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The Design of Hybrid System for Servicing Process Support in Small Businesses

The paper gives a survey of a hybrid system, where Expert System (ES) output represents Decision Support System (DSS) input. The hybrid system has been developed for the needs of fault diagnosis performed by ES, while the output i.e. a diagnosed faulty component is DSS input, where supplier selection for faulty component replacement is made, using a multicriteria analysis. The hybrid system has been developed for motocultivator, motor saw and grass mower fault diagnosis. The system was applied in a small company which is an importer and a distributor and performs servicing of the mentioned products. Concrete results mirror themselves in a shortened period of time for fault diagnosis and fast supply and replacement of faulty components, facilitated and better quality services for customers.

Keywords: *expert system, decision support system, ahp, supplier selection.*

1. INTRODUCTION

Hybrid systems are developed by integrating two or more computerized information systems. Today, it is spoken of several classes of hybrid systems, the basic ones being: integration of systems for decision making support and expert systems, expert systems and neural networks as well as aspects of several globally integrated information systems. The forms of integration of two or more computerized information systems differ from one another in architectural solutions of systems integration.

When choosing the form of integration of computerized information systems, the leading idea should be that integration of the current information systems generates unified characteristics of integrated systems. This provides a considerably more comfortable work for users, shortened time of activities – so, labor output and employees' satisfaction are increased. Implementation of integrated systems, on the other hand, requires investment of extra resources for building a global system and for hardware components procurement.

In professional literature there are no data on the expert system for motocultivator, motor saw and grass mower fault diagnosis. There are developed expert systems for engine fault diagnosis [1-3], the analysis most commonly being done for passenger car engines.

2. DEFINING THE PROBLEM

One of the major operations of the company dealing with import and distribution of products, such as motocultivators, motor saws and grass mowers is rendering services for customers. To provide satisfactory services, efficient fault diagnosis and repair of machines should be done.

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The company estimates that critical activities are fault diagnosis and supply of parts so as to repair a fault. That is why the management has set the task to make those two activities as efficient as possible. The task anticipated the expert system design for the needs of fault diagnosis and model design within the system of decision-making support for the identified faulty component supply.

To identify the components that service quality control should be satisfied for, the procedure was developed to:

- compile a list of products
- compile a list of structural components
- identify the quantities monitored in some components (pressure, noise, vibrations and the like)
- take over allowable limits, in compliance with manufacturer's instructions, for the monitored parameters in some components
- identify the components that have not met the set criteria.

3. KNOWLEDGE DATABASE DESIGN FOR FAULT DIAGNOSTICS BY THE APPLICATION OF EXPERT SYSTEM

There are a number of ways in which the expert system support is provided for maintenance. For maintenance needs, it is possible to introduce:

- An expert system, where a user consults the expert system for the emerged problem (fault) in order to harmonize the activities in fault repair and undertake corrective activities;
- An expert system which assists in fault identification in a certain machine or in a production process. It is possible to make a distinction here between, first, expert systems in which a user enters data into an expert system about the current state of the system and based on which an expert system builds an expertise and, second, expert systems that by means of special control devices monitor continually the

operating of the system and determine an instant when to inform the user about the need for undertaking certain preventive activities;

- A special group embraces expert systems for management of equipment maintenance activities, which generate a report on the basis of keeping the balance between needs, demands and available resources.

The selection of expert system for maintenance should be done, depending on the company's needs. More recent generations of expert systems for maintenance are made up of a number of modules, and they together constitute a whole that can completely support maintenance management of production equipment. TechMate [4] is an expert system based on a combined "model based" and "case based" reasoning. Reasoning founded on models makes possible to keep in a compact model the design, engineering and servicing knowledge ready for diagnostics of problems not previously recorded. Case-based reasoning enables utilization of information from one case for diagnostics of other cases, even though they are seemingly rather different.

TechMate, presented in Figure 1, is a software tool that is used by technicians to quickly repair a fault in a subassembly or in a whole system. TechMate assists in solving technical problems, thus making the process more efficient, accurate and productive. TechMate reduces time for identifying the fault location by 25 – 60 %. It automatically generates diagnostics estimates for block diagram schemes (entered manually or electronically). For a specified series of symptoms and results testing, TechMate diagnostics algorithm identifies the likely problems and rates them. This expert system identifies and quantifies the test that can be applied to isolate a fault, thereafter proposing the most profitable test.

