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DETERMINANT FACTORS FOR MODELING CONFLICT SYSTEMS
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ABSTRACT
In this paper we develop a probabilistic computer simulation model, based on feedback principles, to examine how conflict between two groups evolves over time. Group differences and the occurrence of inter-group incidents drive the model. The model examines various scenarios and produces output that can be used to examine various strategies to reduce conflict over time.

INTRODUCTION
Conflict occurs on all levels -- between individuals, groups, organizations, ethnic groups, countries, or even alliances of countries. In this paper we develop a simple computer simulation model based on feedback principles that incorporate probabilistic elements, to examine how conflict between two hypothetical groups evolves over time. Real conflict on any level is much more complicated than what is modeled here or indeed, what may be modeled anywhere. Models, however, can help researchers study system response to various scenarios to better understand the underlying system. This is our goal here.

Models have a rich history in the conflict literature. They have been used on the international scale [Munvaster and Zinnes 1982, Wolfson 1973], at the group level regarding ethnic conflicts [Carment 1995, Dian 1997], and the individual level [Bender 1993, Axelrod 1980]. Many of these models are based on systems of differential equations that change over time. Some, such as Karrneshu et.al. 1990, derive conditions for which the conflict situation either reaches a state or equilibrium or continues to evolve. Wolfson et. al. 1992 also traces the dynamic evolution toward a state or equilibrium. Our model differs from these in its simplicity and its use of probabilistic elements in a simulation setting. The model is based on other models discussed in the literature. For example, Carment discusses some theoretical arguments explaining ethnic conflict. Instrumental arguments posit that conflict is unrelated to ethnic ties, but is more related to political or economic interests. Affective motivation arguments present factors, on the other hand, that depend on ethnicity. Schock 1996 discusses a "conjunctural" model where simultaneous combinations of income inequalities and political opportunities drive violent conflict. Carlson 1995 discusses how conflict escalates and hypothesizes that as the disparity between player's cost tolerance increases, the lower cost tolerant actor tends to escalate. In our model we use these insights to inform our use of the two factors driving our model's evolution: differences between two groups (as measured by a characteristic attribute variables growing at different rates) and by the presence of major inter-group incidents. We also incorporate feedback from behavior in past periods. In the remainder of the paper we present the model, discuss the results from applying the model to several scenarios, and some conclusions and directions for future research.

THE MODEL
We developed a simulation model to represent conflict between two groups. One may think of conflict escalation as needing a motive, a means, and a spark. In our model, the motive is the disparity between each group's economic power and its memory of past major incidents; the means are how past incidents manifest themselves in current actions; and the spark comes from probabilistic random acts occurring in an environment of mutual group hostility. The model's parameters are not based on empirical data. Some key base case model characteristics are as follows:

- Two groups, A and B, vie for the same resource. In our example we assume this resource is economic, but it could be other resources without loss of generality.
- Each group starts off with the same amount of the resource, which each period grows at a rate unique to the group (and is affected by random error). The same initial resources are for the base case but are not required for all scenarios.
- The primary model outputs are the probabilities of a major incident between the two groups in the period in question -- i.e., A initiating and incident against B and B initiating an incident against A.
For each group (e.g., group A) the probability of the incident is a combination of the probability of incidents initiated by the group for the previous period, an adjustment factor (see below), and the probability in the previous period of the other group (e.g., group B) initiating an incident. The adjustment factors depend upon the larger of two quantities: the absolute value of the difference in each population's portion of the "total resource pie," and whether or not major incidents have occurred in the past two periods. Although not probabilities, these values fall between 0 and 1 and are used to adjust the probabilities PAB and PBA in the sense that trends are incorporated in exponential smoothing models.

Whether or not a major incident occurs in a period depends on the probability of a major incident occurring in that period and random events. Given this overview, the specific model variables and relationships are as follows (t denotes the period):

- **GRA** Growth rate of group A = a constant KA plus a random error term, ε
  \[ GRA(t) = KA + \varepsilon, \quad (\varepsilon \text{ is normally distributed with mean zero and a given standard deviation}) \]

- **GRB** Growth rate of group B = a constant KB plus a random error term
  \[ GRB(t) = KB + \varepsilon, \quad (\varepsilon \text{ is normally distributed with mean zero and a given standard deviation}) \]

- **DIA** Development index of group A
  \[ DIA(t) = DIA(t-1) \times [1 + GRA(t-1)] \]

