Spare Parts Management for the Repair of Machine Tools Using Fuzzy Logic Approach

إدارة قطع الغيارالللازمة لإصلاح ماكينات القطع باستخدام نـهج المنطق الضبابي

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الملخص العربي

ان مخزون قطع الغيار يعد من العوامل الهامة التى تساعد القائمين على الصيانة في الحفاظ على المعدات في ظروف التشغيل . وبالتالي فإن مستوى قطع الغيار المخزنة يؤثر بشكل مباشر على المعدات و جاهزيتها للعمل. هناك الكثير من النماذج الرياضية الكلاسيكية التى تم وضعها لتحديد مستوى المخزون الأمثل لكنها فى معظمها معقدة. فى هذا البحث سوف يتم استخدام مفهوم المنطق الضبابي (fuzzy logic) و ايجاد حلول مثلى لتحديد مستوى المخزون المطلوب . هذا النهج لا يتطلب نماذج و حلول رياضية معقدة لأنه يقوم على مقارنة بسيطة بين الطلب على ماركة معينة من قطع الغيار مع الكمية المتاحة منها فعلا فى نفس الوقت في المستودعات و من ثم يتم اتخاذ القرار برفع أو خفض مستوى المخزون المطلوب.

Abstract

Spare parts inventories assist maintenance staff to keep equipment in operating conditions. Thus the level of spares stocked has a direct bearing on machine availability. One of the causes of downtime equipment in the repair process is the lack of necessary spare parts at the time of repair and maintenance actions. The minimization of the spare parts storage cost in enterprises is very important. The models of this theory are built according to the classical scheme of mathematical programming. Construction of such models requires definite assumptions, for example, of orders flows, time distribution laws and others. On the other hand, experienced managers very often make effective administrative decisions on the common sense and practical reasoning level. Therefore, the approach based on fuzzy logic can be considered as a good alternative to the classical inventory control models. In this paper, a fuzzy logic approach is introduced. This approach requires neither complex mathematical models construction no search of optimal solutions on the base of such models. It is based on simple comparison of the demand for the stock of the given brand at the actual time moment with the quantity of the stock available in the warehouse. Depending upon it inventory action is formed consisting in increasing or decreasing corresponding stocks. Expert decisions are considered for developing the fuzzy models, and the approach is based on method of nonlinear dependencies identifications by fuzzy knowledge. The linguistic variables are considered for the membership functions. Simple IF-Then rules are used with expert advices.

Keywords:

Inventory management, machine tool , spare parts, fuzzy logic, fuzzification, defuzzification.

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1. Introduction

The economy system for repair and maintenance of machine tools belonging to the category of complex systems , operates with certain restrictions. Of these, there are three main restrictions that directly affect the amount of spare parts for repair of machine tools :

- minimum working capital for the purchase of spare parts and wearing parts ;
- duration of the repair works , resulting from annual schedule repair of process equipment;
- availability of skilled labor

The most important of these three restrictions is to minimize the cost and storage of spare parts.

Spare parts inventories assist maintenance staff to keep equipment in operating conditions. A shortage or not enough supply of spare parts can disrupt manufacturing plan.

The process inventory management of spare parts required during repair and maintenance of machine tools requires definite assumptions, for example, orders flows, time distribution laws and others.

Therefore, to find the exact amount of spare parts with restriction of minimum working capital is difficult.

The inventory management defines how often the stock level is reviewed to determine when and how much to order. It is performed on either a continuous or periodic basic types. In a continuous inventory control system, an order is placed for the same constant amount whenever the inventory on hand decreased to a certain level, whereas in a periodic system, an order is placed for a variable amount after the specific regular time interval [1]. Some of uncertainties within inventory systems cannot be considered appropriately using concepts of probability theory, fuzzy set theory has been used in modeling of inventory systems since 1980s. Fuzzy set theory, originally introduced by Zadeh [2], provides a framework for considering parameters that are vaguely or unclearly defined or whose values are imprecise or determined based on subjective beliefs of individuals. Some researches applied fuzzy set and fuzzy number to determined uncertainties in demand, order quantity and lead time [3-5]. Roy and Maiti [6], [7] solved the classical EOQ problem with a fuzzy goal and fuzzy inventory costs using a fuzzy non-linear programming method. However, these methods are complicated and difficult to understand.

