A Primitive Study of Logrolling in e-Negotiation

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Abstract

e-Negotiation involves two or more agents multilaterally bargaining for mutual gain, using information technologies in a cooperative problem-solving (CPS) environment. This paper only focuses on integrative negotiations. For example, one party reaches its goals and the other party also gains benefits. One of the strategies for achieving integrative solutions is called logrolling. Logrolling in two-issue two-party negotiation is defined as the exchange of loss in one issue for gain in other issues that result in an increase of the overall value for both parties. Each party can increase the overall value by trading the less preferred issue for the more preferred, provided that a trade-off ratio is satisfactory. Traditionally, the concept of logrolling has only been applied in the trading of votes by legislators. For example, a legislator offers to another to trade his vote on a certain bill in return for the other's votes on other bills. Not much research work about logrolling has been studied in other research areas such as operation research, information systems and electronic commerce. This paper overviews the issues of logrolling in the context of e-Negotiation. In particular, this paper introduces a linear programming model for optimizing trade-off ratios in the context of two-issue two-party logrolling.

1. Introduction

Traditionally, there are two types of negotiations. Competitive negotiations (also known as zero-sum and distributive negotiations) are classified as win-lose negotiations. For example, one party reaches its goals and the other party must fail to realize it. On the other side, collaborative negotiations (also known as integrative and cooperative negotiations) are classified as win-win negotiations. For example, one party reaches its goals and the other party also gains benefits. Negotiation is a decision process in which two or more parties make individual decisions and interact with each other for mutual gain (Hung and Mao 2002). Proposals are sent to other parties, and a new proposal may be generated after receiving a counter offer. The process continues till an agreement or a deadlock is reached, or even one or more parties quit.

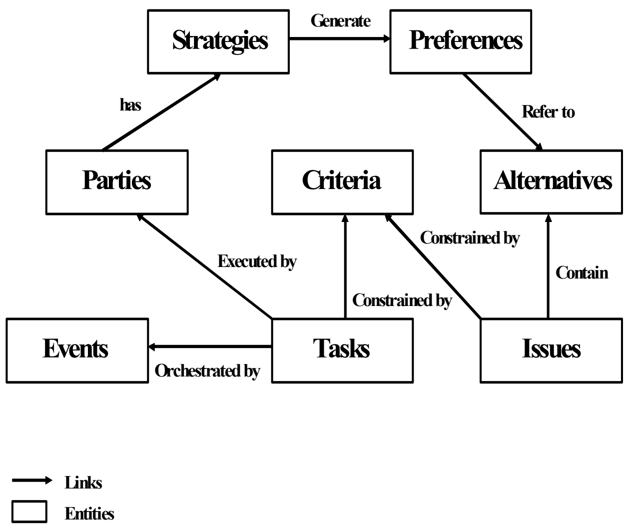

Figure 1. Relationships of Negotiation Entities

In Figure 1, negotiation includes a set of tasks, such as problem definition, generation of alternatives, evaluation of alternatives, preference modeling and consensus building, that are orchestrated by a set of events and executed by a set of parties. In particular, each negotiation involves at least two parties. On the other hand, negotiation involves a set of issues and every issue contains a set of alternatives. Further, the set of issues may also be constrained by a set of criteria. In order to reach a settlement, all parties must take complementary actions on each issue. Each party has a set of strategies such as Multi-Attribute Decision-Making (Hwang and Yoon 1981) for generating its set of preferences on the issues and alternatives. Each party has a set of preferences with respect to what alternatives are taken on each issue and how important these matters are.

