Masters of Negotiated Studies: Negotiated Project 4 (60 Credit)

# The Investigation and Development of a PCG Arcade Gun System for Co-op Shooter Games

Christopher Boyce

Student Number: 19016871
Email: b0196871j@student.staffs.ac.uk
Supervisor: Shaun Reeves

# Glossary

**Algorithm:** A set of rules or processes followed by a computer to solve a problem or generate content.

**Drop Rates:** The frequency or probability with which in-game items, such as weapons, are obtained by players.

**Distribution Mechanisms:** Methods by which game items are made available to players.

**Game Balancing:** Adjusting game mechanics to ensure fair and enjoyable gameplay.

**Replayability:** The extent to which a game can be played repeatedly without becoming repetitive or boring.

**Procedural Generation:** Procedural generation is the algorithmic creation of data and content in video games, such as levels, maps, and items, to enhance diversity and replayability with minimal human intervention (Shaker, Togelius, & Nelson, 2016; Hendrikx et al., 2013).

# Key Words

**Procedural Generation, Unreal Engine C++, Multiplayer, Drop Pools, Gun System**

# Table of Contents

## Section 1 : Introduction

In the games market it is estimated that FPS and Shooter games dominate the highest revenue with a combined thirty-billion-dollar market (Phang, 2024). This massive percentage shows the importance of creating diverse and new experiences for players as a very saturated market. The gun systems in these games are critical to the gameplay and feel of the title. In this market “Arcade Style” style systems often characterised by the fast pace and diverse weapon are a considerable importance within many of these games. Games take serval approaches to how the systems work which will be explored throughout the research paper.

One of the core appeals of gun systems is the sense of the power and progression that provided to the player either levelling up, unlocking or finding new weapons allows the player more capable of completing the game. Weapon systems also can contribute to the four pillars of player motivation, these are collector, explorer, killer, and socializer. In a weapon system it can hit all four in diverse ways. The first is the collector that will be hunting for a certain gun or a complete set of a unique item. Explorer will enjoy discovering new types of attributes to take to new areas and content in the game. Killers will seek the best weapon and to utilise this to dominate and find the most effective to weapon to take out enemies. The socializer will focus on team mechanic and how synergise their equipment effectively.

Due to the creation of unique weapons being highly resource dependent Procedural Content Generation (PCG) can be used to make variations or different types of weapons using the same code allowing for more diverse feel to each weapon.

Procedural Content Generation (PCG) is an algorithmic creation of game content that allows the player a large variety of worlds, items and unique scenarios with reduced developer involvement (Shaker, Togelius, & Nelson, 2016; Hendrikx et al., 2013). This approach is wildly used in modern game development as it increases replayability and allows for the creation of unique personal experiences in a game. By using PCG is allows for a rich variety of content that keeps the player engaged over a longer period and ensuring the gameplay feels distinct.

Additionally, PCG in gun systems helps maintain game balance by ensuring that weapon drops, and their effectiveness remain consistent, therefore providing a fair yet dynamic experience. This artifact is also going to have to account for the Coop and multiplayer features to the game dealing with weapon sharing, and multiplayer aspects of weapon systems such a replicating shooting mechanics, bullets and drop pools.

## 1.1 : Aims

This research paper will investigate and develop a solution for implementing PCG arcade gun system in Unreal Engine, the system will be tested for the drop rate and pool as well as the usability and enjoyment from the gun system. This project will include an artifact of a third person shooter game the incorporated these game mechanics that will be used for the testing data.

## 1.2 : Objectives

- Investigate current games that use arcade weapon style with PCG and analysis the use cases looking at the algorithms that contributes to the gun mechanics.
- Explore how PCG influences gameplay and the player experience.
- Develop a system in Unreal Engine 5 that uses the current literature and expand using different systems and mechanics
- Create, develop and test a plan to see if the system works and if players believe it to be enjoyable
- Analysis the results of the test and implement and suggest improvements to the system

## 1.3 : Project Planning

This project will begin by reviewing the current literature and solutions that have been developed. Using this knowledge of existing research in the field, the project will create an Unreal Engine project that uses these systems for the drop rate and PCG. The artifact developed will first be testing for the functionality of the gun system using mathematical analysis and black box testing to ensure the mechanic's function. The second test will look at user testing to test for enjoyment and feel of the weapon system. The outcomes will be analysed with issues identified, broken down and potential updates or fixes will be added.

# Section 2 : Literature Review

## 2.1 : Current Weapon Systems

### 2.1.1 Weapon Rarity

Over the last decade a common thread in many video games has become rarity or tiers of weapons, these are now become accustom with colour correlated with them (Belghast, 2020). The origin of this practised is widely unknown the population of this comes from Diablo. The colour systems help easily identify the higher rarities with more vibrant colours normally starting with a light grey to pinks and purples finishing with red or gold being the rarest. This helps with games that “Throw Loot” at the player, and they need to filter through the important items first.

The idea of the colours links back to colour theory within games (Fishman, 2018). Low-level items contain less hue, which attracts the player's eyes less. The blue and greens for the mid-level are representative of primary colours that are prominently found in nature, therefore indicating more common drops. Purple colours indicate wealth and are a less common colour found in nature, therefore more likely to stick out to the player. Finally, red and golds have the same theory of sticking out to the player but also the association with rarity, with gold being linked with the real-world material.

Items rarity in games can be linked to several factors including the strength or scaling the attributes to the gun as well as the link to the lower drop rate (Borderlands Wiki, n.d.a). The Borderlands franchise (Gearbox Software, 2009), a popular RPG looter shooter, uses rarity to add bonuses to weapons, including secondary actions and different projectile types. This directly links to the power building and fantasy that games try to build throughout the game and to supply the player with more capable weapons so the player can complete the game.

Rarity can introduce the idea of collecting items or groups of items to the game. Players in games such as Destiny (Bungie, 2014) will grind missions to gain rewards, which have potentially higher rarity if completed until a lucky drop or till they have completed a collection. This directly correlates to replayability, not due to the game adding more features but the sense of unlocking or finding a superior item in the game.

### 2.1.2 Gun Levelling

#### *Static Weapon Level*

Static weapon levels are a system where a level is selected upon the generation of the weapon. This level has an impact, usually positive, on the attributes of the weapon. This allows for a drop system to impact the potential for better items in a game. A game that uses this system is Roboquest (RyseUp Studios, 2020). The level ranges between one and thirteen, meaning each item can be dropped at any of these levels, but the base stats are improved with each level (Roboquest Wiki, 2024).

This allows the developer control of game design by limiting the level of the runs in the early stages of the game and allow them to open at later stages of the game. Scaling the weapon level in games such as Borderlands uses a Scale of 1.13X per level allowing a weapon at the start of the game to deal 11 damage and a level 50 to deal over 5000 per shot (Borderlands Wiki, n.d.b).

### *Variable Weapon Levelling Systems*

One way to improve a weapon if the player is forced or chooses to keep a weapon is through a game is levelling system similar to RPG games (Dr Gasiorowski, 2020), where through using the item, it will increase in and therefore gain power over time. This allows the player to become comfortable with their arsenal. This system usually makes gaining XP between levels longer, as an example Pokémon uses Figure 1 to calculate the XP needed between levels. This allows for a faster progression when the player first uses the item and slows down in the later game. One of the most popular weapon level systems come from Call of Duty franchise (Activision, 2003) which uses the levelling system to increase the amount of attachments at lower level and higher levels the type of attachment that can be equipped to a weapon (Call of Duty Wiki, n.d.).

