Modeling of Decision-making Processes to Ensure Sustainable Operation of Multiservice Communication Network

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Abstract. This paper shows the modeling of decision-making processes to ensure stable operation of multiservice communication networks (MCNs) using the mathematical apparatus of fuzzy logic models. A classification of the main factors affecting the stability of an MCN is given. The main factors affecting the structural stability of MCNs are external factors, internal factors, energy factors, and maintenance factors. A decision-making strategy (DM) was chosen. The main factors that affect the stability of the functioning of an MCN are characterized by heterogeneity. Therefore, the task of the DM to ensure stability of the functioning of the MCN was reduced to producing a sequential solution of the following interrelated tasks: identification of the MCN by a systematic analysis of the main factors affecting the stability of the MCN, ranking the states of the MCN, and definition of the decision-making criteria. The first point is implemented by setting up a complex model of the MCN based on integration of the principles of fuzzy set theory (FST). A promising method for choosing a rational alternative is the method of non-dominated alternatives (MNDA), based on the aggregation of fuzzy information to characterize the relationship between the alternatives according to certain criteria.

Keywords: *algorithm of rational choice of alternatives; energy factors; falsified information; fuzzy set theory; maintenance factors; multi-service communications network; structurally complex system; method of non-dominated alternatives; system fuzzy-logic models.*

1 Introduction

A multiservice communication network (MCN) is a structurally complex system with dispersed objects and processes. Violation of the stability of a multiservice communication network, even for a short time interval, can lead to the loss of a large amount of information, serious technical and financial consequences, and deterioration of the quality of services. To analyze the methods of improving reliability, it is necessary to specify the question of how the reliability indicators of information and communication systems can be

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evaluated. Currently, several methods and parameters have been developed that are effectively used to characterize the state of reliability of such systems. Below, the main parameters for characterizing the degree of reliability of the components and the network as a whole are discussed in a systematic way.

MCN reliability is characterized by two aspects. The first is the reliable functioning of its components. The second is the ability of the network to continue to function when individual components fail. The first characteristic of reliability is determined by the network's availability to work. The second characteristic consists of structural solutions that allow traffic to choose routes and processing systems that bypass failed network components.

Methods to improve reliability, as a rule, are divided into structural and informational. Increasing the level of MCN reliability with the help of structural methods is achieved, first of all, by minimizing design, technological and operational errors, i.e. eliminating the causes of network failure. Redundancy is a way to improve reliability, which consists of duplicating individual modules or MCN elements, which involves the inclusion of additional elements that allow compensating for failures of individual parts of devices and ensure the MCN's reliable operation.

Three types of redundancy can be distinguished: (a) permanent redundancy (redundant elements are included together with the main one and operate in the same mode), (b) substitution reservation, and (c) sliding reservation.

Information methods for improving the reliability of MCNs are implemented through the use of correction code. In this regard, it is necessary to develop a science-based methodology for the investigation of MCNs from the perspective of system analysis of its components and decision-making. The main tool for the implementation of such an approach is the integration of the principles of the theory of fuzzy sets (TFS), which is a promising way of investigating complex systems, for example the topology and structure of MCNs, to find small (short-term) disturbances (noise), violations of the reliability of individual elements or nodes, short-term power outages, and other causes [1]. The main factors affecting the structural stability of MCNs are external factors, internal factors, energy factors, and maintenance factors [2,3].

2 Problem Statement

2.1 Choice of Decision-Making (DM) Strategy

The main factors that affect the stability of an MCN are characterized by heterogeneity, i.e. requiring different measurement scales (quantitative, qualitative). Therefore, we reduced the task of the DM to ensure sustainability of the operation of the MCN to producing a sequential solution of the following interrelated tasks:

1. Identification of the status of the MCN through a systematic analysis of the main factors affecting the stability of the MCN.
2. Ranking of MCN states.
3. Determination of decision-making criteria.