One of the strategies for achieving *integrative* solutions is called *logrolling* (Pruitt 1981). Logrolling (Tajima and Fraser 1998) in two-issue two-party negotiation is the exchange of loss in one issue for gain in the other, which results in an increase of the overall value for both parties. Each party can increase the overall value by trading the less preferred issue for the more preferred, provided that a trade-off ratio is satisfactory. For illustration, Figure 2 shows a mapping between the negotiation entities (Figure 1) and a simple trading example. In this simple trading example, Party 1 and 2 are negotiating over two issues: apples and bananas. There is a set of alternatives in those two issues such as Party 1 has 3 apples and 10 bananas and Party 2 has 10 apples and 2 bananas. Further, Party 1 may assign a criteria weight 0.7 to apples and 0.3 to bananas for representing the importance of each issue (the sum of criteria weights is 1), and Party 2 may also assign a criteria weight 0.2 to apples and 0.8 to bananas. As a word, it means that Party 1 prefers more apples than bananas and Party 2 prefers more bananas than apples. This is a simple situation where logrolling can be implemented between Party 1 and Party 2, and this example will be applied through this paper.

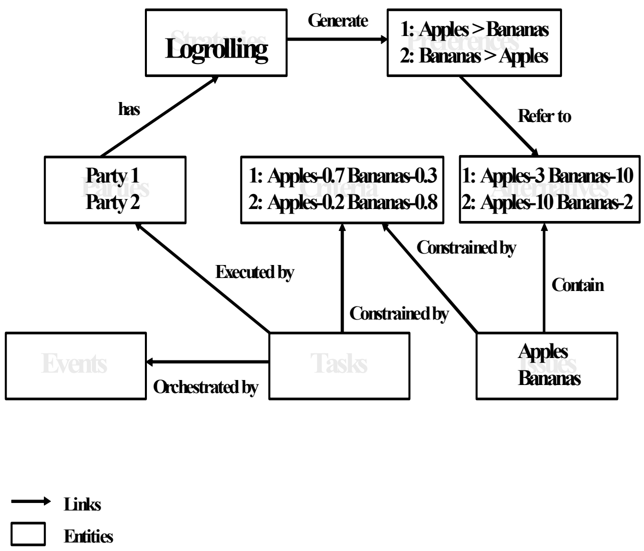

Figure 2. Mapping the Negotiation Entities into a Simple Trading Example

Hung and Mao (2002) considers *electronic negotiation (e-Negotiation)* as conducted by two or more agents (either human negotiators or computer programs) multilaterally bargaining for mutual gain, using tools and techniques of information technologies in a cooperative problem-solving (CPS) environment. This paper only focuses on integrative negotiations. As there is not much research work in applying the concept of logrolling in e-Negotiation, this research is doing a primitive study of logrolling. It is important to get a better insight of logrolling before it is really implemented into e-Negotiation. This paper has two salient features, as it is aimed at: (1) studying the negotiation issues for the concept of logrolling, and (2) proposing a linear programming model for optimizing trade-off ratios. The remainder of this paper is organized as follows: Section 2 discusses related work in the literature. Next, Section 3 presents an overview of issues in the context of e-Negotiation. Then, Section 4 presents a linear programming model for optimizing trade-off ratios for logrolling. Lastly, Section 5 discusses the conclusion and future research.

2. Literature Review

In political sciences, logrolling means the trading of votes by legislators (Wilson 1969). For example, a legislator offers to another to trade his vote on a certain bill in return for the other's votes on a second and a third bill. In general, logrolling (Froman and Cohen 1970) is defined as one-actor trades a concession on one or more issues for reciprocal concessions on other issues by his bargaining opponent. However, negotiators have cognitive biases (Foroughi and Jelassi 1990). It means that negotiators tend to consider issues one at one time that is also called compromise (Froman and Cohen 1970), because it is cognitively difficult for negotiators to integrate multiple issues into a single package. For example, Table 1 shows the utility value (Stigum and Wenstop 1983) in term of dollars for each party based on different alternatives. It is assumed that every rational party prefers a higher number of dollars than a lower number. If Party 1 and 2 bargain on apples, Party 1 will prefer alternative 1 while Party 2 will want alternative 3. In a result, the most likely outcome is a compromise at alternative 2. In a similar way, the negotiation process on bananas will also be a compromise at alternative 2. In this situation, both parties will get a value of \$8. However, if Party 2 accepts alternative 1 on apples and Party 1 accepts alternative 1 on bananas. Both parties will get a value of \$16. This example illustrates the manner in which logrolling may be more efficient and effective than compromising. As a result, Party 1 loses in bananas and gains in apples and Party 2 loses in apples and gains in bananas.

