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Analysis of Aggregated Claim Numbers with Geometric Distribution and Claim Sizes with Weibull Distribution Using Convolution Method

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Abstract

An insurance claim is a form of claim from the insured party to the insurer, in this case the insurance company, which is submitted when a disaster or event that causes loss occurs. This claim is based on an agreement contract in the form of an insurance policy that has been agreed upon by both parties. Claims that arise every time a risk occurs are known as individual claims, while the total of individual claims that occur during a certain insurance period is called an aggregate claim. Aggregate loss refers to the total loss that must be borne by the insurance company due to claims filed by policyholders in a certain period. This study aims to estimate the total aggregate claim (aggregate loss) by modeling the number of claims using the Geometric distribution and the size of the claim using the Weibull distribution. The research was conducted using simulated data from PT Insurance XYZ. The method used in this research is the convolution method, which allows the calculation of the distribution of total aggregated claims based on the pairwise multiplication of the probability density function. To support the analysis, Easyfit and R Studio software were used in data processing and simulation. The results showed that the estimated total aggregate claim (aggregate loss) for a 12-month period on the simulated data was IDR2,809,454,000 using the Geometric distribution for the number of claims and the Weibull distribution for the size of the claim. In addition, the variance value obtained from the simulation results is 5.051215e-06. These findings provide an important overview of the estimation of potential losses that must be borne by insurance companies and can be used as a reference in risk management and the establishment of a more optimal financial strategy.

Keywords: Claim Insurance, Geometric Distribution, Weibull Distribution, Convolution Method.

1. Introduction

Insurance is a way to transfer risk from the insured party (first party) to the insurer (second party) through a mutually agreed legal agreement. In this agreement, the insured party is obliged to pay a premium to the insurer, which is then officially stipulated in the insurance policy. In return, the insurer or insurance company is responsible for bearing the risks faced by the insured party by providing insurance money in the event of a loss. The sum insured, often referred to as the claim amount or loss value, is the amount that must be paid by the insurer to the insured party in accordance with the provisions contained in the insurance policy (Fauzana & Mutaqin, 2023).

Insurance companies have the potential to face losses if the number of claims submitted by policyholders exceeds the planned claim reserves. This potential represents the risk that insurance companies need to manage in order to avoid losses. This risk can be considered as a random variable with a certain claim distribution, which is often the basis for calculating risk with chance models, such as the aggregate loss model. This model is a representation of the total of all claims that occur in a pool of insurance policies. Aggregate loss models can be analyzed using the collective risk approach, where the number of claims is considered a discrete random variable, while the magnitude of claims is treated as a continuous random variable (Gao & Ren, 2024).

Aggregated claims and claim probability distributions can be formed from patterns in the number and size of claims. Discrete probability distributions are widely used to model the number of claims, one example is the Geometric distribution. Then, one of the probability distributions for modeling claim size is the Weibull distribution. Modeling aggregated claims can use the convolution method. The method for determining the claim distribution model in this study uses the convolution method. The differences between this research and previous studies can be seen in Table 1.

Table 1: Research Gap

Author	Research Topic	Using Geometric Distribution for Claim Numbers	Using Weibull Distribution for Claim Sizes	Using Data of Claim Numbers and Claim Sizes
Amaliah *et al.*, (2019)	Analysis of Aggregated Claims Amount Using Convolution Method	-	-	✓
Sumarni *et al*., (2022)	Aggregated Claims Model for Number of Claims and Claim Size	-	-	✓
Fauzana & Mutaqin (2023)	Modeling of Insurance Loss Data	-	✓	-
This research	Analysis of Aggregated Claim Numbers and Claim Sizes Using Convolution Method	✓	✓	✓

Several previous studies have analyzed insurance aggregation claims with some differences. For research conducted by Amaliah et al., (2019) focuses on analyzing the number of aggregation claims with Negative Binomial distribution and the size of claims with Uniform distribution using the convolution method, obtained an estimate of the total aggregate loss claims each month based on Jasa Raharja insurance claim data. Then for research conducted by Sumarni et al., (2022) focused on the number of Poisson-distributed claims and the size of Rayleigh-distributed claims with the aggregation claim model, obtained the total pure contribution value and the total maximum risk with the aggregation claim model at *BPJS Ketenagakerjaan*. Meanwhile, research conducted by Fauzana & Mutaqin (2023) focuses on modeling large motor vehicle insurance loss data using the Weibull-Loss distribution, it is found that large motor vehicle insurance loss data comes from a Weibull-Loss distributed population.