**Medium Slow**

$$EXP = \frac{6}{5}n^3 - 15n^2 + 100n - 140$$

*Figure 1 : Pokémon Levelling Formula (Medium Slow) : Bulbapedia (2024)*

This system allows for player completion for each weapon and them to master the weapon on the way to maximum level. The attachment system allows to player to adapt each weapon to their play style and means every weapon should be viable for every player. This system allows the player customisation compared to PCG systems but could be integrated into a base PCG system for this artifact.

## 2.1.3 Attachments

Many weapons in games are broken down into parts just like in real life (Appendix A). This allows for a great variety and customisation for each weapon. They can either be selected by the play in a menu system or attachment system in the game or can be randomly generated using a PCG system when the weapon is spawned. These parts can be directly affected to attributes in the game for example, magazines can directly link the amount of ammunition, reload speed and calibre of bullet. There can then be modified by the game designer to balance the game to allow for rarity and fairness for each gun. Due to other concurrent systems such as levelling and rarity an attachment system would be incorporate these variables when in the design phase. For example, fire rate would have to be capped at a certain level due to the limitations of the game engine or playability reasons but some variables may infinity scale with level.

### *User Selected Attachments*

Looking at the front runner of FPS franchise Call of Duty there are 4 main attachments. The first is “Optics” this changes the weapon from using the Iron Sights to scopes, there change the players Hip-Firing to Aim Down Sight (ADS) speed but allows the player potentially longer-range scopes as well as more precise targeting.

“Barrels” including suppressors have a range of attributes such as allows quieter firing of weapons and not appearing on the mini map to enemies. Muzzle breaks allow for lower recoil either horizontally of vertically and length barrels such as short or long barrels allow for higher velocity of bullets. These come with negatives such as weight of the gun or handle in some form such as slower sprint to fire speeds or ADS time.

“Grips” contribute to the recoil of the gun to allow for more accurate shots and less screen shake and sway as well as reduced pull on the players crosshair allowing for longer ranged

fights and more precise targeting to the enemy. Grips may have several negatives attributes including increased recoil on horizontal or vertical recoil but also handing penalties.

Finally, “Magazines” effect the capacity as well as reload speed, this can be used to synergise the players style depending on how they would like the gun to feel. Magazines can affect the handling and ADS speed to balance the gun to the designers’ specifications.

## 2.2 : PCG Weapon System

### 2.2.1 Unreal Tournament 3

Unreal Tournament used PCG weapon systems to create variety in the guns. They used 10 variables (shown in Figure 2), allowing for great variation and unique situations (Gravina et al., 2009).

| Name | Range | Description |
|---|---|---|
| Rate of Fire | [0, 4] | Shooting frequency of the weapon: number of bullets shot per second. |
| Spread | [0, 3] | This parameter affects the random deviation of the bullets trajectory: the higher the spread the less accurate would be the shooting. |
| Shot Cost | [1, 9] | Number of bullets shot at once by the weapon. |
| Life Span | [0, 100] | Amount of time the bullets remain in game when shot. |
| Speed | [0, 1000] | Speed of the bullets when shot. |
| Damage | [0, 100] | The amount of damage that each bullet deals when it hits an opponent; the highest damage, 100, also corresponds to the highest player's health value in UT3 (excluding temporary effect of power-ups). |
| Damage Radius | [0, 100] | Radius of the bullets shot by the weapon (in UT3, bullets are logically represented as spheres for computing damages and collisions). |
| Gravity | [−250, 250] | Gravity force applied to bullets shot by the weapon: the larger the value of this parameter, the stronger will be the gravity force that affects each bullet shot by the weapon; negative values means that gravity force will be upside-down, i.e., when shot bullets will go upward. |
| Explosive | [0, 300] | When a bullet hits a target, either an opponent or any object in the game, it generates an explosion; this parameter defines how big is the radius of this explosion; all the players that falls within the radius of such explosion would receive a *splash damage*, i.e., a fraction of the weapon's damage depending on the distance from the center of the explosion. |
| Ammo | [0, 999] | Maximum amount of ammunition for the weapon that a player can carry around. |

*Figure 2 : Variable for weapon in Unreal Tournament*

To test the weapon system to find out how balanced and effective the weapon were they used a simulated approach placing two bots against each other in deathmatch and evaluated their performance. They took into consideration the kill performance, the deaths and the longest kill streak. Other statistics are recorded during the match such as accuracy, average hit distance and hit time. Using this data, they could calculate the balance of each of the weapons comparing the entropy of the kill difference. They could also calculate the effectiveness of each weapon by comparing the kills per match to the total kills possible during the match. And finally, they tested the safety of the weapon due to using explosives feature they wanted to make sure that weapons wouldn’t kill the player to often even when used correctly. (Gravina et al., 2009)

They also used user testing to discover if their PCG weapons were under or overpowered in the aspect of the game as well as the level of fun they experienced in the game (Gravina et al., 2009). This allowed 30 people to play a game versus a bot in deathmatch and rate the guns on each category. These questions asked in the questionnaire will also be asked in the participants of Testing Methodology 2 in this paper.

### 2.2.2 : Team BlockHead

Researchers created a multiplayer game that created weapons using a PCG system and then placed players in a 1v1 arena. These players would then play a deathmatch scenario, they would be able to select one of several guns. The participants then played the game and data on the amount of time the player used the weapon and the number of kills with each weapon was collected. Using this, they gained data and concluded players' use cases varied greatly depending on the weapon's attributes. There wasn't any numerical data presented, but they confirmed that the implementation showed promise and set out to modify and improve the systems (Pantaleev, 2013).

What this paper can take away is the usefulness of the guns can be measured not only by the kills but the time the player uses the weapon, as if it isn't a fun experience or the weapon doesn't feel like it contributes to the system, it may be unbalanced or broken (Pantaleev, 2013). These two papers covered are some of the only research at an academic level that could be

directly correlated to the artifact this research is creating, so both of these papers are important to consider when it comes to the testing methodologies and many of the practices are going to be emulated.

### 2.2.3 Borderlands

The Borderlands franchise uses a PCG system to select gun parts (barrel, grip, stock, scope, body, and accessories) and calculate the resulting stats Due to the game's less realistic, more arcade-like style, each part affects the gun in inventive, often exaggerated ways (shown in Appendix 1). These components are randomly combined, creating seventeen million possible outputs, none of which are pre-selected by the player (Togelius et al., 2011).

Borderlands uses "Brands" to show the synergy in guns, for example, a large magazine along with a higher fire rate is more favourable, meaning getting a magazine and barrel from the same "Brand" is preferred (Togelius et al., 2011). This means a lot of guns may have a mix of attributes and therefore will create guns that aren't built with a certain playstyle in mind, making them ineffective. This mechanic means it is up to the player to decide if they wish to pick up the item or not. This could create balancing issues that the designer needs to take into consideration.

Borderlands uses a seed system, this is proven when looking at the seed of 2 of the same item in the save file when it is unencrypted Each of these seeds correspond to the item "Major Tom" in Borderlands Pre-Sequel (Gearbox, 2014).

