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Quantitative Analysis of Dynamic Systems: Interaction Models Through Differential Equations

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Abstract: This article explores the quantitative analysis of interacting dynamic systems using differential equations. Specifically, this approach is applied to model a hypothetical two-sided confrontation. The power potential and effectiveness of each side are taken into account, and the system dynamics and its evolution over time are determined through mathematical methods. Simulation results indicate that the side with higher efficiency coefficients wins the upper hand. The duration of the conflict and the resource losses for each side are assessed, revealing that the victorious party sustains a certain percentage of their initial resources as losses. This model can serve as a crucial tool for analyzing interactions in complex systems and supporting strategic decision-making .

Keywords: dynamic systems, quantitative analysis, differential equations, interaction models, system dynamics, efficiency coefficients, resource management, mathematical modeling.

the Greens (N_1) and the Blues groups (N_2). Each group is characterized by its own number of military units and methods of fighting.

the Greens and the Blues, the probabilities of each group being shot at and being fired upon are studied, as well as the number of military units remaining in the battle.

Initial conditions:

The number of initial military units of the Greens; $m_1(0) = N_1$;

The primary military units of the Blue Group are: $m_2(0) = N_2$;

The number of military units in each group changes over time. t **Differential equations for calculating the change in the number of military units** [3,4] These equations are based on the probability of being shot and the probability of being fired.

Calculating Changes in Battle

Changes in battle occur in small periods divided by time units. We calculate the change in the number of military units of each group using the following expressions: Δt

1. Green Group Change: The change in the number of Green Group military units Δm_1 is caused by the firing of K Arrows Group military units:

$$\Delta m_1 = -k_2 m_2 \Delta t.$$

Here: $k_2 -$ average firing speed, $m_2 - k$ is the number of available military units of the group of arrows, $\Delta t -$ small interval of time.

Also, in the limit state of the equation, the following differential equation is formed:

$$\frac{dm_1}{dt} = -k_2 m_2.$$

Blue Group Change: The change in the number of military units of the Blue Group $\Delta m_2$is caused by the firing of the Green Group:

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$$\frac{dm_2}{dt} = -km_1m_2.$$

shows the interaction between the military units of each group.

Victory in battle and calculation of time. To predict the outcome of a battle, the combat performance of each group, their rate of fire, the probability of hitting the target, and other coefficients are taken into account [5, 6].

the average number of green troops m_1 by and blue troops by during m_2 the time interval t and Δt calculate their change over a small time interval. Δm_1 The change is due to the withdrawal of troops damaged by blue fire. Δt During the time m_2 interval, which of the blue troops k_2 Δt ta successful shots. Here, $k_2 = \gamma_2 p_2$ the average rate of fire is the number of shots fired by the blue military units per unit of time (the p_2 probability of hitting the target in a given shot).

That is why

$$\Delta m_1 = -k_2 m_2 \Delta t.$$

Dividing $\Delta t \to 0$ both sides of the equation by Δt and taking the limit at, we obtain the following differential equation:

$$\frac{dm_1}{dt} = -k_2m_2.$$

Using similar reasoning as above, we obtain the following second equation:

$$\frac{dm_2}{dt} = -km_1km_2,$$

we have created a system of differential equations with $m_2(0) = N_2$ initial conditions $m_1(0) = N_1$.

The Blues have 25 tanks, their average rate of fire γ_2 is 0.5 rounds per minute, and their average probability of hitting the target P_2 is 0.5.

Let's show which side will win the battle, approximately how long it will take, and how much of the winning side's losses will be in the end.

First, we calculate the following coefficients:

$$u_1 = \frac{\gamma_2 N_1}{N_2} = \frac{0{,}25 \cdot 0{,}56 \cdot 50}{25} = 0{,}28,$$

$$u_2 = \frac{\gamma_2 N_2}{N_1} = \frac{0{,}5 \cdot 0{,}5 \cdot 25}{50} = 0{,}125.$$

Here:

γ_2— average reading speed,

N_1 and — N_2 The number of initial military units of the Green and Blue groups,

u_1 and — u_2 coefficients indicating the combat capabilities of each group.