This study aims to compare the analysis of the number of claims and the size of the aggregation claim by utilizing the Geometric distribution for the number of claims and the Weibull distribution for the size of the claim. With this approach, the research is expected to provide new insights in more accurate insurance risk modeling and can be used as a reference in the risk management of insurance companies.

2. Literature Review

2.1. Insurance

Insurance is a risk transfer mechanism from the insured party (first party) to the insurer (second party) based on a legal agreement agreed by both parties. This agreement stipulates that the insured party is obliged to pay a premium to the insurer, which is then formalized through an insurance policy. As a consequence, the insurance company (insurer) is responsible for covering the risk of the insured party by providing sum insured in the event of a loss. The sum insured, also known as the claim amount or loss value, is the amount that must be paid by the insurer to the insured party in accordance with the provisions stated in the insurance policy (Fauzana & Mutaqin, 2023).

The basic idea of insurance is the risk of loss of property due to unexpected events and the risk of disruption of health or loss of life from unexpected causes. Insurance has three basic functions, namely property function, financial function, and social function. The property function aims to protect assets through damage prevention, risk reduction, as well as compensate for damage through the payment of claims from the premium funds collected. The financial function involves upfront premium payments that are then invested to generate profits, so insurance also acts as a form of long-term savings. The social function ensures that individuals who lose their property but have insurance coverage do not become a burden on the state's social funds, so insurance contributes to the economic and social stability of society (Živković, 2020).

2.2. Insurance Claim

An insurance claim is a claim from the insured party to the insurer (insurance company) when a disaster occurs in connection with an agreement contract in the form of an insurance policy that has been agreed upon by both parties. Insurance claims submitted by the insured party will not be immediately approved by the insurance company because there are conditions that must be met, then checked for validity by the insurance company. After the agreed conditions are met, the submitted insurance claim can be processed by the insurance company for approval (Sri, 2020).

General provisions when submitting an insurance claim include, the claim submitted is in accordance with what is recorded on the insurance policy, the policy owned is still valid, the policy is not in the waiting period or the start of insurance protection, and the claim is included in the coverage or the claim submitted is not an exception stated in the policy. There are three stages in the claim, namely, the notification stage which refers to the deadline for reporting claims, the investigation stage which refers to the request for several documents proving the value of the loss, and the stage of collecting claim documents requested by the insurer to be checked for suitability before the claim is approved (Sri, 2020).

2.3. Distribution of Claim Amount and Claim Size

The claim amount distribution is a distribution that provides the frequency or number of losses without looking at the nominal loss in a certain period. Meanwhile, the claim size distribution is a distribution that provides the average amount of loss in a certain period (Yang, et al., 2021).

The frequency of insurance claims is an integer so it is modeled using a discrete distribution. Commonly used discrete distribution models for the frequency or amount of insurance claims are the Negative Binomial, Geometric, and Poisson distributions. The claim size can be a decimal number so it is modeled using a continuous distribution. Commonly used continuous distribution models for claim amounts are the Uniform, Gamma, Weibull, Exponential, and Pareto distributions (Mujiati, 2017).

3. Materials and Methods

3.1. Materials

The calculation in this study focuses on the frequency of claims and the size of insurance claims. The data used is simulated data. An insurance company, PT Insurance XYZ, records the frequency and size of insurance claims for the past year, which is detailed in 12 months. The data is presented in Table 2.