The implementation of the first DM point is carried out by setting up a complex MSS model based on integration of the principles of the theory of fuzzy sets (TFS) as in following Eqs. (1) to (5):

$$S = f_S(S_1, S_2, S_3, S_4), \tag{1}$$

$$S_1 = f_{S_1}(x), \tag{2}$$

$$S_2 = f_{S_2}(y), \tag{3}$$

$$S_3 = f_{S_3}(z), \tag{4}$$

$$S_4 = f_{S_4}(p), \tag{5}$$

The following designations are accepted here:

S – <multiservice communication networks providing different types of services> S$\{S_1, S_2, S_3, S_4\}$
S_1 – <access level>
S_2 – <transport layer>
S_3 – <level of management>
S_4 – <level of service >
x, y, z – influence of external, internal and energy factors
p – maintenance factor

Assessment of the stability of an MCN on the basis of complex model (1) is implemented by designing an information model of the MCN based on the information unit for each item (object, communication node, station) presented in the form of an information matrix $A^U = (a_{ij}), i = \overline{1, n}; j = \overline{1, m},$ where the elements a_{ij} are formed as in Eq. (6):

$$A = (a_{ij}), a_{ij} = i_1 i_2 i_3 i_4 i_5 i_6 i_7 i_8 i_9 \tag{6}$$

i_1 – access network equipment, i_1 = 1 – various terminals, i_1 = 2 – equipment of different gateways, i_1 = 3 – IAD equipment, i_1 = 4 – DSLAM equipment, i_1 = 5 – MSAN equipment, i_1 = 6 – communication channel; i_2 – transport level equipment, i_2 = 1 – communication channel, i_2 = 2 – layer 3 switch equipment,

i_2 = 3 – router equipment; i_3 – control level equipment, i_3 = 1 – communication channel, i_3 = 2 – softswitch hardware; i_4 = equipment level of service, i_4 = 1 – communication channel, i_4 = 2 – application server hardware, i_4 = 3 – database server hardware, i_4 = 4 – file server, i_4 = 5 – 'wireless' server, i_4 = 6 – proxy server, i_4 = 3 – mail server, i_4 = 3 – DHCP server; $i_5 i_6 i_7 i_8 i_9 = 1 \div 3$ – influence of factors, i_5 = 1 – BN (below normal), i_5 = 2 – N (within the norm), i_5 = 3 – AN (above the norm), i_6 – external factors, i_7 – internal factors, i_8 – energy factors, i_9 – maintenance factors.

The initial values of the parameters $i_1 - i_4$ are determined on the basis of the MCN topology, whereas $i_5 - i_9$ are determined on the basis of appropriate calculations, modeling, expert assessments, etc.

Further, on the basis of this information, a set of possible situations, $S = (x_{ij}^H, y_{ij}^H, z_{ij}^H, p_{ij}^H)$, is formed on the basis of which the information model is formed in matrix form.

Here, $x_{ij}^H, y_{ij}^H, z_{ij}^H, p_{ij}^H$ are acceptable values of external, internal, energy and service factors.

Further, the set of possible situations, S_{ij}^B, is formed. Let us introduce the following term-set types: SBN (significantly below normal), BN (below normal), N (normal), AN (above the norm), SAN (significantly above the norm), meaning <much lower than the norm>, <below the norm>, <normal>, <much higher than the norm>. These will allow the set of possible situations (S^B) to highlight the set of typical situations (S^T), i.e. $S^T \subset S^B$, card (S^T)$\ll$card (S^B).

A set of typical situations sufficiently describes the possible state of the object (MCN), taking into account uncertain factors affecting the stability of the MCN [4,5].

3 Problem Decision

Thus, it can be stated that a limited set of fuzzy situations (typical) can describe an almost infinite number of states of the control object (the MCN). Based on the situation analysis, the decision process to ensure sustainable functioning of the MCN can presented in the following order:

1. Many possible situations formed (S^B);
2. The set of typical situations (S^T) is determined, the input situation (S^B) for the object (communication node, station, etc.) is compared with the typical

situations from S^T stored in the database, and the output fuzzy situation is determined;

3. Based on the analysis of the output, the fuzzy situation necessary for the situation solution is determined;
4. At the same time, to formalize the fuzzy situation constructions of the following form are used:

$$< \Delta\widetilde{U}, R, \widetilde{C_{(\iota)}} > \quad (7)$$

where $\Delta\widetilde{U}=\begin{pmatrix}\Delta\tilde{x}\\ \Delta\tilde{y}\\ \Delta\tilde{z}\\ \Delta\tilde{p}\end{pmatrix}, R = \begin{pmatrix}x\\ y\\ z\\ p\end{pmatrix}, \widetilde{C_{(\iota)}}=\begin{pmatrix}\widetilde{C_{(1)}}\\ \widetilde{C_{(2)}}\\ \widetilde{C_{(3)}}\\ \widetilde{C_{(4)}}\end{pmatrix}$