- **DIB** Development index of group B
  \[ DIB(t) = DIB(t-1) \times [1 + GRB(t-1)] \]

- **DIA%** Development index of A as a percent of the total
  \[ DIA\%(t) = DIA(t) / [DIA(t) + DIB(t)] \]

- **DIB%** Development index of B as a percent of the total
  \[ DIB\%(t) = DIB(t) / [DIA(t) + DIB(t)] \]

- **PAB(t)** Probability of a major incident initiated by group A against group B
  \[ PAB(t) = a \times PAB(t-1) + P \times DIA\%(t-1) + S \times PBA(t-1); \text{ where } a + P + S = 1 \]

- **PBA(t)** Probability of a major incident initiated by group B against group A
  \[ PBA(t) = a \times PBA(t-1) + P \times DIB\%(t-1) + S \times PAB(t-1); \text{ where } a + P + S = 1 \]

- **GD(t)** Adjustment factor used due to group differences in growth rates - A minus B
  \[ GD(t) = \text{Absolute value}[DIA\%(t-1) - DIB\%(t-1)] \]

- **XAB(t)** 1 or 0 indicating an incident initiated by A against B
  \[ XAB(t) = 1 \text{ or 0, depending on whether a random number in } [0, 1] < PAB(t-1) \]

- **XBA(t)** 1 or 0 indicating an incident initiated by B against A
  \[ XBA(t) = 1 \text{ or 0, depending on whether a random number in } [0, 1] < PBA(t-1) \]

- **LlBA(t)** Adjustment factor to PBA: Depends on group differences and events
  \[ LlBA(t) = \text{Max}[\text{Average}[GD(t-1), GD(t-2)], \text{Average}[XAB(t-1), XAB(t-2)] \]

**RESULTS AND DISCUSSION**

Because the model contains random error terms in the growth rates of each group as well as for the occurrence of major events it is said to be probabilistic. This means that even with fixed parameters and relationships, the output of the model will change each time the model is run. The output variables for each period are the probability of a major incident. We ran the model for 101 periods (a base period plus 100). In the model the probabilities of group A initiating an incident against group B and vice versa for period 101 may be viewed as a final output of the model. For example, in our base case, the growth rate of population A is 4% per year and the growth rate for population B is 2% per year.

The random error terms for each growth rate are normally distributed with mean 0 and standard deviation of 0.1. The values of the weights α, β, and δ are such that calculated PAB and PBA are, respectively, 0.5, 0.25, and 0.25. The initial condition for PAB and PBA were assumed to equal 0 — i.e., starting out, there was zero probability for major events between the two groups. The times series for PAB and PBA exhibit an upward trend, and for about the first 15 periods, then diverge to reach a maximum probability of about 0.90 in period 101. For Base Case 1 there were 35 major incidents of A acting against B and 45 for B acting against A. The Mean Absolute Deviation (MAD) measures the average absolute difference between the PAB and PBA time series and can be viewed as how close each time series is to the other — i.e., the MAD is a "tracking indicator." For Base Case 1 the MAD was .003.

In our analysis, we examined four scenarios. The data we will present is for a single data point for each case. In each example, the case is identical to the base case, except for the changes noted (see Appendix for results):

**Case 1:** Growth rate for group A is 10% (as opposed to the 4% used in the base case)

**Case 2:** The values of α, β, and δ are (respectively): 0.1, 0.1, and 0.8. This places higher weight on the other group's probability for an incident in the prior period.

**Case 3:** The values of α, β, and δ are (respectively): 0.1, 0.8, and 0.1. This places higher weight on the adjustment factor (a function of differences in group "power" and previous major events.

**Case 4:** Unequal initial major incident probabilities for each group: PAB = 5 and PBA = 0.0.

The graphs for the time series PAB and PBA for the four cases appear below in the Appendix.

Case 1 represents a situation where one group grows at a significantly faster rate than the other. The graph tracks closely between the two groups, especially for the last 50 periods where each group approaches probabilities of 1.0 - - an indicator of hostility and a high likelihood of major events. Indeed, two distinguishing characteristics for this case are the high number of major incidents (73 and 76 in the 100 periods) that occur and the speed with which relative large-event probabilities are reached. For example, a probability of 0.90 is reached on about the 50th period for Case 1. This is in contrast to the base cases where PAB and PBA never reach 0.90, even after 101 periods.