Table 2: Data of Claim Number and Claim Size

No	Claim Number	Claim Size
1	20	IDR422,411,425
2	50	IDR822,299,812
3	70	IDR1,098,372,823
4	90	IDR1,283,928,399
5	40	IDR698,328,983
6	150	IDR2,580,590,543
7	50	IDR859,839,984
8	70	IDR1,009,348,402
9	20	IDR398,348,223
10	20	IDR400,939,833
11	160	IDR2,698,372,823
12	10	IDR283,928,399

3.2. Methods

3.2.1. Geometric Distribution

The Geometric Distribution is defined as the distribution that describes the probability of obtaining the first success after failing consecutive Bernoulli trials. The Geometric Distribution is also a distribution of discrete random variables that has a mean value that is different from its variance value and the smallest possible value of its random variable is not equal to zero. In the Geometric distribution, the smallest value of the random variable is one because the number one is a factor of all integers (Sudarno & Mukid, 2016).

The probability density function of the Geometric distribution is expressed by

$$f(x) = p(1-p)^{x-1} = pq^{x-1}, x = 1,2,\ldots \tag{1}$$

with

p : probability of success ($0 \le p \le 1$),

q : probability of failure.

The moment generating function of the Geometric distribution is expressed by

$$M(t) = \sum_{x=1}^{\infty} e^{tx} p(1-p)^{x-1} = \frac{p}{q}\frac{qe^t}{1-qe^t} = \frac{pe^t}{1-qe^t}, \text{ for } qe^t < 1 \tag{2}$$

The first and second derivatives of the moment generating function of the Geometric distribution are

$$M'(t) = \frac{pe^t}{(1-qe^t)^2} \tag{3}$$

$$M''(t) = \frac{pe^t(1-q^2e^{2t})}{(1-qe^t)^4} \tag{4}$$

The mean and variance of the Geometric distribution are

$$E(X) = M'(0) = \frac{p}{(1-q^2)} = \frac{1}{p} \tag{5}$$

$$E(X^2) = M''(0) = \frac{p(1-q^2)}{(1-q)^4} = \frac{p(1-q^2)}{p^4} = \frac{1-q^2}{p^3} = \frac{2p-p^2}{p^3} = \frac{2-p}{p^2} \tag{6}$$

$$Var(X) = M''(0) - \left(M'(0)\right)^2 = \frac{2-p}{p^2} - \frac{1}{p^2} = \frac{1-p}{p^2} = \frac{q}{p^2} \tag{7}$$

3.2.2. Weibull Distribution

Weibull distribution is a continuous random variable distribution introduced by Waloddi Weibull in 1951. The Weibull distribution is one of the distribution models that has a wide range of applications and is often used to handle component reliability problems with its main advantage being to provide failure accuracy with very small samples (Gebizlioglu et al., 2011). The cumulative distribution function of the Weibull distribution with two parameters is expressed by

$$F(x;\alpha,\beta) = 1 - exp\left\{-\left(\frac{x}{\alpha}\right)^{\beta}\right\}, x \geq 0, \alpha > 0, \beta > 0 \tag{8}$$

The probability density function of the Weibull distribution is obtained from the derivative of the cumulative distribution function.

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x}{\alpha}\right)^{\beta}}, x \geq 0, \alpha > 0, \beta > 0 \tag{9}$$

The mean and variance of the Weibull distribution are

$$E(X) = \alpha\Gamma\left(1 + \frac{1}{\beta}\right) \tag{10}$$

$$Var(X) = \alpha^2\left[\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)\right] \tag{11}$$

with $\Gamma(n)$ is the Gamma function which can be calculated by

$$\Gamma(n) = \int_0^{\infty} u^{n-1} e^{-u} du \tag{12}$$

3.2.3. Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov test is one of the methods used to test the suitability of the distribution of a data set. The hypothesis for the Kolmogorov-Smirnov test is

H_0 : the data comes from a population with a certain distribution,

H_1 : the data does not come from a certain distributed population.

Suppose X is a random variable of size n, namely $X_1, X_2, \ldots, X_n$, where the random samples are $x_1, x_2, \ldots, x_n$. The test statistic for the Kolmogorov-Smirnov test is

$$D = \max_{1\leq i\leq n} |F_n(x_i) - F^*(x_i)| \tag{13}$$

with

$F_n(x_i)$: empirical distribution function for the i −th observation data,

$F^*(x_i)$: the cumulative distribution function of the tested model for the i −th observation.

The critical values of the Kolmogorov-Smirnov test are presented in Table 3.