Another approach to simplify complicated system is to use Fuzzy Logic Control (FLC). FLC has been applied in many applications in industry [8].
the approach based on fuzzy logic (FL) can be considered as a good alternative to the classical inventory control models.

In this paper a Fuzzy Logic approach is proposed for optimizing spare parts inventories of machine tools based on demand and stock quantity on hand. This approach requires neither complex mathematical models construction no search of optimal solutions on the base of complex models. It is based on simple comparison of the demand for the stock of the given brand at the actual time moment with the quantity of the stock available in the warehouse. Depending upon it inventory action is formed consisting in increasing or decreasing corresponding stocks and materials.

2. Fuzzy Logic Inference System

Fuzzy inference systems FIS are also known as fuzzy rule-based systems, fuzzy model, fuzzy expert system, and fuzzy associative memory. *This is a major unit of a fuzzy logic system* [9]. This system formulates the mapping from a given input to an output using fuzzy logic. The most important types of fuzzy inference method are Mamdani’s fuzzy inference method, which is the most commonly seen inference method. This method was introduced by Mamdani and Assilian [10]. Another wellknown inference method is the so-called Sugeno or Takagi–Sugeno–Kang method of fuzzy inference process. This method was introduced by Sugeno [11].This method is also called as TS method. The main difference between the two methods lies in the consequent of fuzzy rules. Mamdani fuzzy systems use fuzzy sets as rule consequent whereas TS fuzzy systems employ linear functions of input variables as rule consequent [9]. There are five primary GUI tools for building , editing, and observing fuzzy inference system or FIS editor, the Membership Function Editor, the Rule Editor, the Rule Viewer and Surface Viewer . Fugure.1 [12].

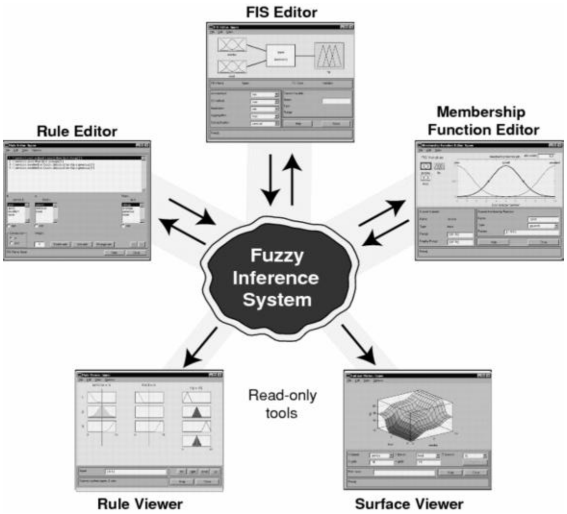

Fig 1.Fuzzy Inference System

The process of applying fuzzy logic is performed in three stages: fuzzification, decision-making and defuzzification. Fuzzification is the process of changing a real scalar value into a fuzzy value. This is achieved with the different types of fuzzifiers (membership functions). In decision-making, once the input and output variables and membership functions are defined, we have to design the rule-base composed of expert IF <antecedents> THEN <conclusions> rules. These rules transform the input variables to an output. Defuzzification is the process of producing a quantifiable result in fuzzy logic.

The quality of fuzzy model depends substantially on the rules and membership functions, describing fuzzy values («terms»). The more successful selected fuzzy rules and membership functions, the more adequate managerial decision.

3. Fuzzy Logic Inventory Control Model for Machine Tool Spare Parts Management.

Let us present the inventory control system of machine tools spare parts (for example turning machines) in the form of the object with two inputs (BO(t) , OH(t)) and single output (S(t)), where: BO(t) is demand of spare parts, i.e. the number of spare parts of the stocks of the given brand, which is needed at time moment t; OH(t) is stock (spare parts) quantity-on-hand, i.e. the number of spare parts of the stocks of the given brand which is available in the factory at moment t; S(t) – inventory action at moment t, consisting in increasing decreasing the stocks of the given brand Figure 2.