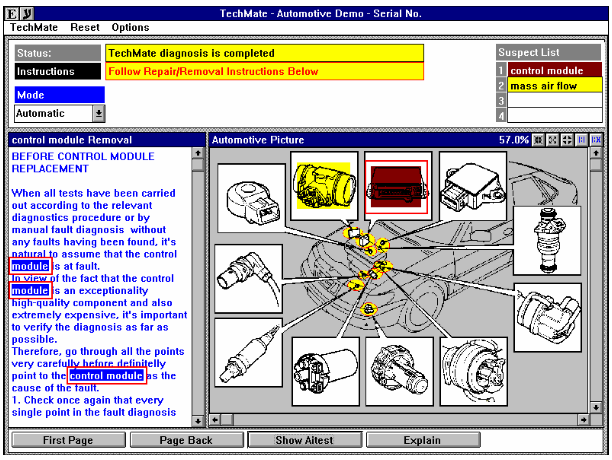

Figure 1. Presentation of the ES TechMate work

An example of diagnostics expert system will be deployed to show the possibility of its application to solving the problem of equipment servicing i.e. expert systems that belong to the first group according to the above mentioned classification.

Fault diagnosis can be realized within the framework of expert system by the knowledge database design. Knowledge database was designed by forward chaining of production rules, therefore it is necessary to previously:

- make questions Q1 – Qn,
- determine variables V1 – Vn,
- establish production rules R1 – Rn.

On the basis of the relevant procedure (above mentioned) for identifying the component where replacement should be done, a set of questions was formed, which an expert system asks the customer. By linking the production rules, it is possible to finally isolate the required component. Knowledge database contains questions and answers for all components related to all three types of products (and all their versions determined in a production program) that need servicing i.e. motocultivators, motor saws and grass mowers. So after the answer to the first question, the expert system focuses only on the observed product. By using this procedure, the expert system was designed to cover all servicing products, making it unnecessary to generate a separate knowledge database for each type of product.

The following set of questions was formed:

- Q1: The name of the product?
- Q2: What kind of problem occurs?
- Q3: Is it a gasoline or a diesel engine?
- Q4: Is there radial clearance in the crankshaft?
- Q5: Has engine got a compression stroke?
- Q6: Can engine be ignited?
- Q7: Is there oil consumption or leakage?
- Q8: Is engine heated?
- Q9: Has engine got power output and sufficient number of rpm?
- Q10: Is there fuel supply to the high-pressure pump?
- Q11: Is there fuel supply from the high-pressure pump to the injector?
- Q12: Is fuel passing through the injector?
- Q13: Does needle valve let the pressure?
- Q14: Do problems arise when the engine is heated or cold?
- Q15: Is sealing in the working condition?
- Q16: Are rubber gaskets on the pipe lifter in the working condition?
- Q17: Can engine be switched on?
- Q18: Is starter switch in the working condition?
- Q19: Are brushes in the working condition?
- Q20: Is rotor in the working condition?
- Q21: Is condenser in the working condition?
- Q22: Is grass mower knife in the working condition?
- Q23: Is screw tight enough?
- Q24: Has gearbox not got gears at all or does not operate in some gear?
- Q25: Is selector in the working condition?
- Q26: Is fork in the working condition?
- Q27: Are bearings in the working condition?
- Q28: Can engine be started?
- Q29: Is there fuel in the tank?
- Q30: Does oil leak through the tap?

The likely answers to some questions were determined (Goals):

- G1: The engine needs overhaul.
- G2: Replace piston rings and valves.
- G3: Adjust the valves.
- G4: Replace injector cartridge.
- G5: Replace the high-pressure pump component.