Table 3: Critical Values of Kolmogorov-Smirnov Test

Significance Level (α)	0.20	0.10	0.05	0.02	0.01
Critical Values	$\frac{1.07}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.35}{\sqrt{n}}$	$\frac{1.52}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

Based on the critical value, the Kolmogorov-Smirnov test criterion is to reject H_0 if the value of the test statistic, D, is greater than the critical value at the specified significant level (Nugraha & Mutaqin, 2023).

3.2.4. Aggregate Loss Model

Aggregate Loss is the total policyholder loss that must be borne by the insurance company in a certain period (Mujiati, 2017). The random variable S represents aggregate loss and the random variable N represents the number of claims in one period. The aggregate loss model is expressed by

$$S = X_1 + X_2 + \cdots + X_N; N = 0,1,2,... \quad (14)$$

with
X_N : size claim in the N period.

The number of claims is expressed as a random variable N with mean $E(N)$ and variance $Var(N)$. While the size of claims is expressed by random variables $X_1, X_2, ..., X_N$ with mean $E(X)$ and variance $Var(X)$.

3.2.5. Convolution Method

Convolution method is a method of calculating the sum of pairwise multiplication of a probability density function. The distribution of the number of claims is combined with the distribution of the size of the claim to obtain an expected value as an estimate of the total value of the aggregate loss claim (Amaliah *et al.*, 2019). The mixture distribution of a random number S can be determined by

$$F_S(x) = \Pr(S \le x)$$
$$= \sum_{n=0}^{\infty} P_n \Pr(S \le x | N = n)$$
$$= \sum_{n=0}^{\infty} P_n F_X^{*n}(x)$$

The probability function for the mixture distribution S is

$$f_S(x) = \sum_{n=0}^{\infty} P_n f_X^{*n}(n) \quad (15)$$

$F_X^{*n}(x)$ is the n-fold convolution of the cumulative distribution function X obtained from

$$F_X^{*n}(x) = \begin{cases} 0, x < 0 \\ 1, x \ge 1 \end{cases} \quad (16)$$

If X is a continuous random variable with zero probability at negative values, then the equation becomes

$$F_X^{*k}(x) = \int_0^x F_X^{*(k-1)}(x-y) f_X(y) dy \quad (17)$$

with
$F_X^{*k}(x)$: k-fold convolution of the cumulative distribution function X,
$F_X^{*(k-1)}(x)$: (k-1)-fold convolution of the cumulative distribution function X,
x : value of the random variable in X,
y : value of the random variable in Y,
$f_X(y)$: density function of the random variable X in y.

The corresponding probability density function is expressed by

$$f_X^{*k}(x) = \sum_{y=0}^{x} f_X^{*(k-1)}(x-y) f_X(y) \quad (18)$$

with
$f_X^{*k}(x)$: k-fold convolution of the probability density function X,
$f_X^{*(k-1)}(x)$: $(k-1)$-fold convolution of the probability density function X,
x : value of the random variable in X,
y : value of the random variable in Y,
$f_X(y)$: density function of the random variable X in y.

If X is a discrete random variable with the probability function value of X at x is $f(x)$, then the average of the random variable X is defined by

$$E[X] = \sum_x x f(x) \quad (19)$$

with
$E[X]$: mean of random variable X,
x : probability of random variable X,
$f(x)$: density function of random variable X in x.

Variance can be calculated using the following equation

$$S^2 = \sum \frac{(x_i - \mu)^2}{n} \quad (20)$$

with
S^2 : variance of random variable X,
x_i : value of the $i-$th data,
μ : mean of data,
n : number of data.

3.2.6. Research Steps

The steps in this research are

1. Collecting the necessary data, namely the number of claims and the size of insurance claims.
2. Perform parameter estimation and statistical tests, namely the Kolmogorov-Smirnov test on the number of claims data that follow the Geometric distribution using Easyfit software.
3. Perform parameter estimation and statistical tests, namely the Kolmogorov-Smirnov test on size claim data that follows the Weibull distribution using the Easyfit software.
4. Determining the probability density function value of the number of claims data following the Geometric distribution.
5. Determine the value of the probability density function of the size claims data following the Weibull distribution.
6. Determine the total value of aggregate loss claims using the estimated mixture distribution obtained numerically by the convolution method.
7. Determine the mean and variance values to obtain the total aggregate loss claim estimate.

