

December 2003

Agent-based Simulation of Alliance Formation and its Stability Analysis: Application to Aviation Industry

Kyoichi Kijima
Tokyo Institute of Technology

Follow this and additional works at: <http://aisel.aisnet.org/pacis2003>

Recommended Citation

Kijima, Kyoichi, "Agent-based Simulation of Alliance Formation and its Stability Analysis: Application to Aviation Industry" (2003).
PACIS 2003 Proceedings. 81.
<http://aisel.aisnet.org/pacis2003/81>

This material is brought to you by the Pacific Asia Conference on Information Systems (PACIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in PACIS 2003 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact elibrary@aisnet.org.

Agent-based Simulation of Alliance Formation and its Stability Analysis: Application to Aviation Industry

Kyoichi Kijima

Graduate School of Decision Science and Technology, Tokyo Institute of Technology
2-12-1 Ookayama, Meguro-ku, Tokyo, Japan 152-8552
kijima@valdes.titech.ac.jp

Abstract

The purpose of this paper is two-fold: The first is to develop an agent-based simulation model for simulating alliance formation processes of the business world, and to analyze stability of alliance structures generated by it. The second purpose is to apply the simulation model to the civil aviation industry for validating it as well as for obtaining insightful and unique findings about the industry. As the results, we find the alliances in the industry are basically formed for network connectivity rather than management complementarities. We also suggest possibility that American Airlines and British Airways may get separated.

Keywords

Agent-based simulation, Landscape Theory, Alliance formation, Stability analysis, Aviation industry

1 Introduction

We can observe alliance formations very commonly everywhere in the world and anytime in the history. On the present international political scene, for example, the US is eager to increase its alliance members for managing the Iraqi problem through formal and informal negotiations.

The industrial world is not exception, of course. In particular, in the industries like banks, life insurance and chemical companies as well as the civil aviation industry, alliance formations are often drastic due to many and interacted factors such as business globalization, R&D cost management and changes of product life cycle.

In most situations we can find not only traditional pairwise (company-to-company) coalitions but also alliances of a variety of sizes. The purpose of this paper is two-fold: The first is to develop an agent-based simulation model for simulating alliance formation processes of the business world, and to analyze stability of the

generated alliance structures. An alliance structure is a collection of alliances and simply a partition of the set of agents or decision makers. In the former our focus is on how each agent forms alliances and/or coalitions by seeking "good partners" from a short-term viewpoint. The basic ideas of the algorithm come from Landscape Theory originally proposed by R. Axelrod [1]. It provides a well-known agent based simulation model for analyzing and predicting alliance formation processes and has been applied to several actual problems to obtain interesting insights [1][4]. However, though its fundamental assumptions seem reasonable, the basic algorithm depends on rather strong and limited premises, as discussed in the next section. We will generalize it by relaxing some of them to propose a generalized Landscape Theory.

In the latter, on the other hand, we are interested in long term decisions of each agent on whether it will keep to stay in its present alliance or leave it. Since the Landscape Theory, either original or generalized, is mainly interested in alliance formation process, whether or not an alliance structure generated is stable is out of its main concern. In this sense arguments here on stability of alliance structures should complement the Landscape Theory.

The second purpose is to apply the simulation model to the civil aviation industry for validating it as well as for obtaining insightful and unique findings about the industry. Indeed, since the Congress of the United States passed the Airline Deregulation Act in 1978, this industry has formed and dissolved quite a plenty of comprehensive alliances. That is why we choose the aviation industry as a target of our application. In early 1990s, the airlines in the United States were very concerned with comprehensive alliances to protect their rights and interests of the international flights, so that as of 2000 we have the four major alliances: Star Alliance, One World, Sky Team and NWA + KLM Alliance. Each of them includes airlines in the United States, Europe and Asia [3][6].