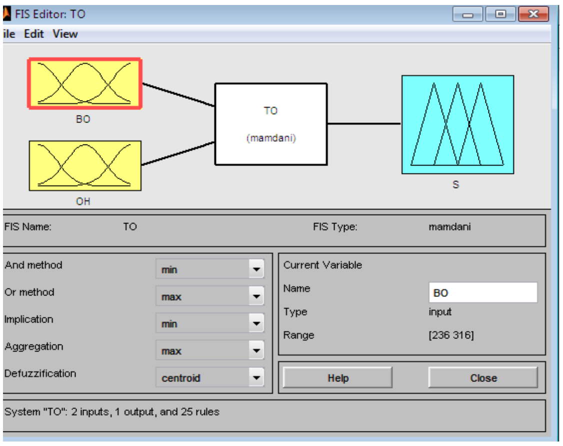

Fig 2. FIS editor for two inputs BO (t), OH(t) and one output S(t)

System state parameters BO (t) , OH (t) and inventory action S(t) are considered as linguistic variables as following in table 1.

The Mamdani was selected as the fuzzy inference system. One membership functions was selected to be combined for the two inputs BO(t), OH(t) and the output S(t); this is the generalized Gaussian curve (gaussmf), figures 3,4,5.

Table 1.

Linguistic variables of BO(t)		Linguistic variables of OH (t)		Linguistic variables of S(t)	
very low	B1	very low	O1	reduce sharply	C1
low	B2	low	O2	reduce moderately	C2
costant	B3	sufficient	O3	reduce slowly	C3
high	B4	high	O4	should be at the same level	C4
Very high	B5	Very high	O5	increase slowly	C5
				increase moderately	C6
				increase sharply	C7

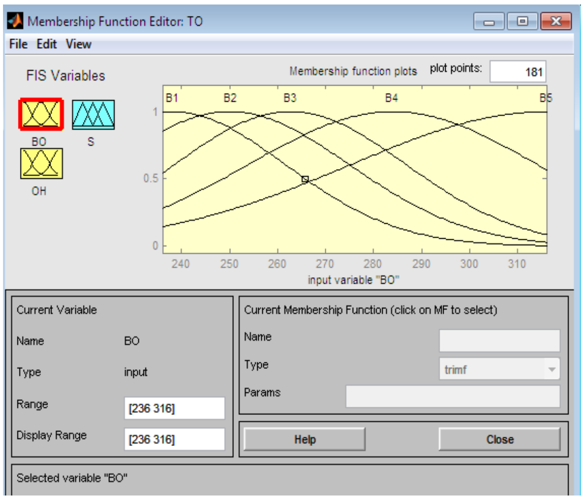

Fig 3. Membership function editor for BO(t)

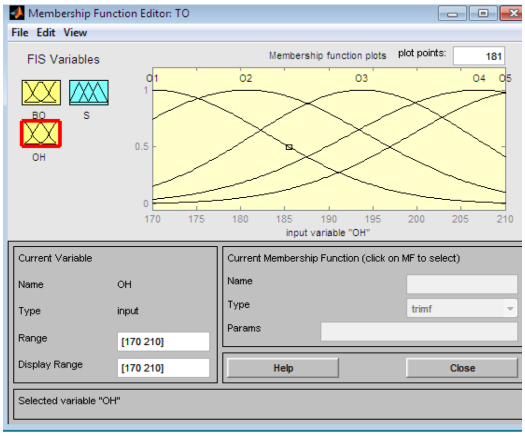

Fig 4. Membership function editor for OH(t)

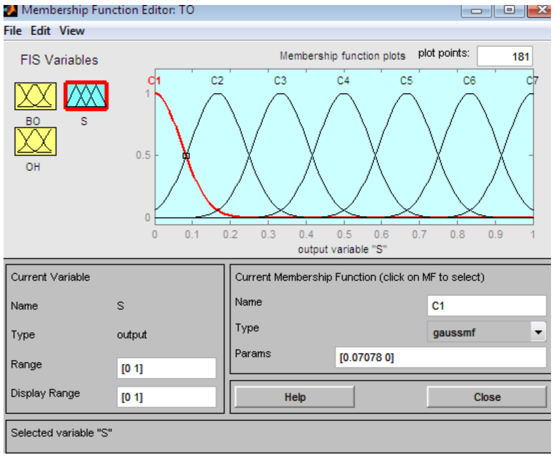

Fig 5. Membership function editor for S (t)

25 fuzzy rules were made in FIS rule viewer, some of these are shown in figure 6 and table 2.

For Defuzzification i.e. to convert the linguistic value into the crisp output the Centroid method is used with Mamdani approach.

