Neutrosophic Linear Programming Problems

Abstract

Smarandache presented neutrosophic theory as a tool for handling undetermined information. Wang et al. introduced a single valued neutrosophic set that is a special neutrosophic sets and can be used expediently to deal with real-world problems, especially in decision support. In this paper, we propose linear programming problems based on neutrosophic environment. Neutrosophic sets are characterized by three independent parameters, namely truth-membership degree (T), indeterminacy-membership degree (I) and falsity-membership degree (F), which are more capable to handle imprecise parameters. We also transform the neutrosophic linear programming problem into a crisp programming model by using neutrosophic set parameters. To measure the efficiency of our proposed model we solved several numerical examples.

Keywords

Linear Programming Problem; Neutrosophic; Neutrosophic Sets.
incomplete and imprecise information. And in Linear programming problems the
decision maker may not be able to specify the objective function and/or
neutrosophy which is the study of neutralities as an extension of dialectics.
Neutrosophic is the derivative of neutrosophy and it includes neutrosophic set,
neutrosophic probability, neutrosophic statistics and neutrosophic logic.
Neutrosophic theory means neutrosophy applied in many fields of sciences, in
order to solve problems related to indeterminacy. Although intuitionistic fuzzy
sets can only handle incomplete information not indeterminate, the neutrosophic
set can handle both incomplete and indeterminate information. [2,5-7]
Neutrosophic sets characterized by three independent degrees namely
truth-membership degree (T), indeterminacy-membership degree (I), and falsity-
membership degree (F), where T,I,F are standard or non-standard subsets
of ]0',1'[, the decision makers in neutrosophic set want to increase the degree of
truth-membership and decrease the degree of indeterminacy and falsity
membership.

The structure of the paper is as follows: the next section is a preliminary
discussion; the third section describes the formulation of linear programing
problem using the proposed model; the fourth section presents some illustrative
examples to put on view how the approach can be applied; the last section
summarizes the conclusions and gives an outlook for future research.

2 Some Preliminaries

2.1 Neutrosophic Set [2]

Let X be a space of points (objects) and x∈X. A neutrosophic set A in X is
defined by a truth-membership function T(x), an indeterminacy-membership
function (x) and a falsity-membership function (x). T(x), I_A(x) and F_A(x) are real
standard or real nonstandard subsets of ]0',1'[, I(x):X→]0-,1+[ and F_A(x):X→]0',1'[, There is no restriction on the sum of
T(x), I_A(x) and F_A(x), so 0≤ T_A(x) ≤ supI_A(x) ≤ F_A(x) ≤ 3^+.

2.2 Single Valued Neutrosophic Sets (SVNS) [7,8]

Let X be a universe of discourse. A single valued neutrosophic set A over
X is an object having the form

A = { (x, T_A(x), I_A(x), F_A(x)) : x∈X }, where T_A(x):X→[0,1], I_A(x):X→[0,1]
and F_A(x):X→[0,1] with 0≤ T_A(x)+ I_A(x)+ F_A(x)≤3 for all x∈X. The intervals
T(x), I_A(x) and F_A(x) denote the truth-membership degree, the
indeterminacy-membership degree and the falsity membership degree of x to A, respectively.
For convenience, a SVN number is denoted by $A = (a, b, c)$, where $a, b, c \in [0, 1]$ and $a + b + c \leq 3$.

2.3 Complement [3]

The complement of a single valued neutrosophic set $A$ is denoted by $c(A)$ and is defined by

\begin{align*}
T_c(A)(x) &= F(A)(x), \\
I_c(A)(x) &= 1 - I(A)(x), \\
F_c(A)(x) &= T(A)(x), \text{ for all } x \text{ in } X.
\end{align*}

2.4 Union [3]

The union of two single valued neutrosophic sets $A$ and $B$ is a single valued neutrosophic set $C$, written as $C = A \cup B$, whose truth-membership, indeterminacy membership and falsity-membership functions are given by

\begin{align*}
T(C)(x) &= \max ( T(A)(x), T(B)(x) ) , \\
I(C)(x) &= \max ( I(A)(x), I(B)(x)) , \\
F(C)(x) &= \min( F(A)(x), F(B)(x) ) \text{ for all } x \text{ in } X.
\end{align*}

2.5 Intersection [3]

The intersection of two single valued neutrosophic sets $A$ and $B$ is a single valued neutrosophic set $C$, written as $C = A \cap B$, whose truth-membership, indeterminacy membership and falsity-membership functions are given by

\begin{align*}
T(C)(x) &= \min ( T(A)(x), T(B)(x) ) , \\
I(C)(x) &= \min ( I(A)(x), I(B)(x)) , \\
F(C)(x) &= \max( F(A)(x), F(B)(x) ) \text{ for all } x \text{ in } X.
\end{align*}