$\Delta\widetilde{U}$ are the considered language evaluation factors, R is the universe according to the factors, $\widetilde{C_{(\iota)}}$ – function that sets the changes of the factors determined by:

$$\widetilde{C_{(\iota)}} = \{< \alpha_i/T_1^i >, < \beta_i/T_2^i >, < \gamma_i/T_3^i >, < \delta_i/T_4^i >, < \eta_i/T_5^i >\}, \quad (8)$$

where $T_1^i, T_2^i, T_3^i, T_4^i, T_5^i$- is the linguistic assessment of changes of factor i, the essence of the elements of the set {SBN, BN, N, AN, SAN}.

The subsystem of fuzzy information processing receives falsified information about changes in the factors (x, y, z, and p), checks the MCN for the presence of violations of the standard of functioning, diagnoses the condition, i.e. model (1) defines a fuzzy estimation of states S_1, S_2, S_3, S_4, i.e. $\mu(S_1)$, $\mu(S_2)$, $\mu(S_3)$, $\mu(S_4)$.

The decisions, depending on the state (situation) of the MCN, may have a preventive, warning, localization or recovery nature.

In the next stage, the issues of choosing the management decision and its justification are solved. At the same time, the following designations are introduced in relation to the decisions (alternatives):

A_U – < any possible solutions >
A_D – < the set of feasible possible solutions >
$A_U^{\text{ПР}} -< \textit{the set of solutions of a preventive nature} (PC) >$
$A_U^{\text{П}} -< \textit{the set of solutions of a warning nature} (W) >$
$A_U^{\text{вс}} -< \textit{the set of solutions of a restorative nature} (R) >$
$A_U^{\text{Л}} -< \textit{the set of solutions of alocalization nature} (L) >$

It is clear, that

$$A_D \subset A_U,\ A_U = A_U^{\text{ПР}} \cup A_U^{\text{П}} \cup A_U^{\text{вс}} \cup A_U^{\text{Л}} \quad (9)$$

It is advisable to represent the A_U set as a matrix $A = (a_{ij})$ based on Table 1, where i = 1,2,3,4 are the numbers of the alternatives, chosen according to the set {PC,W, R, L}.

Table 1 Classification of main factors affecting the stability of multiservice communication networks.

Factors	Decision-alternatives
External factors: - physical origin - deliberate	1. Correcting code 2. Feedback methods 3. Cryptography 4. Duplication 5. Repair 6. Training of maintenance personnel in decision-making under the influence of external factors
Internal factors: - parametric failures (failures) - catastrophic failures (damage)	1. Reservation parameter 2. Regulation of power supply 3. Frequency control voltage 4. Damage reservation 5. Damage repair 6. Training of maintenance personnel in decision-making under the influence of internal factors
Energy factors: - short-term trips - renewable energy	1. Automatic reserve entry 2. Damage reservation or repair 3. Switching to a backup source to accept energy factors 4. Training of maintenance personnel in decision-making under the influence of energy factors
Service factors: - poor training of maintenance personnel, - lack of necessary training material for the operation of the MCN, - no way of quickly checking the level of readiness of staff to work	1. Development of electronic training materials for training and testing the level of knowledge and skills of staff

The element $a_{ij} \in A$ means the choice of a solution corresponding to factor i. For example, a_{34} is the choice of a solution of a reducing nature in accordance with the energy factors (short-term or emergency shutdown, choice of energy type). In this case, the choice of a specific solution (alternative) from the possible solutions is based on the adopted evaluation criteria [6]. Criteria for decision-making can be reliability, efficiency, ease of use, security, reliability, etc.