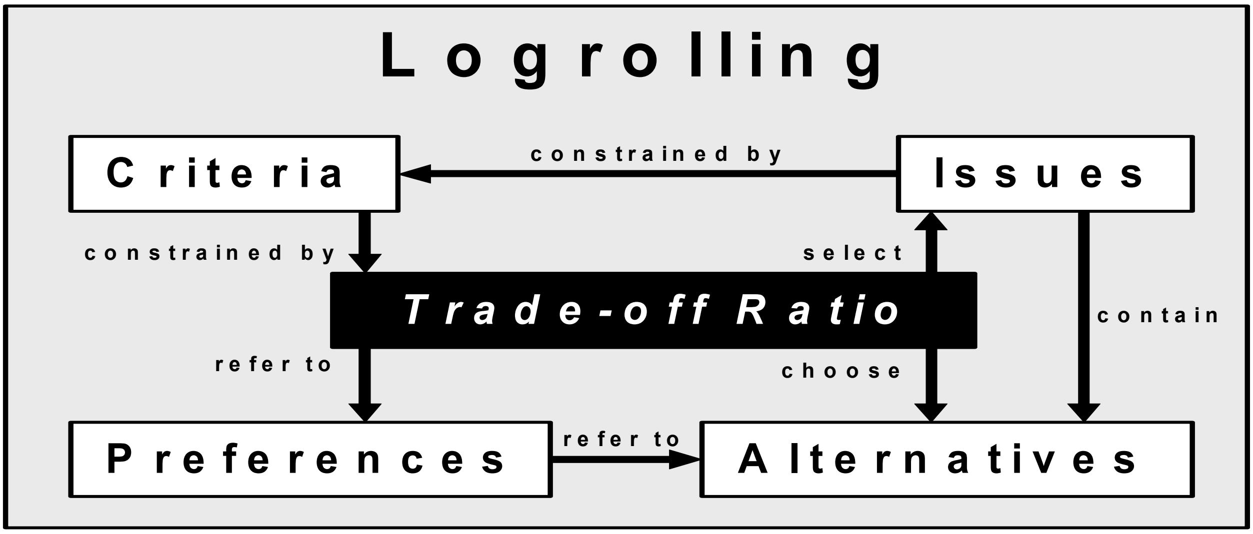

Figure 3. Trade-off Ratio in Negotiation

	Apples		
Parties	**1**	**2**	**3**
1	**$18**	**$8**	**$-3**
2	**$-2**	**$0**	**$2**

	Bananas		
Parties	**1**	**2**	**3**
1	**$-2**	**$0**	**$2**
2	**$18**	**$8**	**$-3**

Table 1. Example of Logrolling and Compromise

In fact, negotiation is key to a wide range of managerial activities (Ancona et al. 1996). One of the strategies for achieving *integrative* solutions is called *logrolling* (Pruitt 1981). Logrolling (Tajima and Fraser 1998) in two-issue two-party negotiation is the exchange of loss in one issue for gain in the other, which results in an increase of the overall value for both parties. This concept is similar with the approach proposed by Gosselin (1993). In his article "Negotiating With Your Boss," it proposes an approach of "if/then" trade-offs that is offering something else in return for what you ask. As a word, the concept of logrolling exists in the literature of negotiation for a long time. However, not much research has focused on supporting logrolling activities with some formal methodologies. This is the first major motivation of this study.

Referring to the simple trading example, each party can increase the overall value by trading the less preferred fruit for the more preferred, provided that a trade-off ratio (exchange rate) is satisfactory. This exchange of fruits is an example of logrolling since it results in mutual gain. The relationship between the trade-off ratio and other entities in logrolling is depicted in Figure 3. However, most of the related works such as Tajima and Fraser (1998), Foroughi and Jelassi (1990) and Froman and Cohen (1970) do not provide a mathematical model for optimizing the trade-off ratio. This is the second major motivation of this study.