3 Neutrosophic Linear Programming Problem

Linear programming problem with neutrosophic coefficients (NLPP) is defined as the following:

Maximize $Z = \sum_{j=1}^{n} c_j x_j$

Subject to

\begin{align*}
\sum_{j=1}^{n} a_{ij} x_j &\leq b_i \quad 1 \leq i \leq m \\
x_j &\geq 0, \quad 1 \leq j \leq n
\end{align*}

(1)

where $a_{ij}$ is a neutrosophic number.
The single valued neutrosophic number \((a_{ij}^n)\) is donated by \(A=(a,b,c)\) where \(a, b, c \in [0,1]\) And \(a, b, c \leq 3\)

The truth- membership function of neutrosophic number \(a_{ij}^n\) is defined as:

\[
T a_{ij}^n(x) = \begin{cases} \frac{x-a_1}{a_2-a_1} a_1 \leq x \leq a_2 \\ \frac{a_2-x}{a_3-a_2} a_2 \leq x \leq a_3 \\ 0 & \text{otherwise} \end{cases} \tag{2}
\]

The indeterminacy- membership function of neutrosophic number \(a_{ij}^n\) is defined as:

\[
I a_{ij}^n(x) = \begin{cases} \frac{x-b_1}{b_2-b_1} b_1 \leq x \leq b_2 \\ \frac{b_2-x}{b_3-b_2} b_2 \leq x \leq b_3 \\ 0 & \text{otherwise} \end{cases} \tag{3}
\]

And its falsity- membership function of neutrosophic number \(a_{ij}^n\) is defined as:

\[
F a_{ij}^n(x) = \begin{cases} \frac{x-c_1}{c_2-c_1} c_1 \leq x \leq c_2 \\ \frac{c_2-x}{c_3-c_2} c_2 \leq x \leq c_3 \\ 1 & \text{otherwise} \end{cases} \tag{4}
\]

Then we find the upper and lower bounds of the objective function for truth-membership, indeterminacy and falsity membership as follows:

\[
z_U^T = \max\{z(x_i^*)\} \text{ and } z_L^T = \min\{z(x_i^*)\} \text{ where } 1 \leq i \leq k
\]

\[
z_U^P = z_U^T \quad \text{and} \quad z_L^P = z_L^T - R(z_U^T - z_L^T)
\]

\[
z_U^F = z_U^L \quad \text{and} \quad z_L^F = z_L^L - S(z_U^T - z_L^T)
\]

where \(R, S\) are predetermined real number in \((0, 1)\).

The truth membership, indeterminacy membership, falsity membership of objective function are as follows:

\[
T_0^Z(z) = \begin{cases} 1 & \text{if } z \geq z_U^T \\ \frac{z-z_L^T}{z_U^T-z_L^T} & \text{if } z_L^T \leq z \leq z_U^T \\ 0 & \text{if } z < z_L^T \end{cases} \tag{5}
\]

\[
I_0^Z(z) = \begin{cases} 1 & \text{if } z \geq z_U^L \\ \frac{z-z_L^L}{z_U^L-z_L^L} & \text{if } z_L^L \leq z \leq z_U^L \\ 0 & \text{if } z < z_L^L \end{cases} \tag{6}
\]
\[ F_0^{(Z)} = \begin{cases} 
1 & \text{if } z \geq z_u^T \\
\frac{z_L^T - z}{z_u^T - z_L^T} & \text{if } z_L^T \leq z \leq z_u^T \\
0 & \text{if } z < z_L^T 
\end{cases} \] (7)

The neutrosophic set of the \( i^{th} \) constraint \( c_i \) is defined as:

\[ T_{c_i}^{(x)} = \begin{cases} 
1 & \text{if } b_i \geq \sum_{j=1}^{n} (a_{ij} + d_{ij}) x_j \\
\frac{b_i - \sum_{j=1}^{n} a_{ij} x_j}{\sum_{j=1}^{n} d_{ij} x_j} & \text{if } \sum_{j=1}^{n} a_{ij} x_j \leq b_i < \sum_{j=1}^{n} (a_{ij} + d_{ij}) x_j \\
0 & \text{if } b_i < \sum_{j=1}^{n} a_{ij} x_j 
\end{cases} \] (8)

