

Star Reachers

Towson University

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Background

- By 2175, space mining is essential due to Earth resource depletion
- Cosmic Quarry operates numerous mines across 5 solar systems, two of which are new business operations
- Operations face extreme environmental and operational risks
- As the actuarial team at Galaxy General, our goal is to design an insurance program for Cosmic Quarry's new operations
- Key hazard areas:
 - Equipment failure
 - Cargo loss
 - Workers' compensation
 - Business interruption

Goals

- Quantify and **model risk** using aggregate loss, frequency, and severity
- Design an innovative, **risk-differentiated pricing model** that is adaptable to the four hazard areas
- Develop structured **product designs** with tailored coverage triggers, exclusions, and benefits

Results & Key Insights

Results:

- Recommended pricing framework and risk evaluation using hazard historical claims data
- Frequency and severity models to predict and implement risk-differentiated pricing strategy based on robust simulation of losses and costs

Key Insights:

- Proposed product designed to remain adaptable:
 - Adjustable pricing models
 - Operational coverage triggers and exclusions
- Each hazard's coverage is designed to properly handle risks

Assumptions

Assumption	Rationale
Claim frequency and severity follow their respective best-fit distributions.	We used BIC and test MSE to determine the best fit.
Aggregate losses follow a collective risk framework.	This gave us a transparent estimate of expected costs and tail risk required for pricing.
Claim frequency is relatively stable, and claim severity increases only by inflation.	This a common actuarial assumption (Green & larkowski, 2021).

Data Limitations: Errors & Clean-Up

Total percentage of data with errors: <5% of all rows

Errors:

- Mis-formatted values
 - Correct formatting where possible
- Values out of range
 - If reasonable, make ranges less conservative
- Missing or NA values
 - Exclude row

Data cleaning techniques and rationales backed by (Van den Broeck, 2005).

Data Limitations: Historical vs. New Data

New data and historical data mismatch

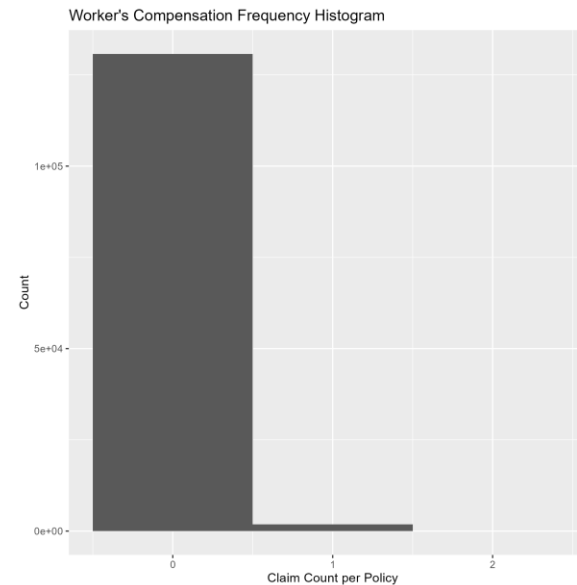
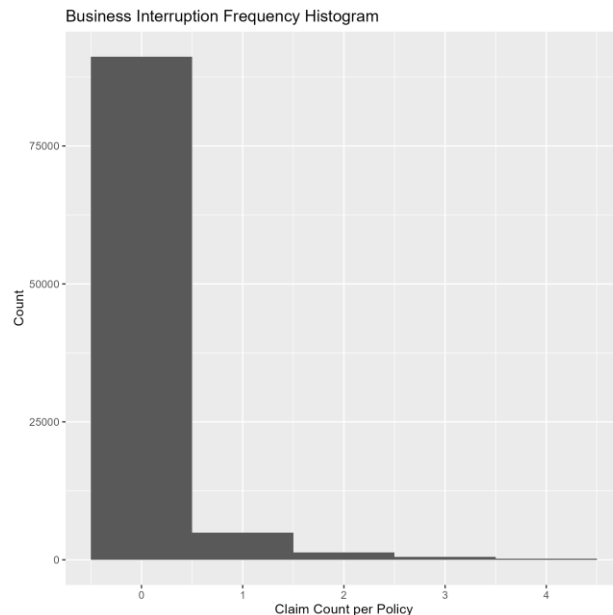
- Historical data features not present in new data
 - New data needed for simulations
 - Will be important to mitigate