3.1 Substantiation

The formation of sets of possible alternatives (A_U, A_D), as well as decision-making (warning, preventive, localization or restorative) is very complex and is based on verbal assessment of the impact of the factors on the stability of the MCN. Testing the validity of the decisions is advisable to be implemented through the involvement of leading experts (experts) serving the MCN. The head of the expert group – the person decision-maker (PDM) – forms the group of experts, i.e. persons competent in the operation and maintenance of the MCN. Further, from them a group of experts is formed with a stable opinion (GSO) on the results of the survey in different conditions. The choice of the best alternative solutions ($A_U^{\text{ПР}}, A_U^{\text{П}}, A_U^{\text{вс}}, A_U^{\text{Л}}$) is based on fuzzy-multiple analysis of the MCN information model formed on the basis of the results of the fuzzy-logical model (1)-(5) and a set of typical situations.

At the same time, the person decision-maker (PDM) focuses on the following possible consequences of the factors' influence on the stability of the MCN: deterioration of the quality of the transmitted information, reduction of the amount of information transmitted, the occurrence of short-term and long-term interruptions in the data transmission system, distortion of the content of the transmitted information [7,8].

In addition, when choosing the best alternatives, the PDM or the group of experts assesses the selected solution based on the following criteria (determined by experts): reliability, efficiency, efficiency, ease of use, security, etc. A promising method of choosing a rational alternative is the method of non-dominated alternatives (MNDA) of Orlovsky, based on the aggregation of fuzzy information characterizing the relationship between alternatives according to certain criteria.

3.2 Formation of Original Data

1. According to the MNDA algorithm a set of alternatives $X = \{x_1, x_2, \ldots., x_n\}$ is introduced and sets of features $P = \{p_1, p_2, \ldots, p_n\}$ characterizing each of the alternatives.
2. For each feature $P_l \in P$, R_l, $l = 1 \div r$, matrices of non-strict preference are constructed based on the principle $R_l = \left[\mu_{R_l}(x_i, x_j)\right], i, j = 1, \bar{n}$.

Some problems can be solved by taking measures without incurring any costs ('preventive' solutions); more complex damage can be solved by attracting highly qualified specialists or carrying out more complex preventive works ('prophylactic' solutions); some damages can be fixed by 'overhanging' (i.e. replacing a certain part that failed) of the specific equipment ('local' solution), or replacing the failed equipment with a completely new one ('restoring' solution). In the next stage, the issues of choosing the governing decision and its justification are resolved.

3.3 Algorithm for Choosing a Rational Alternative

1. The intersection of relations (R_l) is found:

$$Q_1 = R_1 \cap R_2 \cap \ldots \cap R_l$$

2. Q_1 is the non-dominated set of alternatives according to the algorithm. For Q_1, the transposed matrix Q_1^{-1} is determined by the principle:

$$\mu_{Q_1^{-1}}(x, y) = \mu_{Q_1}(y, x).$$

The matrix Q_1 is formed based on the principle:

$$q_1^0(x, y) = \mu_{Q_1^0}(x, y) = \max\left(0, \mu_{Q_1^{-1}}(x, y) - \mu_{Q_1}(y, x)\right).$$

The maximum values of the elements of each line Q_1^0 are determined by:

$$\lambda(x_i) = max\{q_1^0 i, j\};$$

Calculate $\mu_{Q_1^{HD}}(x_i) = \lambda(x_i), i = 1, \overline{n}.$
Formed set Q^{HD}:

$$\mu_{Q^{HD}}(x_i) = \left\{\frac{\mu_{Q_1^{HD}}(x_1)}{x_1}, \frac{\mu_{Q_2^{HD}}(x_2)}{x_2}, \ldots., \frac{\mu_{Q_n^{HD}}(x_n)}{x_n}\right\}.$$

3. R^{HD} is defined for R; let $l_1 = \mu_{R^{HD}}(P_1), l_2 = \mu_{R^{HD}}(P_2), \ldots, l_r = \mu_{R^{HD}}(P_r)$. Calculated using the weights for each of the signs in the formula:

$$t_i = \frac{l_i}{\sum_{i=1}^{r} l_i}, j = 1; i = 1, r.$$

4. Matrix Q_2 is constructed by the formula:

$$\mu_{Q_2}(x, y) = \sum_{m=1}^{r} t_m \mu_{R_m}(x, y)$$

Example. Let there be a need to solve a problem in the operation of an MCN that depends on the energy factors. Let us assume that the PDM has the following alternative solution for the energy factors [9,10].

