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FUZZY DECISION-MAKING APPROACH IN GEOMETRIC PROGRAMMING FOR A SINGLE ITEM EOQ MODEL

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ABSTRACT. **Background and methods**: Fuzzy decision-making approach is allowed in geometric programming for a single item EOQ model with dynamic ordering cost and demand-dependent unit cost. The setup cost varies with the quantity produced/purchased and the modification of objective function with storage area in the presence of imprecisely estimated parameters are investigated. It incorporates all concepts of a fuzzy arithmetic approach, the quantity ordered, and demand per unit compares both fuzzy geometric programming technique and other models for linear membership functions.

Results and conclusions: Investigation of the properties of an optimal solution allows developing an algorithm whose validity is illustrated through an example problem and the results discussed. Sensitivity analysis of the optimal solution is also studied with respect to changes in different parameter values.

Key words: fuzzy, GPP, Setup cost, EOQ, Single item.

INTRODUCTION

In the classic economic production quantity (EPQ) models, the square root formula for the economic order quantity (EOQ) was used in the inventory literature for a pretty long time. Ever since its introduction in the second decade of the past century, the EOQ model has been the subject of extensive investigations and extensions by academicians. Although the EOQ formula has been widely used and accepted by many industries, some practitioners have questioned its practical application. For several years, classical EOQ problems with different variations were solved by many researchers and therefore the research on the inventory problems with EOQ formula has become a hot issue in enterprises and academia.

Taha [1976], Urgeletti Tinnarelli [1983] initially proposed an EOQ model that deals with different variations of formula. But various Paradigmatic changes in science and mathematics concern the concept of uncertainty. In Science, this change has been manifested by a gradual transition from the traditional view, which insists that uncertainty is undesirable and should be avoided by all possible means. According to the traditional view, science should strive for certainty in all its manifestations; hence uncertainty is regarded as unscientific. According to the modern view, uncertainty is considered essential to science; it is not any an unavoidable plague but has; in fact, a great utility. But to tackle non-random uncertainty no other mathematics was developed other than fuzzy set theory and showed the intention to accommodate uncertainty in the presence of random variables. From literature survey, the

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EOQ model in inventory systems, where uncertainty for single item is tackled from the traditional probability theory is assessed by a crisp value. But practical situations, precise value of the total cost are seldom achieved as they may be vague and imprecise to certain extent. Thus in inventory system, the decision maker may allow some flexibility in the parameter values in order to tackle the uncertainties which always fit the real situations.

Following Zadeh [1965], significant contributions in this direction have been applied in many fields including production related areas. Sommer [1981] applied fuzzy dynamic programming to an inventory and production scheduling problem in which the management cuisses to fulfill a contract for providing a product and then withdraw from the market. Kacprzyk et al. [1982] introduced the determination of optimal of firms from a global view point of top management in a fuzzy environment with fuzzy constraints improved on reappointments and a fuzzy goal for preferable inventory levels to be attained. Park [1987] examined the EOQ formula in the fuzzy set theoretic perspective associating the fuzziness with the cost data. Here, inventory costs were represented by trapezoidal fuzzy numbers (TrFN) and the EOQ model was transformed to a fuzzy optimization problem.

Recently, for a single product with demand related to unit price Cheng [1989] has solved the EOQ model by geometric programming method. His treatments are fully analytical and much computational efforts were needed there to get the optimal solution. But Roy et al. [1995, 1997] have considered the space constraint with the objective goal in fuzzy environment and attacked the fuzzy optimization problem directly using either fuzzy non-linear or fuzzy geometric programming technique similarly Lee et al. [1998] and Vujosevic et al. [17] have applied fuzzy arithmetic approach in EOQ model without constraints. Tripathy et al. [2009, 2011, 2011a] also investigated fuzzy EOQ models where demand is deterministic and unit cost of production is a function of both process reliability and demand. Tripathy et al. [2008] developed the fuzzy model by imposing entropy cost to modify the traditional EOQ model with stock dependent demand where pre- and post deterioration discounts are allowed.