Inadequate inflation and interest data

- Not enough data for standard modeling method
- Modeling will require a different approach

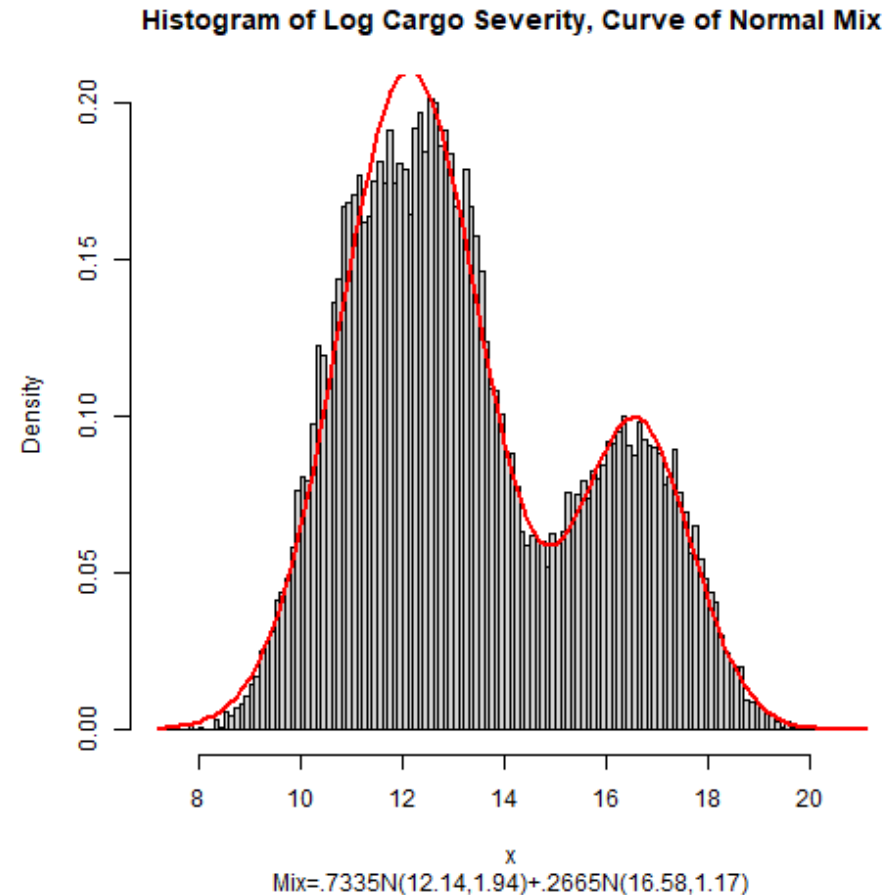
Aggregate Loss Modeling: Frequency

- Count data has high proportion of zeros
- Three areas indicate overdispersion (more zeros than expected)
- To handle, tested a variety of typical models, chose best performing by AIC and test MSE for a simple but predictive model



Aggregate Loss Modeling: Severity

- Log-transformed data is easier to handle
- Business Interruption appeared nicely normal
- Cargo Loss is mixture of two normals (Hugen, 2015)



Model Simulation: Creating Target Dataset

- Historical claim data includes many features that help models understand risk of given item
- Target data includes counts of items/personnel, but minimal info about those features
- To make new data match historical, sample each value, potentially with bias based on known descriptive info
 - Exposure is universal; unbiased simulation
 - Oryn has many asteroids; sample biased towards higher debris density
 - Cargo value depends heavily on cargo type; simulate cargo type first then sample cargo value from historical values for that cargo type