The structure of paper is as follows: In Section Two we will generalize the Landscape Theory to develop our algorithm for simulating alliance formation processes. Then, Section Three introduces indices to measure stability of an alliance structure. Finally, in Section Four we apply it to the civil aviation industry and discuss the results.

2 Generalized Landscape Theory for Simulating Alliance Formation Process

The original Landscape Theory [1] makes two basic assumptions. The first assumption is that an agent is myopic in its assessments. In other words, an agent evaluates how well it gets along with any other agent independent of all the other members in the system. By making only pairwise evaluations,

the agent avoids the difficult problem of assessing all combinations of agents at once.

The second is that adjustments to alliances take place by incremental movement of individual agent. This rules out the possibility that a coalition will form within an alliance and then switch the alliance as a block. This strong assumption is appropriate when information regarding payoffs is uncertain, resulting in causal ambiguity between alliance actions and payoffs.

Under these assumptions, the theory simulates an alliance formation process by supposing that each agent behaves in such a way that it tries to minimize its frustration, based on the following two key premises. The first is that each pair of agents, i and j in N , has propensity, p_{ij} , $-1 \leq p_{ij} \leq 1$, to work together, where $N = \{1, 2, \dots, n\}$ denotes a set of agents. It is a measure of how willing the two agents are to be in the same alliance together. The propensity is positive and large if the two agents get along well together and negative if they have many sources of conflict. To make the theory operational, it is critical that propensity is assumed symmetric, that is, $p_{ij} = p_{ji}$ for every i and j in N .

The second is that each agent belongs to one and only one grouping and that the number of alliances is restricted to two, *i.e.*, at any moment N is partitioned into two parties.

Though the two basic premises underpinning the theory make the model simple and operational, they do not always reflect alliance formation processes in real situations. Our generalized Landscape Theory relaxes the two premises as follows:

- Each agent i is associated with propensity p_{ij} but it may be asymmetric.
- Each agent identifies another agent only as either a partner or non-partner, but the number of alliances may be more than two.

Without the two basic premises, we need, instead, to add the following third assumption to the two basic assumptions (*i.e.*, myopic agents and incremental movement) to make our algorithm work. That is,

- Each agent cannot identify all propensities between any pair of agents, but can estimate how it is seen by the other agents and knows their propensities toward it.

It implies that an agent is not able to see the whole world due to its bounded rationality but can estimate "reputation" about itself.

Under those settings, we formulate our model as follows: Let N be a set of agents. Given an alliance structure X , a partition of N , we define distance $d_{ij}(X)$ between i and $j \in N$ by

$$d_{ij}(X) = \begin{cases} 0, & \text{if } i \text{ and } j \text{ are in the the same alliance} \\ 1, & \text{otherwise} \end{cases}$$

It is because we suppose that for any i and $j \in N$ i does care whether j belongs to the same alliance or not, but does not care which alliance j belongs to [2].

Using distance and propensity, we first define a measure of frustration of i caused by X by

$$F_i(X) = \sum_{j \neq i} s_j p_{ij} d_{ij}(X)$$

where s_j is the size of j , p_{ij} is the propensity of i to be close to j , and $d_{ij}(X)$ is the distance from i to j in X . The summation is taken over all agents except $j = i$.

Note that the definition of frustration weights propensities to work with or against another agent by the size of the other agents. This takes account of the fact that a source of conflict with a "small" agent is not as important for determining alliances as an equivalent source of conflict with a "large" agent. We can also observe that the myopic assumption is built into the definition of frustration, because a given agent's evaluation of an alliance depends on its pair wise propensities with each of the other agents and does not take into account any higher-order interactions among groups of agents.