- G6: Clean the fuel filter if possible, if not replace it.
- G7: The high-pressure pump component is worn, replace it.
- G8: Engine main variator is worn, replace the variator cup.
- G9: Replace valve rubber gaskets.
- G10: Piston rings are worn, replace them.
- G11: Seals need replacement.
- G12: Sealing needs replacement.
- G13: Fuel filter needs replacement; pre-ignition point should be adjusted to optimal.
- G14: Switch needs replacement.
- G15: Brushes need replacement.
- G16: Rotor needs replacement.
- G17: Condenser needs replacement.
- G18: Stator needs replacement.
- G19: The problem is in the cable or in house installation.
- G20: The screw has to be tightened.
- G21: Wedge needs replacement.
- G22: Selector needs replacement.
- G23: Fork needs replacement.
- G24: Bearings need replacement.
- G25: Upper and lower beam gearing needs replacement.
- G26: Gearing of the gear in which clutch jams needs replacement.
- G27: Fill fuel into the tank.
- G28: Clean the tap but if the problem recurs, it needs replacement.
- G29: Valves and head sealing need replacement.
- G30: Diaphragm has a hole, replace a set of diaphragms.
- G31: Clean the carburetor, but if the problem recurs, replace the carburetor.

In the presented concrete example of servicing one motor saw, the following production rules were applied: If Q1 (Name of the product. = Motor saw.) and Q2 (What problem occurs? = Motor saw sends fuel back to the carburetor.) and Q13 (Does needle let the pressure? = No, it does not.) THEN G30 (The diaphragm has a hole, replace a set of diaphragms.)

Carburetor diaphragm in a motor saw is marked (Fig. 2) as an isolated component which needs replacement.

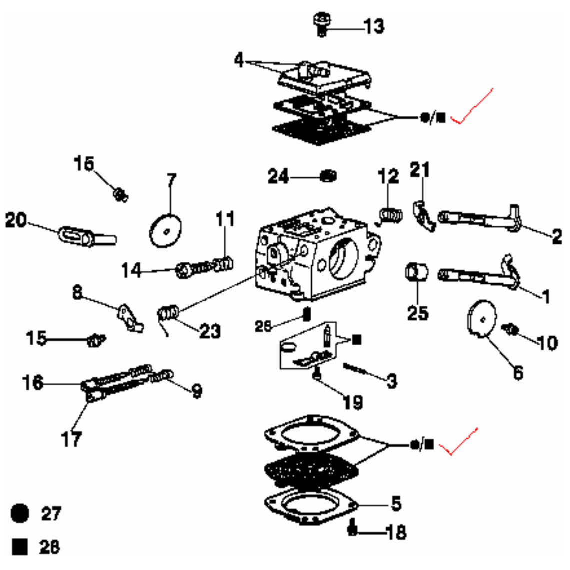

Figure 2. Motor saw carburetor

Supplier selection by applying Decision Support System

Decision Support Systems are suitable for the needs of decision making on purchase/replacement of a certain part, assembly, semi-manufactured product or product, supplier selection, supply strategy selection and maintenance program [5]. So, for all decisions where selection is made among a number of alternatives, when several criteria can be taken into account, software support can be expected from the decision support system.

The ES output represents information about the component whose replacement is necessary. Information on the isolated component opens a model in the decision support system for a suitable supplier selection. Since there are different components in different suppliers' offers, the supplier selection models for different components have similar criteria for supplier selection but different alternatives. It is implied that models contain the defined alternative solutions (potential suppliers) that fully meet the characteristics of components determined by manufacturer's instructions.

Further modeling procedure for supplier selection deployed the decision support system based on the AHP (Analytic Hierarchy Processing) technique. Saaty [6,7] developed the following steps for applying the AHP:

- Define the problem and determine its goal.
- Structure the hierarchy from the top through the intermediate levels, the criterion on which subsequent levels depend, to the lowest level which usually contains the list of alternatives.
- Construct a set of pair-wise comparison matrices (size $n \times n$) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement. The pair-wise comparisons are done in terms of which one element dominates the other.
- There are $n(n-1)/2$ judgments required to develop a set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
- Hierarchical synthesis is now used to weight the eigenvectors by weights of the criteria and the sum is taken over of all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
- Having made all the pair-wise comparisons, the consistency is determined by using the eigenvalue λ_{max}, to calculate the consistency index, CI as follows: $CI = (\lambda_{max} - n) / (n - 1)$, where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value. The CR is acceptable if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain consistent matrix, judgments should be reviewed and improved.