\[ I_{c_i}^{(x)} = \begin{cases} 
0 & \text{if } b_i < \sum_{j=1}^{n} a_{ij} x_j \\
\frac{b_i - \sum_{j=1}^{n} a_{ij} x_j}{\sum_{j=1}^{n} d_{ij} x_j} & \text{if } \sum_{j=1}^{n} a_{ij} x_j \leq b_i < \sum_{j=1}^{n} (a_{ij} + d_{ij}) x_j \\
0 & \text{if } b_i \geq \sum_{j=1}^{n} (a_{ij} + d_{ij}) x_j 
\end{cases} \] (9)

\[ F_{c_i}^{(x)} = \begin{cases} 
1 & \text{if } b_i < \sum_{j=1}^{n} a_{ij} x_j \\
1 - T_{c_i}^{(x)} & \text{if } \sum_{j=1}^{n} a_{ij} x_j \leq b_i < \sum_{j=1}^{n} (a_{ij} + d_{ij}) x_j \\
0 & \text{if } b_i \geq \sum_{j=1}^{n} (a_{ij} + d_{ij}) x_j 
\end{cases} \] (10)

4 Neutrosophic Optimization Model

In our neutrosophic model we want to maximize the degree of acceptance and minimize the degree of rejection and indeterminacy of the neutrosophic objective function and constraints. Neutrosophic optimization model can be defined as:

\[ \text{max} T_{(x)} \]
\[ \text{min} F_{(x)} \]
\[ \text{min} I_{(x)} \]

Subject to

\[ T_{(x)} \geq F_{(x)}, \]
\[ T_{(x)} \geq I_{(x)}, \]
\[ 0 \leq T_{(x)} + I_{(x)} + F_{(x)} \leq 3, \] (11)
\[ T_{(x)}, I_{(x)}, F_{(x)} \geq 0, \ x \geq 0, \]
where $T(x), F(x), I(x)$ denote the degree of acceptance, rejection, and indeterminacy of $x$ respectively.

The above problem is equivalent to the following:

$max \alpha, \ min \beta, \ min \theta$

Subject to

\[
\begin{align*}
\alpha & \leq T(x), \\
\beta & \leq F(x), \\
\theta & \leq I(x), \\
\alpha & \geq \beta, \\
\alpha & \geq \theta, \\
0 & \leq \alpha + \beta + \theta \leq 3, \\
x & \geq 0,
\end{align*}
\]

(12)

where $\alpha$ denotes the minimal acceptable degree, $\beta$ denotes the maximal degree of rejection and $\theta$ denotes the maximal degree of indeterminacy.

The neutrosophic optimization model can be changed into the following optimization model:

$max(\alpha - \beta - \theta)$

Subject to

\[
\begin{align*}
\alpha & \leq T(x), \\
\beta & \geq F(x), \\
\theta & \geq I(x), \\
\alpha & \geq \beta, \\
\alpha & \geq \theta, \\
0 & \leq \alpha + \beta + \theta \leq 3, \\
\alpha, \beta, \theta & \geq 0, \\
x & \geq 0.
\end{align*}
\]

(13)

The previous model can be written as:

$min \ (1- \alpha) \beta \theta$

Subject to
\[ \alpha \leq T(x) \]
\[ \beta \geq F(x) \]
\[ \theta \geq I(x) \]
\[ \alpha \geq \beta \]
\[ \alpha \geq \theta \]
\[ 0 \leq \alpha + \beta + \theta \leq 3 \]  
\[ x \geq 0. \]  

5 The Algorithm for Solving Neutrosophic Linear Programming Problem (NLPP)

**Step 1.** solve the objective function subject to the constraints.

**Step 2.** create the decision set which include the highest degree of truth-membership and the least degree of falsity and indeterminacy memberships.

**Step 3.** declare goals and tolerance.

**Step 4.** construct membership functions.

**Step 5.** set \( \alpha, \beta, \theta \) in the interval \([0, 1] \) for each neutrosophic number.

**Step 6.** find the upper and lower bound of objective function as we illustrated previously in section 3.

**Step 7.** construct neutrosophic optimization model as in equation (13).

6 Numerical Examples

To measure the efficiency of our proposed model, we solved many numerical examples.

