

Two-Way and Three-Way Pistol Duel Puzzles

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Introduction

This project focus on solving two interesting puzzles, a two-way pistol duel and a three-way pistol duel. 3 alternative approaches will be presented for solving the two-way duel,

- **geometric series approach;**
- **conditional probability approach;**
- **system of linear equations approach;**

The linear system of linear equations approach can be considered as a preparation for solving the three-way duel.

We've also developed web-based numerical simulations to verify the theoretical solutions. Please visit jjjzhang.com



Two-way Duel

Two players **A** and **B** start a pistol duel. Respectively, **A** and **B** have $0 < \alpha, \beta \leq 1$ of chances on average hitting the target. If **A** takes the first shot, what is the chance that **A** survives? What if **B** shoots first?



Slide 3/29: Two-Way Duel 2/7

Solution: Let x be the probability that **A** survives if **A** shoots first and y be the probability that **B** survives if **B** shoots first.

Geometric Series Approach: When **A** shoots first **A** has a chance of α hits **B** in the 1st round. If both **A** and **B** miss their first shots in the 1st round then, by the Probability Multiplication Rule, **A** has a chance of $(1 - \alpha)(1 - \beta)\alpha$ hits **B** in the 2nd round, then, a chance of $[(1 - \alpha)(1 - \beta)]^2\alpha$ in the 3rd, so on and so forth. Thus, the total chance that **A** survives is

$$x = \sum_{j=0}^{\infty} [(1 - \alpha)(1 - \beta)]^j \alpha = \frac{\alpha}{1 - (1 - \alpha)(1 - \beta)} \quad (0 \leq (1 - \alpha)(1 - \beta) < 1).$$

Analogously, when **B** shoots first the total chance that **B** survives is

$$y = \frac{\beta}{1 - (1 - \alpha)(1 - \beta)}.$$



Slide 4/29: Two-Way Duel 3/7

That is, when **A** shoots first the chance that **A** survives is

$$x = \sum_{j=0}^{\infty} [(1-\alpha)(1-\beta)]^j \alpha = \frac{\alpha}{1 - (1-\alpha)(1-\beta)},$$

and the chance that **B** survives is

$$1 - x = 1 - \frac{\alpha}{1 - (1-\alpha)(1-\beta)} = \frac{(1-\alpha)\beta}{1 - (1-\alpha)(1-\beta)}.$$

This solution can also be derived/explained by the other two approaches below.



Conditional Probability Approach:

Denote by U the event that player **A** hits the target;

Denote by V the event that the duel ends at the 1st round;

$$\begin{aligned} P(U|V) &= \frac{P(U \cap V)}{P(V)} = \frac{P(U)P(V|U)}{P(V)} \\ &= \frac{\alpha \cdot 100\%}{1 - (1 - \alpha)(1 - \beta)} = \frac{\alpha}{1 - (1 - \alpha)(1 - \beta)} \end{aligned}$$

That is, under the condition that the duel ends at the 1st player **A**'s survival probability is

$$\frac{\alpha}{1 - (1 - \alpha)(1 - \beta)}$$



Slide 6/29: Two-Way Duel 5/7

If the duel doesn't end at the 1st round it goes to the 2nd round. Analogously, if the duel ends at the 2nd round the conditional probability that **A** survives is still

$$\frac{\alpha}{1 - (1 - \alpha)(1 - \beta)},$$

and so it is if the duel ends at the 3rd round, the 4th round, ... Thus, in the entire duel **A**'s survival probability is

$$\frac{\alpha}{1 - (1 - \alpha)(1 - \beta)}, \text{ and } \mathbf{B}'\text{'s survival probability is}$$

$$1 - \frac{\alpha}{1 - (1 - \alpha)(1 - \beta)} \quad \text{or} \quad \frac{(1 - \alpha)\beta}{1 - (1 - \alpha)(1 - \beta)},$$

given that the duel process is convergent (since $0 < \alpha, \beta \leq 1$).