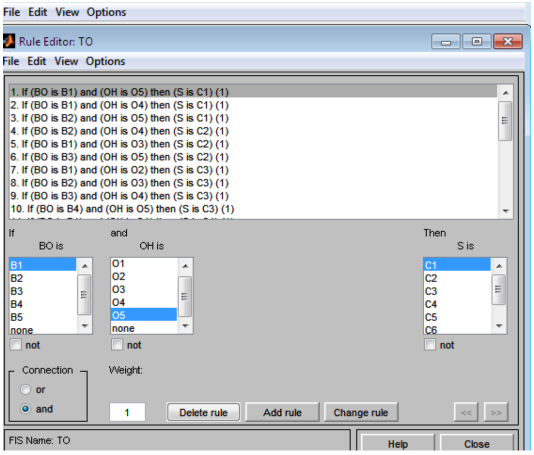

Fig 6. FIS rule editor showing part of rules used.

Table 2.

If BO(t)		and OH(t)		Then S(t)	
demand BO(t)		Stock quantity-on-hand OH(t)		inventory action at moment t S(t)	
very low	B1	very high	O5	reduce sharply	C1
very low	B1	sufficient	O3	reduce moderately	C2
low	B2	high	O4	reduce moderately	C2
constant	B3	very high	O5	reduce moderately	C2
constant	B3	high	O4	reduce slowly	C3
high	B4	very high	O5	reduce slowly	C3
very low	B1	very low	O1	should be at the same level	C4
very high	B5	very high	O5	should be at the same level	C4
low	B2	very low	O1	increase slowly	C5
very high	B5	very high	O5	increase slowly	C5
constant	B3	very low	O1	increase moderately	C6
high	B4	low	O2	increase moderately	C6
very high	B5	low	O2	increase sharply	C7

The values of parameters of BO (t) and OH (t) are calculated according to certain laws that determine the action of repair for each machine in the factory table 3 [13].

Table 3.

The fixed and variable data	
Organizational form and the amount of machines in maintenance ΣR.	Centralized, $\Sigma R=1000$
Category complexity of the machine-repair representative in each group of machines (turning, drilling, boring, grinding, milling, gear, etc.).	R_{icn}
Structure of overhaul cycle of maintenance (for machines up to 10 tons).	KP – O – TP – O – TP - O – CP – O – TP – O – TP – O – CP – O – TP – O – TP – O – KP where O: inspection TP: current repairs CP: medium repairs KP: major repairs
Duration overhaul period, $T_{мр}$ months	$T_{мр}$ = 12 months.
The carrying value of machines in each group $C_{бi}$, thousand roubles	$C_{бi} = \Sigma C_c\, n_i$
The total carrying value of equipment maintenance and repair C, thousand rubles	$C = \Sigma C_б$
Revolving funds in of repair production Φ, thousand roubles	Φ (5,10,15% from cost of the equipment)
The cost of spare parts for the planning period of maintenance by groups of machines and repair actions, , thousand rubles	$C_з$ (according to the price-sheets of manufacturers)
The system time interval t, months.	$t = T_{мр}$
Calculating the number of machines that will be repaired in each group n_i	$n_i = \beta_i \, \Sigma R / R_{icn}$ where β_i is the proportion of this group of machines in the overall park of maintained equipments,%;
Determining the number of repair actions in each time period $P_{вi}$ groups of machines.	Based on the structure of overhaul cycle and the system time interval t
Determining the number of spare parts for each maintained equipment group	

Determination of numerical values of basic linguistic variable B3	B3
Determination of numerical values of other linguistic variables BO (t) taking into account the discrete step	B1; B2; B4; B5.
Determination of numerical values of basic linguistic variable B3	O3
Determination of numerical values of other linguistic variables OH (t) taking into account the discrete step	O1; O2; O3; O4.

Linguistic variables and their parameters values for BO (t) and OH (t) as inputs are shown in table 4, 5 consequently in cases of spare parts of for turning and grinding machine.

Linguistic variables inventory level S (t) is in the range of [0,1] as following :

C1=0, C2=0,16, C3= 0,33, C4=0.5, C5=0.66, C6=0,83, C7=1.

Table 4.

Linguistic variables of input of BO (t)	parameters values in case of turning machine	parameters values in case of grinding machine
B1	236	22
B2	256	27
B3	276	32
B4	296	37
B5	314	42

Table 5.