Table 1. Summary of the related research
Tabela 1. Podsumowanie pokrewnych badań

Authors	Demand	Setup cost	Holding cost	Unit cost of production	Constraint	Planning horizon	Structure of the Model	Model class
Vujosevic et al. (1996)	Constant	Constant	$\frac{\tilde{c}_h c_p Q}{2 \times 100}$	Constant	No	Finite	Fuzzy	Defuzzifi-cation
Tripathy et al. (2009)	Constant	Constant	$\frac{Hr^2 q^2}{2\lambda}$	Reliability and demand	Reliability	Infinite	Fuzzy	NLP
Tripathy et al. (2011)	Constant	Constant	$\frac{H\lambda q^2}{2r^2}$	Reliability and demand	Reliability	Infinite	Fuzzy	NLP
Tripathy et al. (2011)	Constant	Constant	$\frac{Hq^2}{2r^2\lambda}$	Reliability and demand	Reliability	Infinite	Fuzzy	NLP
Roy et al. (1995)	Constant	Variable	$\frac{1}{2}C_1 q$	No	Space	Infinite	Fuzzy	NLP
Roy et al. (1997)	Constant	Variable	$\frac{1}{2}C_1 q$	Demand	Space	Infinite	Fuzzy	NLP, GPP
Present paper (2014)	Constant	Variable	$\frac{1}{2 \times 100} C_1 K D^{-\beta} q$	Demand	Space	Infinite	Fuzzy	GPP

In this paper a single item EOQ model is developed where unit price varies inversely with demand and setup cost increases with the increase of production. In company or industry, total expenditure for production and storage area are normally limited but imprecise, uncertain, non-specificity, inconsistency vagueness and flexible. These are defined within some ranges. However, the non stochastic and ill formed inventory models can be realistically represented in the fuzzy environment. The problem is reduced to a fuzzy optimization problem associating fuzziness with the storage area and total expenditure. The optimum order quantity is evaluated by fuzzy geometric programming (FGP) method and the results are obtained for linear membership functions. The model is illustrated with numerical example and with the variation in tolerance limits for both shortage area and total expenditure. A sensitivity analysis is presented. The numerical results for fuzzy and crisp models are compared.

The remainder of this paper is organized as follows. In section 2, assumptions and notations are provided for the development of the model and the mathematical formulation is developed. In section 3, mathematical analysis of fuzzy geometric programming (FGPP) is formulated. The solution of the FGPP inventory is derived in section 4. The numerical example is presented to illustrate the development of the model in section 5. The sensitivity analysis is carried out in section 6 to observe the changes in the optimal solution. Finally section 7 deals with the summary and the concluding remarks.

MATHEMATICAL MODEL

A single item inventory model with demand dependent unit price and variable setup cost under storage constraint is formulated as

Min C (D,q) = $C_{03}q^{\nu-1}D + KD^{1-\beta} + \frac{1}{2\times 100}C_1 KD^{-\beta}$q

s.t. Aq ≤B

∀ D, q > 0 (1)

where

q = number of order quantity,

D = demand per unit time

C_1 = holding cost per item per unit time.

C_3 = setup cost = C03 q^{ν},

(C_{03} (> 0) and ν (0< ν < 1) are constants)

P = unit production cost = $KD^{-\beta}$, K (> 0) and β (> 1) are constants.

Here lead time is zero, no back order is permitted and replenishment rate is infinite. A and B are nonnegative real numbers, B is the space constraint goal. The above model in a fuzzy environment is

$\widetilde{Min}$ C (D,q) = $C_{03}q^{\nu-1}D + KD^{1-\beta} + \frac{1}{2\times 100}C_1 KD^{-\beta}$q

s. t. Aq ≤ $\tilde{B}$

∀ D, q > 0 (2)

(A wavy bar (~) represents fuzzification of the parameters).

MATHEMATICAL ANALYSIS OF FUZZY GEOMETRIC PROGRAMMING (FGP)

A fuzzy non linear programming problem with fuzzy resources and objective are defined as

$\widetilde{Min}\ g_0$(x)

s.t. $g_i(x) \leq \tilde{b}_i$ i=1, 2, 3, ……m.

In fuzzy set theory, the fuzzy objective and fuzzy resources are obtained by their membership functions, which may be linear or nonlinear. Here μ_0 and μ_i (i = 1, 2 ...., m) are assumed to be non increasing continuous linear membership functions for objective and resources respectively such as

$$\mu_i\,(g_i(x)) = \begin{cases} 1 \ \ if\ g_i(x) < b_i, \\ 1 - \frac{g_i(x)-b_i}{P_i}\ if\ b_i \leq g_i(x) \leq b_i + P_i, \\ 0\ if\ g_i > b_i + P_i, \end{cases}$$

i = 0, 1, 2,...., m.

In this formulation, the fuzzy objective goal is b_0 and its corresponding tolerance is P_0 and for the fuzzy constraints, the goals are b_i's and their corresponding tolerances are P_i's (i = 1, 2, ..., m). To solve the equation (3), the max - min operator of Bellman et al. [1970] and the approach of Zimmermann [1976] are implemented.

