# A Method to Compute International Relations Using Relation Algebra

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## ABSTRACT

*This publication presents relation algebra for an international relations computation using mathematical modeling. It studies trust for international relations and its calculus, which is related to Bayesian inference, Dempster-Shafer theory, subjective logic and reputation system. Observation in current literature has shown that there is no literature discussing a calculus method for evaluating international relations. To bridge this research gap, we propose the relation algebra method for the international relations computation. The proposed method will allow the*

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*international relations computation which previously was subjective and incomputable. We also present international relations between the United States of America–Great Britain (USA-GBR), United States of America–Iran (USA-IRN) and United States of America–India (USA-IND) as case studies to demonstrate the use of the proposed method on real-world scenarios. The case studies have been selected to show examples of friendly, neutral and hostile relations.*

***Keywords:*** *International Relations, Foreign Policy, Dempster-Shafer, Relation Algebra, Reputation System, Subjective Logic.*

## 1.0 INTRODUCTION

This publication describes an extension of our previous works related to trust issues in international relations. The trust issues become prominent due to a complexity of international relations in digital world. To explore the trust issues, we have investigated existing literatures that discuss trust (e.g. definition, formalism and theory) and international relations. From an observation of the literatures, we found none of the existing literatures which discusses a calculus model for the international relations. Many literatures in politics and social sciences discussed the trust and international relations in philosophical forms which are subject to ambiguity of natural languages [1]–[3]. A few literatures in computer science and applied mathematics discuss trust as mathematical models [4], [5]. However, the mathematical trust models in existing literatures are too general and it is not sufficient to be used in modeling the trust issues in international relations. Probabilistic theories in works related to trust modeling such as Bayesian, Dempster-Shafer, Josang‟s subjective logic [6]–[8], do not directly address the trust issues for international relations. A brief discussion regarding the previous literatures and its related theories are discussed in the Literature Review section. In this

work, we model the international relations between nations using a calculus model, based on relation algebra. The proposed method will allow a relation computation, which previously was subjective and incomputable.

In previous works [9]–[11], we have mentioned the need for a "*trust model*" in Common Criteria (CC). Trust is an important element to ensure Common Criteria‟s participant nations are able to recognize and consume Common Criteria‟s products. Our previous works‟ motivation has been influenced by Kallberg‟s suggestion that "the long-term survival of CC requires abandoning the global approach and instead use established groupings of trust" [12]. We also mentioned about game theory as a strategic decision-making engine to evaluate the trust model. However, our preceding publications did not describe the implementation of relation algebra for international relations model. This publication covers the relation algebra for the development of an international relations model. The aim of this work is to propose the relation algebra for relation computations and trust modeling in the international relations. The proposed relation algebra is then evaluated using case studies. The proposed relation algebra will provide mathematical evaluations of international relations between nations.

The outline of this paper as follows: Our research motivations and objectives are presented in Motivation section, while Literature Review section examinations literature related to trust and international relations. The research methodology for the relation algebra is described in Methodology section. We explain the relation algebra method, definition and notation in Relation Algebra section. In Case Study section, we test the relation algebra using public data (e.g. internet and research literature) as case studies for the international relations. We provide results and discussions of the case studies in Result and Discussion sections, while our research contributions and future works in Contribution

and Future Work section. Finally, the Conclusion section summarizes this research work.

## 2.0 RELATED WORK

In this section, trust definitions and its modeling works will be discussed in the sub-sections.

### 2.1 Trust Relation Definition

Keywords "*trust*" and *"relation"* provide many definitions in various disciplines. According to Cambridge Dictionary (http://dictionary.cambridge.org), trust is defined as:

> *"to believe that someone is good and honest and will not harm you, or that something is safe and reliable"* and *"to hope and expect that something is true"*

Searching the keywords in a search engine reveals the varieties of trust definitions. The definitions can be linked to economic and political science studies at the earliest stage of trust definition. Later the definitions have evolved due to its expansion in computer science studies. A trust relation definition in the social science can be categorized as an expectation about other motives in a specific situation or state [13]. This definition is rooted in relationships between two entities (trustor and trustee); a willingness to be vulnerable or taking a risk [14]; a belief or faith about honesty [2], [13], benevolence of another entity in relationships [15]; and an experience and knowledge that are cultivated over time between entities [16], [17].

In this paragraph, we focus on trust relation definitions that are related to international relations which are the main theme in this publication. Trust can be defined as a clustering of perception [18]; an optimism about trustworthiness of others in mutually beneficial relations [19]; an expression of people in evaluating others in any given society and its evaluation will be affected based on changes in the external world [20]; and a trust level can

be mapped to the amount of risk one is willing to take in relations [14]. A variety of trust quotations from the international relations literatures are:

> "*trust seems to be an expression of how people evaluate the world around them because trust statistics in any given society sometimes increase or decrease quite rapidly, and this seems to be a response to variations in the external world*" [20].
>
> "*Trust can change over time … when the states' national security interests are at stake and their chain of considerations becomes more selfish and focused on protecting their own interest.*" [12].
>
> "*Trust is a subjective probability by which an individual expects that another individual performs…*" (reliability trust) and "*Trust is the extent to which one party is willing to depend on something or somebody in given situation … even though negative consequences are possible.*" (decision trust) [21].

Computer science literatures rely on the political and social sciences literatures for the trust relation definitions. The only difference is that, researchers in the computer science (or applied mathematics) try to represent (or formalize) the ambiguousness of *"trust"* and *"relation"* definitions of natural languages into a scientific and practical approach for a computation. A formalism of the relation computation is rooted in probability studies. In earlier stages, Bayes‟s probability and Dempster-Shaffer theory [22] were used in belief function for the relation computation. Later, a subjective logic [7], [23] is introduced as a formalism for the relation computation in computer science. An expansion to the subjective logic was offered by [24] for a trust modeling (e.g. trust operators) in computer networks such as trust management in web

services, social networks, e-voting, etc. As a conclusion to the trust definitions in the computer science, computer scientists do not define or redefine the trust definitions, it provides a methodology [24] for the relation computation and its statistical inferences.

## 2.2 Trust Modeling

Referring to the previous section, there are many trust definitions that were expressed in natural languages. To enable relation computation in computing systems, the trust definitions need to be conveyed in a measurable or quantifiable notations such as statistical representations. The first attempt to represent trust in the statistical notations was by Dempster [6]. Dempster showed a probability measurement that is to define an upper and lower probabilities for a multivalued mapping. The probability measurement is a generalization of calculus in Bayesian theory. His statistical scheme is adopted by Shaper [22], [25] and it provides an elegant method to compute trust. Many researchers later (in 1980-1995) addressed both works as the foundation for a concrete relation computation, which they began to call as Dempster-Shafer theory in the early 1980s [26]. Later Jøsang [4] provided an extension to a probabilistic calculus for the Dempster-Shaper theory by introducing an artificial reasoning, named subjective logic. The following subsections will further discuss the Bayesian theory, Dempster-Shafer theory and subjective logic.