*Seed 1 (Major Tom : Cryo) : igAAAACntQDC6oA7ACMD1AD6AYQARAEQEaAHQBaA/v8nAGEENAHk*

*Seed 2 (Major Tom : Fire) : igAAAAD76wDC6oA7ACMD1AD6AYQARAEQESAIQBaA/v8nAGEENAHk*

*Seed 3 (Hail Cryo) : igAAAAAXTgDESoA7BCMDxAASAiQAZAHQESAJQBaA/v8PAHkE9ADk*

*Figure 3 : Seed For Spawning Guns In Borderlands The Pre-Sequel (Gearbox, 2014)*

The four characters highlighted are representative of the element type on the gun While specific technical details about the seed system in "Borderlands" are proprietary, these strings are distributed into the algorithm with each specific part being spawned from a set of characters The system could be used as a Lookup table to define each part of the weapon, it is hard to tell due to "Seed 3" also being a "Cyro" type weapon but not using the same character to represent it.

## 2.3 : Drop Rates / Pool

A drop rate in video games is commonly the percentage of time an item is dropped when a combatant is defeated (Hindle, 2020). Within the confines of this artifact it is going to be weapons for the player to use. This feature is important when trying to balance a game because you want to make the player feel they are fairly rewarded for their achievement. This can be shown in a majority of video games due to boss battles giving the player more or better loot. The simplest loot system is a loot table and a "Random Number Generation Based Loot Systems". This is where a random number is generated between two values and if it falls between these it will search on the loot table a drop the item linked in the table. Due to it being total randomised it can potentially cause over and under supply to the player and this is where the game designer will have to adjust the scale of each fairly.

Other systems include a pity rating where if the player hasn't been dropped an item the percentage chance of an item dropping it increased in small increments each time and when a drop has occurred it will the reset to the base amount. This is used in "Tom Clancy Random Six Siege" for package drops but could be implemented in games when look at enemy drops. This could also be incorporated as well into different rarity drops if the designer intended.

The Chi-Squared Test can be used to check the odds and percentages, in this test you can record the data and compare it to the expected outcome using the formula you will gather χ which will represent the discrepancies from the expected outcome. This can mathematically inform the developer if the system is working as intended.

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

*Figure 4 : Chi - Squared Formula*

## 2.4 : What makes an "Arcade Weapon"

### 2.4.1 Features of Arcade Weapons

To design effective and engaging weapons systems video games need to consider a variety of key concepts, the first outlined in the paper *"Weapon Development in Computer Games" (*Nai & Digaswala, 2024) is the effectiveness of using each weapon. The gravity of using each weapon needs not only to be unique but also match the weapon desired feel. This can be reached by using visual and audio feedback to the player and specifically outlines a consistent weight to firing the shot.

The paper covers the topic of balancing weapons and the importance due to a prevention of a single weapon domination the game and potentially making the gameplay stale and repetitive. This also comes with the notation that each weapon should have a niche and function within the game allowing the player to have distinct loadout and multiple different solutions for overcoming encounters. The paper also includes a clear statement that each weapon should have strengths weaknesses and traits to allows players to find a playstyle that fits them and feels comfortable to use.

Weapon variety is important when considering creation of PCG weapons. Variety can be with the use cases for example shotguns for close range and snipers to take ranged duels, this allows for different gameplay senecios to unfold but also player decision making when they are completing a loadout. Variety also encourages experimentation when a player sees a new weapon or feature on an item, they are more likely to engage with it. Variety can also be in themes of weapons this may include visuals that are linked with gameplay features.

Borderlands 3 (Gearbox Studio, 2019) covers this by using brands that cover a large weapon variety but each having a unique feel and gameplay style. This also come with a unique weapon theme. An example of this would be “Dahl” the unique traits of this weapon is that is always a burst fire when scoped and they have higher stability than other weapons.

### 2.4.2 Balancing of Arcade Weapons

#### *Clear Trade-offs:*

When designing weapons, there need to be clear trade-offs that make each weapon viable but not overpowered. This involves balancing the stats of each weapon. Due to the PCG systems, this will be even harder to control as each component is selected. To overcome this, a large amount of weapon testing and player feedback will need to be collected to identify any overpowered weapons. Testing for “Damage Per Second” (DPS) can be calculated to ensure weapons of the same level are reasonably within the same range. However, due to many other variables being used, this can only account for the damage aspect.

#### *Skill-Based*

Each weapon shouldn't be judged solely by its power but by how the player uses it. It should encourage the player's talents and become more effective through skilful use. Therefore, the harder a weapon is to use, the more skill the player needs, and the greater the potential reward. A common debate in games is about the sniper rifle. Many believe using a sniper rifle is harder due to the need for precise aiming and having only one chance to hit the target. If they miss, they are usually punished more severely than players using higher fire rate weapons. The benefit of a sniper rifle is that it typically results in a one-shot kill to critical points on the body. This high-risk, high-reward dynamic can make the game more engaging, as it challenges players to improve their accuracy and strategic thinking. Ultimately, weapon effectiveness should balance power with the player's skill, ensuring that mastery of a difficult weapon is rewarded appropriately in the game.

## 2.5 : Coop Shooter Considerations

### 2.5.1 Sharing Drop Pools

In looter shooters and cooperative shooter games managing loot distribution is critical to help the players succeed together. Sharing the same dropped items means one player can monopolizing good items, to counter this player would require teamwork, communication and fairness to distribute the items fairly. Implementing a system where each player receives individual drops can reduce conflicts and ensure everyone feels adequately rewarded but can still cause issues with players receiving different items. Other systems include protected rewards, round robin systems and need before greed systems. Which are all ways items are fairly disputed between a team of players without advanced communication needed.

### 2.5.2 Friendly Fire

Friendly fire is the act of a player being able to damage their own teammate. This is a key consideration when looking at team-based shooters, as allowing players to harm each other can add a layer of realism and require more strategic gameplay. However, it can also lead to frustration and accidental team-killing. When looking at more arcade-style shooting games, this isn't normally enabled, with the option being enabled by the user in some games. An example of this is Call of Duty (Activision, 2003), which in the "Hardcore" mode enables team damage. Penalty systems can be implemented where repeated friendly fire results in reduced damage or debuffs can be applied to the player. A notable game that uses this is Tom Clancy's

Rainbow Six Siege (Ubisoft, 2015), which applies damage to the player after a significant amount of friendly fire.

### 2.5.3 Enemy Difficulty

Adjusting Enemy Difficulty based on the number of players is mandatory in the game, as many of the levels would be too easy if not designed for multiple players (Adams & Rollings, 2010). Several other features and balancing mechanics can be added to increase the enemy difficulty in multiplayer scenarios.

One of the primary methods to adjust enemy difficulty is scaling based on the number of players. Research suggests that dynamically adjusting difficulty based on player count can lead to a more engaging gameplay experience (Hunicke, 2005). This can include modifying enemy health, damage output, and even the number of enemies that spawn. Scaling the enemy health means more coordinated attacks must be executed by a team. This method maintains the challenge by ensuring that enemies do not become too easy to defeat as the team's firepower grows.

Increasing the number of enemies in response to large teams allows to make battles more intense and rely on teamwork and coordination to take out large waves (Salen & Zimmerman, 2004). It also relies that each player is providing an equal amount of output to be as successful. As noted by Salen and Zimmerman (2004), increasing enemy numbers can create a more dynamic and engaging combat environment.