System of Linear Equation Approach:

When **A** starts the duel and misses the first shot, the duel actually becomes being led by **B**. By the Multiplication Rule and the fact that the sum of **A**'s and **B**'s survival probabilities must be 100% either when **A** starts or **B** starts the duel, we have

$$\begin{cases} x + (1 - \alpha)y = 1 \\ (1 - \beta)x + y = 1 \end{cases} \implies$$

$$\begin{cases} x = \frac{\alpha}{1 - (1 - \alpha)(1 - \beta)} \\ y = \frac{\beta}{1 - (1 - \alpha)(1 - \beta)} \end{cases} \quad \text{Eqn. (1)}$$



Slide 8/29: Two-Way Duel 7/7

For Example, $\alpha = 0.3$ and $\beta = 0.8$.

When **A** shoots first

A's survival probability is $x = \frac{\alpha}{1 - (1 - \alpha)(1 - \beta)} \approx 0.3488$

B's survival probability is $1 - x$ or $(1 - \alpha)y \approx 0.6512$

When **B** shoots first

B's survival probability is $y = \frac{\beta}{1 - (1 - \alpha)(1 - \beta)} \approx 0.9302$

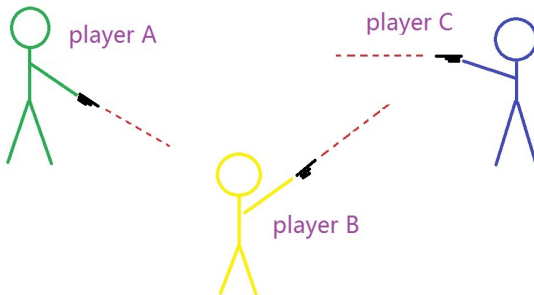
A's survival probability is $1 - y$ or $(1 - \beta)x \approx 0.0698$



Three-way Duel

Part I: **A**, **B** and **C** take turn to shoot at each other in an order of **A**, **B**, **C**, **A**, Respectively, **A**, **B** and **C** have α, β and γ ($0 < \alpha, \beta, \gamma \leq 1$) of chances on average hitting the target. They choose target also in the order of **A**, **B**, **C**, **A**, ... unless one of them has already been eliminated. If **A** takes the first shot what are the chances that **A**, **B**, **C** survive?

Part II: What is they randomly and evenly choose target?



Slide 10/29: Three-Way Duel 2/19 Part I

Part I Solution: Let the chance that **A**, **B** or **C** survives when **A**, **B** or **C** starts the duel be x , y or z , respectively.

The linear system approach used in the two-way duel can be applied to solve the three-way version by setting up 3 linear equations each based on that **A**, **B** or **C** leads the duel.

The first linear equation: **A** starts the duel. the chance that **A** survives, the chance that **B** survives and the chance that **C** survives must add up to 1 as calculated below.



Slide 11/29: Three-Way Duel 3/19 Part I

When **A** starts the duel,

- The chance **A** survives is x .
- The chance that **B** survives is $(1 - \alpha)y$ that is determined by the only non-zero-chance case: **A** misses.
- The chance that **C** survives is determined by the union of two exclusive non-zero-chance cases: (i) **A** hits **B** then the duel becomes two-way between **C** and **A** led by **C**, (ii) Both **A** misses their shots.

Thus, The chance that **C** survives is

$$\alpha \cdot \frac{c}{1 - (1 - \alpha)(1 - \gamma)} + (1 - \alpha)(1 - \beta)z$$



Slide 12/29: Three-Way Duel 4/19 Part I

The first linear equation that describes the duel led by **A** is

$$x + (1 - \alpha)y + \alpha \cdot \frac{c}{1 - (1 - \alpha)(1 - \gamma)} + (1 - \alpha)(1 - \beta)z = 1$$

By accordingly rotating/exchanging x , y , z , α , β and γ we have the other two linear equations that describe the duel led by **B** and the duel led **C** to form the system as

$$\left\{ \begin{array}{l} x + (1 - \alpha)y + \alpha \cdot \frac{\gamma}{1 - (1 - \alpha)(1 - \gamma)} + (1 - \alpha)(1 - \beta)z = 1 \\ \beta \cdot \frac{\alpha}{1 - (1 - \alpha)(1 - \beta)} + (1 - \beta)(1 - \gamma)x + y + (1 - \beta)z = 1 \\ (1 - \gamma)x + \gamma \cdot \frac{\beta}{1 - (1 - \beta)(1 - \gamma)} + (1 - \alpha)(1 - \gamma)y + z = 1 \end{array} \right.$$