## 2.3 Bayesian Theory

The Bayesian theory is widely used in probability studies such as statistical inference. The statistical inference is a process to deduce a conclusion from a given hypothesis using data that were sampled from a population. Through the statistical inference, a probability of the hypothesis to be either true, false or unknown can be derived using Bayesian probability. The Bayesian probability can be computed using Bayesian inference (or rule). The Bayesian inference allows an update of the probability of a given hypothesis when a new evidence was found. It is contributed to a non-monotonic logic [27] that allows a tentative conclusion

(previously deduced conclusion) to be retracted when the new evidence invalidates the tentative conclusion. This formal logic is used in an artificial intelligent (AI) study for a decision making when past experiences and new experiences are accumulated. In the AI literature, this work is called *belief revision* [28]. Below is the Bayes‟s theorem that is used as an inference rule for belief computation as well as belief update.

Where is a posterior probability[3] of hypothesis after datum is observed. Let and be probabilities of two separate events without regard to each other. is a prior probability of hypothesis before datum is observed. is a probability of datum given that hypothesis is true.

## 2.4 Dempster-Shafer Theory

The theory is also known as the theory of belief function. In the Bayesian theory, each question of interests (or events) requires probabilities that are assigned to each of them. The belief function [22] measures the *degree of belief* (or *mass*) for one question using subjective probability for a related question. The degree of belief may not be bound to mathematical probabilities and its probabilities depending on how closely questions (or events) are related. The belief for one question can be combined using Dempster‟s rule that when the question relies on independent items of evidence. The belief function will assign a mass for every hypothesis (or question of interests). A total mass is a measurement of the entire evidence (or a belief of given hypothesis ). The total mass that supports the given hypothesis

[3] Prior probability: probability that an observation will fall into hypotheses *before data collection.* Posterior probability (or conditional probability): probability of assigning observations to the hypotheses *by given collected data (e.g. new evidences).*

will form a lower bound of belief. Plausibility is a total mass measurement of the entire evidence that contradicts to the given hypothesis . The plausibility is an upper bound of the given hypothesis would be true. Let:

, s.t. is a set of all evidence

total evidence of the given hypothesis

total evidence that contradicts the given hypothesis

is a total mass of belief .

is a plausibility of belief .

Example 1: An agent A observes a relation between two nations. Given two hypotheses:

**TABLE 1**
Relations between two nations

| Hypothesis | Mass | Belief | Plausibility |
|---|---|---|---|
| NULL (Neither FRIENDLY or HOSTILE) | 0% | 0% | 0% |
| FRIENDLY | 15%, 5% | 20% | 50% |
| HOSTILE | 20%, 25%, 5% | 50% | 80% |
| EITHER (FRIENDLY or HOSTILE) | 30% | 100% | 100% |

From

TABLE 1, belief is a total mass (e.g. belief for friendly hypothesis is 20% = 15% + 5%). Plausibility for friendly hypothesis is 50% = 100% – belief not friendly (or hostile 50%=20% + 25% + 5%) and hostile hypothesis is 80% = 100% –

belief not hostile (or friendly 20%). The Null hypothesis is always 0% because it has no solution. Mass for either (hostile or friendly) hypothesis is a gap (or uncertainty) between mass friendly and mass hostile such that 30% = 100% – ((15% + 5%) + (20% + 25% + 5%)). Belief and plausibility are always 100% because the universality of the hypothesis either (friendly or hostile) and this hypothesis is always true in this case.

*2.5* Subjective Logic (Algebra)

The subjective logic is used for modeling and analyzing of incomplete information that involves uncertainty in a belief reasoning calculus. Each belief is represented as a collection of opinions in a finite state space [4] . The opinions may contain a degree of uncertainty about its probability [7]. The degree of uncertainty can be interpreted as ignorance about the truth of a given state (or actual probability). The calculus for the subjective logic consists of an ordered quadruple as an opinion proposition such that:

***belief*** , is a belief mass that a proposition is true.

***disbelief*** , is a belief mass that a proposition is false.

**uncertainty** , is a belief mass that an unknown neither true nor false of a given proposition.

***base rate*** , is a priori[5] probability with the absence of evidence.

Where:

, s.t.

When:

[4] In the original literature, it was called a frame of discernment. In this work, we have simplified many notations for ease of reader to grasp the basic ideas of the original literature.

[5] A priori probability is a probability that is deduced from current evidence without concerning other factors that may directly or indirectly affect a given proposition such as perceptions, past experiences, insight, etc. The probability is presumed in the absence of further evidence.

, is a binary logic TRUE.

, is a binary logic FALSE

is a traditional probability (e.g. , s.t. is using complement)

, is a degree of uncertainty.

, is a complete uncertainty.

, is a probability projection for .

Binomial opinions of triple can be presented as graphical representation using an equilateral triangle diagram in Figure 1. The binomial and multiple of binomial opinions (or multinomial) can be computed using subjective logic operators such as complement (NOT), addition (ADD), subtraction (SUB), Comultiplication (OR), etc. An example of ADD operation[6] [29] between two opinions and **is** illustrated in Figure 2 and Figure 3.

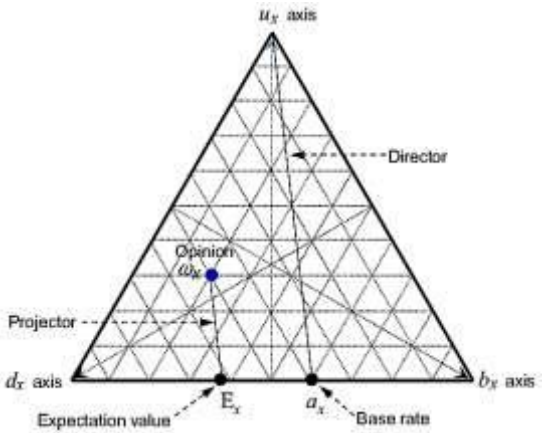


*Figure 1. Binomial Opinion [7]*

[6] We tested using Java Applet application in the given website.