Steps 3 – 6 are performed for all levels in the hierarchy.

4. THE AHP MODEL DESIGN

The mentioned theoretical steps were applied to a concrete example of the supplier selection [8-10]:

Step 1: Structuring the supplier selection problem

A group of company's experts compiled a list of criteria that they had estimated were key components for their customers in the selection of the supplier for motocultivators, grass mowers and motor saws' spare parts. Seven criteria at the top level and corresponding sub-criteria (Tab. 1) along with defining verbal or numerical scales they are describing constitute a decision-making model.

Table 1. Hierarchical structure

Objective	Criterion	2nd level of sub-criterion	3rd level of sub-criterion
To choose supplier for spare part	C1: Price		
	C2: Manufacturer		
	C3: Delivery terms	C31: Promptness of delivery	
		C32: Transport costs	
	C4: Warranty		
	C5: Terms of payment	C51: Payment immediately	
		C52: Deferred payment	C521: For one year
			C522: For six months
			C523: For three months
	C6: Fringe benefits		
	C7: Up-to-then business cooperation		

Step2: Measurement and data collection

Weighting of spare parts alternative suppliers for some criteria is done by the customer in terms of price criteria, terms of payment that are solely dependent on the customer. However, some criteria were weighted by repair and maintenance service and refer to the criterion of previous experience in cooperation with the supplier, fringe benefits (in the case when more than one piece of spare parts is ordered and the like) [11]. Weighting method can be either direct or pair-wise. The concrete example shows the direct method. Numerical scales were used to determine the criteria boundaries, whose weight can be numerically expressed. In other cases, verbal scales were defined in such way that the customer i.e. the client can most readily express the priority of a certain criterion against a higher-level criterion as well as relative weight for alternatives according to corresponding criteria.

Table 1 presents the generated hierarchy of criteria and sub-criteria. Table 2 presents relative significance of Level 2 criteria against Level 1 criteria, as well as verbal scale used.

Table 2. Criteria weight

Criterion	Value	Sub-criterion	Value
C1: Price	Critical		
C2: Manufacturer	Critical		
C3: Delivery terms	Very important	C31: Promptness of delivery	Critical
		C32: Transport costs	Very important
C4: Warranty	Very important		
C5: Terms of payment	Important	C51: Payment immediately	Critical
		C52: Deferred payment	Critical
C6: Fringe benefits	Important		
C7: Up-to-then business cooperation	Important		

Table 3 presents relative significance of Level 3 criteria against Level 2 criteria, as well as verbal scale used.

Table 3. Level 2 criteria weight

Criterion	Sub-criterion	Value
C52: Deferred payment	C521: For one year	5
	C522: For six months	3
	C523: For three months	1

Numerical scale: 1 – 5.

Table 4. Weights for alternatives against Level 1 criteria

Criterion alternative	C1: Price	C2: Manufacturer	C4: Warranty	C6: Fringe benefits	C7: Up-to-then business cooperation
Scale	VG (very good) G (good) FG (fairly good) RU (rather unfavorable) N (unfavorable)	VR (very reliable) QR (quite reliable) PN (quite unreliable) NN (totally unreliable)	TH (3 years) TW (2 years) O (1 year)	F (fringe benefits) B (benefits) N (no benefits)	VS (very successful) S (successful) RS (fairly successful) LU (rather unsuccessful) U (unsuccessful)
A1: *Atomik*, Niš	N	QR	TH	N	S
A2: Company *Jovanovic*, Niš	VG	QR	TW	N	LU
A3: *Lombardini*, Gorobilje	N	VR	O	N	RS
A4: *IMT*, Knjaževac	FG	VR	O	F	
A5: *21. maj*, Belgrade	FG	QR	TW	N	VS
A6: *IMT*, Boljevac	FG	VR	TW	B	