3. An Overview of Issues in e-Negotiation

One of the important steps in negotiations is to define the issues to be deliberated. There is usually one major issue (e.g., price) and several minor issues in negotiations. In negotiations (Lewicki and Litterer 1985), a complete list of the issues at stake is often derived from: (1) an analysis of the conflict problem, (2) past experience in similar conflicts, (3) gathering information through research and consultation with experts, (4) studying precedents and legal frameworks, (5) brainstorming on what might be an ideal settlement, and (6) define the intangible goals which are most important for the negotiations. A negotiation agenda is a list of all the issues involved in a particular negotiation, and the combination agendas from each party in the negotiation are called the bargaining mix (Lewicki and Litterer 1985). In theory, larger bargaining mixes would take a longer negotiation activity because there would have more possible combinations of issues to be considered. In Hung and Mao (2002), sets of issues (I), alternatives (ALT) and preferences (P) respectively, as illustrated with the simple trading example:

- $I = \{i_1, i_2, \ldots, i_p\}$ is the set of *p* issues involved, e.g., "the number of apples" as one of the issues.
- $ALT = \{alt_1, alt_2, \ldots, alt_q\}$ is the set of *q* alternatives,

e.g., 5 apples as one of the alternatives of the issue "the number of apples."

In order to specify issues for logrolling, this paper proposes three major steps for it: (1) group the issues into different types, (2) define the relations of issues, and (3) determine the priorities of issues. In general, every negotiation activity involves at least one issue. In the first step, the parties have to group the issues into different types. There are four types of negotiation issues (Meister 1993):

- Primary issues are those matters that must be negotiated.
- Auxiliary issues could be negotiated but are not important or relevant enough to introduce initially.
- Fixed issues are so important to the party that under no circumstances is any compromise possible.
- Inconsequential issues are relatively unimportant so that the party is willing to agree to whatever the other side has proposed.

Therefore, the relationship between issues and types can be defined as the following:

- I^{TYPE} : I $\rightarrow$ TYPE is a one-to-one mapping that gives the type of the given issue where TYPE = {primary, auxiliary, fixed, inconsequential}. In the simple trading example, I^{TYPE} (apples) = "primary" and I^{TYPE} (bananas) = "inconsequential" for Party 1.

In the second step, the parties have to define the relations of issues. For another simple example (Cheung et al. 2002), the landlord and tenant would like to negotiate for a rental contract for an apartment. There are five issues involved in this negotiation: *start date*, *lease period*, *facilities provision*, *management fee*, *deposit* and *rent*. If the issues are separate, the issues can be easily added or subtracted. On the other hand, the settlement on one issue will be related to settlement on the other issues if the issues are connected (Lewicki and Litterer 1985). Based on this rental contract example, the relation between two issues could fall into one of the three following categories:

- The issues have to be negotiated in a bundle at the same time, such as the *facilities provision*, *lease period* and *rent*.
- The issues have a partial order, where one should be negotiated before another, such as the rent and deposit.
- The issues are to be individually negotiated, such as the *start date* and *management fee*.

In particular, Cheung et al. (2002) focuses on two relations among issues: (1) an issue *precedes* another issue if the former is to be refined before the latter, and (2) an issue indivisibly relates to another issue. To model the intention to negotiate some issues before others, Cheung et al. (2002) introduces the *precede* relation. An issue x *precedes* another issue y, written as $x \Rightarrow y$, where the negotiation of issue x is to *precede* that of issue y. In general, *precede* relation between issues can be found in the following situations:

- An issue is factored into several other sub-issues. Therefore, these sub-issues should be negotiated before the issue. For example, the issue *rent* can be factored into *basic rent* and *property tax*. Thus, (*basic rent*, *property tax*) $\Rightarrow$ *rent*.
- An issue depends on another issue, which requires the latter to be negotiated before the former. For example, the *deposit* may depend on the amount of *rent*. Thus, *rent* $\Rightarrow$ *deposit*.
- Two issues can be mutually derived from one another but one is more predominant, and the more predominant one is used in the negotiation. For example, the issue of *rent* is more predominant than another related issue *stamp duty*. Therefore, *rent* $\Rightarrow$ *stamp duty*.