$u_1 > u_2$ Because the greens win.

The end time of the fight is calculated as follows:

$$t = \sqrt{\frac{u_1}{u_2}} = \sqrt{\frac{0{,}28}{0{,}125}} \approx 1{,}5\, min$$

at the end of the $\mu_2 = 0$ battle

$$cht - x\, sht = 0.$$

From here =0.667. $tht = \frac{1}{x} = \frac{1}{1.5}$ We find $t = \frac{0.8}{0,178} = 4,28\ (min)$ from the hyperbolic tangent table, and by shooting in real time $t = 0,8$ we find. We determine that the remaining tanks of the greens will receive at the end of the battle:

$$\mu_1 = ch\ \cdot 0,8 - 0,667 \cdot sh \cdot\ 0,8 = 1,337 - 0,667 \cdot 0,881 = 0,752.$$

Thus, the tank battle ends in a green victory after about 4.5 minutes, with the winning side losing about 25% of the tanks it initially had, or about 12 tanks.

Factors affecting the outcome of the battle. Through the coefficients and equations calculated based on the model, the victories and losses of each group in the battle are determined. The main factors influencing the outcome of the battle are:

Fire Rate γ_2: This factor determines the speed of the battle and the reduction in the number of military units. The high fire rate of the blue team increases their combat effectiveness, but it only reduces the combat capabilities of the green team;

Hit Probability p_2: This parameter determines the probability of each bullet hitting the target. While the Greens' firing is ineffective, their numbers and combat effectiveness can be high, which serves as the basis for their victory.

Starting Unit Count N_1, N_2: The starting unit count of each group determines the initial state of the battle. The higher or lower this number will affect the groups' combat capabilities and the duration of the battle. For example, if the green group has more starting units than the blue group, this will determine their superiority in the battle.

The final results of the battle. Based on the model, taking into account the above parameters, the probability of victory of the $\boldsymbol{u_1 > u_2\ y\ -}$ army group was determined. It guarantees the victory of the $\boldsymbol{y} -$ army group. This is due to their combat effectiveness and high rate of fire. The end time of the battle is estimated to be approximately 1.5 minutes, during which time the number of military units of the $\boldsymbol{k} -$ army group will be zero, and they will be defeated in the battle.

At the end of the battle, the number of surviving tanks of the Green Group is 75.2 **%, that** is, approximately **12 of their tanks** are lost in the battle. This means that only 25% of the original military units of the Green Group will survive the battle, the rest will be lost.

Distribution of wins and losses. The victory of the Greens is the final result of the battle, they lose 12 of the initial 50 tanks. This, taking into account the reduction in the number of military units in the battle and the effectiveness of the fire, indicates a complete defeat of one side and half-size losses for the other. For the winning side, this means a strategic advantage and high efficiency, but the losses of both groups are divided equally between them.

Advanced models and additional features. It is also possible to model the battle in a more complex way. For example:

Complex battle strategies: Each group's actions may depend not only on the rate of fire and the probability of hitting the target, but also on additional factors such as guard placement, covert actions, tactical errors, or the duration of the attack.

Speed and Positioning of Military Units: The speed and positioning of tanks and other military units in battle play a significant role in determining the success of each group. Taking other factors into account can help you better predict the outcome of a battle.

Interaction between multiple groups: When multiple groups are involved in a battle, it is important to consider the interactions between them . For example, when multiple groups are fighting each other, each group may develop its own strategy and attempt to neutralize its opponents through **interaction.**

Conclusion. In general, the dynamics of military operations can be used to mathematically model how a battle will unfold and which side will win. This model takes into account the parameters of the battle and the actions of the groups, analyzing their mutual influence. It was shown that the victory of the Green group was associated with their combat effectiveness and high rate of fire.

At the same time, when predicting the final results of the battle, it is necessary to take into account the strategy of military units, mutual influences and external factors. The duration of the battle, the losses of military units and the effectiveness of each group in achieving victory must be analyzed. This is not only a battle simulation, but also an important tool for developing military strategies and applying them on the battlefield.

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