# Section 3 : First Test

## 3.1 : Planning

### 3.1.1 Objective

The first test is going to be checking the “Rating” of each weapon. In the artifact a gun first generates a value of a weapon between 0 and 99. This is then places onto an exponential decay curve that transforms the value. This is done to reduce the amount of rare weapons spawning. From this value each component is spawned with a value and adjusted from the base value of the weapon to make sure each component fits with the guns level. This test is going to investigate the amount of high-level weapon spawning and look at the percentage of weapon drops.

During this period values for what each weapon class is will be recorded to see if equal amounts of weapon types are being spawned. This will be categorised into SMG, Rifle, Sniper and Pistol.

### 3.1.2 Methodology Description

The test is going to be conducted by spawning in 100 weapons, during there spawn time each weapon is doing to write the gun level as well as all the components level. This will give 7 values for each weapon. Using this data the amount of different level weapons can be binned into a histogram. The binning process will first look at the distance of 10 being the intervals the show equidistant bins but will also be binned into category of weapons from Gold, Pink, Purple, Blue and Grey to show what the player will be shown. This will not be equidistant and will be helpful to know percentages for the player.

The results will also be compared using the  Chi-Squared function to see if the output is the expected level that the game designer intended, the Chi-Squared function will need to be revised depending on the exponential decay function values that are currently implemented.

The test is going to be run 3 times to ensure variation is at a minimum and to compare for outliers. During this time none of the variables in the exponential decay function are going to be changed.

If the results are above the expected drop rate the values of the exponential decay function of this will be changed and the test will be run again from the start to ensure all data is collected accurate to the final version of the drop system. Each of these tests will be represented in the results section and analysis.

All raw data will be shown in  Appendix B.

## 3.2 : Results

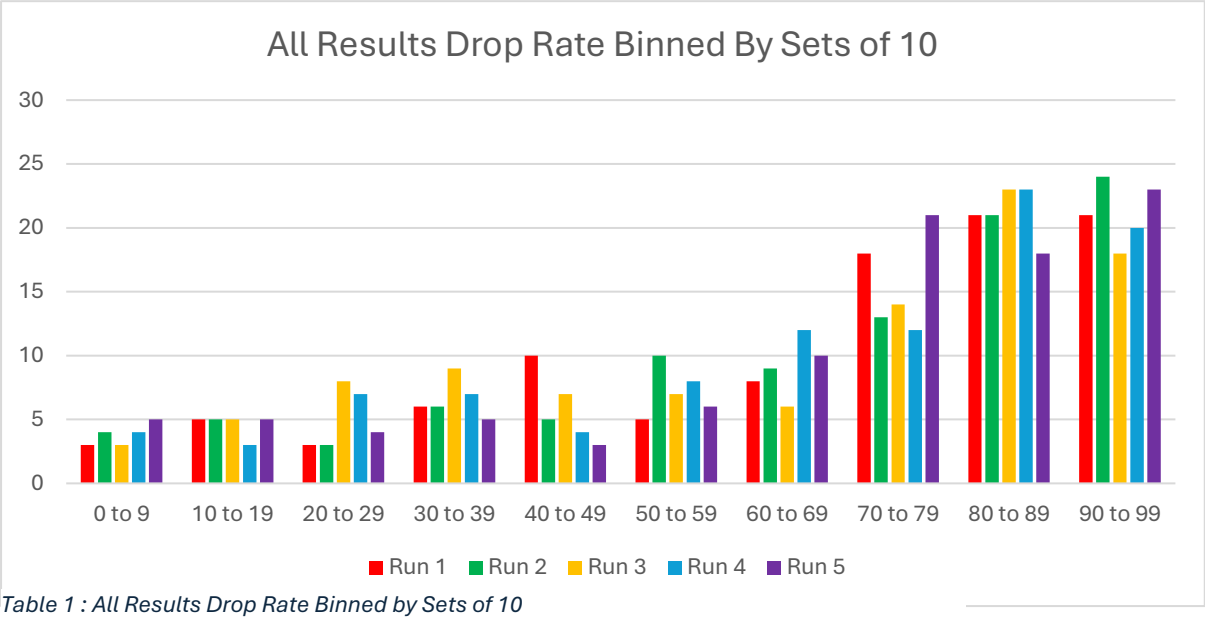


*Table 1 : All Results Drop Rate Binned by Sets of 10*

Table 1 shows each the number of guns spawned with a 10-set data bin. These are then placed next to each other to show the deviation from the runs and the potential change. The graphs show a slow curve upwards which is expected this the exponential decay formula. At the tail end of the graph there is a large deviation in the spawn rate, this will be explored in the analysis section.

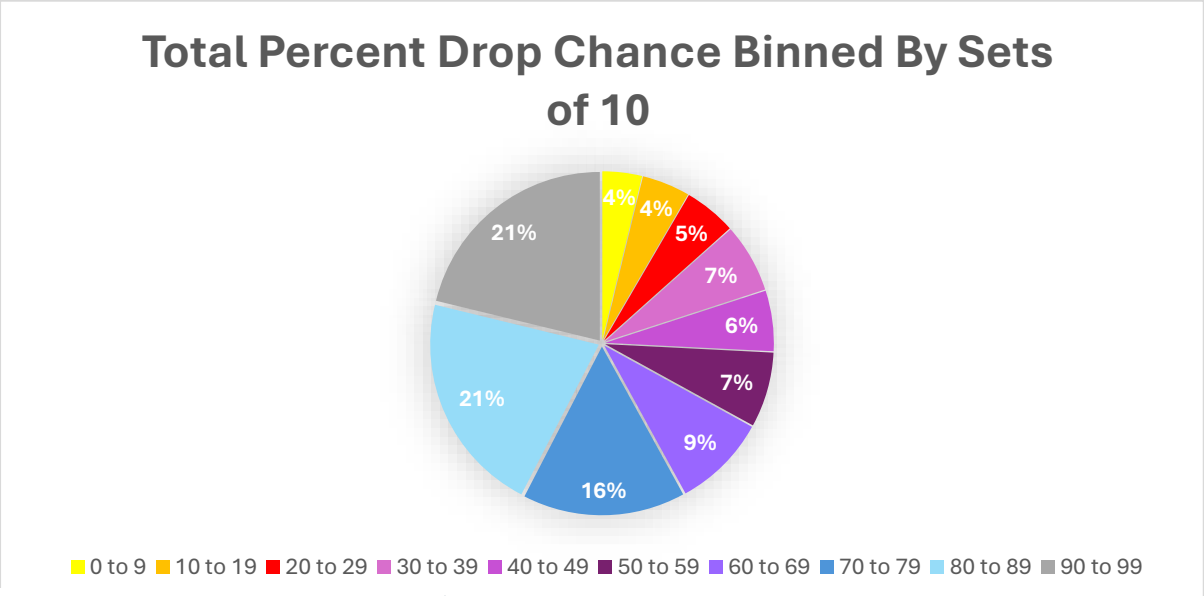


*Table 2 : Total Percentage Drop Chanced Binned by Sets of 10*

Table 2 shows the percentage of each number of guns spawned with a 10-set data bin this helps visualising the number of guns spawned on average in each section. It shows the lower numbers spawning at a significantly few rates, with it slowly gaining more when going up the chart. A relevant statistic is the 80 to 89 and 90 to 99 being the same percentage as well as the 0 to 9 and 10 to 19 being similar.