Case 2 represents a situation where the highest weight is placed on the other group's probability for an incident in the prior period. This represents high intensive feedback between groups. From the case 2 graph, we see the two time series track closely. Since the probabilities for major events do not necessarily indicate that the events themselves occur, the close tracking may be interpreted as each groups feelings of "hostility" toward the other, which ratchets up together quite closely in linear fashion. Here, PAB and PBA never reach 0.80 and the number of major events (31 and 34) are the lowest for all four cases examined.

Case 3 represents a situation where the highest weight is placed on the adjustment factor (the ΔAB and ΔBA variables), which is a function of differences in group "power" (the GD variables) and previous major events (the
RESULT AND DISCUSSION

Because the model contains random error terms in the growth rates of each group as well as for the occurrence of major events it is said to be probabilistic. This means that even with fixed parameters and relationships, the output of the model will change each time the model is run. The output variables for each period are the probability of a major incident occurring in that period and random events.

Given this overview, the specific model variables and relationships are as follow (t denotes the period):

- **GRA**
  - Growth rate of group A = a constant ka plus a random error term, c
  - GRA(t) = ka + c, (c is normally distributed with mean zero and a given standard deviation)

- **GRB**
  - Growth rate of group B = a constant kb plus a random error term
  - GRB(t) = kb + c, (c is normally distributed with mean zero and a given standard deviation)

- **DIA**
  - Development index of group A
  - DIA(t) = DIA(t-1) * [1 + GRA(t-1)]

- **DIB**
  - Development index of group B
  - DIB(t) = DIB(t-1) * [1 + GRB(t-1)]

- **DIA%**
  - Development index of A as a percent of the total
  - DIA(t)/DIA(t) + DIB(t)

- **DIB%**
  - Development index of B as a percent of the total
  - DIB(t)/DIA(t) + DIB(t)

- **PAB**
  - Probability group A initiates a major incident against B
  - PAB(t) = α * PAB(t-1) + β * ΔAB(t-1) + δ * PBA(t-1), where α + β + δ = 1

- **PBA**
  - Probability group B initiates a major incident against A
  - PBA(t) = α * PBA(t-1) + β * ΔBA(t-1) + δ * PAB(t-1), where α + β + δ = 1

- **GD**
  - Adjustment factor used due to group differences in growth rates - A minus B
  - GD(t) = (absolute value of DIA(t-1) - DIB(t-1))

- **XAB**
  - XAB[1] = 1 or 0 indicating an incident initiated by A against B

- **XBA**
  - XBA[1] = 1 or 0 indicating an incident initiated by B against A

- **ΔAB**
  - Adjustment factor to PAB: Depends on group differences and events
    - ΔAB(t) = Max(Average(GD(t-1), GD(t-2)), Average(XAB(t-1), XBA(t-2)))

- **ΔBA**
  - Adjustment factor to PBA: Depends on group differences and events
    - ΔBA(t) = Max(Average(GD(t-1), GD(t-2)), Average(XAB(t-1), XBA(t-2)))

In the above table, note that the weights α, β, and δ sum to 1, and their values define various scenarios. They may be thought of as the importance attached to the last period's A on B major incident probability, the last period's adjustment factor, and the last period's B on A major incident probability. A schematic of the relationships is:

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**Case 1**: Growth rate for group A is 10% (as opposed to the 4% used in the base case)

- The values of α, β, and δ are (respectively): 0.1, 0.8, and 0.1. This places higher weight on the other group's probability for an incident in the prior period.
- Unequal initial major incident probabilities for each group: PAB = 0.5 and PBA = 0.0.

**Case 2**:

- The graphs for the time series PAB and PBA for all four cases appear below in the Appendix.

**Results**

The random error terms for each growth rate are normally distributed with mean of 0 and standard deviation of 0.1. The values of the weights α, β, and δ = 0.8 - used to calculate PAB and PBA -- are, respectively, 0.5, 0.25, and 0.25.

The initial condition for PAB and PBA were assumed to equal 0.1, i.e., starting out, there was zero probability for major events between the two groups. The times series for PAB and PBA exhibit an upward trend, and for about the first 15 periods, then diverge to reach a maximum probability of about 0.80 in period 101. For Base Case 1 there were 35 major incidents of A acting against B and 45 for B acting against A. The Mean Absolute Deviation (MAD) measures the average absolute difference between the PAB and PBA time series and can be viewed as how close each time series is to the other. The MAD is a "tracking" indicator. For Base Case 1 the MAD was 0.065.