4. Results and Discussion

This study uses simulated data in the form of claim frequency and the size of insurance claims. An insurance company, PT Insurance XYZ, recorded the frequency and size of insurance claims for the past year which is detailed in 12 months as in Table 2. Furthermore, parameter estimation and statistical tests were carried out on the total claim data of PT Insurance XYZ using Easyfit software.

Table 4: Parameter Estimation of the Distribution of the Claim Number

No	Distribution	Parameter
1	Uniform	$a = -19, b = 144$
2	Geometric	$p = 0.01575$
3	Logarithmic	$\theta = 0.9973$
4	Negative Binomial	$n = 1, p = 0.02775$
5	Poisson	$\lambda = 62.5$
6	Bernoulli	No fit
7	Binomial	No fit
8	Hypergeometric	No fit

Table 4 shows the parameter estimates of the distribution of the number of claims of PT Insurance XYZ. For the Geometric distribution, the p value is 0.01575. Next, the Kolmogorov-Smirnov test is performed to test the suitability of the distribution of a data set.

Table 5: Kolmogorov-Smirnov Test for Geometric Distribution

Sample Size	12				
Statistic Value	0.20014				
P-Value	0.65235				
Significance Level (α)	0.20	0.10	0.05	0.02	0.01
Critical Value	0.29577	0.33815	0.37543	0.41918	0.44905
Reject H_0?	No	No	No	No	No

From the Kolmogorov Smirnov test results, it is obtained that the H_0 hypothesis fails to be rejected, meaning that the data on the number of insurance claims of PT Insurance XYZ comes from a population that is Geometrically distributed.

Furthermore, parameter estimation and statistical tests were carried out on the size claim data of PT Insurance XYZ using Easyfit software.

Table 6: Parameter Estimation of the Distribution of the Claim Size

No	Distribution	Parameter
1	Weibull	$\alpha = 1.504, \beta = 1.0271 \times 10^9$
2	Gamma	$\alpha = 1.6829, \beta = 6.2177 \times 10^8$
3	Uniform	$a = -3.5069 \times 10^8, b = 2.4435 \times 10^9$
4	Lognormal	$\sigma = 0.68852, \mu = 20.526$
5	Rayleigh	$\sigma = 8.3490 \times 10^8$

Table 4 shows the parameter estimates of the distribution of PT Insurance XYZ's large claims. For the Weibull distribution, the values $\alpha = 1.504$ and $\beta = 1.0271 \times 10^9$ are obtained. Next, the Kolmogorov-Smirnov test is performed to test the suitability of the distribution of a data set.

Table 7: Kolmogorov-Smirnov Test for Weibull Distribution

Sample Size	12				
Statistic Value	0.14829				
P-Value	0.92				
Significance Level (α)	0.20	0.10	0.05	0.02	0.01
Critical Value	0.29577	0.33815	0.37543	0.41918	0.44905
Reject H_0?	No	No	No	No	No

From the Kolmogorov Smirnov test results, it is obtained that the H_0 hypothesis fails to be rejected, meaning that the data on the size of insurance claims of PT Insurance XYZ comes from a population that is Weibull distributed.

Based on parameter estimation and statistical tests on frequency data or the number of claims and the size of claims that have been obtained, the value of the probability density function will then be determined. First, determine the value of the probability density function for the number of claims data using the parameters in table 4.

The output of the probability density function value for the number of claims data with Geometric distribution using Easyfit software can be seen in table 8.

Table 8: Probability Density Function (pdf) for the Distribution of Claim Number

No	Claim Number	pdf (P_n)
1	20	0.01146
2	50	0.00712
3	70	0.00518
4	90	0.00377
5	40	0.00835
6	150	0.00146
7	50	0.00712
8	70	0.00518
9	20	0.01146
10	20	0.01146
11	160	0.00124
12	10	0.01344

Second, determine the probability density function value for size claims data using the parameters in table 6. The output of the probability density function value for the number of claims data with the Weibull distribution using Easyfit software can be seen in table 9.