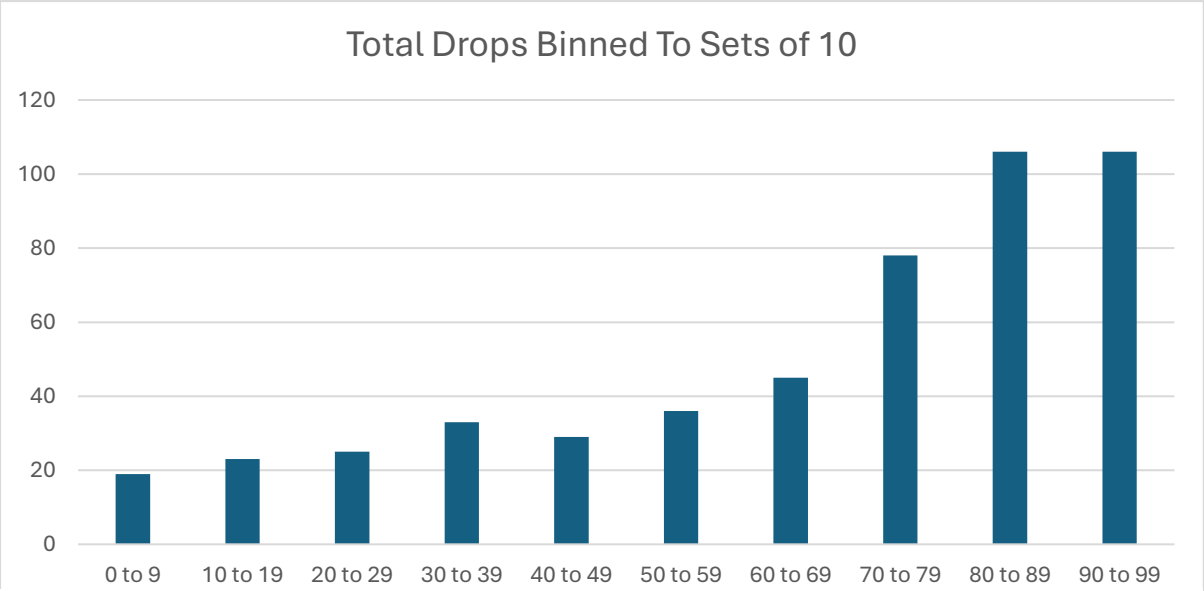


*Table 3 : Total Drops Binned to Sets of 10*

Table 3 shows the disruption of weapons from all 5 tests. This means all 500 weapons and shown in this graph and there are some key signifiers that the exponential function has a limitation from the middle of the pack weapons from around 40 to 49. As well as this the same equal distribution from 80 to 89 and 90 to 99 are very similar which was also representative of the pie chart above.

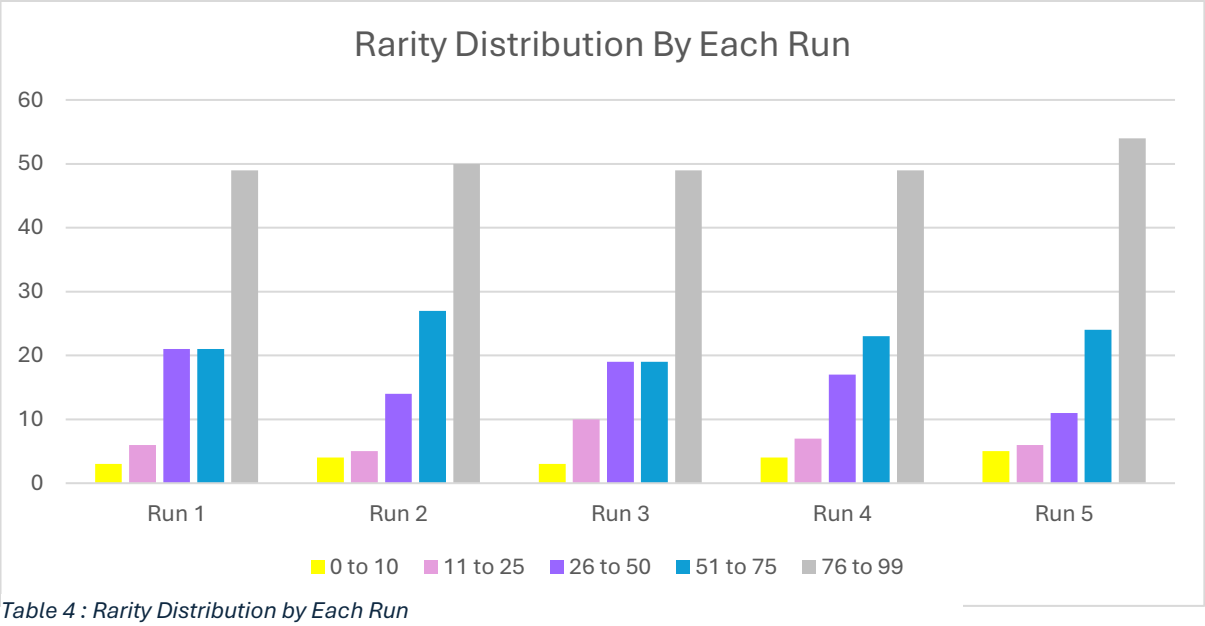


*Table 4 : Rarity Distribution by Each Run*

Table 4 shows the different runs how the actual number of items that spawn by the rarity class. This graph shows the distribution of rarer items begin lower represented by the yellow bar which correlates to the legendary items in the game. This graph shows out of 100 items how many are at each rarity and is helpful for the game designer to balance.

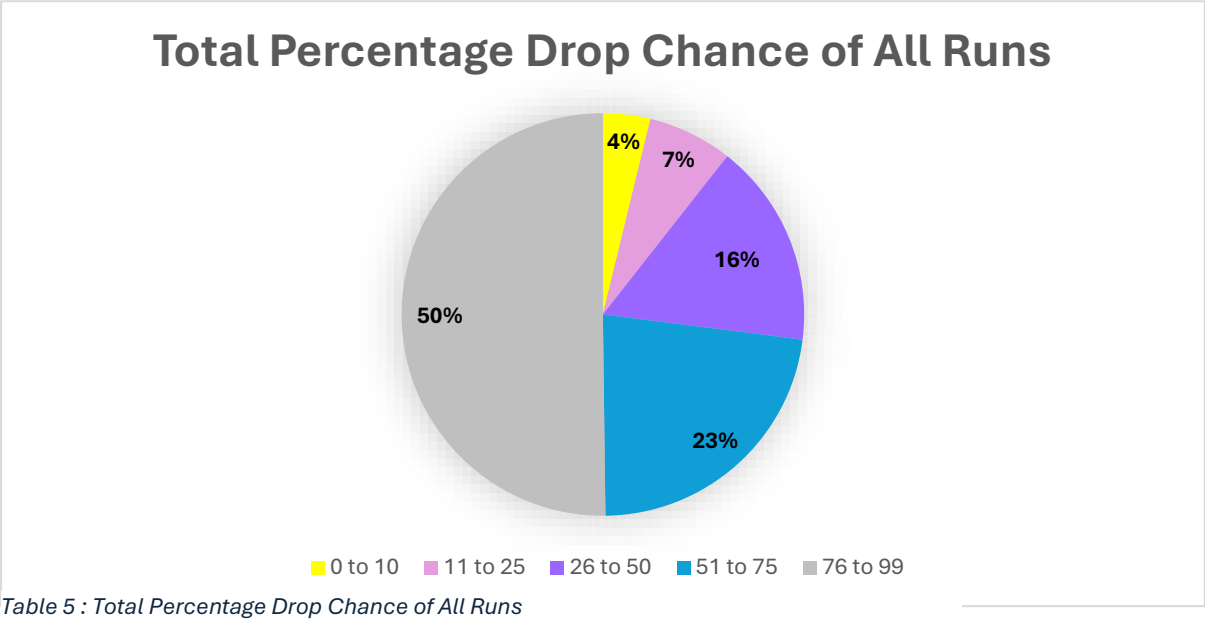


*Table 5 : Total Percentage Drop Chance of All Runs*

Table 5 shows the average of all 5 runs and the percentage drop chance of a specific class of weapon, this is a summary of table 4 but doesn't show the intricates of each run. Overall, this table allows the developer to read the commonly expected results and be able to interpret the exact drop percent for each rarity.