Table 5. Weights for alternatives against Levels 2 and 3 criteria

Criterion alternative	C31: Promptness of delivery	C32: Transport costs	C51: Payment immediately	C521: For one year	C522: For six months	C523: For three months
Scale	5(Very fast) 4(fast) 3 (neither fast nor slow) 2 (rather slow) 1 (very slow)	5 (very low) 4 (quite low) 3 (low) 2 (quite high) 1 (very high)	5 (10 % discount) 4 (5 % discount) 3 (2 – 5 % discount) 2 (2 % discount) 1 (no discount)	NK (no interest) K (2 % interest) K1 (4 % interes)		
A1: *Atomik*, Niš	3	5	5	K	NK	NK
A2: Company *Jovanovic*, Niš	5	2	5			K
A3: *Lombardini*, Gorobilje	3	5	4			
A4: *IMT*, Knjaževac	2	1	2	K1		NK
A5: *21. maj*, Belgrade	1	1	1		K1	K
A6: *IMT*, Boljevac	2	4	2		K1	K

Table 6. Weights and priorities

GOAL	Weights	Priorities	Rating set	Criterion	Weights	Priorities	Rating Set	Sub-criterion	Weights	Priorities	Rating set	Lowest criteria	A1	A2	A3	A4	A5	A6
													Priorities					
Supplier selection	100	0.231	C1	C1			Altern.	C31			Altern.	C1		0.4	0	0.2	0.2	0.2
	100	0.231	C2	C2			Altern.	C32			Altern.	C2	0.133	0.133	0.2	0.2	0.133	0.2
	66.67	0.154	C3	C3	100	0.578	C31	C51			Altern.	C31	0.2	0.4	0.2	0.1	0	0.1
	66.67	0.154	C4		72.87	0.422	C32	C52	100	0.667	C521	C32	0.333	0.111	0.333	0	0	0.222
	33.33	0.077	C5	C4			Altern.		50	0.333	C522	C4	0.4	0.2	0	0	0.2	0.2
	33.33	0.077	C6	C5	100	0.5	C51		0	0	C523	C51	0.3	0.3	0.2	0.1	0	0.1
	33.33	0.077	C7		100	0.5	C52					C521	1					0
				C6			Altern.					C522	0.5				0.25	0.25
				C7			Altern.					C523	0.286	0.143		0.286	0.143	0.143
												C6	0			0.75		0.25
												C7	0.3	0.1	0.2		0.4	

Table 4 presents qualitative weighting for alternatives against Level 1 criteria. Table 5 presents quantitative and qualitative weights for alternatives against Levels 2 and 3 criteria.

Step 3: Determination of normalized weights

On the basis of the entered relative weights in the decision support system, the overall relative weights for alternatives were determined against the lowest-level criteria.

Table 7. Decision scores

Alternative	Decision scores
A1: *Atomik*, Niš	0.200
A2: Company *Jovanovic*, Niš	0.212
A3: *Lombardini*, Gorobilje	0.110
A4: *IMT*, Knjaževac	0.150
A5: *21. maj*, Belgrade	0.142
A6: *IMT*, Boljevac	0.186

The final decision score is presented in Table 7, which indicates that the most suitable supplier for motor saw carburetor diaphragm is *Jovanovic Co.* from Niš (A2).

Considering the fact that the most important weighted criteria were price (Fig. 3) and manufacturer (Fig. 4), further analysis comprises sensitivity graphs for those two criteria.