Table 9: Probability Density Function (pdf) for the Distribution of Claim Size

No	Claim Size	pdf ($f_X(x)$)
1	IDR422,411,425	7.1946×10^{-10}
2	IDR822,299,812	6.3990×10^{-10}

3	IDR1,098,372,823	5.0108×10^{-10}
4	IDR1,283,928,399	4.0454×10^{-10}
5	IDR698,328,983	6.8877×10^{-10}
6	IDR2,580,590,543	4.2795×10^{-11}
7	IDR859,839,984	6.2273×10^{-10}
8	IDR1,009,348,402	5.4796×10^{-10}
9	IDR398,348,223	7.1418×10^{-10}
10	IDR400,939,833	7.1483×10^{-10}
11	IDR2,698,372,823	3.3162×10^{-11}
12	IDR283,928,399	6.6282×10^{-10}

The values of the probability density functions of the Geometric and Weibull distributions will be used to determine the total aggregate loss claim using mixed distribution estimation with the convolution method. The value of x is the size of the umpteenth claim, $f_X(x)$ is the value of the probability density function of the size claim distribution, namely the Weibull distribution, P_n is the value of the probability density function of the distribution of the number of claims, namely the Geometric distribution, and $f_S(x)$ is the value of the probability density function of the mixture distribution for the total aggregate loss claim of PT Insurance XYZ.

Table 10: Calculation Results for Aggregate Loss Claim Probability Using Convolution Method

x	$f_X(x)$	P_n	$f_S(x)$
0	1	0	1.146000×10^{-2}
1	7.1946×10^{-10}	0.01146	5.122555×10^{-12}
2	6.3990×10^{-10}	0.00712	4.556088×10^{-12}
3	5.0108×10^{-10}	0.00518	3.567690×10^{-12}
4	4.0454×10^{-10}	0.00377	2.880324×10^{-12}
5	6.8877×10^{-10}	0.00835	4.904042×10^{-12}
6	4.2795×10^{-11}	0.00146	3.047371×10^{-13}
7	6.2273×10^{-10}	0.00712	4.433837×10^{-12}
8	5.4796×10^{-10}	0.00518	3.901475×10^{-12}
9	7.1418×10^{-10}	0.01146	5.084962×10^{-12}
10	7.1483×10^{-10}	0.01146	5.089590×10^{-12}
11	3.3162×10^{-11}	0.00124	2.360993×10^{-13}
12	6.6282×10^{-10}	0.01344	4.719277×10^{-12}
⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮
23	0	0	0
24	0	0	0
25	0	0	0

The value of the probability density function of the aggregate loss claim that has been obtained is used to determine the mean value and variance for estimating the total claim. The calculation results using R Studio and Microsoft Excel can be seen in table 11.

Table 11: Estimation of Mean and Variance of Total Claims Distribution

Mean and Variance	Estimation Values
Mean $E(S)$	$2.8094540 \times 10^{-10}$
Variance $Var(S)$	5.051215×10^{-6}

Based on the information in table 11, the total estimated aggregate loss claim each month is IDR2,809,454,000. The total value of this aggregate loss claim is obtained from the product of the expected value or mean distribution of the total insurance claims of PT XYZ with a unit of severity or the size of the claim so that the interpretation of the estimated mean value becomes billions of rupiah in accordance with the original data.

5. Conclussion

Based on the results of the research that has been done, to obtain an estimate of the total aggregate loss claim can be done by modeling historical data from insurance claim data consisting of data on the number of claims and the size of claims. The data processed is the number of claims data using the Geometric distribution, while the size of claims data uses the Weibull distribution. The calculation results are obtained from the convolution method using the help of Easyfit software, R Studio, and Microsoft Excel.

The calculation of the total estimated aggregate loss claims each month using simulation data for 12 months was obtained at IDR2,809,454,000 and a variance value of 5.051215e-06. This means that the total aggregate loss claim that must be prepared by PT Insurance XYZ is IDR2,809,454,000 for each month and the variance value shows that the data spreads by that value from the average. With the total aggregate loss claim, it is expected that the insurance company can fulfill the claims submitted each month assuming that the next year's claim event does not deviate from historical data.

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