When we run algorithm, we use weighted frustration $E_i(X)$ of agent i in X defined by

$$E_i(X) = s_i F_i(X) = s_i \sum_{j \neq i} s_j p_{ij} d_{ij}(X).$$

On the other hand, since, due to the third assumption, agent i can identify every p_{ji} , $j \in N$, we define weighted frustration $E_{-i}(X)$ of the other agents toward i caused by X by:

$$E_{-i}(X) = s_i \sum_{j \neq i} s_j p_{ji} d_{ji}(X).$$

An basic idea of our algorithm is that each agent is not so selfish and cares about the other agents in the world to some extent; formally, each agent i tries to shift its alliance in order to decrease $E_i(X)$ as much as possible, as far as the shift does not increase $E_{-i}(X)$ toward i . The idea is implemented as follows:

1. The first step creates a list of initial alliance structures. The initial alliance structures cover all alliance structures, or all possible partitions of N .
2. The second step selects an alliance structure, say X , from the list.
3. At the third step each agent i generates a set of adjacent alliance structures to X . An adjacent alliance structure to X for i is an alliance structure in the list generated from X by a move of i .

4. At the fourth step i selects its optimal adjacent alliance structure X_i^* by solving the problem
- $$\min_{X': \text{adjacent alliance of } X} E_i(X') - E_i(X) \text{ s.t. } E_{-i}(X') - E_{-i}(X) \leq 0.$$

X_i^* is such an alliance structure that attains the lowest value among all the adjacent alliance structures to X under the condition that $E_{-i}(X') - E_{-i}(X)$ is not positive. This formulation explicitly implements a kind of group-minded behavior of agents described above. X_i^* is an alliance structure expected to occur next to X .

5. The fifth step randomly selects an agent, say k , from N by employing a roulette selection rule and associates k with the optimal alliance structure X_k^* obtained at the previous step. The random selection is carried out according to the rule: To each i we assign probability $P(i) = \frac{(1/s_i)}{1/(\sum_j(1/s_j))}$, based on the idea that the smaller the agent is, the easier it can move between the alliances.
6. At the sixth step, if $X_k^* = X$ holds, the algorithm records $X_k^* = X$ as an equilibrium alliance structure and returns to the second step to try another initial alliance structure. Otherwise, we go back to the fifth step to try another k .
7. The seventh step checks whether all the initial alliance structures have been examined at the second step or not. If not, the flow goes back to the second step. If all the initial alliance structures have examined, we have created a list of the equilibrium alliance structures and the algorithm stops.

3 Stability of Alliance Structures

In the generalized Landscape Theory developed in the previous section, each agent is, based on short-term rationality, assumed to try to seek good partners and to exclude "opponent" agents from its alliance as much as possible when making its alliance. That is, it cares only about frustration to agents outside its alliance and ignores that to agents inside its alliance.

Once an alliance structure has settled, however, it is natural for each agent to worry about frustration from the members in the same alliance because of the long-term "comfortability". In this section we define such an index as to measure frustration within an alliance.

Let X be an alliance structure and A_k ($k = 1, 2, \dots, m$) be an alliance in X , *i.e.*, $X = \{A_k | k = 1, 2, \dots, m\}$. Let us suppose the number of agents in alliance A_k is n_k , where $\sum_{k=1}^m n_k = n$. First we

define discontent of agent i against j by $q_{ij} = (1 - p_{ij})/2$, where $0 \leq q_{ij} \leq 1$ and $q_{ii} = 0$. It is clear that it takes the highest value if the propensity is -1 while the lowest value if the propensity is 1 .

Next, let us define total-discontent Q_i of agent $i \in A_k$ as a weighted sum of its discontent to other agents in the same alliance by $Q_i(X) = \sum_{j \in A_k} (s_i/s_j)q_{ij}$. The weight is set such that discontent q_{ij} is more discounted for a relatively more important j , following the same principle of the Landscape Theory that the larger the size of an agent is, the more important the agent is. We do not necessarily mean that an agent with high value of total-discontent immediately withdraws from its alliance; rather the total-discontent indicates possibility of withdrawal of the agent in the near future.