Slide 13/29: Three-Way Duel 5/19 Part I

In matrix-vector form:

$$\begin{bmatrix} 1 & (1-\alpha) & (1-\alpha)(1-\beta) \\ (1-\beta)(1-\gamma) & 1 & (1-\beta) \\ (1-\gamma) & (1-\alpha)(1-\gamma) & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$
$$= \begin{bmatrix} 1 - \frac{\alpha\gamma}{1-(1-\alpha)(1-\gamma)} \\ 1 - \frac{\alpha\beta}{1-(1-\alpha)(1-\beta)} \\ 1 - \frac{\beta\gamma}{1-(1-\beta)(1-\gamma)} \end{bmatrix}$$



Slide 14/29: Three-Way Duel 6/19 Part I

The inverse of the coefficient matrix (the augmented matrix):

$$\begin{bmatrix} 1 & (1-\alpha) & (1-\alpha)(1-\beta) \\ (1-\beta)(1-\gamma) & 1 & (1-\beta) \\ (1-\gamma) & (1-\alpha)(1-\gamma) & 1 \end{bmatrix}^{-1} =$$

$$\frac{1}{1 - (1-\alpha)(1-\beta)(1-\gamma)} \begin{bmatrix} 1 & \alpha-1 & 0 \\ 0 & 1 & \beta-1 \\ \gamma-1 & 0 & 1 \end{bmatrix}$$



The solution

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{1 - (1 - \alpha)(1 - \beta)(1 - \gamma)} \begin{bmatrix} 1 & \alpha - 1 & 0 \\ 0 & 1 & \beta - 1 \\ \gamma - 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 - \frac{\alpha\gamma}{1 - (1 - \alpha)(1 - \gamma)} \\ 1 - \frac{\alpha\beta}{1 - (1 - \alpha)(1 - \beta)} \\ 1 - \frac{\beta\gamma}{1 - (1 - \beta)(1 - \gamma)} \end{bmatrix}$$



Slide 16/29: Three-Way Duel 8/19 Part I

For example, when $\alpha = 0.12$, $\beta = 0.34$, $\gamma = 0.56$, the solution is

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{1 - (1 - \alpha)(1 - \beta)(1 - \gamma)} \begin{bmatrix} 1 & \alpha - 1 & 0 \\ 0 & 1 & \beta - 1 \\ \gamma - 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 - \frac{\alpha\gamma}{1 - (1 - \alpha)(1 - \gamma)} \\ 1 - \frac{\alpha\beta}{1 - (1 - \alpha)(1 - \beta)} \\ 1 - \frac{\beta\gamma}{1 - (1 - \beta)(1 - \gamma)} \end{bmatrix}$$
$$\approx \begin{bmatrix} 0.1289 \\ 0.5639 \\ 0.4566 \end{bmatrix}.$$



Slide 17/29: Three-Way Duel 9/19 Part I

For example, $\alpha = 0.12$, $\beta = 0.34$, $\gamma = 0.56$

When **A** leads the duel,

the chance that **A** survives is $x \approx$ **0.1289**,

the chance that **B** survives is $(1 - \alpha)y \approx$ **0.4962**,

the chance that **C** survives is

$$\alpha \cdot \frac{\gamma}{1 - (1 - \alpha)(1 - \gamma)} + (1 - \alpha)(1 - \beta)z \approx \mathbf{0.3749}.$$



Part II Solution: Let the chance that **A**, **B** or **C** survives when **A**, **B** or **C** starts the duel be x , y or z , respectively.

The Solution II used in the 2-way duel can be applied to solve the 3-way version by setting up 3 linear equations.

The first linear equation: **A** starts the duel. The sum of the chance that **A** survives, the chance that **B** survives and the chance that **C** survives must equal to 1 as calculated below.