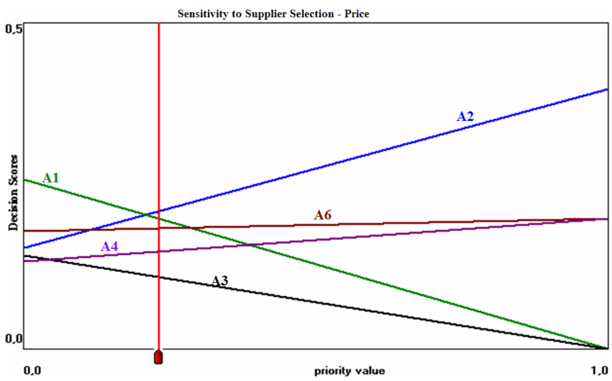

Figure 3. Sensitivity analysis to the criterion – price

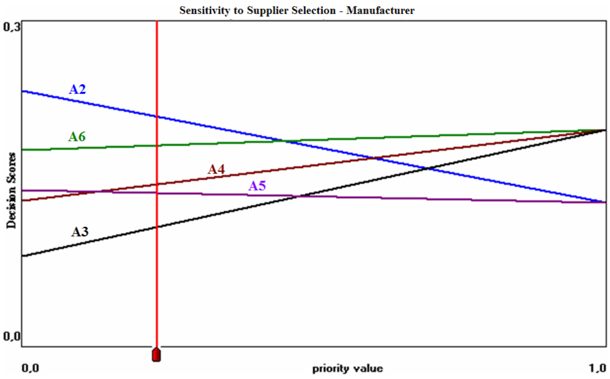

Figure 4. Sensitivity analysis to the criterion – manufacturer

Sensitivity graph to the criterion "price" indicates that decision is highly sensitive to the change of relative weights for criteria in hierarchy Level 1. However, according to the criterion "manufacturer" (Fig. 4), the final decision is stable against relative changes in Level 1 criteria.

Further testing of sensitivity to the rest of criteria showed that decision A2 is very stable.

5. CONCLUSION

The application of expert systems in equipment maintenance is characterized by considerable reduction of maintenance costs, increase of productivity and achievement of highly reliable manufacturing equipment. The factors stemming directly from the application of expert systems for maintenance are presented. Consequently there also emerge lubricants saving, safety increase, reduction in necessary repairs etc. So, the application of expert systems significantly improves quality of work in the domain of maintenance, where prominent role belongs to those expert systems that accommodate self-contained module for frequency optimization of performing preventive maintenance activities as well as optimization of maintenance costs.

Emphasis should be placed on fault diagnosis speed, which is a basic idea underlying the expert systems application for maintenance and equipment servicing respectively.

Expert systems can make a diagnosis, identify the component where fault occurred as well as advice on how to repair a fault, which has to be the task of the future designed expert system. For decision making influenced by a number of criteria, decision support systems are suitable. Decision support systems make possible for a decision user to form a decision-making model for a short time and thereafter to make a decision of his own using the rated alternatives and sensitivity analysis.

The development of information technologies is increasing the potentials of expert systems for equipment maintenance, so it is realistic to expect the growing presence of computerized systems in the maintenance domain. In our manufacturing practice the expert systems are not used that much. Hence, one of the solutions for improving business operations is to be looked for in expert systems application as has been done by well-known world firms.

The designed hybrid system for equipment servicing needs has proved to be a very useful tool in practice, increasing the efficiency of labor and employees' satisfaction in general. Its building and implementation did not require much investment resources. It is possible to modify and improve this hybrid system if employees learn new things and gain new experience in equipment maintenance.

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NOMENCLATURE

CI	consistency index
CR	consistency ratio
n	matrix size
λ_{max}	larges eigenvalue

ПРОЈЕКТОВАЊЕ ХИБРИДНОГ СИСТЕМА ЗА ПОДРШКУ ПРОЦЕСА СЕРВИСИРАЊА У МАЛИМ ПРЕДУЗЕЋИМА

Драган Д. Милановић, Мирјана Мисита, Данијела Тадић, Драган Љ. Милановић

У раду је дат приказ хибридног система у којем Експертни систем (ЕС) представља компоненту Система за подршку одлучивању. Хибридни систем је развијен за потребе дијагностике квара, што обавља експертни систем, а излаз односно дијагностификована неисправна компонента представља улаз у систем за подршку одлучивању у којем се на основу вишекритеријумске анализе врши избор добављача за замену неисправне компоненте. Хибридни систем развијен је за дијагностификовање квара код мотокултиватора, моторне тестере и косилице за траву, а примењен је у малом предузећу које је увозник, дистрибутер и обавља сервисирање наведених производа. Конкретни резултати примене хибридног система огледају се кроз скраћено време дијагнозе квара, брзу набавку и замену неисправних компоненти, олакшан сервис и квалитет услуге купцима.