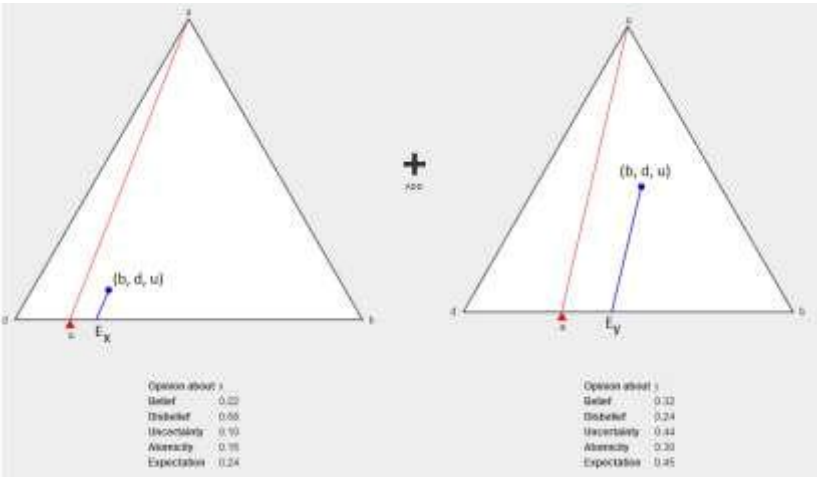


*Figure 2. Opinions and*

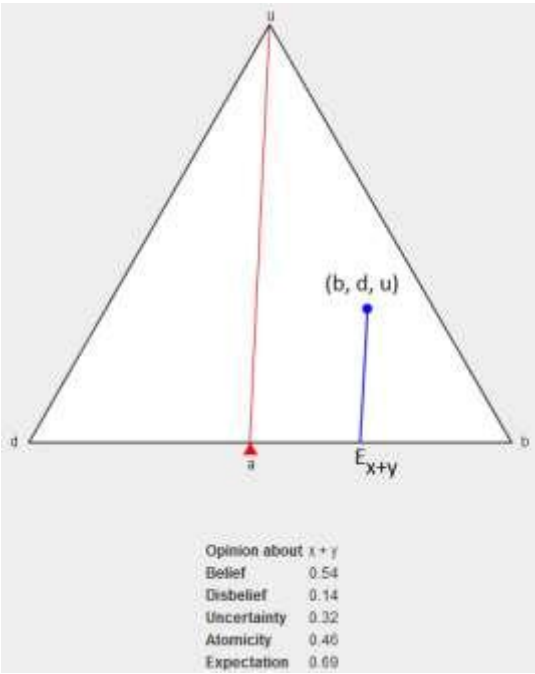


*Figure 3. Result of operation and*

Trust on International Relations

McGillivray and Smith [30] discussed an international cooperation that can reflect trust relationships between nations. He argued that punishments for those who defect the international cooperation can be used to make partner nations become more honest and trustworthy. Newton [20] explored an empirical relationship between social and political trust. The author‟s suggestion is to evaluate trust at a society level with consideration of external world factors rather than just an individual level. Kydd [16] debated about roles of trust and mistrust in international relations as well as its effects in the Cold War. The author has summarized a trust definition as *a belief that another entity is trustworthy and willing to establish cooperation*; and mistrust is *a belief that another entity is untrustworthy with the intention to exploit the cooperation*. Oelsner [31] criticized that a regional peace is not enough to enable regional friendships. J.Wheeler [1] studied challenges and clarifications in building trust relationships for international relations when conflict situations happened. The author has discussed diversity trust relationships from the origin of trust definitions, identification of mistrust issues in international relations, and challenges in sustaining and improving the trust relationships. Rohner et al. [32] proposed a theory for studying trust and conflict by an international trade. Yan and Holtmanns [33] discussed a transformation of social trust into a digital trust that can be used in trust modeling and trust management. Walter et al [34] present a trust model using a recommendation system in a social network. Kallberg [12] identified trust as an element that is important to ensure that members of CC are able to recognize and consume CC certified products. The literature discussed trust on international relations as a general discussion that based on social science perceptive, which not included any mathematical analysis method. This work focuses on the mathematical analysis method but not the general discussion.

## 3.0 METHODOLOGY

In this section, we present a brief summary of our research methodology. We have begun the research works by constructing research hypotheses. We derived our research hypotheses by literature reviews that are related to trust and international relations. During the literature reviews phase, we have identified case studies for the relation algebra (in Case Study section). Based on the case studies, we collected data that are needed to compute the relation algebra for the international relations. The outcomes of the research works that are a method to compute trust between nations (or trust value) wherein a trust perception is derived from the trust value.

## 4.0 RELATION ALGEBRA: DEFINITION AND NOTATION

In this section, we present the relation algebra and its examples.

**DEFINITION 1**. A nation state is a sovereign nation and recognized by the United Nation (UN). Referring to the UN‟s Charter [35]:

Chapter I, Articles 1: "*To maintain international peace and security…*" and "*to develop friendly relations among nations based on respect for the principle of equal rights…*". Articles 2: "*…principle of the sovereign equality of all its Members.*".

Chapter II, Articles 4: "*Membership in the United Nations is open to all other peace-loving states which accept the obligations contained in the present Charter … and, in the judgment of the Organization, are able to carry out these obligations*".

Referred to the UN‟s Charter, we defined a *nation* term as the nation state or any UN member states.

**DEFINITION 2.** A relation is international relations between Nation A and Nation B. The relation can be either friendly (ally,

positive), neutral, or hostile (enemy, negative). The relation denotes a *trust perception* of Nation A toward Nation B. Let assume that:

;

**Remark 2.1.** The relation for is reflexive with always friendly. We assumed that a nation always trust itself.

**Remark 2.2.** The relation for is not always symmetric. In this thesis, we assumed that is symmetric, which is to simplify the modeling work.

**Remark 2.3.** Relation for and does not always imply that is transitive for relations between Nation A, Nation B and Nation C.

**Remark 2.4.** The relation for and are commutative for binary operation for addition and multiplication operations.

**DEFINITION 3.** A relation for Nation A and Nation B is undefined for .

**Remark 3.1.** The relation for is undefined when the relation between Nation A and Nation B is neither friendly, neutral, nor hostile. The state of the relation is unknown.

**Remark 3.2.** If a definition of a *nation* is reduced to **DEF 1** then international relations always exists because of diplomatic relations and recognitions. Later we will show that the undefined

relation (total uncertainty) does not exist in the real world except in a mathematical form.

**DEFINITION 4.** A weightage is used for a linear normalization of trust perception between Nation A toward Nation B. The weightage will help to identify the significance the trust perception. It is almost similar to a base rate in a subjective logic.

**THEOREM 1.** Mass Weightage

Let assume that:

Mapped matrix:

**Remark 4.1.** One may choose to use a priori probability to evaluate (assign value) for every . Given that a cardinality is equal to three, then each is equal to – . One may also use a different value of that is based on the number of properties as mentioned in Theorem 3. For large numbers of the properties for a given , the should be increased to represent large samples of the properties . However, the value of is subjective to an observer. For example, if the observer wants to see differences between hostile and friendly relations for , then a neutral should be decreased; while a friendly and hostile should be increased.

**DEFINITION 5**. A scalar determines an interval scale for international relations, which is either friendly, neutral, or hostile.

**THEOREM 2.** Mass Scalar

Let assume that:

One may choose scalar signs: either "+" or "–")[7].