The membership function of the decision set, $\mu_D(x)$, is

$\mu_D(x) = \min\{\mu_0(x), \mu_1(x), ..., \mu_m(x)\}, \forall x \in X$

The min operator is used here to model the intersection of the fuzzy sets of objective and constraints. Since the decision maker wants to have a crisp decision proposal, the maximizing decision will correspond to the value of x, x_{max} that has the highest degree of membership in the decision set.

$\mu_D(x_{max}) = \max_{x \geq 0}[\min\{\mu_0(x), \mu_1(x) \ldots, \mu_m(x)\}]$.

It is equivalent to solving the following crisp non linear programming problem.

$$\begin{aligned} &\text{Max } \alpha \\ &\text{s.t. } \mu_0(x) \geq \alpha \\ &\mu_i(x) \geq \alpha \ (i = 1, 2, \ldots, m) \qquad (4) \\ &\forall x \geq 0, \alpha \in (0, 1) \end{aligned}$$

If the objective function and the constraints, $g_0(x)$ and $g_i(x)$ (i = 1, 2, ...m) are of posynomial form, then the equation (3) reduces to a fuzzy geometric programming (FGP) problem. Proceeding as before, the expression (4) is obtained in an alternative farm as

$$\text{Min } \alpha^{-1}$$

$$\text{s.t. } \frac{g_i(x)}{b_i+P_i} + \frac{P_i}{b_i+P_i} \qquad (5)$$

$\forall \quad x \geq 0, \alpha \in (0, 1)$,

where $x = (x_1, x_2 \ldots x_n)^T$

Now the equation (5) is solved by the usual crisp geometric programming problem.

SOLUTION OF THE PROPOSED (FGP) INVENTORY MODEL

From Equation (2), it is obtained as per Equation (5)

Min α^{-1}

s.t.

$$B_1 D q^{\nu-1} + B_2 D^{1-\beta} + B_3 D^{-\beta} q + B_4 \alpha \leq 1$$

$$B_5 q + B_6 \alpha \leq 1$$

$$\forall \quad D, q > 0, \alpha \in (0, 1) \qquad (6)$$

where

$$B_1 = \frac{C_{03}}{(C_0 + P_0)}, \ B_2 = \frac{K}{(C_0 + P_0)}$$

$$B_3 = \frac{C_1 K}{2 \times 100 (C_0 + P_0)}, \ B_4 = \frac{P_0}{C_0 + P_0}$$

$$B_5 = \frac{A}{(B+P)}, \ B_6 = \frac{P}{B+P}$$

The dual of Equation (6) is given by

$$\text{Max } d(\lambda) = \left(\frac{1}{\lambda_0}\right)^{\lambda_0} \left(\frac{B_1}{\lambda_1}\right)^{\lambda_1} \left(\frac{B_2}{\lambda_2}\right)^{\lambda_2} \left(\frac{B_3}{\lambda_3}\right)^{\lambda_3} \left(\frac{B_4}{\lambda_4}\right)^{\lambda_4} \times \left(\sum_{i=1}^{4} \lambda_i\right)^{\sum_{i=1}^{4} \lambda_1} \left(\frac{B_5}{\lambda_5}\right)^{\lambda_5} \left(\frac{B_6}{\lambda_6}\right)^{\lambda_6} \left(\sum_{i=5}^{6} \lambda_i\right)^{\sum_{i=5}^{6} \lambda_i} \qquad (7)$$

where,

$$\begin{aligned} &\lambda_0 = 1 \\ &-\lambda_0 + \lambda_4 + \lambda_6 = 0 \\ &\lambda_1 + (1-\beta)\lambda_2 + (-\beta)\lambda_3 = 0 \\ &(\nu - 1)\lambda_1 + \lambda_3 + \lambda_5 = 0 \end{aligned}$$

Let $\lambda_1 = t_1$, $\lambda_3 = t_2$, $\lambda_4 = t_3$, solving the above equations,