6.1. Illustrative Example #1

Beaver Creek Pottery Company is a small crafts operation run by a Native American tribal council. The company employs skilled artisans to produce clay bowls and mugs with authentic Native American designs and colours. The two primary resources used by the company are special pottery clay and skilled labour. Given these limited resources, the company desires to know how many bowls and mugs to produce each day in order to maximize profit. The two products have the following resource requirements for production and profit per item produced presented in Table 1:
Table 1. Resource requirements of two products

<table>
<thead>
<tr>
<th>product</th>
<th>Resource Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Labour(Hr./Unit)</td>
</tr>
<tr>
<td>Bowl</td>
<td>̃1</td>
</tr>
<tr>
<td>Mug</td>
<td>̃2</td>
</tr>
</tbody>
</table>

There are around 40 hours of labour and around 120 pounds of clay available each day for production. We will formulate this problem as a neutrosophic linear programming model as follows:

\[
\text{max } 40x_1 + 50x_2 \\
\text{S.t. } 1x_1 + 2x_2 \leq 40 \quad 4x_1 + 3x_2 \leq 120 \\
x_1, x_2 \geq 0 \quad (15)
\]

where

\[
\begin{align*}
C_1 &= \{ (30, 40, 50), (0.7, 0.4, 0.3) \}; \\
C &= \{ (40, 50, 60), (0.6, 0.5, 0.2) \}; \\
a_{11} &= \{ (0.5, 1, 3), (0.6, 0.4, 0.1) \}; \\
a_{12} &= \{ (0, 2, 6), (0.6, 0.4, 0.1) \}; \\
a_{21} &= \{ (1, 4, 12), (0.4, 0.3, 0.2) \}; \\
a_{22} &= \{ (1, 3, 10), (0.7, 0.4, 0.3) \}; \\
b_1 &= \{ (20, 40, 60), (0.4, 0.3, 0.5) \}; \\
b_2 &= \{ (100, 120, 140), (0.7, 0.4, 0.3) \};
\end{align*}
\]

The equivalent crisp formulation is:

\[
\text{max } 15x_1 + 18x_2 \\
\text{S.t. } x_1 + x_2 \leq 12 \\
3x_1 + 2x_2 \leq 45 \\
x_1, x_2 \geq 0
\]

The optimal solution is \(x_1 = 0; x_2 = 12\); with optimal objective value = 216$. 

22
6.2. Illustrative Example #2

\[
\begin{align*}
\text{max } & \tilde{5}x_1 + \tilde{3}x_2 \\
\text{s.t. } & \tilde{4}x_1 + \tilde{3}x_2 \leq \tilde{12} \\
& \tilde{1}x_1 + \tilde{3}x_2 \leq \tilde{6} \\
& x_1, x_2 \geq 0
\end{align*}
\] (16)

where

- \( c_1 = \tilde{5} = \{(4, 5, 6), (0.5, 0.8, 0.3)\} \);  
- \( c_2 = \tilde{3} = \{(2.5, 3, 3.2), (0.6, 0.4, 0)\} \);  
- \( a_{11} = \tilde{4} = \{(3.5, 4, 4.1), (0.75, 0.5, 0.25)\} \);  
- \( a_{12} = \tilde{3} = \{(2.5, 3, 3.2), (0.2, 0.8, 0.4)\} \);  
- \( a_{21} = \tilde{1} = \{(0, 1, 2), (0.15, 0.5, 0)\} \);  
- \( a_{22} = \tilde{3} = \{(2.8, 3, 3.2), (0.75, 0.5, 0.25)\} \);  
- \( b_1 = \tilde{12} = \{(11, 12, 13), (0.2, 0.6, 0.5)\} \);  
- \( b_2 = \tilde{6} = \{(5.5, 6, 7.5), (0.8, 0.6, 0.4)\} \).

The equivalent crisp formulation is:

\[
\begin{align*}
\text{max } & 1.3125x_1 + 0.0158x_2 \\
\text{s.t. } & 2.5375x_1 + 0.54375x_2 \leq 2.475 \\
& 0.3093x_1 + 1.125x_2 \leq 2.1375 \\
& x_1, x_2 \geq 0
\end{align*}
\]

The optimal solution is \( x_1 = 1; x_2 = 0 \); with optimal objective value 1 $.
6.3. Illustrative Example #3

\[
\begin{align*}
\text{max} & \ 25x_1 + 48x_2 \\
\text{s.t.} & \\
15x_1 + 30x_2 & \leq 45000 \\
24x_1 + 6x_2 & \leq 24000 \\
21x_1 + 14x_2 & \leq 28000 \\
x_1, x_2 & \geq 0
\end{align*}
\] (17)

where

\[c_1 = \tilde{25} = \{(19, 25, 33), (0.8, 0.1, 0.4)\};\]

\[c_2 = \tilde{48} = \{(44, 48, 54), (0.75, 0.25, 0)\}.\]