**Lemma 2.1.** Lower bound, middle bound and upper bound in Mass Scalar (interval scale).

**DEFINITION 6.** Perception is a collection of relation properties or elements that are used to determine a relation alignment for

. The relation properties are nominal data that assigned with some value based on qualitative statistics or by an observer intuition.

**Remark 6.1** Relations will have a collection of relation properties for each relation perception (e.g. ). Each trust property can be mapped into nominal data with values such as war ally , war enemy , politic , trade , spy and counter intelligent etc.

**THEOREM 3.** Mass Properties

Assume that:

[7] We chose to use a negative sign for a hostile and positive sign for a neutral and friendly relations. By common sense, the negative sign may suitable to be used for the hostile relation.

Let cardinalities:

**DEFINITION 7.** Relation is a product of Mass Perception . The Mass Perception is a point that resides in a relative distance between a lower bound and upper bound of Mass Scalar. To determine international relations for , which either friendly, neutral or hostile:

- If the point falls into less than middle bound, it is a hostile relation;
- If the point falls into greater than middle bound, it is a friendly relation; and
- If the point falls into the middle bound, it is a neutral relation.

**Remark 7.1.** Theorems 1 through 4 rely on three major conditions of international relations, which are hostile, neutral and friendly. One may define more than triple conditions to implement granularity and fuzziness in the international relations. For example, a septuple with additional three relations such as Near-Hostile, Near-Neutral and Near-Friendly as shown in Figure 4 can be used.

**Remark 7.2.** One should not modify the triple conditions to implement additional relations because it will increase difficulties in properties classification and nominal data (value assignment). For an example, to identify and assign nominal values for Hostile‟s properties is much easier compared to doing a similar

action for Near-Hostile‟s properties. These will increase statistical efforts for data collection, data interpretation, data analysis, data computation etc. We usually apply qualitative methods for international relations [36]–[38] and most data that are in raw forms (e.g. plaintexts in news, books, research publications, government official portal, documentary, online media, hacked/leaked classified information in public domains[8] etc.), and some data (e.g. classified data) are not always available on the Internet because it was protected by government[9]. As a suggestion to having more than triple scalar of relations, the septuple scalar could be directly mapped to the Mass Perception‟s value in the Theorem 4 as shown in Figure 4. One must define a lower bound and an upper bound for each new relation element. The new relation element is a subset of the existing triple (e.g. Near-Hostile Hostile).

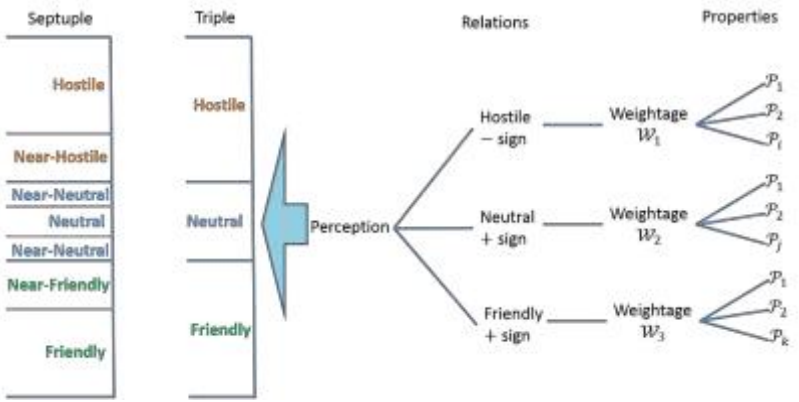


*Figure 4.* A summary of algebra relation for international relations

**THEOREM 4.** Mass Trust Perception

[8] In this research work, we do not obtain or consume any material that may lead to actions of a cyber-criminal, terrorism, spying activities and any other illegal activities.

[9] An attempt to obtain and consume the classified information may lead to a cyber-crime (or spying) activity – it may happen unintentionally.

Mapped matrix

;

**Lemma 4.1.** Strength of Mass Perception

**Remark 7.3.** The is a total of all masses without applying negative value (not apply negative scalar sign) to hostile properties. The purpose of the is to evaluate relations (or enabled properties) between hostile properties, and neutral and friendly properties. It used as a probability function (PF) wherein is conserved as the total probability for all enabled masses in given relations. The following paragraph
discuss some examples of interpretations between and
.

When is near to 1, may represent many contradiction of opinions between relations hostile and friendly. This may happen if it involves a long duration of sampling (or observation) of international relations between two nations. If the is a product of a 15-year observation period for the international relations between two nations: it may consist of a year of war, a year of military ally, a year of politics disagreement, a year of economy sanction etc. If the is a product of less than a 5-years observation period, the contradiction of opinions may occur when a nation leader or ruling party [37]–[41] was changed due to an election, revolution, installation of puppet leader (e.g. Karzai-Afghanistan [42]) as a post-war outcome etc.

When is near to 0.5 (or middle), may represent a fair opinion that either relation hostile or friendly. If the is a product of observation for many years (e.g. 15 years), it may represent consistent international relations in that duration. When is near to , represents a bias to a relation neutral. If the is a product of observation for many years, it may represent a firm of relation neutral at that moment. When and are identical in a positive value, it indicates that there are no hostile properties in the calculation (or observation).

**TABLE 2**
An Example of Relation Computation

| **Relation** | **Hostile** | **Neutral** | **Friendly** |
|---|---|---|---|
| Properties | *= 0.5*<br>*= 0.3*<br>*= 0*<br>*= 0.15*<br>*= 0.05*<br>*= 0* | *= 0.5*<br>*= 0*<br>*= 0*<br>*= 0.1* | *=0.05*<br>*=0*<br>*=0*<br>*= 0*<br>*= 0*<br>*= 0.1* |
| Weightage | 0.45 | 0.10 | 0.45 |
| Scalar Sign | | | |

Referring to Theorem 4 and Lemma 4.1, the given example has shown that a relation between Nation A and Nation B is hostile. The strength of the relation is near to 0.5 such that it represents a consistent hostile relation during the observation.

## 5.0 CASE STUDIES: INTERNATIONAL RELATIONS

In this section, we explore international relations between the USA-GBR, USA-IRN and USA-IND. We deliberated about the properties that were associated with international events. We also discuss some of the problems encountered during data collections and testing of the relation algebra with the given case studies.

### 5.1 Properties

We have clustered events that may affect international relations as showed in TABLE 3, 4 and 5. Clustering or grouping the related events for certain properties will reduce complexities for determining the properties‟ values and it will help to reduce the searching time of the whole data in public domains (e.g. Internet, news, etc.). If at least a single event is found to be related to the given properties, then the given properties will be included in a relation computation. It may not be strong enough to be held as solid evidence for the given properties, but it will help to enable the relation computation. The Dempster-Shafer‟s theory of evidence may also be applied in event verifications. However, it requires too much effort. Another issue with the properties, which one or more events that were assigned to properties may enable and disable (or toggle multiple times) during the observation period. For an example, in neutral‟s properties, a diplomatic mission (or embassy) may open while a negotiation is still

acceptable but later it was closed due to relation crisis – how do we evaluate this toggled event? Should the observer choose to enable or disable the properties, or enable the properties by dividing it into half of the properties‟ value?