For example:

$$\begin{cases} x_1 - < \text{automatic reserve entry} > \\ x_2 - < \text{preservation or repair of damages} > \\ x_3 - < \text{switching to a redundant industrial network source} > \\ x_4 - < \text{service personnel training} > \end{cases}$$

The best selection criteria can be: reliability P_1, efficiency P_2, ease of application P_3, security P_4.

It is advisable to present set A_S in the form of a matrix, $A = (a_{ij})$, based on Table 1, where i = 1,2,3,4 are the numbers of the alternatives chosen in accordance with set $\{PS, P, L, RS\}$. Element $a_{ij} \in A$ means the choice of a solution corresponding to factor i. For example, a_{34} is the choice of a solution of a restoration nature in accordance with engineering factors (short-term or emergency shutdown, choice of energy type, etc.).

4 Results

According to the proposed algorithm, the MDNA fuzzy information is represented in the form of preference matrices:

$$R_1 = \begin{matrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{matrix} \begin{bmatrix} 1 & 0.6 & 0.8 & 0.6 \\ 0.2 & 1 & 0.5 & 0.7 \\ 0.7 & 0.4 & 1 & 0.3 \\ 0.2 & 0.4 & 0.2 & 1 \end{bmatrix}, \quad R_2 = \begin{matrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{matrix} \begin{bmatrix} 1 & 0.4 & 0.7 & 0.8 \\ 0.7 & 1 & 0.6 & 0.6 \\ 0.7 & 0.6 & 1 & 0.4 \\ 0.2 & 0.3 & 0.2 & 1 \end{bmatrix},$$

$$R_3 = \begin{matrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{matrix} \begin{bmatrix} 1 & 0.7 & 0.3 & 0.6 \\ 0.2 & 1 & 0.4 & 0.3 \\ 0.6 & 0.3 & 1 & 0.4 \\ 0.8 & 0.4 & 0.2 & 1 \end{bmatrix}, \quad R_4 = \begin{matrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{matrix} \begin{bmatrix} 1 & 0.8 & 0.7 & 0.2 \\ 0.3 & 1 & 0.4 & 0.2 \\ 0.7 & 0.3 & 1 & 0.3 \\ 0.8 & 0.7 & 0.8 & 1 \end{bmatrix}$$

Step 1. Let us formulate matrix Q_1:

$$Q_1 = \begin{bmatrix} 1 & 0.4 & 0.3 & 0.2 \\ 0.2 & 1 & 0.4 & 0.2 \\ 0.6 & 0.3 & 1 & 0.3 \\ 0.2 & 0.3 & 0.2 & 1 \end{bmatrix}$$

Step 2. Find Q_1^{HD}:

$$Q_1^{-1} = \begin{bmatrix} 1 & 0.2 & 0.6 & 0.2 \\ 0.4 & 1 & 0.3 & 0.3 \\ 0.3 & 0.4 & 1 & 0.2 \\ 0.2 & 0.2 & 0.3 & 1 \end{bmatrix};$$

$$Q_1^0 = \begin{bmatrix} 0 & 0 & 0.3 & 0 \\ 0.2 & 0 & 0 & 0.1 \\ 0.3 & 0.1 & 0 & 0 \\ 0 & 0 & 0.1 & 0 \end{bmatrix}.$$

Q_1^{HD}:

$S_{Q_1^{HD}}(x_1) = 1 - 0.3 = 0.7;$

$S_{Q_1^{HD}}(x_3) = 1 - 0.3 = 0.7;$

$S_{Q_1^{HD}}(x_4) = 1 - 0.1 = 0.9.$

Answer: $S_{Q_1^{HD}}(x) = \left\{\frac{0.7}{x_1}; \frac{0.8}{x_2}; \frac{0.7}{x_3}; \frac{0.9}{x_4}\right\}.$

Step 3. Find R^{HD}:

$$R^{-1} = \begin{bmatrix} 1 & 0.7 & 0.6 & 0.7 \\ 0.8 & 1 & 0.7 & 0.2 \\ 0.3 & 0.6 & 1 & 0.8 \\ 0.6 & 0.5 & 0.8 & 0.7 \end{bmatrix}$$