The *precede* relation is transitive, but not reflexive and not commutative. In negotiations, every party has their own set of *precede* relations. Therefore, a global *precede* relation can be derived from the union of individual relations. If derived *precede* relation violates the commutative property, measures can be taken to resolve inconsistency. For example, if $x \Rightarrow y$ and $y \Rightarrow x$ then both relations are removed from the *precede* relation, where issues x and y become elements of the same indivisible component.

Each party is much more likely to assemble multiple issues together than to try to maximize goals on every individual issue. In addition, some issues have to be negotiated together at the same time. Especially when the trade-offs of these issues cannot be individually or sequentially considered during the negotiation. In the rental contract example, the issues of *facilities provision*, *lease period* and *rent* fall into this category. These issues mutually depend on one another. Cheung et al. (2002) proposes an indivisible package (*IP*) be a set of issues, where every issue in an *IP* mutually depends on each other in the set. In the rental contract example, the set {*facilities provision*, *lease period*, *rent*} is an indivisible package. However, a singleton indivisible package contains only one single issue, which is not to be negotiated with other issues at the same time. Note that each issue belongs to one and only one indivisible package. Two issues can be individually negotiated if they do not belong to the same indivisible package and they are not related by the *precede* relation. Let $IP(i)$ denotes the indivisible package that contains an issue i. Therefore, two issues that are related by the *precede* relation should not belong to the same indivisible package, i.e., for any issue *x* and *y*, $x \Rightarrow y$ if and only if $\neg\exists\ (IP(x) \wedge IP(y))$.

Most of the human-based negotiation plans focus on negotiable issues only, where non-negotiable issues refer to those issues that cannot be negotiated. Referring to the rental contract example (Cheung et al. 2002), the location is a non-negotiable issue because it is fixed. The tenant should have a negotiation plan based on his preferences. Further, the landlord would also have its negotiation plan. In the third step, each party would determine the relative importance of issues. Parties should be clear which issues are most important and which are least important to them. This is not only speeds up the negotiation activity, but also this can lead to more satisfactory settlements (Lewicki and Litterer 1985). Since most parties have a mix of bargaining objectives, they must consider the best way to achieve satisfaction on the issues. Each party needs to have some idea of what each issue in a bargaining mix is worth in terms of the other issues. Therefore, parties can have some way of establishing trade-offs. However, this is difficult to do because different issues will be of different value to different parties in different terms. In convention, many parties place all issues on some common dimension such as a point or utility scale (Lewicki and Litterer 1985). Utility is a numerical representation of preference among different alternatives. If a person prefers alternative *A* than another alternative *B*, then by definition alternative *A* has higher utility. Ordinal representations of preference do not express preferences on some sort of real-valued scale, but rather emphasize the order or position of something (Page 1968). Each party should specify his preferences on a set of issues by making paired comparisons. Strict preference (Kreps 1988) is a binary relation on issues. Here are the properties that this binary relation might possess, where *x* and *y* are two issues:

- Asymmetry: if *x* is strictly preferred to *y*, then *y* is not strictly preferred to *x*.
- Transitivity: if *x* is strictly preferred to *y* and *y* is strictly preferred to *z*, then *x* is strictly preferred to *z*.
- Negative transitivity: if *x* is not strictly preferred to *y* and *y* is not strictly preferred to *z*, then *x* is not strictly preferred to *z*.
- Irreflexivity: no *x* is strictly preferred to itself.