| Run | Chi - Squared Test (P-Value) |
|---|---|
| Test 1 | 0.811494226 |
| Test 2 | 0.967975149 |
| Test 3 | 0.840391703 |
| Test 4 | 0.905367586 |
| Test 5 | 0.819287056 |

*Table 6 : Chi-Squared Test Results VS the expected outcome value*

The P-Value was calculated for each test showing the potential variation from each test versus the average that was calculated using the pervious results. The variation is roughly from the 80% mark to test 2 producing a 96% this means the results from these five tests each produced results within a 20% of expected mark. This Chi – Squared test was the results of the 10 binned set of data due to it having more data points which allowed the results to be more accurate. This behaviour will be analysed in the further section but variation is expected when using PCG and random generation.

## 3.3 : Analysis

Analysis the data provided by these graphs show several key insights into the weapon generation systems functionality. The results from Table 1 and 3 show that the exponential decay function is effectively curbs the frequency of spawning higher rarity weapons aligning with the design intention of the system. However, a notable deviation exists in the spawn rate at the tail end of the distribution of Table 1 and Table 3 with a significant difference between the

least and most frequent spawn rates. This could be attributed to the limitations of the exponential decay function or other factors influencing weapon generation. Table 1 also shows when one of the bars is above average there is a direct correlation with the size of the bars either side being below average meaning that weapons are still being distributed close to expected level, this is the “luck” element to a randomised drop rate therefore is a clear variation in each test.

Table 3 shows a plateau in the middle of the graph this was unexpected and shows that mid-level guns have a lower chance at spawn than expected which is consistent in a majority of the five tests and therefore doesn’t follow a curve perfectly. This can be linked to the formula and decay function that doesn’t have the effect on mid-level spawn rates as expect. When looking at the overall rarity table 5 this doesn’t affect the final games rarity of each gun but should not be overlooked.

The Chi-Squared test results, with P-values around above 80%, indicate that the observed drop rates are generally consistent with the expected values (Table 6). This is consistent but has a 20% deviation rate which could warrant further investigation if the developer needs it to be more accurate. For this test sample size for each one hundred guns 3 to 5 highest tier guns are spawned, which for this game is a perfectly acceptable variation.

One of the main issues with this system is the harder development time and testing needed for the system as it uses a formula that isn’t easily interpreted into outputs such compared to a lookup table. Therefore, adjusting the formula will cause all the results to change and therefore a large-scale test needed to be performed, this means calculating Table 5 would have to be created using new outputs every time this variable is changed.

# Section 4 : Second Test

## 4.1 : Planning

### 4.1.1 Objective

The second test is going to be gathering user data and feedback to understand if the artifact has created a weapons system that is understandable, functional and fun. This is important when developing a system for a game to get user feedback and opinions from a wide range of thought processes. This isn’t going to produce definitive answers but will gain valuable feedback about the current state of the artifact and will give the development process key goals to improve.

### 4.1.2 Methodology Description

The testing will be conducted with an interview process while the player is participating in the artifact. This is to gain the current thoughts of the player as they are fresh in the player's mind. This also allows the interviewer to ask follow-up questions that can be used to gain more valuable information. During the interview, notes will be taken and then afterward, they will be reviewed and refined into several key features that can be later analysed.

These will include the “variety of weapons,” which will ask the participant about their feelings on the variety of weapons and if they feel that even a gun of the same class feels different depending on the attachments. This will also indicate if they want more attachments and gun classes added to the game. They will also then be asked about the viability of all the weapons

they used and if any were overpowered or broken for the balancing of the game, but also find out what the player liked and disliked for future designs.

The feel and feedback of the weapons will be asked to gain knowledge about each of the weapons. This will help the development team with the artifact know if the attachment statistics are in the right ballpark or if the levelling system buffs or debuffs the weapons so they are usable. This also will look into the damage and range that the user felt was good for each weapon to see if the intended design of each class was reached.

Data on Bullet Modifiers will also be collected to see if the participants enjoyed the high-level weaponry and their thoughts on the progression of high-level guns in the game. They will be asked about the feel and feedback as well as what they liked and disliked about each.

The user will be asked about the rarity system and the colour coding that is used to gain valuable knowledge about what item to pick up. This feedback will give insight into potential changes or improvements.

General feedback about the fun of the game and guns will be collected to gain insight into the game's uniqueness and potential future direction. They will be asked if the game compares to anything they play, to potentially look at the genre and other games that have a similar feel and feedback.

Additional feedback about the process and the game will be collected to see if there were any questions the participants wanted to be asked and never got the chance, as well as details they wanted to convey as they played the game.

Finally, data from the game session will be collected to record which guns were used and at what time, to see the progression of the game session and see any trends. This will allow the researcher to look at the guns used when the player is describing their experiences. This data will be shown in Appendix C.

## 4.2 : Results

### 4.2.1 Variety & Viability  of Guns

The majority of feedback from the participants conveyed a clear difference in weapons even those of the same class, with users points out a large difference in fire rate and damage being the most instrumental. An example is “Participant C” saying that each pistol is unique and commenting on the SMG feeling different from each other. “Participant” E also commented on the difference in the attachment system allowing for variety and user choice. Participant F and G were the only users to comment that they felt like too many weapons were the same commenting on both Snipers and SMGs felt the same both times they used them.

While most weapons were agreed to be a viable option several concerns about balancing of the weapons, with the extremes of either with the weapons being too weak for the large hordes of enemies or the wiping the wave to quickly. Participant G spoke on the blackhole, and explosive modifier making the game too easy for hordes and gave the suggestion of reducing the number of times each one of them spawned to balance it. They also believe all the bullets travel time was to slow and wanted to see greater speeds so long-distance fights were more viable.

Participant C commented they the balancing of pistols particularly the grey ones were weak but really enjoyed using the highest-level pistols with modifiers. They main concerns were the skill required to aim precisely with them but also the lack of reward they got for being good with

them. Person A also disliked to the pistols because of the small magazine which was an intended design choice, but they felt like it created an unbalanced meta to the game.

### 4.2.2 Feel and Feedback

One of the overarching feedback was the large amount of screen shake that was displayed when firing the weapons. All six believed it was high and took away from the accuracy and usage of automatic weapons. This was clearly an issue, but the user was not impaired from using the weapons as a large majority used SMGs and Rifles a majority of the time.

Recoil was a more varied result with some Participant B commenting on the difficulty of controlling it in short range fights but other players commenting that the higher levels the better it was which was intended.

Person F commented on the scoping transition time of the weapons feeling too long and some of the animation and functionality of scoping not being reactive enough for the user. This was the only user that commented on the speed but some other commented on the bullet spawn point being different when scoping which was an intended feature.