$\lambda_2 = (\beta t_2 - t_1) / (1 - \beta)$

$\lambda_5 = (1 - \nu) t_1 - t_2$

$\lambda_6 = 1 - t_3$, and then, the above dual expression becomes

$$\text{Max } d(t_1, t_2, t_3) = \left(\frac{B_1}{t_1}\right)^{t_1} \left(\frac{B_2(1-\beta)}{(\beta t_2 - t_1)}\right)^{(\beta t_2 - t_1)/(1-\beta)} \left(\frac{B_3}{t_2}\right)^{t_2} \left(\frac{B_4}{t_3}\right)^{t_3}$$

$$\left(\frac{B_5}{((1-\nu)t_1 - t_2)}\right)^{(1-\nu)t_1 - t_2} \left(\frac{B_6}{1-t_3}\right)^{1-t_3} \left(t_1 + \frac{\beta t_2 - t_1}{1-\beta} + t_2 + t_3\right)^{t_1 + \frac{\beta t_2 - t_1}{1-\beta} + t_2 + t_3} \times$$

$$(1 + (1-\nu)t_1 - t_2 - t_3)^{1 + (1-\nu)t_1 - t_2 - t_3} \qquad (8)$$

Solving the equations $\frac{\partial d}{\partial t_1} = 0, \frac{\partial d}{\partial t_2} = 0, \frac{\partial d}{\partial t_3} = 0$, t_1^*, t_2^*, t_3^* are evaluated and here λ_0^*,

$\lambda_1^*, \lambda_2^*, \lambda_3^*, \lambda_4^*, \lambda_5^*, \lambda_6^*$ are also determined Therefore, optimum values are

$$q^* = \frac{\lambda_5^*}{B_5^*}(\lambda_5^* + \lambda_6^*)^{-1}, D^* = \left(\frac{\lambda_2^*}{B_2^*}(\lambda_1^* + \lambda_2^* + \lambda_3^* + \lambda_4^*)^{-1}\right)^{\frac{1}{1-\beta}}, \quad \alpha^* = \frac{\lambda_4^*}{B_4^*}(\lambda_1^* + \lambda_2^* + \lambda_3^* + \lambda_4^*)^{-1}$$ and

$$C^*(D^*, q^*) = C_{03} q^{*\nu-1} D^* + K D^{*1-\beta} + \frac{1}{2\times 100} C_1 K D^{*-\beta} q^*$$

So, by FGP technique, the optimal values of q, D and α the corresponding minimum cost are evaluated for the known values of other parameters.

NUMERICAL EXAMPLE

For a particular EOQ problem, let C_{03} = Rs. 200, K = 100, C_1 = Rs. 100, ν = 0.5, β = 1.5, A = 10 units, B = 50 units, C_0 = Rs. 2000 and $P_0 = 20$ and P=15 units. For these values the optimal value of productions batch quantity q*, optimal demand rate D*, minimum average total cost C* (D*, q*) and Aq* obtained by FGP are given in Table 2.

After 66 iterations Table 2 reveals the optimal replenishment policy for single item with demand dependent unit cost and dynamic setup cost. In this table the optimal numerical results of fuzzy model are compared with the results of crisp model. The optimum replenishment quantity q^* and Aq^* are both -6.56% and 12.93% more than that of fuzzy and crisp models of Roy et al. [1981] respectively, the optimum quantity demand D^* is 9.70 but 9.81 and 9.21 for comparing models, hence 5.34% more from the crisp model and -1.06% less from the other fuzzy model. The minimum total average cost $C^*(D^*, q^*)$ is 48.62 but 49.60 and 53.93 comparing models, hence -10.67% and -9.85% less from crisp and other fuzzy model respectively.

Table 2. Optimal values for the proposed inventory model
Tabela 2. Optymalne wartości dla proponowanego modelu zapasów

Model	Method	Iteration	q^*	D^*	$C^*(D^*, q^*)$	α^*	Aq^*
Fuzzy model	FGP	66	5.646723	9.702505	48.623	0.56885	56.46723
Fuzzy model, Roy et al. (1997)	FGP	-	6.043	9.8068	53.9328	0.3043	60.43
% Change	-	-	-6.5576	-1.0635	-9.8452	86.9372	-6.5576
Crisp Model, Roy et al. (1997)	NLP	-	5	9.21	54.43	1	50
% Change	-	-	12.93446	5.34750	-10.6687	-43.115	12.93446