Under these preparations we define stability of an alliance in terms of the average and uniformity of the total-discontent of all the agents in it. It seems intuitively appropriate that the lower the average of total-discontent of the agents in the alliance is and the more uniform total-discontent is located among the agents in it, the more stable the alliance is from the long-term viewpoint.

This intuition induces stability index $S(A_k)$ of A_k , ($k = 1, 2, \dots, m$) defined by

$$S(A_k) = \frac{C(A_k)}{R(A_k)}$$

where $C(A_k)$ is an index for measuring the uniformity while $R(A_k)$ is one for measuring the average. If $R(A_k) = 0$, then we define $S(A_k) = \infty$. We adopt the entropy function, a well-known measure of uniformity [5], as $C(A_k)$; $C(A_k) = -\sum_{i \in A_k} \tilde{Q}_i \log_{\mathcal{E}_{n_k}} \tilde{Q}_i$, where $\tilde{Q}_i = Q_i / (\sum_{i \in A_k} Q_i)$ is the normalized total-discontent. The average of the total-discontent in A_k is simply defined as $R(A_k) = (1/n_k) \sum_{i \in A_k} Q_i$.

By employing $S(A_k)$, $k = 1, 2, \dots, m$, we now measure stability of alliance structure X itself by

$$S(X) = \min_{A_k \in X} S(A_k).$$

We claim that the higher the value of $S(X)$ is, the more stable the alliance structure X is.

4 Application to the Civil Aviation Industry

Now we will return to the initial problem: First we will simulate alliance formation processes in the civil aviation industry by our generalized Landscape Theory and, then, we will analyze long term stability of the resulting alliance structures.

4.1 Data Preparations

We will examine twelve airlines; four each from the United States, Europe and Asia, all of which have given great influence on the formation of comprehensive alliances in the aviation industry (refer

Table 1: Selected twelve airlines

United States	Europe	Asia
American Airlines (AA)	Air France (AF)	Japan Airlines (JL)
Delta Air Lines (DL)	British Airways (BA)	Korean Air (KE)
Northwest Airlines (NA)	KLM Royal Dutch Airlines (KL)	All Nippon Airways (NH)
United Airlines (UA)	Lufthansa German Airlines (LH)	Cathay Pacific Airways (CX)

to Table 1). Hereafter, however, we will treat KLM and North West as one because of their extremely strong connection [7].

It is critical how to define the size and propensities of each airline when applying our model. As far as the sizes of airlines are concerned, we prepare Revenue Passengers (RP) and Revenue Passenger Kilometers (RPK) as of 2000 (Refer to Table 2).

Table 2 also shows two types of the normalized sizes within the range of $0 \leq s_i^1, s_i^2 \leq 10$, where s_i^1 is the size of airline i measured by RP and s_i^2 is by RPK while $R(s_i^1)$ is the ranking of airline i measured by RP and $R(s_i^2)$ is by RPK.

Table 2: The values of RP and RPK of all the agents

No. i	Airline	RP (million)	RPK (million)	s_i^1 normalized RP	s_i^2 normalized RPK	$R(s_i^1)$	$R(s_i^2)$
1	AA	86.0	186550	7.2	9.2	2	2
2	DL	119.9	180797	10.0	8.9	1	3
3	UA	85.0	203093	7.1	10.0	3	1
4	NA + KL	74.9	139459	6.2	6.9	4	4
5	AF	40.0	93334	3.3	4.6	8	6
6	BA	44.5	123197	3.7	6.1	6	5
7	LH	47.0	92200	3.9	4.5	5	7
8	NH	43.7	58817	3.6	2.9	7	9
9	CX	11.8	47097	1.0	2.3	11	10
10	JL	33.9	90492	2.8	4.5	9	8
11	KE	22.1	40606	1.8	2.0	10	11

On the other hand, we use six criteria, I_r , $1 \leq r \leq 6$, to establish propensities of airline i to j , where $1 \leq i, j \leq 11$. I_1 is concerned with whether or not i understands j is alliance-oriented. I_2 is related with whether or not j has code-share agreements with i . Those are the most crucial factors for alliance formation according to [3]. I_3 is concerned with whether or not the mileage is credited to

FFP¹ of i when passengers of i travel on flights of j . Although this looks similar to I_2 , it is not the case. Code-share agreements are set up for improving network connectivity, while FFP agreements are not.