Apart from this criticism a majority of players praised the overall feel of the weapons, especially the pistols, describing them as "satisfying" (Participant C) and "smooth and responsive" (Participant D). Weapon weight and interactions were generally perceived as positive, contributing to a sense of realism (Participant C).

Players appreciated the variety in damage output across weapon types and rarities, contributing to strategic depth. Clear damage numbers for headshots and body shots were also praised for providing feedback (Participant C).

Participant A and C both commented on longer distance fights being harder but Participant A found that to be frustrating but Participant C seeing it as the classes of the weapons being more important to think about and it being more player choice in the scenario. Person C did have criticisms of the low level (grey) pistols being very ineffective even at short range compared to other class of the same level.

### 4.2.3 Weapon Modifiers

Each of the players did interact with a gun with bullet modifiers and had a large range of opinions on each. The first and most controversial was the “Blackhole” bullet modifier. Participant A said it was interesting and unique but found it underwhelming and lacking personal impact due to them not doing direct impact and that it was less rewarding. On the contrary, Participant F love the “Blackhole” modifier as they could literally make the enemies fly and they comment on it being their favourite weapon but also called it over powered.

The “Explosive” modifier was well received with players enjoying the added damage and area of effect capabilities. They explained it feeling powerful and giving good feedback to the player when the enemies were damage. Participant C enjoyed it especially when using it with a burst fire weapon because they could take out a horde of enemies with a couple bursts. Participant D did comment on the balancing concerns as they felt it was slightly overpowered.

Players who encountered weapons with a “magnetic” feature reported a positive experience. They felt it improved the weapon's effectiveness, making it feel like the hitbox was bigger or making it easier to hit targets (Participant B). Many players didn’t notice the modifier as much as the others and therefore commented on it less.

The “bounce” modifier was generally seen as a positive addition, allowing for creative and unexpected strategies, especially in enclosed spaces (Participant E). A player didn’t realise they had picked up a weapon with that modifier and were therefore surprised when they used it for the first time (Participant F). The ricochet effect was mentioned as an interesting and potentially overpowered feature of legendary weapons (Participant A) but also noted it adding a uniqueness to combat.

Overall, the unique characteristics and legendary weapons were a highlight for many players, adding depth, excitement, and strategic possibilities to the gameplay. However, some balancing concerns were raised, and there was a desire for more information and clarity on the effects of certain modifiers in the UI was suggested by Participant B.

### 4.2.4 Rarity UI and Colour Scheme

The rarity system seems to confuse around half the Participants with them guessing the order wrong. Lots of people commented think purple was the highest because it was the brightest (Participants B & C) or that red meant bad (Participants F) but there was always a clear sign that grey was the lowest level. On the contrary Participants A,D and E specifically mentioned that the color-coded rarity system was easily understood, helping them quickly identify the power level of weapons.

Many people asked for more distinct systems such as more or brighter particles, clearer information and potentially adding sound Cues to extremely rare items, giving an example of Fortnite. When viewing all the participants it was noted that many of them didn’t use the UI when picking their next weapons with Participant C going with what he was familiar with in other games before looking at the statistics.

Participant A and C when asked about the icons on the UI could gather a lot of information about the weapon but Participant F really struggled with the icons not being able to understand what they are portraying. This is a clear sign that improvement would be needed as all players need to be able to understand them. Participant B commented saying they didn’t need to see all the statistics all the time a recommended a pop out UI or comparative UI with the weapon they were currently using.

Participant G gave massive feedback on the UI and discussed major overhaul to the system including the placement of the UI not being the centre, clearer readability to the elements of each gun and the colour being to vary. As well as other improvements to the gameplay UI such as ammo amount being larger, and a gun equipment display on the screen.

### 4.2.5 Fun Factor

Most players found the guns fun and satisfying to use, with unique modifiers and the variety of weapons contributing to enjoyment. The ability to experiment with different weapons and playstyles was seen as a major plus. All players felt like the game had interesting factors but could be improved in many ways.

The two key things that took away from the fun factor of the game was the feedback of running out of bullets and the lack of reload animation but also the screen shake making the game jarring to play if using a high fire rate weapon. Many people commented on the movement of the game feeling good but Participant B did comment on the potential of having too many ways to move round the map.

When in the interviews it was noted the movement while in combat wasn't used to evade of dodge projectiles but once the encounter was over it was used to move around the map faster. Participant B clearly stated that they would have enjoyed a sprint button and not just a default jog from the normal directional keys.

### 4.3 : Analysis

The player feedback on the variation and viability of the weapons is the crux of this investigation. Gaining positive feedback from the participants regarding the usability of most weapons greatly supports PCG weapon systems. Players' main criticism was the chance of being overpowered. This overpowered feeling of high-level weapons was expected due to their only being one enemy class. If the project continued to develop, more enemy types with more health and attributes could be added to balance this out, thereby reducing the feeling of overpowered weapons. While the current artifact has some limitations, this doesn't invalidate the positive results from player testing.

The promising feedback of having great variation of weapons was a clear positive factor for the artifact, with a majority of people believing weapons had very different feels from each other. This was a goal set out in the literature review section, which emphasizes the importance of diverse arsenals to enhancing player engagement and promoting experimentation (Nai & Digaswala, 2024). The feedback from this section suggests a need for further refinement and more attachments and adjustments to each weapon class to ensure a fair and enjoyable experience for all players and to provide more diversity in gameplay. This can come from adding new weapon classes, new bullet modifiers, and implementing a Borderlands-style element system that was not developed in the artifact but was considered.

People generally commented that they enjoyed the use of the weapons. The main criticism given was that the screen shake was too much, potentially causing inaccuracy. This is a clear criticism and something that needs to be changed when developing the artifact in the future. Linking the screen shake to the attachment system, but also testing multiple values and gaining more feedback will help with the overall feel of the weapons.

Participant G also commented on the recoil reset speed being too slow, but they were the only person to comment on this. However, it will be another variable that could be linked to an attachment and not assigned a constant value. The feedback on the weapon balance and feel underscores the challenges in balancing that were discussed in the literature review (Togelius et al., 2011). With more constant testing, like in a production game, these challenges could have been tackled earlier in development, but due to the restrictions of limited development time and academic formats, this was not possible.

The range of opinions on modifiers like "Blackhole" and "Explosive" further highlights the complexities of balancing unique features within the PCG gun system. It also highlights the differences in player choice and playstyles, which gives a positive outlook on even the negative feedback received (Hunicke, 2005). Since all players enjoyed at least a couple of the modifiers, it shows the innovative and engaging gameplay mechanics that can be added to arcade shooter games and the benefits of adding them to weapons using PCG systems to give new experiences to every player (Shaker, Togelius, & Nelson, 2016).

The confusion surrounding the rarity system, despite its basis in established colour theory principles (Fishman, 2018), suggests the need for a more intuitive and universally understood visual language. This could be achieved by using potentially fewer colours on the screen, thus

reducing player confusion, and more stimuli to represent a rare gun. Additionally, feedback from participants suggests that the differences in the look and colours of the physical gun could be more pronounced to allow for greater understanding. Also, due to the lack of progression, players could instantly find high-tier weapons, not understanding that they are hard to find and discounting the colours. Therefore, several improvements highlighted can be used to improve upon these systems.