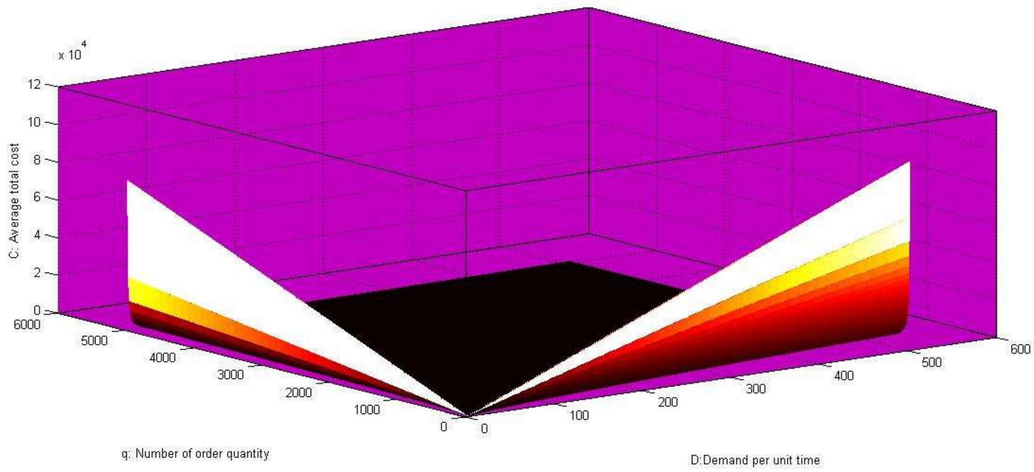

Fig. 1. Mesh plot of Demand per unit time, number of order quantity q and average total cost C
Rys. 1. Wykres popytu w jednostce czasu, liczby zamówień wielkości q i średniego kosztu C

It permits the better use of present fuzzy model as compared to the crisp model and other fuzzy model. The results are justified and agree with the present model. It indicates the consistency of the fuzzy space of EOQ model from other models. Fig. 3 depicts the mesh plot of demand per unit time D, number of order quantity q and average total cost C (D, q).

SENSITIVITY ANALYSIS

Now the effect of changes in the system parameters on the optimal values of q, D, C (D, q) and Aq when only one parameter changes and others remain unchanged the computational results are described in Tables 3 and 4. As a result α^*, q^*,D^*, $C^*(D^*,q^*)$ and Aq^* are less sensitive to the parameters P_0 and P. Following Dutta et al. [1993] and Hamacher et al. [1978] it is observed that the effect of tolerance in the said EOQ model with the earlier numerical values and construct Tables 3 and 4 for the degrees of violation $T_0(=(1-\alpha)P_0)$ and T(=(1-α)P) for two constraints given by equation (6) .

From Table 3, it is seen that: (i) For higher tolerances of P_0, the value of α_{max} does not achieve 1, (ii) For higher acceptable variations P_0, the optimal solutions remain invariant and the optimal solutions are very close to the solutions (q^* =5.646723, $D^*=9.702505$, $C^*(D^*,q^*)=48.62299$ and $Aq^*=56.46723$) of fuzzy model and (q^* =5, $D^*=9.308755$, $C^*(D^*,q^*)=49.60392$ and $Aq^*=50)$ of the crisp model without tolerance ($\alpha=1$) respectively.

From Table 4 it is shown that: (i) For different values of P, degrees of violations T_0 and T are never zero, i.e. different optimal solutions are obtained. (ii) As P increases from 16, the minimum average cost $C^*(D^*,q^*)$ decreases, q^* and D^*increase.

Table 3. Sensitivity Analysis on P_0
Tabela 3. Analiza wrażliwości na P_0

P_0	Iteration	α^*	q^*	D^*	T_0	T	$C^*(D^*,q^*)$	Aq^*
25	64	0.648263	5.527604	9.632260	8.793425	5.276055	48.79344	55.27604
50	36	0.802115	5.275082	9.825778	9.89425	2.968275	49.18562	52.75082
100	45	0.895938	5.140674	9.613929	10.4062	1.56093	49.38490	51.40674
150	44	0.936990	5.094514	9.368276	9.4515	0.94515	49.45155	50.94514
200	51	0.952556	5.071165	9.353637	9.4888	0.71166	49.48888	50.71165
1000	54	0.990419	5.014369	9.317855	9.581	0.143715	49.58054	50.14369

Table 4. Sensitivity Analysis on P
Tabela 4. Analiza wrażliwości na P

P	Iteration	α^*	q^*	D^*	T_0	T	$C^*(D^*,q^*)$	Aq^*
16	66	0.571577	5.685475	9.725153	8.56846	6.854768	48.56846	56.85475
20	87	0.581970	5.836061	9.812222	8.3606	8.3606	48.36059	58.36061
23	62	0.589273	5.944672	9.874131	8.21454	9.446721	48.21454	59.44672
36	33	0.616977	6.378881	10.11459	7.66046	13.78883	47.66046	63.78881
38	70	0.620764	6.441093	10.14817	7.58472	14.41097	47.58471	64.41093
40	63	0.624444	6.502223	10.18096	7.51112	15.02224	47.51111	65.02223