**TABLE 3**
Friendly (positive) relation

| | **Descriptions** |
|---|---|
| 0.5 | War ally and mutual defense pact during war. |
| 0.2 | Share/trade nuclear technologies and materials (e.g. uranium) or mass destruction weapon for warfare.<br>Arm collaboration in R&D for warfare.<br>Financial aid for warfare. |
| 0.1 | Head of the state political sentiment and relationships. |
| 0.1 | Loan or share strategic technologies and equipment.<br>Civil nuclear trade and agreement.<br>Defense pact that enable during peace. |
| 0.075 | Share military intelligent.<br>Large scale of joint military drills. |
| 0.025 | Global War on Terrorism (GWOT) |
| 1.0 | TOTAL |

**TABLE 4**
Neutral relation

| | **Descriptions** |
|---|---|
| 0.25 | Member of UN or nation state recognized by UN. |
| 0.35 | Economic cooperation. E.g. Bilateral trade, multilateral open market, free trade. |
| 0.40 | Diplomatic mission (embassy or representative). Disaster aid and peacekeeping. |
| 1.0 | TOTAL |

**TABLE 5**
Hostile (negative) relation

| | **Descriptions** |
|---|---|
| 0.5 | War Enemy |
| 0.2 | Strong disapproval of share/trade/usage nuclear technologies and materials, or mass destruction weapon. E.g. nuclear testing, intercontinental ballistic missile (ICBM) development and testing, and arms races. |
| 0.075 | Economy blockage or sanction.<br>Embargo or boycott. (e.g. large scale product boycott, ban visa) |
| 0.125 | Closed border military aggressive or hostility. Including land, air, maritime trespassing and terrorism.<br>*peaceful dispute through international law is not included. |
| 0.05 | Political sentiments and threat by the head of state. |
| 0.05 | Kill or arrest another nation diplomats.<br>Espionage. (e.g. spying and hacking) |
| 1.0 | TOTAL |

## 5.2 Weightage

We chose to implement 40%:20%:40% as weightages for hostile, neutral and friendly relations. The weightage percentages were decided based on the number of properties for the given relations.

## 5.3 Case 1: The USA and GBR (1999-2014)

The United States of America and Great Britain enjoy a long lasting of good international relations [43]. The British-America (or Anglo-American) relation remains intact as a close military ally since the World War II. Both nations also share many strategic resources [43] and information (e.g. UKUSA Agreement [44] ).

**TABLE 6**
Properties of the USA and GBR

| | **Hostile** | **Neutral** | **Friendly** |
|---|---|---|---|
| Properties | *= 0*<br>*= 0*<br>*= 0*<br>*= 0*<br>*= 0*<br>*= 0* | *= 0.25*<br>*= 0.35*<br>*= 0.40* | *= 0.5*<br>*= 0.2*<br>*= 0.05*<br>*= 0.125*<br>*= 0.075*<br>*= 0.05* |
| Weightage | 0.40 | 0.20 | 0.40 |
| Scalar Sign | | | |

;

indicates that the and are identical. When both variables are identical in a positive value, it indicates that there is no hostile property in the observation. The strength of the relations is greater than 0.5, which represent an excellence friendly relations in 1999 until 2014.

5.4 Case 2: The USA and IRN (1999-2014)

The United States of America and Islamic Republic of Iran did not have a formal diplomatic relation by an ambassador or diplomat. Both nations established indirect diplomatic using other

nation embassies, for examples Iran use Pakistan embassy in Washington D.C. [45] and the USA use Switzerland embassy in Tehran [46]. There were many international conflicts happened for both nations during the observation period. The USA saw Iran as a threat to the world peace when Iranian Government began to utilize nuclear energy. Later, Iran was accused of doing a mass destruction weapon development instead of a civil nuclear development [47]. The international relations for both nations were severely strained by the nuclear issue and it elevates to international sanction by the USA [48]–[50]. After the September 11 attacks on the USA and invasion of Iraq by the USA in 2003, Iran was accused of supporting and exporting terrorism in the world, which included terrorism in Afghanistan and other nations [48], [51]–[53].

**TABLE 7**
Properties of the USA and IRN

| | **Hostile** | **Neutral** | **Friendly** |
|---|---|---|---|
| Properties | *= 0*<br>*= 0.2*<br>*= 0.075*<br>*= 0.125*<br>*= 0.05*<br>*= 0.05* | *= 0.25*<br>*= 0.35/2*<br>*= 0* | *= 0*<br>*= 0*<br>*= 0*<br>*= 0*<br>*= 0*<br>*= 0* |
| Weightage | 0.40 | 0.20 | 0.40 |
| Scalar Sign | | | |

indicates that the has fallen into a negative value and it is less than . This denotes that there were many hostile‟s properties in the observation. The strength of the relations is not within boundaries, which represent a strong of hostility relations in 1999 until 2014. Observe that, there is a toggled property in neutral = *0.35/2*, which cause the value to be divided by 2. We assumed it as a toggled event because of the international trade sanction imposed by the USA, but simultaneously the USA is still establishing trade with Iran, which reported by the U.S. Census Bureau [54].

5.5 Case 3: The USA and IND (1999-2014)

The United States of America and India relations or Indo-American relations had been improving during the observation period. The USA President Bill Clinton imposed economic sanctions on India because Indian Prime Minister Atal Bihari Vajpayee had authorized nuclear weapon testing at Pokhran [55], [56]. *“"They clearly create a dangerous new instability in their region and, as a result, in accordance with U.S. law, I have decided to impose economic sanctions against India," Clinton said. Sanctions are mandatory under U.S. law when an undeclared nuclear state explodes a nuclear device. …"In hopes of averting an arms race in southern Asia, specifically in next-door Pakistan, Clinton urged India's neighbors "not to follow the dangerous path India has taken."”*[57]. The relations of both

nations improved after the India-United States Civil Nuclear Agreement (or 123 Agreement) signed on 10 October 2008, which allowed India to use civil nuclear energy and it also enabled civil nuclear trade for both nations [58], [59]. India supported President Bush and Obama in a war against terrorism and both nations had waged a war against the Taliban Government in Afghanistan [60], [61].