## Section 5 : Conclusion

This project's main aims were to research current games that utilize PCG weapon systems to create diverse and unique arsenals and then replicate this in an Unreal Engine artifact. Throughout this research and development, an emphasis was placed on user experience and understanding, as well as multiplayer considerations. The results of the first test demonstrate a positive outlook on the weapons in terms of drop rate, PCG weapon creation, a controllable spawn system, and a level system that affects all weapon attachments.

The second test proves that the PCG weapon system has great potential for creating unique and varied weapon types that produce exciting gameplay implications. This diversity contributes significantly to player engagement and satisfaction. It is clear that more refinement and balancing of weapon modifiers and attachments is needed if this prototype were to be developed into a released project. This highlights the increased reliance on testing when creating weapons using PCG systems and the meticulous attention to detail and testing that published games have undergone to achieve a balanced system.

The creation of the artifact was a successful implementation and demonstrates the possibility of creating PCG weapon systems that are flexible and easy to integrate into Unreal Engine. Developing a more refined system with greater polish was challenging within the limited timeframe, but key fundamental systems like the UI and weapon functionality were prioritized as "must-haves" and were robust and functional for player testing. Future updates to the project will focus on improving the UI and how guns are presented to players, as well as reworking the projectile system.

The implications of this research are clear. PCG offers a powerful tool for creating unique and varied gameplay experiences, but developers need to be aware of the challenges of balancing. The future of games is uncertain, but with expanding worlds and experiences, PCG weapons could become a catalyst for innovation, leading to new and profound gameplay experiences within the shooter genre.

## Section 6 : Reflection and Further Work

The immediate updates to this project following user testing will be to create an increased variety of enemy types and difficulty levels. This will allow players to experience greater threats and scenarios, leading to more comprehensive research and refinement of weapon balancing. Additionally, a new drop pool system linked to player level can be implemented so players must progress through the game rather than acquire better weapons solely through luck. A more structured game with clear level progression and difficulty should also be added to counter players' increasing skill and weapon power. Finally, additional weapon types, such as shotguns or grenade launchers, should be added to provide even more gameplay features and options for players.

The current research utilized a relatively simple exponential decay function for weapon generation. Further research could explore the use of more advanced algorithms, such as machine learning or evolutionary computation, to create even more diverse and complex weapon systems. A project comparing these generated weapons and their usability would be a valuable asset to future research.

Longitudinal studies on player progression and experience would be a significant improvement from the average twenty-minute play session. This would provide valuable insights into how PCG can contribute to the longevity and replayability of games. Research into player habits and correlations between weapon types picked up could also be conducted to enhance the gameplay and experience for each player.

Multiplayer testing needs to be a greater consideration in future testing. This project was primarily tested in single-player mode to gather individual thoughts, but as the artifact was created for a co-op experience, testing with pairs of players could be conducted. This would provide more insight into the balancing of the game for pairs of players and the impact of PCG when used collaboratively.

# Bibliography


Adams, E. & Rollings, A. (2010) Fundamentals of Game Design. Prentice Hall.

Borderlands Wiki (n.d.a) Borderlands 2 Weapons Rarity. Available at: https://borderlands.fandom.com/wiki/Borderlands_2_Weapons#Rarity (Accessed: 06 June 2024).

Borderlands Wiki (n.d.b) Borderlands 2 Weapons Level. Available at: https://borderlands.fandom.com/wiki/Borderlands_2_Weapons#Level (Accessed: 06 June 2024).

Belghast (2020) Origins of Color-Coded Loot. Available at: https://aggronaut.com/2020/09/03/origins-of-color-coded-loot/ (Accessed: 06 June 2024).

Bulbapedia (2024) Experience. Available at: https://m.bulbapedia.bulbagarden.net/wiki/Experience#Medium_Slow (Accessed: 06 June 2024).

Call of Duty Wiki (n.d.) Attachment. Available at: https://callofduty.fandom.com/wiki/Attachment (Accessed: 06 June 2024).

Call of Duty Wiki (n.d.) Call of Duty game engine mechanics. Available at: https://callofduty.fandom.com/wiki/Call_of_Duty_game_engine_mechanics (Accessed: 06 June 2024).

Fishman (2018) How Color Theory Codifies Item Quality in Video Games. Available at: https://medium.com/@ClaireFish/how-color-theory-codifies-item-quality-in-video-games-104d8118044#:~:text=Grey%20and%20white%20%E2%80%9Cquality%E2%80%9D%20items,released%20in%20the%20Legion%20expansion.) (Accessed: 06 June 2024).

Hendrikx, M., Meijer, S., Van Der Velden, J. & Iosup, A. (2013) 'Procedural content generation for games: A survey'. ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM), 9(1), pp.1-22.

Hunicke, R. (2005) 'The Case for Dynamic Difficulty Adjustment in Games'. ACM SIGCHI International Conference on Advances in Computer Entertainment Technology.

Sarthak Nai, Prof. Frenisha J Digaswala (2024) Weapon Development in Computer Games. Available at: https://www.ijprems.com/uploadedfiles/paper/issue_3_march_2024/32998/final/fin_ijprems1711301537.pdf (Accessed: 06 June 2024).

Pantaleev, A. (2013) Procedural Weapons Generation for Unreal Tournament III. Available at: http://cs.oswego.edu/~alex/AlexPantaleevPCG2013.pdf (Accessed: 06 June 2024).

Dr Pawel Gasiorowski (2020) Level Systems and Character Growth in RPG Games. Available at: https://pavcreations.com/level-systems-and-character-growth-in-rpg-games/ (Accessed: 06 June 2024).

Phang, J. (2024) The State of the FPS Market. Available at: https://naavik.co/digest/state-of-fps-market/#:~:text=They%20have%20also%20become%20more,greater%20share%20of%20all%

20releases.&text=Looking%20at%20Steam's%20Best%20of,the%20games%20on%20that%20list (Accessed: 06 June 2024).

Smith, Gillian & Gan, Elaine & Othenin-Girard, Alexei & Whitehead, Jim (2013) PCG-based game design: Enabling new play experiences through procedural content generation. Available at: https://www.researchgate.net/publication/229020641_PCG-based_game_design_Enabling_new_play_experiences_through_procedural_content_generation (Accessed: 06 June 2024).

Roboquest (2024) Weapons. Available at: https://roboquest.miraheze.org/wiki/Weapons (Accessed: 06 June 2024).

Salen, K., & Zimmerman, E. (2004). Rules of Play: Game Design Fundamentals. MIT Press.

Shaker, N., Togelius, J. & Nelson, M.J. (2016) Procedural Content Generation in Games: A Textbook and an Overview of Current Research. Springer.

Hindle, A., (2020) Statistics and probability for randomized games (loot shooters, roguelites, roguelikes, etc.) [Blog post]. Available at: https://softwareprocess.es/homepage/posts/stats-for-games/ (Accessed 9 July 2024).

# Appendices

## Appendix A : Borderlands Attachment Systems : Borderlands 2 Weapon Parts.

Available at: https://imgur.com/gallery/borderlands-2-weapon-parts-wkkWi (Accessed: 06 June 2024).


## Appendix B : Raw Data for Test 1

Linked To SharePoint : Appendix B Test 1 Results.xlsx

## Appendix C : Collected Data for Test 2 & Graphs

Linked To SharePoint : Appendix C Data Collection Person A to G.xlsx

## Appendix D : User Feedback Writeups

Linked To SharePoint : Appendix D Participant Notes A-G.docx