Linguistic variables of input OH (t)	parameters values in case of turning machine	parameters values in case of grinding machine
O1	170	28
O2	180	34
O3	190	40
O4	200	46
O5	210	52

4- Results and discussion

Figure 7 and 8 show the results of applying the above method of fuzzy logic spare parts inventory control for turning, drilling and grinding machines. For example, if input parameters: demand (BO) equal 276, 32 and stock on hand (OH) equal 179, 40 then stock level (S) should be equal to 0.604, 0.482 for turning and grinding machines spare parts consequently. (Figure (7. a,b)). Figure (8. a,b) shows the effect of demand (BO) and stock on hand (OH) on the level of stock (S) for spare parts of turning, drilling and grinding groups. Fgure (9. a) shows the effect of demand BO on the level of stock S and figure (9. b) shows the effect of stock on hand OH on the stock level in case of turning groups. Also Figures 10 a,b in case of grinding groups

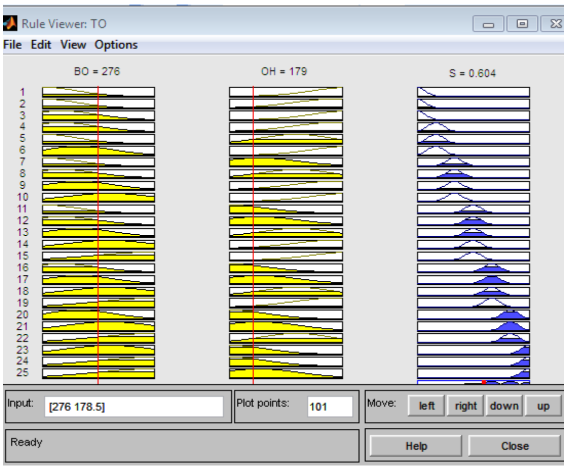

Fig 7.a. FIS rule viewer for inventory control of turning machine spare parts.

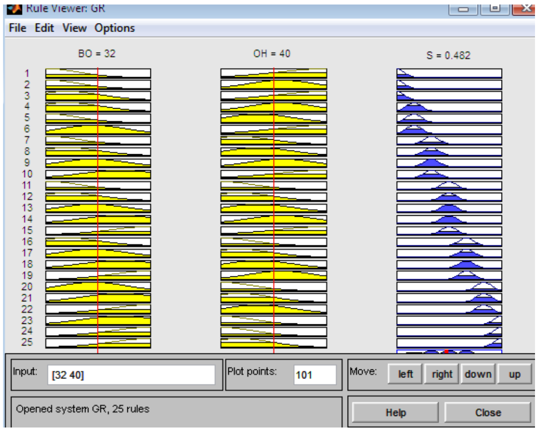

Fig 7.b. FIS rule viewer for inventory control of grinding machines spare parts.

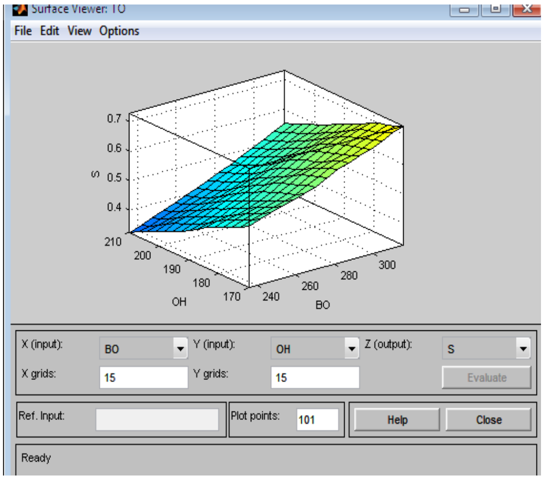

Fig 8. a. FIS surface viewer showing the effect of the demand BO and stock on hand OH on stock level S in case of turning machine.

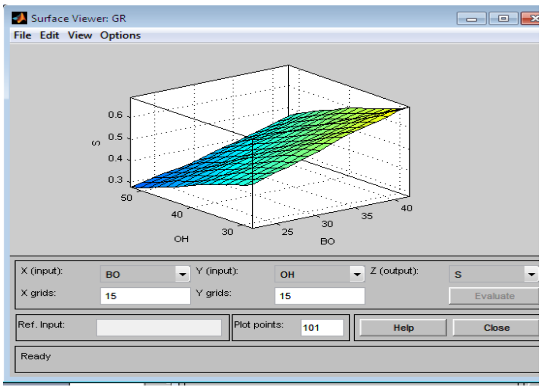

Fig 8. b. FIS surface viewer showing the effect of the demand BO and stock on hand OH on stock level S in case of grinding machine.