**TABLE 8**
Properties of the USA and IND

| | ***Hostile*** | ***Neutral*** | ***Friendly*** |
|---|---|---|---|
| Properties | *= 0*<br>*= 0.2*<br>*= 0.075*<br>*= 0*<br>*= 0*<br>*= 0.05* | *= 0.25*<br>*= 0.35/2*<br>*= 0.40* | *= 0*<br>*= 0*<br>*= 0*<br>*= 0.125*<br>*= 0.075*<br>*= 0.05* |
| Weightage | 0.40 | 0.20 | 0.40 |
| Scalar Sign | | | |

shows that there exists a difference of 0.26 between and . When both variables are identical in a positive value and a gap between both values (0.26) is greater than (>0.2), it indicates that there exist both hostile and friendly properties in the observation. The strength of the relations is less than 0.5 and the gap is greater than , which represents a fragile neutral relations in 1999 until 2014.

## 6.0 RESULT AND DISCUSSION

We have presented case studies for the relation algebra in the Relation Algebra section. The case studies discussed the international relations between USA-GBR (friendly relation), USA-IRN (hostile relation) and USA-IND (neutral relations) respectively. The weightage for trust perceptions in the relations are proportioned to 2:1:2. The total properties that were considered in the observation are fifteen. Properties identification and properties value assignment were the most difficult parts of the relation evaluation process. Clustering or grouping the related events for certain properties will reduce complexities for determining the properties‟ value. There must be a justification for each selected properties and its values. The justification efforts required an assistance of political and social science experts in the domain. A consul (or officer) in a foreign ministry may not give an honest answer if asked directly for their opinion regarding properties‟ value and weightages, due to possibly classified information policy concerning its foreign relations. But, if the relation algebra method is used by the foreign ministry or defense ministry, the relation algebra computation will be more accurate because the method can use classified information, which known

by the ministry. We can conclude that, the properties and weightages are subjective to the observers. In this work, the properties and weightages chosen by the authors are based on public information available in the literatures (refer to the Literature Review section) and the Internet[10].

Dempster-Shafer‟s theory allows multiple events and its observation results (or opinions based on evidences) to be combined to derive a degree of belief or belief function [22]. To test a Dempster‟s rule, one may use evidence operators based on subjective logic [7]. It allows multiple agents (observers) to observe for one event at the same time or at difference periods, then all observation results can be combined to draw a tentative conclusion. Additional events and its evidences, and new observers may change the present result (the tentative conclusion). These three independent variables become input to decide wherein an event is fall to a given property or not. At this point, we also do not include a base value for a biased observer [62]. The bias observer has a difference threshold in making a judgment, which leads by individualism (e.g. experience, knowledge and personal interest), internal influences (e.g. Ph.D. supervisor) and external influences (e.g. sponsor and government policy).

The USA-IND relations consist of a toggle event that is a property (economic cooperation). The economic cooperation ceased because of economic sanctions during a certain time frame and later it was revoked. The toggle event may enable and disable (or toggled multiple times) during the observation period. For an example, a diplomatic mission (or embassy) may open when a negotiation is still acceptable, but later it is closed due to relation crisis – how to evaluate this toggled event? Should an observer decide on enable or disable this property? or enable the property

[10] We do not obtain or use any material that may lead to actions of a cyber-crime, terrorism, spying or any other illegal activities.

by divide it into a half of the property‟s value? – We have chosen to divide it by a half of the property‟s value. It is a trivial solution.

The news related to the international relations circled in a terrorism and global war on terrorism, conflicts in a middle east, nuclear and mass destruction weapon, head of state relation and sentiment, economy collaboration and sanctions, close border hostility and trespassing, diplomatic and espionage, and humanity and disaster relieve aid. We used these data as International Relations case study. However, it is very difficult to balance between nations that in world headline news such as the USA, UK, Israel, Iran, Afghanistan, Pakistan etc. and less in world news such as Estonia, Belgium, Germany etc. If the nations have more international news coverages, then we will have more data for relation algebra, which is important to assign for relation properties. Refer to the case studies, we presented the USA, India and Iran because there are many public information regarding international relations between these nations. If we choose nations that are not involved in international conflicts in the given observation period, all case studies for relation algebra computation will fall into neutral relations. Based on the case studies, we had shown examples of friendly, neutral and hostile relations. The outcome suggested as a tentative result, which is due to absent of complete evidence in the international relations between these nations. Further evidence may change the international relations for the given case studies.

Without the relation algebra, we can only use unsystematically way to identify relations between nations. For an example, refer to international relations between the USA and IND in the Case 3 section, one may directly interpret that both nations were in a hostile relation because of the President of the USA had said "… *decided to impose economy sanctions against India… Sanctions are mandatory under U.S. law when an undeclared nuclear state explodes a nuclear device.*". Through the relation algebra, we

found that for , which represent a fragile neutral relation. The relation algebra provides wider international relations assessments because it integrates multiple properties in its relations computation. The given tentative conclusions may change due to new evidence and new events that will be known by the observer in future. Furthermore, different observers may have different views regarding properties and events. One may use the Dempster-Shafer theory to evaluate (or combine) each observer‟s results. Later, one may further analyze the observer‟s results using Josang‟s subjective logic for an arithmetic and logic operations.

## 7.0 CONTRIBUTION AND FUTURE WORK

We have presented relation algebra method for international relations. The proposed method has enabled relation computation, which is previously subjective and unquantifiable. The method seamlessly works together with the existing trust methodologies, which are Dempster-Shafer theory, Josang‟s subjective logic and Bayesian theory. We have also presented interesting case studies to demonstrate the practicality of the proposed method. We believe that our method can assist researchers studying in the field of international relations. Government officers working in foreign ministry or defense ministry may adopt our method as a quantitative methodology for international trust evaluations between foreign nations. Department of Defense may use our method to identify a nation that can be identified as trusted or neutral; or a hostile nation that can be anticipated as a terrorist nation or unsettled nation. It also can provide a baseline for a future prediction of international relations. The baseline can be fixed using a quantitative of relation properties as aforementioned in Tables 3, 4 and 5.

The most significant contribution of the proposed method that it will help to find the most trusted authorizing nation in Common Criteria. Trust is an important element to ensure Common

Criteria‟s participant nations are able to recognize and consume Common Criteria‟s products. Choosing the most trusted authorizing nation for product evaluations will secure a value chain of the entire architecture of Comment Criteria. Relation algebra allows relation computations between nations that contribute to trust credentials in the Common Criteria‟s participant nations. The method allows one to test the Kallberg‟s hypothesis

[12] regarding the *"long-term survival of CC requires abandoning the global approach and instead use established groupings of trust"*. To test the hypothesis, we need a relation computation method for international relations – that is using relation algebra. Later, we need to evaluate trust relations between the Common

Criteria‟s participant nations. Then, it will reveal that either the given hypothesis is valid or not.

Refer to the Literature Review section, we have done an exhaustive search for a method to perform an international relations computation. To the best of our knowledge, this is the first attempt in computer science in the area of information security research to model the international relations using relation algebra. We also acknowledge that, the proposed method is not fully completed , and that there are many research gaps and opportunities that are still available for a future research work.