I_4 shows whether or not the ranking of j is higher than that of i by six in the two types of sizes: $R(s_i^1) - R(s_j^1) \geq 6$ and $R(s_i^2) - R(s_j^2) \geq 6$. I_5 expresses whether or not the ranking of j is lower than that of i by six in the two kinds of sizes: $R(s_j^1) - R(s_i^1) \geq 6$ and $R(s_j^2) - R(s_i^2) \geq 6$. I_4 and I_5 are concerned with difference of the sizes between the airlines. The present paper supposes that an airline is much larger/smaller than another if the rankings of the sizes of the two are different by six in both RP and RPK. Six means just a half of the size of the industry. A smaller airline may tend to be a follower of a bigger one.

I_6 expresses the "regionality", since it is concerned with whether or not the home ground of j is different from that of i . This is the criterion which has been important considering alliance formation historically [3].

Based on them, for each i let us define $m_{jr}^i = 1$ if I_r is satisfied, and $m_{jr}^i = 0$ otherwise, where $1 \leq i, j \leq 11$ and $1 \leq r \leq 6$. We assume $m_{ir}^i = 1$ for every i and r . Then, we can obtain a vector $m_j^i = (m_{jr}^i)_r$. Let us illustrate it by taking the case of American Airlines (AA) ($i = 1$). Since AA has code-share agreements with JL ($i = 10$), we set $m_{10\ 2}^1 = 1$. By repeating similar procedures, we can obtain $m_{10}^1 = (0, 1, 1, 0, 1, 1)$.

Finally, we define propensity p_{ij} by $p_{ij} = \sum_r w_r m_{jr}^i$, where each weight w_r , $1 \leq r \leq 6$, is set such as (0.10, 0.35, 0.10, 0.05, 0.05, 0.35). The setting here emphasizes I_2 and I_6 by assuming that the airlines are basically interested in enhancement of network connectivity and extension of flight networks. According to the definition, for example, propensity of AA to JL is calculated by $p_{1\ 10} = 0.35 + 0.10 + 0.05 + 0.35 = 0.85$. We later will argue how appropriate the weight setting is.

4.2 Simulation Results and their Findings

Because we believe the alliances are formed under initiative of the airlines in the United States and Europe, this paper focuses on the behavior of seven airlines in the United States and Europe, *i.e.*, $i = 1, 2, \dots, 7$ in Table 2. We limit the number of the agents to seven due to limitation of our computer ability as well. The present actual alliance structure is expressed by [1, 2, 3, 4, 2, 1, 3], which means that $i = 1$ and 6 are in one alliance while $i = 2$ and 5 are in another and so on.

First we use RP as the size of each airline and iterate the simulation 5000 times, then we generate

¹FFP stands for Frequent Flyers Program.

fifteen equilibrium alliance structures, among which the followings are the five most stable. The last number of each row shows stability of the alliance structure.

[[1, 2, 3, 4, 2, 5, 3], 2.75737624072494340]
[[1, 2, 3, 4, 2, 1, 3], 1.3359484417440877]
[[1, 2, 3, 4, 2, 1, 5], 1.3359484417440877]
[[1, 2, 3, 4, 5, 1, 3], 1.3359484417440877]
[[1, 2, 3, 1, 2, 4, 3], 1.3071635691998946]

Next, we employ RPK, instead of RP, as the size of each airline and iterate the simulation 5000 times. Then we generate thirteen equilibrium alliance structures. The followings are the five most stable equilibrium alliance structures.

