plant Maintenance Productivity (TPMP) for Periods before Evaluation (bE) and during Evaluation (dE) of Silicate Glass Plant Expert System

S/N	Sub-assembly	Failure/Fault	TPMP bE	TPMP dE	%Increase in TPMP
1	Variable Screw Feeder	Stiff and inoperative Screw feeder	5.54 E -5	6.87E-5	24.01
2	Slat Conveyor	Slat Conveyor Tripped off	1.47 E -4	2.17 E -4	47.63
3	Slat Conveyor	Slat Conveyor Chain Cut1	5.46 E -5	5.87 E -5	7.51
4	Slat Conveyor	Slat Conveyor Chain Cut2	7.25 E -5	1.19 E -4	64.14
5	Combustion Blower	Combustion Blower Vibrating	1.02 E -5	1.18 E -5	15.69
6	Water Jacket Screw Feeder	Water Jacket Screw Feeder Stiff	6.75 E -5	9.80 E -5	45.19

It was recorded that the expert system gave diagnosis of test case that were similar to how the human experts would have given. The results obtained from the field test showed that an overall average reduction in Silicate Glass Plant down time of about 36.62% is possible.

CONCLUSION

The developed expert system has been shown to have the capability of enhancing the performances of the Silicate Glass Plant maintenance staff as a result of the decline in DTI, DMC and TMC on one hand and increase in PA and TPMP on the other hand.

REFERENCES

Adejuyigbe, S. B. 2002. CAD/CAM for Manufacturing, TOPFUN Publications, Akure, Nigeria.

Adewunmi, A. A. 2008. Selection of Simulation Variance Reduction Techniques through a Fuzzy Expert System, Doctoral Research Thesis, University of Nottingham.

Al-Taani, A.T. 2005. An Expert System for Car Failure Diagnosis, *World Academy of Science, Engineering and Technology* 7(12): 457-460.

Davies, C., Greenough, R. 2000. The Use of Information Systems in Fault Diagnosis. Proceedings of the 16th National Conference on Manufacturing Research. University of East London pp37-42.

Emerson Process Management 2009. Work Orders for Operations Maintenance Activities (Online). http://emersonprocess.com/ home/news/resources/smarts.pdf(19 Dec. 2012).

Newell, A., Simon, H.A. 1972. Human Problem Solving, Englewood Cliffs, NJ: Prentice-Hall, Pittsburgh, U.S.A.

Noran, O. S. 2005. The Evolution of Expert Systems(Online). Griffith University. http://cit.gu.edu.au/~noran(19 Dec. 2012)

Peter N. 2006. An Expert System for Diagnosing Heavy Duty Diesel Engine Faults, Master's Research Thesis, Makerere University, Uganda.

Strasser, K. 2012. wiseGEEK Clear Answers for Common Questions (Online). Conjecture Corporation. http://www.wisegeek.org(30 Oct. 2012)

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