## 8.0 CONCLUSION

In this work, we have modeled relation algebra for international relations. The purpose of the relation algebra method is to allow relation computations and trust modeling. Previously, there is no such method to perform the relation computations for international relations which used to be subjective and unquantifiable. We have also presented the international relations between USA-GBR, USA-IRN and USA-IND as case studies to demonstrate the proposed method in a real-world scenario. We have met our research objectives by applying and verifying the

relation algebra with the case studies. We plan to publish the relation algebra for Common Criteria‟s participant nations in the next publication.

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## 10.0 REFERENCES

[1]N. J.Wheeler, "Trust-Building in International Relations," *Peace Prints South Asian J. Peacebuilding*, vol. 4, no. 2, p. 21, 2012.

[2]D. H. Mcknight and N. L. Chervany, "Trust and Distrust Definitions : One Bite at a Time," *Trust Cyber-societies, Lect. Notes Comput. Sci.*, vol. 2246, pp. 27–54, 2001.

[3]D. Jelenc and D. Trček, "Qualitative trust model with a configurable method to aggregate ordinal data," *Auton. Agent. Multi. Agent. Syst.*, vol. 28, no. 5, pp. 805–835, 2014.

[4]A. Jøsang, "Artificial Reasoning with Subjective Logic," in *Artificial Reasoning with Subjective Logic*, 1997, pp. 1–17.

[5]S. Hallerstede, M. Jastram, and L. Ladenberger, "A method and tool for tracing requirements into specifications," *Sci. Comput. Program.*, vol. 82, pp. 2–21, 2014.

[6]a P. Dempster, "Upper and lower probabilities induced by a multivariate mapping," *Ann. Math. Stat.*, vol. 38, no. 1, pp. 325–339, 1967.

[7]A. Jøsang, *Subjective Logic*. 2013.

[8]A. Abdel-hafez, "Trust, Privacy, and Security in Digital Business," vol. 8058, no. SEPTEMBER 2014, 2013.

[9]Mohd Anuar Mat Isa, Jamalul-lail Ab Manan, Ramlan Mahmod, Habibah Hashim, Nur Izura Udzir, Ali Dehghan Tanha, and Mar Yah Said, "Game Theory: Trust Model for Common Criteria Certifications & Evaluations," *Int. J. Cyber-Security Digit. Forensics*, vol. 1, no. 1, pp. 50–58, 2012.

[10]Mohd Anuar Mat Isa, Jamalul-lail Ab Manan, Ramlan Mahmod, Habibah Hashim, Mar Yah Said, Nur Izura Udzir, and Ali Dehghan Tanha, "Finest Authorizing Member of Common Criteria Certification," in *The International Conference on Cyber Security, CyberWarfare and Digital Forensic 2012 (CyberSec12)*, 2012, pp. 166–171.

[11]Mohd Anuar Mat Isa, R. Mahmod, N. I. Udzir, A. Jøsang, J. A. Manan, and A. D. Tanha, "A Formal Calculus for International Relations Computation and Evaluation," *J. Curr. Res. Sci.*, vol. 2016, no. 2, pp. 177–194, 2016.

[12]J. Kallberg, "Common Criteria meets Realpolitik - Trust, Alliances, and Potential Betrayal," *Secur. Privacy, IEEE*, vol. 10, no. 4, 2012.

[13]D. H. Mcknight and N. L. Chervany, "The Meanings of Trust," 1996.

[14]F. Schoorman, R. Mayer, and J. Davis, "An integrative model of organizational trust: Past, present, and future," *Acad. M anagement Rev.*, vol. 32, no. 2, pp. 344–354, 2007.

[15]P. L. Porta and R. Scazzieri, "Towards an economic theory of international civil society: Trust, trade and open government," *Struct. Chang. Econ. Dyn.*, vol. 8, no. 1, pp. 5–28, 1997.

[16]A. H. . Kydd, *Trust and Mistrust in International Relations*. Princeton University Press, 2005.

[17]X. Jiang, F. Jiang, X. Cai, and H. Liu, "How does trust affect alliance performance? The mediating role of resource sharing," *Ind. Mark. Manag.*, 2015.

[18]H. C. White, *Identity and Control: A Structural Theory of Social Action*. 1992.

[19]R. Hardin, "The Street-level Epistemology of Trust.pdf," *Polit. Soc.*, vol. 21, no. 4, pp. 505–529, 1992.

[20]K. Newton, "Trust, social capital, civil society, and democracy," *Int. Polit. Sci. Rev.*, vol. 22, no. 2, pp. 201–214, 2001.

[21]D. Trček, "Managing Trust in Services Oriented Architectures," in *Proceedings of the 9th WSEAS international conference on Applied informatics and communications. World Scientific and Engineering Academy and Society (WSEAS)*, 2008, pp. 23–28.

[22]G. Shafer, *A Mathematical Theory of Evidence*. Princeton

Univiversity Press, 1976.

[23]A. Jøsang, “a Logic for Uncertain Probabilities,” *Int. J. Uncertainty, Fuzziness Knowledge-Based Syst.*, vol. 09, no. 03, pp. 279–311, 2001.

[24]D. Trček, “A formal apparatus for modeling trust in computing environments,” *Math. Comput. Model.*, vol. 49, no. 1–2, pp. 226–233, 2009.

[25]G. Shafer, “Allocations of Probability,” *Ann. Probab.*, vol. 7, no. 5, 1979.

[26]J. Shafer, “A Mathematical Theory of Evidence,” 2015. [Online]. Available:http://www.glennshafer.com/books/amte.html. [Accessed: 01-Jan-2015].

[27]G. Brewka, “Nonmonotonic Reasoning: Logical Foundations of Commonsense,” in *Cambridge University Press, ACM SIGART Bulletin*, vol. 3, no. 2, 1992, pp. 28–29.

[28]W. Wobcke, “Belief Revision, Conditional Logic and Nonmonotonic Reasoning,” *Notre Dame J. Form. Log.*, vol. 36, no. 1, pp. 55–102, 1995.

[29]S. Pope, S. Hird, and M. Davey, “Subjective Logic Operators Demo,” 2011. [Online]. Available: http://folk.uio.no/josang/sl/Op.html. [Accessed: 10-Jun-2014].

[30]F. McGillivray and A. Smith, “Trust and cooperation through agent-specific punishments,” *Int. Organ.*, vol. 54, no. 04, pp. 809–824, 2000.

[31]A. Oelsner, “Friendship, mutual trust and the evolution of regional peace in the international system,” *Crit. Rev. Int. Soc. Polit. Philos.*, vol. 10, no. 2, 2007.