Calculate Q_2:

$S_{R^{HD}}(P) = \left\{\frac{0.7}{P_1}; \frac{0.9}{P_2}; \frac{1}{P_3}; \frac{1}{P_4}\right\};$ $t_1 = 0.19$; $t_2 = 0.25$; $t_1 = 0.28$; $t_1 = 0.28$.

$$S_{Q_2} = \begin{bmatrix} 1 & 0.63 & 0.6 & 0.54 \\ 0.56 & 1 & 0.47 & 0.42 \\ 0.67 & 0.4 & 1 & 0.35 \\ 0.88 & 0.46 & 0.37 & 1 \end{bmatrix};$$

$$S_{Q_2}^{-1} = \begin{bmatrix} 1 & 0.56 & 0.67 & 0.88 \\ 0.63 & 1 & 0.4 & 0.46 \\ 0.6 & 0.47 & 1 & 0.37 \\ 0.54 & 0.42 & 0.35 & 1 \end{bmatrix};$$

$$S_{Q_2}^{0} = \begin{bmatrix} 0 & 0 & 0.07 & 0.34 \\ 0.07 & 0 & 0 & 0.04 \\ 0 & 0.07 & 0 & 0.02 \\ 0 & 0 & 0 & 0 \end{bmatrix};$$

Step 4.

$S_{Q_2^{HD}}(x_1) = 0.66;$

$S_{Q_2^{HD}}(x_2) = 0.93;$

$S_{Q_2^{HD}}(x_3) = 0.93;$

$S_{Q_2^{HD}}(x_4) = 1;$

$S_{Q_2^{HD}}(x) = \left\{\frac{0.66}{x_1}; \frac{0.93}{x_2}; \frac{0.93}{x_3}; \frac{1}{x_4}\right\}.$

Step 5.

$$Q = Q_1^{HD} \cap Q_2^{HD} = \left\{\frac{0.66}{x_1}; \frac{0.8}{x_2}; \frac{0.7}{x_3}; \frac{0.9}{x_4}\right\}$$

Thus, the best solution is x_4 , x_2, x_3, and x_1.

The operation of the algorithm was tested on a specific example. Baseline data were borrowed from a company that maintains a modern network.

The value of K_r (coefficient of readiness) was determined on the basis of the above formulas. For example, the K_r of the gateway is equal to

$$K_r^g=T_0^g/(T_0^g+T_в^g)=8758/(8758+3)=0,99965.$$

The degree of reliability of the access level is defined as the product of the availability factors of all of its components, that is:

$$K_r^{al} = \prod_{j=1}^{8} K_r^j = 0,9954$$

As can be seen, the current value of K_r^{al} of the access network is in the 'two nine' area. This is an average result.

The adoption of specific measures to increase the value of availability is implemented using a program that determines vulnerable points on the basis of the initial data. For our example, such sections turned out to be trunk and terminal communication channels as well as some gateways. Further, due to the allocated funds (defined in relative units) and the available opportunities, specific measures are applied, after which a new Kr value of the access network is calculated:

$$K_r^{al} = \prod_{j=1}^{8} K_r^j = 0,9970$$

This is an average result that can be taken as normal.

5 Conclusions

A system of fuzzy-logical models (1)-(5) was used to identify MCN states, after which the fuzzy model of the process of stable operation of the MCN of the following nature was designed:

If the influence of external factors (x) = (L – low, A – average, H – high)
and the influence of internal factors (y) = (L, A, H),
and the influence of energy factors (z) = (L, A, H),
and the effect of service factors (P) = (L, A, H),
and the stability of the MCN (S) = (L, A, H).

The quantitative assessment of the stability of the MCN (S)* for specific values (numerical, linguistic) of the parameters x*, y*, z*, p* is determined by the method of defuzzification.

The substantiation of the decisions made should be carried out on the basis of the involvement of leading experts (experts) serving the MCN. In order to make informed decisions it is advisable to involve leading experts (experts) who are engaged in servicing specific components of the MCN. An expert group is formed, which includes competent specialists in the operation and maintenance of MCN facilities, who have a stable opinion on the results of decisions in various conditions.

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