[[1, 2, 3, 4, 2, 5, 3], 4.895024181860576]
[[1, 2, 3, 4, 2, 1, 3], 1.8172162143436539]
[[1, 2, 3, 4, 2, 1, 5], 1.8172162143436539]
[[1, 2, 3, 4, 5, 1, 3], 1.8172162143436539]
[[1, 2, 3, 1, 2, 4, 3], 1.2827955420320083]

The followings are some of our findings by analyzing the simulation results:

1. As far as the most stable five equilibrium alliance structures are concerned, there is no difference between the two cases. It implies whether we use ARK or RPK does not affect the stability. It also shows robustness of our simulations.
2. In the both cases we can see that the second ranked equilibrium alliance structure corresponds to the present actual one. However, the equilibrium alliance structure where BA ($i = 6$) is independent has the highest stability. It suggests that the present One World may be fragile and it may be possible that AA and BA will get separated in the near future.
3. We can clearly see that in most equilibrium alliance structures the four US-based airlines are independent of each other and never get together. It implies that they take strong initiative to make alliances while the others follow them.
4. The weighting vector adopted so far emphasizes w_2 , code-share agreements and w_6 , the regionality. Since the effect of the regionality on alliance formation is clear, we now examine influence by w_2 . We set $w_6 = 0.3$ in order to fix the influence of the regionality, while we

change w_2 within the interval $[0.3, 0.35]$ by 0.01. The other weights are determined such that any of them do not have outstanding effects. Then, the results for $w_2 \geq 0.32$ is the same as the case of $w_2 = 0.35$.

5. We also have a try with a weighting vector $(0.30, 0.05, 0.05, 0.15, 0.15, 0.30)$, which emphasizes I_1, I_4, I_5 and I_6 by assuming that the airlines form alliances for seeking management complementarities. Then, our simulations generate stable equilibrium alliances relatively inconsistent with the real situation, compared with the case of $(0.10, 0.35, 0.10, 0.05, 0.05, 0.35)$. It implies that the alliance formations in the aviation industry seem to be mainly motivated by network connectivity rather than by management complementarities.

5 Conclusions

One of main methodological contributions of this paper is that we investigate alliance formation processes from two complementary viewpoints; a short-term one and long-term one. By using our generalized Landscape Theory we could simulate how each agent behave to avoid cooperating with opponent agents from a short-term viewpoint under some mild conditions. We next explored which alliance structures are the most stable from a long-term viewpoint by introducing stability indices.

For practical implications from the model, the paper applied it to the aviation industry by defining sets of parameters in several ways. With the data as of 2000, we illustrated the alliance formations in the industry are basically motivated by network connectivity rather than management complementarities. The findings were shown quite robust by conducting sensitivity analysis. We also compared the present situation with the results derived from the simulation in terms of stability, we suggested possibility that American Airlines and British Airways, though they behave as coalition members of One World, may get separated in the near future.

References

- [1] Robert Axelrod. *Complexity of Cooperation: Agent-Based Models of Competition and Collaboration*. Princeton University Press, 1997.
- [2] Masayoshi Iriuchijima. Generalization of Landscape Theory and its Application. Master's thesis in 1999, Tokyo Institute of Technology, 2000. (Japanese).

- [3] Japan Aeronautic Association. *Aviation Statistics Directory*. Japan Aeronautic Association, 2001. (Japanese).
- [4] Kyoichi Kijima. *Invitation to Drama Theory*. Ohmsha, 2001. (Japanese).
- [5] Masanori Ohya. *Introduction to Information Mathematical Sciences*. SAIENSU-SHA Co.,Ltd., 1999. (Japanese).
- [6] Dawna L. Rhoades and Heather Lush. A typology of strategic alliances in the airline industry. *Journal of Air Transport Management*, 3(3):109–114, 1997.
- [7] Kazuki Sugiura. *Big Competition in Aviation Industry*. Chuoshoin, 2002. (Japanese).