Slide 19/29: Three-Way Duel 11/19 Part II

When **A** starts the duel,

- the chance **A** survives is x .
- the chance that **B** survives is determined by the union of 3 exclusive cases:

Case I: **A** chooses to shoot **B** and hits the target. The chance that **B** survives is 0;

Case II: **A** chooses to shoot **C** and hits the target. The duel becomes a two-way duel between **B** and **A** led by **B**. By the results derived in **Part I** (Eqn. (1)) the chance that **B** survives is $\frac{\alpha}{2} \cdot \frac{\beta}{\alpha + \beta - \alpha\beta}$;

Case III: **A** misses the shot. The duel is still a three-way duel led by **B**. The chance that **B** survives is $(1 - \alpha)y$.



Slide 20/29: Three-Way Duel 12/19 Part II

When **A** shoots first the total chance that **B** survives is

$$\frac{\alpha}{2} \cdot \frac{\beta}{\alpha + \beta - \alpha\beta} + (1 - \alpha)y.$$

- The chance that **C** survives is determined by the union of 4 exclusive cases:

Case I: **C** is hit by **A** or **B**. The chance that **C** survives is 0;

Case II: **A** chooses to and hits **B**. The duel becomes two-way led by **C** against **A**. The chance that **C** survives is

$$\frac{\alpha}{2} \cdot \frac{\gamma}{\alpha + \gamma - \alpha\gamma};$$

Case III: **A** misses the shot followed by that **B** chooses to and hits **A**. The duel becomes two-way led by **C** against **B**. The

chance that **C** survives is $(1 - \alpha) \cdot \frac{\beta}{2} \cdot \frac{\gamma}{\beta + \gamma - \beta\gamma};$



Slide 21/29: Three-Way Duel 13/19 Part II

Case IV: Both **A** and **B** miss their shots. The duel is still three-way led by **C** followed by **A** and then **B**. The chance that **C** survives is $(1 - \alpha)(1 - \beta)z$;

When **A** shoots first the total chance that **C** survives is

$$\frac{\alpha}{2} \cdot \frac{\gamma}{\alpha + \gamma - \alpha\gamma} + (1 - \alpha) \cdot \frac{\beta}{2} \cdot \frac{\gamma}{\beta + \gamma - \beta\gamma} + (1 - \alpha)(1 - \beta)z.$$

We have the first equation (**A** starts the duel).

$$x + \frac{\alpha}{2} \cdot \frac{\beta}{\alpha + \beta - \alpha\beta} + (1 - \alpha)y + \frac{\alpha}{2} \cdot \frac{\gamma}{\alpha + \gamma - \alpha\gamma} + (1 - \alpha) \cdot \frac{\beta}{2} \cdot \frac{\gamma}{\beta + \gamma - \beta\gamma} + (1 - \alpha)(1 - \beta)z = 1.$$

By rotating/exchanging $x, y, z, \alpha, \beta, \gamma$ accordingly we have the other two linear equations for the duel that **B** starts the shooting followed by **C** then **A** and for the duel that **C** starts the shooting followed by **A** then **B** to form the following 3×3 linear system.



Slide 22/29: Three-Way Duel 14/19 Part II

Recall the definitions, skill levels of player **A**, **B** and **C** are α, β, γ ; Chances that they survive when they start the duel are x, y, z , respectively. α, β, γ and x, y, z satisfy the linear system below.

$$\begin{cases} x + \frac{\alpha}{2} \cdot \frac{\beta}{\alpha + \beta - \alpha\beta} + (1 - \alpha)y + \frac{\alpha}{2} \cdot \frac{\gamma}{\alpha + \gamma - \alpha\gamma} + (1 - \alpha) \cdot \frac{\beta}{2} \cdot \frac{\gamma}{\beta + \gamma - \beta\gamma} + (1 - \alpha)(1 - \beta)z = 1 \\ \frac{\beta}{2} \cdot \frac{\alpha}{\alpha + \beta - \alpha\beta} + (1 - \beta) \cdot \frac{\gamma}{2} \cdot \frac{\alpha}{\alpha + \gamma - \alpha\gamma} + (1 - \beta)(1 - \gamma)x + y + \frac{\beta}{2} \cdot \frac{\gamma}{\beta + \gamma - \beta\gamma} + (1 - \beta)z = 1 \\ \frac{\gamma}{2} \cdot \frac{\alpha}{\alpha + \gamma - \alpha\gamma} + (1 - \gamma)x + \frac{\gamma}{2} \cdot \frac{\beta}{\beta + \gamma - \beta\gamma} + (1 - \gamma) \cdot \frac{\alpha}{2} \cdot \frac{\beta}{\alpha + \beta - \alpha\beta} + (1 - \alpha)(1 - \gamma)y + z = 1 \end{cases}$$