In our analysis, we examined four scenarios. The data we will present is for a single data point for each case. In each example, the case is identical to the base case, except for the changes noted (see Appendix for results):

**Case 1**: Growth rate for group A is 10% (as opposed to the 4% used in the base case)

- The values of α, β, and δ are (respectively): 0.1, 0.8, and 0.1. This places higher weight on the other group's probability for an incident in the prior period.
- Unequal initial major incident probabilities for each group: PAB = 0.5 and PBA = 0.0.

**Case 2**:

- The graphs for the time series PAB and PBA for all four cases appear below in the Appendix.

**Case 3**: Unequal initial major incident probabilities for each group: PAB = 0.5 and PBA = 0.0.

**Case 4**: Unequal initial major incident probabilities for each group: PAB = 0.5 and PBA = 0.0.

**Results**

The graphs for the time series PAB and PBA for all four cases appear below in the Appendix.

**Case 1**: A represents a situation where one group grows at a significantly faster rate than the other. The graph tracks closely between the two groups, especially for the last 50 periods where each group approaches probabilities of 1.0 -- an indicator of hostility and a high likelihood of major events. Indeed, two distinguishing characteristics for this case are the high number of major events (77 and 76 in the 100 periods) that occur and the speed with which relative large event probabilities are reached. For example, a probability of 0.90 is reached on about the 50th period for Case 1. This is in contrast to the base cases where PAB and PBA never reach 0.90, even after 101 periods.

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**Case 4**: Unequal initial major incident probabilities for each group: PAB = 0.5 and PBA = 0.0.

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XAB and XBA variables). Of all the graphs, those for Case 3 differ most from the others because of a low degree of tracking (the MAD equals 134, over twice that of any other case). One explanation for this is that for Case 3, each group constantly reacts to the spur of the moment, particularly when this involves whether or not a major event occurred. In addition, the variability of Case 3 also illustrates as do the other cases, an increasing underlying trend which indicates increasing likelihood for conflict.

Case 4 presents a situation where at the beginning of the time horizon, one group is significantly more hostile to the other than vice versa (i.e., PAB(t) = 0.5 and PBA(t) = 0.0). Interestingly, after six periods this hostility difference disappears and the graphs track quite closely, albeit not as closely as in case 2. Again, just one "observation" is presented, this behavior occurred in all observations for Case 4. This may illustrate that given an underlying structure -- here, represented by our model -- initial conditions regarding inter-group hostility are less important that low incidents play themselves out over time.

CONCLUSION

The above model and subsequent analysis illustrates how simulation modeling can be used successfully to model conflict situations. The model is based on two principles observed in many conflict situations: Group differences, and how conflict can be exacerbated by major events. The feedback loops caused by each drive the model and help shape some of the results discussed in the prior section.

In our analysis, the model invariably illustrated steadily increasing values of probabilities PAB and PBA. This translates into increasing hostility and increasing likelihood of conflict as time progresses. A fundamental question is how one might eliminate or at least retard this increasing trend. What factors can be incorporated in the model to reduce conflict?

One possibility is when one group refuses to react to the differences or actions of the other, either at the beginning of the time horizon, or in the middle when the situation begins to degenerate (e.g., around period 50 in the base cases). In our model, we treated these by in each period setting PBA(t) = 0 for all periods (Case 5) and setting PBA(t) = 0 for period 51 through 101 in Case 6 -- i.e., after each group had steadily increased its hostility toward the other, as evidenced by the values of PAB and PBA. The graphs below show the results:

For Case 5, not surprisingly, the number of major events and the final probabilities are the lowest of any of the cases examined. Surprisingly, the probability of major events is lower when the group with the lower growth rate decides to take the peaceful path, that when the group with the higher growth rate decides to take the peaceful path, and more power -- selects that path. In Case 6, even though both groups increase their hostility toward the other, once group B makes the decision to adhere to a zero probability of major event against A policy, the behavior of group A also changes. By period 100, the behavior of group A is indistinguishable from its behavior if B had acted this way all along. This may illustrate that regardless of the past history between two groups, there is still hope and unilateral acts toward peace will be reciprocated.

Although elementary, this model or variants of it, can be used to examine strategies for reducing conflict. Various scenarios can be developed that model structural change in the model with values of the parameters to identify paths down which conflict can be managed and reduced. Next steps include validating the model's relationships, extending the model's scope through enhancements such as incorporating more detail in the relationships, using the model in a descriptive mode to better understand conflict behavior, and using the model in a prescriptive mode to predict and prevent conflict events.

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APPENDIX
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