The Impact Density Rate (IDR) Algorithm: A Dynamic Approach to Terminal Ballistics Modeling

Blair T Simpkins

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ABSTRACT

This paper introduces the Impact Density Rate (IDR) as a novel computational metric for simulating projectile penetration in soft media. By integrating instantaneous velocity, mass, and caliber-specific sectional density into a single dimensional value (M^2/T), the IDR algorithm provides a dynamic framework for calculating velocity decay and penetration depth. The simulation utilizes a discrete-step Riemann integration to account for projectile expansion and shifting sectional density, offering a high-fidelity alternative to traditional static terminal ballistics formulas.

I. INTRODUCTION

Standard terminal ballistics often relies on Sectional Density (SD) or Kinetic Energy to predict performance. However, these metrics are often static and fail to account for the iterative changes a projectile undergoes during media transit. This paper defines the Impact Density Rate (IDR) and demonstrates its application in a terminal ballistics simulator programmed in Python.

II. THE IMPACT DENSITY RATE (IDR) FRAMEWORK

The IDR is defined as a 'momentum-density' metric with the dimensions of Mass squared per Time (M^2/T). In ballistic units, we define this as Lbs^2/second. The formula is expressed as:

$$IDR = (v \times w \times SD) \times c$$

Where v is velocity (fps), w is weight (lb), SD is sectional density (lb/in^2), and c is caliber (inches). This metric governs the resistance-overcoming capability of the projectile at any given point in the medium.

III. EXPANSION DYNAMICS AND DYNAMIC SECTIONAL DENSITY

A critical component of this model is the simulation of projectile deformation and the resulting 'Dynamic Sectional Density.' As the projectile expands, its frontal surface area increases while its mass remains constant. The expanded caliber (c_{exp}) at a given depth (d) is modeled using an exponential decay function toward a maximum theoretical expansion (c_{max}):

$$c_{exp} = c_{init} + (c_{max} - c_{init}) \times (1 - e^{-k \times d})$$

This expansion necessitates the recalculation of Sectional Density at each iteration ($SD_{dynamic}$):

$$SD_{dynamic} = w / (c_{exp}^2)$$

As $SD_{dynamic}$ drops, the IDR collapses, which in turn increases the velocity loss per unit of distance. This creates a realistic feedback loop where more aggressive expansion results in shallower penetration and larger wound volumes.

IV. MATHEMATICAL MODELING OF PENETRATION

The simulation models penetration as a discrete-step integration where velocity loss is calculated at high-resolution intervals. The velocity loss (v_{loss}) is governed by the following relationship:

$$v_{loss} = (\rho \times v^2 \times A) / IDR$$

Where ρ (rho) is the media resistance constant (tuned to 0.000550 for ballistic gelatin), A is the instantaneous expanded surface area, and v is the instantaneous velocity.

V. DIFFERENTIAL EQUATION OF PENETRATION

The discrete-step integration utilized in the simulation can be expressed as a continuous first-order differential equation. By relating the instantaneous velocity loss to the change in depth (d), we define the rate of deceleration as:

$$dv/dd = -(\rho \times v^2 \times A(d)) / IDR(d)$$

Substituting IDR's components and highlighting the dependency on depth, the equation becomes:

$$dv/dd = -(\rho \times v \times A(d)) / (w \times SD_{dynamic}(d) \times c_{exp}(d))$$

VI. INTEGRAL FORMULATION OF PENETRATION DEPTH

To determine the total penetration depth (D), we must integrate the differential equation of penetration. By rearranging the first-order differential equation to solve for the change in depth (dd), we can express the relationship as:

$$dd = - [IDR(d) / (\rho \times v^2 \times A(d))]\ dv$$

The total penetration depth (D) is found by integrating from the impact velocity (V_{impact}) to the terminal velocity floor (V_{final}):

$$D = \int_{V_{impact}}^{V_{final}} - [w \times SD_{dynamic}(d) \times c_{exp}(d) / (\rho \times v \times A(d))] \, dv$$

This integral represents the continuous summation of infinite "slices" of media resistance. While implementations utilize discrete Riemann sums, the integral form provides the theoretical limit of the IDR algorithm's precision.

VII. EMPIRICAL CASE STUDY

To validate the model, a .300 AAC Blackout simulation was conducted.
Parameters: 175-grain projectile, .308 caliber, 1700 fps impact velocity.
Results:

- Initial Sectional Density: 0.2635
- Initial IDR: 3.5
- Calculated Penetration Depth: 20.9 inches (0.1" step resolution)

VIII. CONCLUSION

The IDR metric effectively captures the "boring" capacity of a projectile. By treating ballistics as a dynamic rather than a static event, the IDR algorithm allows for more accurate predictions of how weight, velocity, and caliber interact during the terminal phase.

Disclosure: This algorithm was invented by the author but refined with AI. This paper was produced by AI. The author has verified the authenticity of the paper. The author is a programmer and a hunter who has taken big game and witnessed real wound channels.
Contact: Blair T Simpkins | n4omg@pm.me
Code: https://simxnet.com/idr.html | https://github.com/Bonanza55/IDR