CONCLUSIONS

Inventory modelers have so far considered type of setup cost that is fixed or constant. This is rarely seen to occur in the real market. In the opinion of the author, an alternative (and perhaps more realistic) approach is to consider the setup cost as a function quantity produced / purchased may represent the tractable decision making procedure in fuzzy environment. In constraint to Roy et al. [9], the approach in this paper provides solutions better than those obtained by using properties and this paper the real life inventory models for single item in fuzzy environment by FGP technique is investigated. A new mathematical model is developed and numerical example is provided to illustrate the solution procedure. The new modified EOQ model was numerically compared to the traditional EOQ model. Some sensitivity analyses on the tolerance limits have been presented. The results of the fuzzy models are compound with those of crisp model which reveals that fuzzy models obtain better result than the usual crisp models. Finally, the effect of decision space was demonstrated numerically to have an adverse affect on the total average cost per unit. This method is quite general and despite this, this paper has primarily focused on reducing the total average cost with storage constraint. Further research is required to achieve a better trade-off between the constraint and total average cost, thus maximizing market value through greater flexibility/capability in decision parameters to match dynamic ordering cost and demand dependent unit cost and it can be again extended to other similar inventory models including the ones with shortages and deteriorate items.

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ROZMYTE PODEJŚCIE PODEJMOWANIA DECYZJI W PROGRAMOWANIU GEOMETRYCZNYM DLA JEDNOARTYKUŁOWEGO MODELU EOQ

STRESZCZENIE. **Wstęp i metody:** Rozmyte podejmowanie decyzji jest akceptowalną metodą postępowania w programowania geometrycznym dla pojedynczego artykułu w modelu EOQ ze zmiennym kosztem zamówienia oraz jednostkowym kosztem zależnym od popytu. Koszty przezbrojeń zmieniają się wraz z wielkością produkcji/zakupu. Analizie poddano modyfikacje zmiennych funkcji magazynowania w zależności od estymowanych parametrów. Problem ten obejmuje takie zagadnienia jak rozmyte podejście arytmetyczne, wielkość zamówienia, wielkość popytu. Omówiono zarówno metodę rozmytego programowania geometrycznego jak i inne zagadnienie związane z programowaniem liniowym.
Wyniki i wnioski: Analiza właściwości optymalnego rozwiązania pozwoliła na stworzenie algorytmu, którego poprawność przedstawiono na przykładzie liczbowym. Rezultaty zostały poddane dyskusji. Analiza wrażliwości rozwiązania optymalnego została wykonana przy różnych zmianach wartości parametrów.

Słowa kluczowe: rozmyty, GPP, koszty przezbrojenia, EOQ, pojedynczy artykuł.

EINE UNSCHARFE VORGEHENSWEISE BEIM ENTSCHEIDUNGSTREFFEN IM GEOMETRISCHEN PROGRAMMIEREN FÜR EINZELARTIKEL IM EOQ-MODELL

ZUSAMMENFASSUNG. Einleitung und Methoden: Das unscharfe Entscheidungstreffen ist heutzutage eine akzeptable Vorgehensweise beim geometrischen Programmieren für Einzelnartikel im EOQ-Modell mit variablen Bestellungskosten und den von der Nachfrage abhängigen Einzelkosten.Die Umrüstungskosten verändern sich gemäß den Produktions- und Einkaufsgrößen. Einer betreffenden Analyse wurden Modifikationen von variablen Lagerfunktionen in Abhängigkeit von den estimierten Parametern unterzogen. Die Problemstellung umfasst solche Fragestellungen wie unscharfe arithmetische Vorgehensweise und die Bestellungs- und Nachfragegrö?en. Es wurden dabei sowohl die Methode des unscharfen, geometrischen Programmierens, als auch andere mit dem linearen Programmieren zusammenhängende Fragen erörtert.
Ergebnisse und Fazit: Die Anlyse der Vorteile einer opitmalen Lösung erlaubte die Erstellung eines Algorithmus, dessen Richtigkeit anhand eines zahlenmäßigen Beispieles projiziert und nachgewiesen wurde. Die Ergebnisse wurden einer Diskussion unterzogen. Die Analyse der Empfindlichkeit der opitmalen Lösung wurde bei den sich verändernden Parameter-Werten vorgenommen.

Codewörter: uscharf (fuzzy), GPP, Umrüstungskosten, EOQ, Einzelartikel

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