Slide 23/29: Three-Way Duel 15/19 Part II

In matrix-vector form:

$$\begin{bmatrix} 1 & (1-\alpha) & (1-\alpha)(1-\beta) \\ (1-\beta)(1-\gamma) & 1 & (1-\beta) \\ (1-\gamma) & (1-\alpha)(1-\gamma) & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$
$$= \begin{bmatrix} 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha+\beta-\alpha\beta} + \frac{\alpha\gamma}{\alpha+\gamma-\alpha\gamma} + \frac{\beta\gamma}{\beta+\gamma-\beta\gamma} - \frac{\alpha\beta\gamma}{\beta+\gamma-\beta\gamma} \right) \\ 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha+\beta-\alpha\beta} + \frac{\alpha\gamma}{\alpha+\gamma-\alpha\gamma} + \frac{\beta\gamma}{\beta+\gamma-\beta\gamma} - \frac{\alpha\beta\gamma}{\alpha+\gamma-\alpha\gamma} \right) \\ 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha+\beta-\alpha\beta} + \frac{\alpha\gamma}{\alpha+\gamma-\alpha\gamma} + \frac{\beta\gamma}{\beta+\gamma-\beta\gamma} - \frac{\alpha\beta\gamma}{\alpha+\beta-\alpha\beta} \right) \end{bmatrix}$$



Slide 24/29: Three-Way Duel 16/19 Part II

The inverse of the coefficient matrix (the augmented matrix):

$$\begin{bmatrix} 1 & (1-\alpha) & (1-\alpha)(1-\beta) \\ (1-\beta)(1-\gamma) & 1 & (1-\beta) \\ (1-\gamma) & (1-\alpha)(1-\gamma) & 1 \end{bmatrix}^{-1} =$$

$$\frac{1}{1 - (1-\alpha)(1-\beta)(1-\gamma)} \begin{bmatrix} 1 & \alpha-1 & 0 \\ 0 & 1 & \beta-1 \\ \gamma-1 & 0 & 1 \end{bmatrix}$$



The solution

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{1 - (1 - \alpha)(1 - \beta)(1 - \gamma)} \begin{bmatrix} 1 & \alpha - 1 & 0 \\ 0 & 1 & \beta - 1 \\ \gamma - 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha + \beta - \alpha\beta} + \frac{\alpha\gamma}{\alpha + \gamma - \alpha\gamma} + \frac{\beta\gamma}{\beta + \gamma - \beta\gamma} - \frac{\alpha\beta\gamma}{\beta + \gamma - \beta\gamma} \right) \\ 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha + \beta - \alpha\beta} + \frac{\alpha\gamma}{\alpha + \gamma - \alpha\gamma} + \frac{\beta\gamma}{\beta + \gamma - \beta\gamma} - \frac{\alpha\beta\gamma}{\alpha + \gamma - \alpha\gamma} \right) \\ 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha + \beta - \alpha\beta} + \frac{\alpha\gamma}{\alpha + \gamma - \alpha\gamma} + \frac{\beta\gamma}{\beta + \gamma - \beta\gamma} - \frac{\alpha\beta\gamma}{\alpha + \beta - \alpha\beta} \right) \end{bmatrix}$$