[32]D. Rohner, M. Thoenig, and F. Zilibotti, “War Signals : A Theory of Trade , Trust and Conflict,” *Rev. Econ. Stud.*, vol. 80, no. 3, 2012.

[33]Z. Yan and S. Holtmanns, “Trust modeling and management: from social trust to digital trust,” *Comput. Secur. Priv. Polit. Curr. Issues, Challenges Solut.*, p. 27, 2007.

[34]F. E. Walter, S. Battiston, and F. Schweitzer, “A model of a trust-based recommendation system on a social network,” *Auton. Agent. Multi. Agent. Syst.*, vol. 16, no. 1, 2008.

[35]“Charter of the United Nations,” 1945. [Online]. Available: http://www.un.org/en/documents/charter/. [Accessed: 11-Jun-

2015].

[36]Y. W. Detlef F. Sprinz, "Case study methods: Design, use, and comparative advantages," *Model. numbers, cases Methods Stud. Int. relations*, no. November, pp. 19–55, 2004.

[37]M. A. Pollack, "International Relations Theory and European Integration," *J. Common Mark. Stud.*, vol. 39, no. 2, pp. 245–64, 2001.

[38]S. M. Walt, "International Relations: One World, Many Theories," *Foreign Policy*, no. 110, pp. 29–46, 1998.

[39]G. Bansal and F. Mariam, "Trust violation and repair : The information privacy perspective," *Decis. Support Syst.*, vol. 71, pp. 62–77, 2015.

[40]T. Menon, O. J. Sheldon, and A. D. Galinsky, "Barriers to Transforming Hostile Relations: Why Friendly Gestures Can Backfire," *Negot. Confl. Manag. Res.*, vol. 7, no. 1, pp. 17–37, 2014.

[41]C. L. Heitmeyer, "On the Role of Formal Methods in Software Certification: An Experience Report," *Electron. Notes Theor. Comput. Sci.*, vol. 238, no. 4, pp. 3–9, 2009.

[42]T. N. Y. T. Rod Nordland, "In Farewell Speech, Karzai Calls American Mission in Afghanistan a Betrayal," 2014. [Online]. Available: http://www.nytimes.com/2014/09/24/world/asia/hamid-karzai-afghanistan.html?_r=0. [Accessed: 03-Nov-2015].

[43]Great Britain. Parliament. House of Commons. Foreign Affairs Committee, "UK-US Relations : Sixth Report of the Foreign Affairs Committee of Session 2009-10," 2010.

[44]NSA, "UKUSA," 2013. [Online]. Available: https://www.nsa.gov/public_info/declass/ukusa.shtml. [Accessed: 17-Nov-2015].

[45]"Interests Section of the Islamic Republic of Iran," 2015. [Online]. Available: http://www.daftar.org/Eng/default.asp?lang=eng. [Accessed: 17-Nov-2015].

[46]"Embassy of Switzerland -Foreign Interests Section," 2015. [Online].Available: https://www.eda.admin.ch/countries/iran/en/home/representations/embassy-of-switzerland-foreign-interests-section.html. [Accessed: 17-Nov-2015].

[47]K. Katzman, "Iran: U. S. Concerns and Policy Responses," 2009.

[48]W. Sherman, "U.S. Policy Toward Iran," 2013. [Online]. Available: http://www.state.gov/p/us/rm/2013/202684.htm. [Accessed: 17-Nov-2015].

[49]Wikipedia, "Iran–United_States_relations," 2015. [Online]. Available: https://en.wikipedia.org/wiki/Iran%E2%80%93United_States_relations. [Accessed: 17-Nov-2015].

[50]US Department of the Treasury, "Iran Sanctions," 2014. [Online]. Available: http://www.treasury.gov/resource-center/sanctions/Programs/pages/iran.aspx. [Accessed: 17-Nov-2015].

[51]"The „Grand Bargain" Fax: A Missed Oppurtunity," 2002. [Online]. Available: http://www.pbs.org/wgbh/pages/frontline/showdown/themes/grandbargain.html. [Accessed: 17-Nov-2015].

[52]"Public Statement on U.S. Policy Toward the Iran Nuclear Negotiations," 2015. [Online]. Available: http://www.washingtoninstitute.org/policy-analysis/view/public-statement-on-u.s.-policy-toward-the-iran-nuclear-negotiations. [Accessed: 11-Nov-2015].

[53]Mir H. Sadat and J. P. Hughes, "U.S.-Iran Engagement Through Afghanistan," *Middle East Policy*, vol. 17, no. 1, pp. 31–51, 2010.

[54]U. S. D. of Commerce, "Trade in Goods with Iran," 2014. [Online]. Available: https://www.census.gov/foreign-trade/balance/c5070.html. [Accessed: 18-Nov-2015].

[55]Business Standard, "Clinton Imposes Full Sanctions On India," 1998. [Online]. Available: http://www.business-standard.com/article/specials/clinton-imposes-full-sanctions-on-india-198051401086_1.html. [Accessed: 18-Nov-2015].

[56]Dan Balz and William Drozdiak, "U.S. Responds With Penalties, Persuasion," *Washington Post Foreign Service*, 1998. [Online]. Available: http://www.washingtonpost.com/wp-srv/inatl/longterm/southasia/stories/penalties051498.htm. [Accessed: 18-Nov-2015].

[57]CNN, "U.S. imposes sanctions on India," 1998. [Online]. Available: http://edition.cnn.com/WORLD/asiapcf/9805/13/india.us/. [Accessed: 18-Nov-2015].

[58]Council on Foreign Relations, "Agreement for Cooperation Between the Government of the United States of America and the Government of India Concerning Peaceful Uses of Nuclear Energy (123 Agreement)," 2007. [Online]. Available: http://www.cfr.org/india/agreement-cooperation-between-government-united-states-america-government-india-concerning-peaceful-uses-nuclear-energy-123-agreement/p15459. [Accessed: 18-Nov-2015].

[59]J. B. Esther Pan, "The U.S.-India Nuclear Deal," *Council on Foreign Relations*, 2010. [Online]. Available: http://www.cfr.org/india/us-india-nuclear-deal/p9663. [Accessed: 30-Nov-2015].

[60]Wikipedia, "Northern Alliance," 2015. [Online]. Available: https://en.wikipedia.org/wiki/Northern_Alliance. [Accessed: 18-Nov-2015]

[61]BBC News, "Afghanistan's Northern Alliance," 2001. [Online]. Available: http://news.bbc.co.uk/2/hi/south_asia/1552994.stm. [Accessed: 18-Nov-2015].

[62]G. M. Burghardt, J. N. Bartmess-LeVasseur, S. A. Browning, K. E. Morrison, C. L. Stec, C. E. Zachau, and T. M. Freeberg, "Perspectives - Minimizing Observer Bias in Behavioral Studies: A Review and Recommendations," *Ethology*, vol. 118, no. 6, pp. 511–517, 2012.