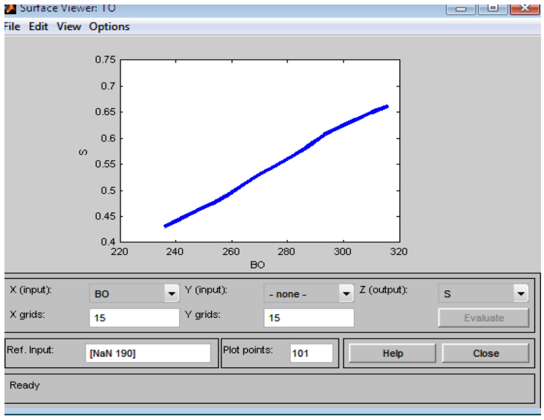

Fig 9. a. FIS surface viewer showing the effect of the demand BO on stock level S in case of turning machine.

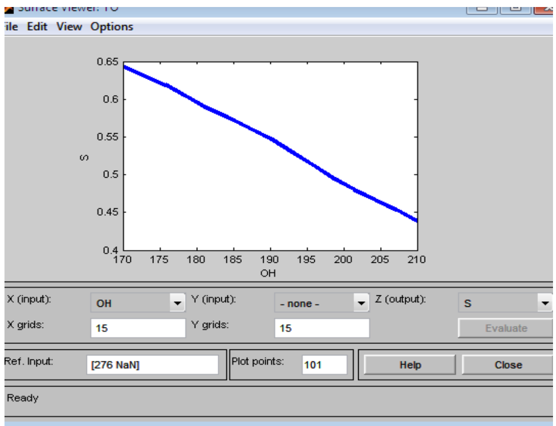

Fig 9. b. FIS surface viewer showing the effect of the stock on hand OH on stock level S in case of turning machine.

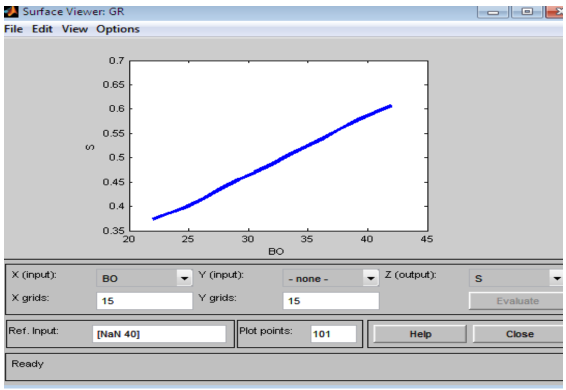

Fig 10. a. FIS surface viewer showing the effect of the demand BO on stock level S in case of grinding machine.

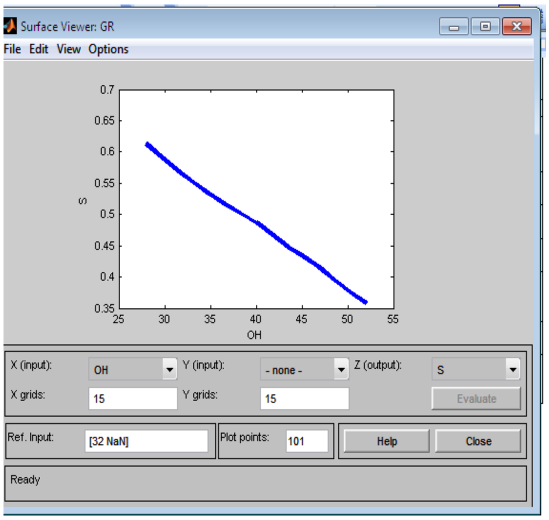

Fig 10. b. FIS surface viewer showing the effect of the stock on hand OH on stock level S in case of grinding machine.

5- Conclusion

Application of fuzzy logic in inventory management allows to optimize the stocks used in the repair of machine tools. In any time interval we don't need complex economic calculations for the provision of the spare parts required to perform repair actions for cutting equipment. This ensures minimize the need of working capital.

The approach proposed can find application in the automated management systems of enterprises and trade firms. It can also be spread on the wide class of the optimal control problems in reliability and complex systems maintenance.

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