Slide 26/29: Three-Way Duel 18/19 Part II

For example, $\alpha = 0.36, \beta = 0.63, \gamma = 0.27$. The solution is

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \frac{1}{1 - (1-\alpha)(1-\beta)(1-\gamma)} \begin{bmatrix} 1 & \alpha-1 & 0 \\ 0 & 1 & \beta-1 \\ \gamma-1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha+\beta-\alpha\beta} + \frac{\alpha\gamma}{\alpha+\gamma-\alpha\gamma} + \frac{\beta\gamma}{\beta+\gamma-\beta\gamma} - \frac{\alpha\beta\gamma}{\beta+\gamma-\beta\gamma} \right) \\ 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha+\beta-\alpha\beta} + \frac{\alpha\gamma}{\alpha+\gamma-\alpha\gamma} + \frac{\beta\gamma}{\beta+\gamma-\beta\gamma} - \frac{\alpha\beta\gamma}{\alpha+\gamma-\alpha\gamma} \right) \\ 1 - \frac{1}{2} \left(\frac{\alpha\beta}{\alpha+\beta-\alpha\beta} + \frac{\alpha\gamma}{\alpha+\gamma-\alpha\gamma} + \frac{\beta\gamma}{\beta+\gamma-\beta\gamma} - \frac{\alpha\beta\gamma}{\alpha+\beta-\alpha\beta} \right) \end{bmatrix}$$
$$\approx \begin{bmatrix} 0.2864 \\ 0.5418 \\ 0.2216 \end{bmatrix}.$$



Slide 27/29: Three-Way Duel 19/19 Part II

$$\alpha = 0.36, \beta = 0.63,$$

$$\gamma = 0.27 \Rightarrow x \approx 0.2864, y \approx 0.5418, z \approx 0.2216.$$

When **A** leads the duel,

the chance that **A** survives is $x \approx$ **0.2864**,

the chance that **B** survives is

$$\frac{\alpha}{2} \cdot \frac{\beta}{\alpha + \beta - \alpha\beta} + (1 - \alpha)y \approx$$
 0.4953,

the chance that **C** survives is

$$\frac{\alpha}{2} \cdot \frac{\gamma}{\alpha + \gamma - \alpha\gamma} + (1 - \alpha) \cdot \frac{\beta}{2} \cdot \frac{\gamma}{\beta + \gamma - \beta\gamma} + (1 - \alpha)(1 - \beta)z$$
$$\approx$$
 0.2183.



Web-Based Numerical Simulators @ jjjzhang.com



Welcome to My Class Project Fall 2024

Two-Way Duel Three-Way Duel Random Three-Way Duel

Two-Way Duel Simulator

Player A and B take turn shooting at each other. [winning rate calculation \(presentation slides\)](#)

Player A Skill Level
in $[0, 1]$
0.12

One Game A Leads

Player B Skill Level
in $[0, 1]$
0.13

One Game B Leads



Theoretical Winning Rate	Player A	Player B
	51.1945%	48.8055%
Multiple Games # of Games	Multiple Games A Leads	A Wins 240/492=50.2075%
999	Multiple Games B Leads	B Wins 240/492=48.7925%



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Pistol Duel Simulator 3 players take turn shooting at each other. The chosen target is evenly RANDOM (unless one of them is already out). Winning rate calculation in [Presentation Slides](#)

Enter Skill Levels in $[0, 1]$

Player A: 0.45
Player B: 0.67
Player C: 0.09

Play One Game

A Leads
B Leads
C Leads

Play Multiple Games

of Games: 999
A Leads
B Leads
C Leads

A-Led One Game (random) Round 1

Theoretical Winning Rate A: 19.6585% B: 34.4246% C: 45.9169%

A is Out

C is Out



B-Led 450 of 999 Games (random) Played

Theoretical Winning Rate		
A: 26.1652%	B: 29.1033%	C: 44.7315%
Experimental Winning Rate		
A: 129/450=28.6667%	B: 119/450=26.4444%	C: 202/450=44.8889%



Reference

1. Class Project, Fall 2024
2. Three Way Duel or Truel at
<https://puzzles.nigelcoldwell.co.uk/fiftyone.htm>
3. Three-Way Duel at
<https://www.youtube.com/watch?v=N9D4CwXTjdQ>