The corresponding crisp linear programs given as follows:

\[
\begin{align*}
\text{max} & \ 11.069x_1 + 22.8125x_2 \\
\text{s.t.} & \\
15x_1 + 30x_2 & \leq 45000 \\
24x_1 + 6x_2 & \leq 24000 \\
x_1, x_2 & \geq 0
\end{align*}
\]

The optimal solution is \(x_1 = 0; x_2 = 1500\); with optimal objective value \(34219 \$\)

6.4. Illustrative Example #4

\[
\begin{align*}
\text{max} & \ 25x_1 + 48x_2 \\
\text{s.t.} & \\
\tilde{15}x_1 + \tilde{30}x_2 & \leq \tilde{45000} \\
\tilde{24}x_1 + \tilde{6}x_2 & \leq \tilde{24000} \\
\tilde{21}x_1 + \tilde{14}x_2 & \leq \tilde{28000} \\
x_1, x_2 & \geq 0
\end{align*}
\] (18)
where

\[ a_{11} = \tilde{15} = \{(14, 15, 17), (0.75, 0.5, 0.25)\}; \]
\[ a_{12} = \tilde{30} = \{(25, 30, 34), (0.25, 0.7, 0.4)\}; \]
\[ a_{21} = \tilde{24} = \{(21, 24, 26), (0.4, 0.6, 0)\}; \]
\[ a_{22} = \tilde{6} = \{(4, 6, 8), (0.75, 0.5, 0.25)\}; \]
\[ a_{31} = \tilde{21} = \{(17, 21, 22), (1, 0.25, 0)\}; \]
\[ a_{32} = \tilde{14} = \{(12, 14, 19), (0.6, 0.4, 0)\}; \]
\[ b_1 = \tilde{45000} = \{(44980, 45000, 45030), (0.3, 0.4, 0.8)\}; \]
\[ b_2 = \tilde{24000} = \{(23980, 24000, 24050), (0.4, 0.25, 0.5)\}; \]
\[ b_3 = \tilde{28000} = \{(27990, 28000, 28030), (0.9, 0.2, 0)\}. \]

The associated crisp linear programs model will be:

\[
\max 25x_1 + 48x_2 \\
\text{s.t.} \\
5.75x_1 + 6.397x_2 \leq 9282 \\
10.312x_1 + 6.187x_2 \leq 14178.37 \\
x_1, x_2 \geq 0
\]

The optimal solution is \( x_1 = 0; x_2 = 1451 \); with optimal objective value 69648$

6.5. Illustrative Example#5

\[
\max 7x_1 + 5x_2 \\
\text{s.t.} \\
\tilde{1}x_1 + \tilde{2}x_2 \leq 6 \\
\tilde{4}x_1 + \tilde{3}x_2 \leq 12 \\
x_1, x_2 \geq 0
\]
where

\[ a_{11} = \tilde{1} = \{(0.5, 1, 2), (0.2, 0.6, 0.3)\}; \]
\[ a_{12} = \tilde{2} = \{(2.5, 3, 3.2), (0.6, 0.4, 0.1)\}; \]
\[ a_{21} = \tilde{4} = \{(3.5, 4, 4.1), (0.5, 0.25, 0.25)\}; \]
\[ a_{22} = \tilde{3} = \{(2.5, 3, 3.2), (0.75, 0.25, 0)\}; \]

The associated crisp linear programs model will be:

\[
\text{max } 7x_1 + 5x_2 \\
\text{S. t} \ \\
0.284x_1 + 1.142x_2 \leq 6 \\
1.45x_1 + 1.36x_2 \leq 12 \\
x_1, x_2 \geq 0
\]

The optimal solution is \( x_1 = 4; x_2 = 4 \); with optimal objective value 48$.

The result of our NLP model in this example is better than the results obtained by intuitionistic fuzzy set \([4]\).

**7 Conclusions and Future Work**

Neutrosophic sets and fuzzy sets are two hot research topics. In this paper, we propose linear programming model based on neutrosophic environment, simultaneously considering the degrees of acceptance, indeterminacy, and rejection of objectives, by proposed model for solving neutrosophic linear programming problems (NIPP). In the proposed model, we maximize the degrees of acceptance and minimize indeterminacy and rejection of objectives. NIPP was transformed into a crisp programming model using truth membership, indeterminacy membership, and falsity membership functions. We also give numerical examples to show the efficiency of the proposed method. As far as future directions are concerned, these will include studying the duality theory of linear programming problems based on Neutrosophic.

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References