Whenever a choice is made, each party evaluates preference over alternatives, even if it is simply choosing to do something over not doing it (Fraser 1994). Therefore, the preferences of a set of issues (Hung and Mao 2002) with different alternatives are defined as the following:

- $P = [p_1, p_2, \ldots, p_x]$ is the finite list of the combination of alternatives of each issue in the descending order where $p_i \gg p_{i+1}$. Note that the notation "$x \gg y$" represents "*x* is more preferable than *y*." In the simple trading example, the preferences can be (6 apples, 5 bananas) » (3 apples, 10 bananas) where the 2-tuple represents (Number of Apples, Number of Bananas).

Though this is not a complete solution for managing issues for logrolling, it does provide some insights (i.e., trade-offs between two issues) for the implementation of logrolling in the context of e-Negotiation. In next section, this paper presents a linear programming model for optimizing trade-off ratios based on the research work done by Tajima and Fraser (2002).

4. Optimizing Trade-off Ratios

If a party's preferences among certain items have a certain pattern such as a linear curve, then his preferences can be represented by a utility function such as $U(x_1)$. Referring to the simple trading example, each party should have a multi-attribute utility function such as $U(x_1, x_2)$. The utility function for two attributes (i.e., apples and bananas) would have the multiplicative-additive form (Fraser and Fynn 1990) as follows:

$$U(x_1, x_2) = k_1 Ux_1(x_1) + k_2 Ux_2(x_2) + k_3 Ux_1(x_1) Ux_2(x_2)$$

where $Ux_1(x_1)$ is a utility function assessed on issue x_1 (e.g., apples) and $Ux_2(x_2)$ is a utility function assessed on issue x_2 (e.g., bananas), and k_1, k_2 and k_3 are weights (i.e., constants). The value of $U(x_1, x_2)$ is from 0 to 1 and $k_1 + k_2 + k_3 = 1$, where $0 \le k_1, k_2, k_3 \le 1$.

In this model, maximizing the utility is the objective for both parties. This study extends the research work done by Tajima and Fraser (1998) and proposes a linear programming model for optimizing trade-off ratios. In general, the trade-off ratio for Party 1 between issues i and j is the ratio of the increase in i to the decrease in j and it is denoted by R_{1i}/R_{1j}, R_{1i}, $R_{1j} > 0$. Similarly the trade-off ratio for Party 2 is R_{2j}/R_{2i}, R_{2i}, $R_{2j} > 0$. The amount Party 1 gains in issue i is equal to the amount Party 2 loses in issue i, i.e., $R_{1i} = R_{2i}$ and $R_{1j} = R_{2j}$. Logrolling is the exchange based on the trade-off ratios which satisfies the condition as follows (Tajima and Fraser 1998):

$$U_1(x_{1i} + R_{1i}, x_{1j} - R_{1j}) > U_1(x_{1i}, x_{1j})$$
$$\text{and}$$
$$U_2(x_{2i} - R_{2i}, x_{2j} + R_{2j}) > U_2(x_{2i}, x_{2j})$$

Further, the range of trade-off ratio can be determined using the parties' criteria weights. For example, wi and wj are Party 1's weights for issues i and j, and zi and zj are Party 2's weights for issues i and j, where wi + wj =1 and zi + zj = 1. Based on Tajima and Fraser (1998), there are three possible situations:

1. If wi>wj and zi<zj, it means that two parties have different priorities on the issues i and j. As a word, both parties gain in their more important issue and lose in the less important issue. Therefore, the ranges of trade-off ratios are shown in *equation (1)* as follows:

$$\frac{wj}{wi} < \frac{\mathrm{R1i}}{\mathrm{R1j}} < \frac{zj}{zi}\ and\ \frac{zi}{zj} < \frac{\mathrm{R2j}}{\mathrm{R2i}} < \frac{wi}{wj} \text{.......... (1)}$$

2. If wi>wj and zi>zj, it means that two parties have the same priority on the issues i and j but at different preference intensity, i.e., (wi/wj)≠(zi/zj). As a word, both parties have the higher (lower) preference intensity gains in issue i (j) and loses in issue j (i). Therefore, the ranges of trade-off ratios are shown in *equation (1)* and *(2)* as follows:

$$If(wi/wj) > (zi/zj), \frac{wj}{wi} < \frac{\mathrm{R1i}}{\mathrm{R1j}} < \frac{zj}{zi}\ and\ \frac{zi}{zj} < \frac{\mathrm{R2j}}{\mathrm{R2i}} < \frac{wi}{wj} \text{........(2)}$$

$$If(wi/wj) < (zi/zj), \frac{wi}{wj} < \frac{\mathrm{R1j}}{\mathrm{R1i}} < \frac{zi}{zj}\ and\ \frac{zj}{zi} < \frac{\mathrm{R2i}}{\mathrm{R2j}} < \frac{wj}{wi} \text{........(3)}$$

3. If wi=zi and wj=zj, it means that two parties have the same priority on the issues i and j at the same preference intensity, i.e., (wi/wj)=(zi/zj). Therefore, the ranges of trade-off ratios do not exist.

In the proposed linear programming model, the objective function is to maximize utility value for both parties. There are two utility function $U_1(x_1, y_1)$ and $U_2(x_2, y_2)$ based on the number of apples (x) and bananas (y) at Party 1 (i.e., x_1 and y_1) and Party 2 (i.e., x_2 and y_2) respectively. Let R_x and R_y be the number of apples and bananas traded between Party 1 and Party 2. However, it also has to minimize the difference between the utility values of Party 1 and Party, i.e., *Max Min*$\{U_1(x_1 + R_x, y_1 - R_y), U_2(x_2 - R_x, y_2 + R_y)\}$. Further, the apples traded (R_x) should be less than the apples at Party 2 (x_2) and also the bananas traded (R_y) should be less than the bananas at Party 1 (y_1), i.e., $R_x \le x_2$ and $R_y \le y_1$. In addition, the trade-off ratio should be within the range as discussed above. The objective function and related constraints are shown as follows:

Max Min$\{U_1(x_1 + R_x, y_1 - R_y), U_2(x_2 - R_x, y_2 + R_y)\}$

Subject to:

$R_x \le x_2$

$R_y \le y_1$

$$If((wx > wy) and (zx < zy)) or ((wx / wy) > (zx / zy)), \frac{wy}{wx} < \frac{\mathrm{Rx}}{\mathrm{Ry}} < \frac{zy}{zx}\ and\ \frac{zx}{zy} < \frac{\mathrm{Ry}}{\mathrm{Rx}} < \frac{wx}{wy}$$

$$If(wx / wy) < (zx / zy), \frac{wx}{wy} < \frac{\mathrm{Ry}}{\mathrm{Rx}} < \frac{zx}{zy}\ and\ \frac{zy}{zx} < \frac{\mathrm{Rx}}{\mathrm{Ry}} < \frac{wy}{wx}$$

$R_x, R_y, x_1, y_1, x_2, y_2, U_1(x_1 + R_x, y_1 - R_y), U_2(x_2 - R_x, y_2 + R_y), wx, wy, zx, zy \ge 0$

Referring to the simple trading example, here is an illustration for calculating trade-off ratios:

Party 1:

x1 (# of apples)	y1 (# of bananas)	wx (the criteria weight of apples)	wy (the criteria weight of oranges)
3	10	0.7	0.3

Party 2:

x2 (# of apples)	y2 (# of bananas)	zx (the criteria weight of apples)	zy (the criteria weight of oranges)
10	2	0.2	0.8

In this example, the range of trade-off ratio is fallen into case 1 as discussed in previous section, i.e., 0.7 > 0.3 (wx > wy) and 0.2 < 0.8 (zx < zy). The constraints are formed as follows:

- wy/wx < Rx/Ry < zy/zx
  = 0.3/0.7 < x/y < 0.8/0.2
  = 0.4285 < x/y < 4
- zx/zy < Ry/Rx < wx/wy
  = 0.2/0.8 < y/x < 0.7/0.3
  = 0.25 < y/x < 2.3333.

For simplification, the utility function $U_1(3+x, 10-y)$ is calculated by a linear curve as follows:

- wy*(1/10)(10-y) + wx*(1/13)*(3+x)
  = 0.3*0.1(10-y) + 0.7*0.0769*(3+x)
  = 0.46149 – 0.03y + 0.05383x

Similarly, the utility function $U_2(10-x, 2+y)$ is calculated by a linear curve as follows:

- zx*(1/10)(10-x) + zy*(1/12)*(2+y)
  = 0.2*0.1(10-x) + 0.8*0.0833*(2+y)
  = 2.13328 – 0.02x + 0.06664y

This case is implemented in LINDO. The code is shown in *Appendix A*, and the result is shown in *Appendix B*.

5. Conclusion and Future Research

Traditionally the concept of logrolling is being applied in the trading of votes by legislators (Wilson 1969) for a period of time. For example, a legislator offers to another to trade his vote on a certain bill in return for the other's votes on other bills. Beside the area of political sciences, not much research work in logrolling has been done in other research areas such as Operation Research (OR) and Information Systems (IS).

Referring to Stigum and Wenstop (1983), it discusses Harsanyi's concept of a solution for n-person simple bargaining games as follows: *"In a simple game G, a given payoff vector u=ū will represent the equilibrium outcome of bargaining among the n players only if no pair of players i and j has any incentive to redistribute their payoffs between them as long as the other players' payoffs are kept constant. Thus we can define multilateral bargaining equilibrium among the n players by the requirement that there should be bilateral bargaining equilibrium between any two players i and j."* Based on the above statements, it is believable that the concept of logrolling should be applied into a bilateral multi-issues negotiation.

This study shows the implications for future research in a number of directions. The first direction is to develop a logical model for managing the preferences of issues in logrolling for e-Negotiation. Based on the logical model, this research can investigate an approach for handling multi-issue multi-party logrolling. Second, this research can also apply other novel optimization models such as integer programming and mixed integer programming for logrolling. Further, this research can also investigate the feasibility of applying the concept of Lagrangean relaxation to logrolling. Overall, the proposed linear programming approach based on logrolling provides opportunities to gain insight into negotiation behavior and strategies for the real-life e-Negotiation practice.

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Appendix A

```
MAX
z

ST
0.05383x - 0.03y - z >= -0.46149
0.06664y - 0.02x -z >= -2.13328
x<=10
y<=10
0.4286y-x<0
x-4y<0
0.25x-y<0
y-2.3333x<0

x>=0
y>=0
END
```

Appendix B

LP OPTIMUM FOUND AT STEP 3

OBJECTIVE FUNCTION VALUE

1) 0.9247900

VARIABLE	VALUE	REDUCED COST
Z	0.924790	0.000000
X	10.000000	0.000000
Y	2.500000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	-1.000000
3)	1.175090	0.000000
4)	0.000000	0.046330
5)	7.500000	0.000000
6)	8.928500	0.000000
7)	0.000000	0.007500
8)	0.000000	0.000000
9)	20.833000	0.000000
10)	10.000000	0.000000
11)	2.500000	0.000000

NO. ITERATIONS= 3

RANGES IN WHICH THE BASIS IS UNCHANGED:

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
Z	1.000000	INFINITY	1.000000
X	0.000000	INFINITY	0.046330
Y	0.000000	0.030000	0.185320

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	-0.461490	0.924790	1.175090
3	-2.133280	1.175090	INFINITY
4	10.000000	23.657940	10.000000
5	10.000000	INFINITY	7.500000
6	0.000000	INFINITY	8.928500
7	0.000000	0.000000	30.000000
8	0.000000	INFINITY	0.000000
9	0.000000	INFINITY	20.833000
10	0.000000	10.000000	INFINITY
11	0.000000	2.500000	INFINITY