Model Simulation: Loss/Cost

To simulate yearly cost or loss distribution for **one hazard area**:

1. Simulate actual dataset
2. Simulate number of claims per item
3. Simulate severity per simulated claim
4. Calculate cost using choice of deductible, policy limit, and coinsurance, or using none of those to compute loss
5. Calculate the sum of cost or loss
6. Repeat steps 2-5 for 500 iterations
7. Repeat steps 1-6 for 100 iterations

This creates a large, robust dataset of simulated loss/cost

Risk Assessment: Main Risks

Financial Risks

Capital adequacy
Inflation
Interest rates

Operational Risks

Environmental
Conditions
Equipment Failure

Risk Assessment: Financial Risks

Description	Mitigation
Capital could be insufficient to handle low frequency and high severity losses.	Reserve a target capital range in excess, buffering heavy losses. Set aside explicit catastrophic reserves and maintain as much liquidity as possible.
Sudden increase in costs and claim sizes due to inflation .	Frequent repricing as a part of flexible cost structures . Pricing models based on tail-risk inflation assumptions.
Increase in costs and a decrease in value of assets emerging from high interest rates .	Ensure prices and premiums are high enough to account for high-rate fluxes. Maintain a scaled balance between investments and capital .

Risk Assessment: Environmental Risks

Each area of operation has different environmental conditions that make extraction hazardous:

- **Helionis Cluster** - asteroid belts are a bit dangerous, but mostly predictable/stable
- **Bayesia System**- lots of radiation and electromagnetic spikes
- **Oryn Delta** - poorly mapped asteroid belt, fluctuating gravitational gradients, low light due to dwarf star

Mitigated through model simulation and product design

Product Design: Benefit Structure

- We propose using a loss-based reimbursement approach
- Equipment failure and cargo loss coverage will reimburse the cost of the repair, replacement, or shipment value
- We propose this because mining insurance policies commonly set deductibles and coverage limits relative to asset values and operational exposure (AXIS, 2024).

Product Design: Benefit Structure

- **Deductible** and **policy limits** were set using historical loss data.
- **Deductibles** are determined from lower percentiles, so smaller and more frequent losses are partly paid for by the insured. (Wang & Huang, 2016).
- **Policy limits** are determined from higher percentiles to make sure coverage still protects against large, less frequent losses while capping the insurer's exposure (Frees, 2025).

Product Design: Business Structure

We also include an 80% coinsurance requirement (Fischer, 1981).

- This encourages policyholders to insure their assets at an appropriate value, which helps reduce underinsurance and promotes better risk management.

Product Design: Coverage Triggers

Coverage	Trigger	Condition/Verification
Equipment Failure	Mechanical breakdown, debris impact, or radiation malfunction	Confirmed through operation records
Cargo Loss	Collision, structural breach, navigation failure, or debris impact	Confirmed through vessel tracking
Workers' Compensation	Injury from equipment malfunction, radiation exposure, or environmental hazard	Occurs during work hours, and reported in 7 days, must have medical records.
Business Interruption	Unexpected shutdown, radiation spikes, infrastructure damage, or system failure	Shown in operational records, a 48-hour waiting period

Product Design: Exclusions

Designed to eliminate predictable and preventable losses, or losses not directly related to covered operational hazards

Coverage	Key Exclusions
Equipment Failure	Outdated shielding, maintenance protocol violations, repeated known environmental exposure
Cargo Loss	Unauthorized routes, improper gravitational anchoring
Workers' Compensation	Injuries outside of mining areas, safety violations, undocumented claims, non-work injuries
Business Interruption	Market fluctuations, planned maintenance, overlapping coverage events

Sensitivity Analysis

As expected, our worst-case scenario is a combination of **low interest rates and high inflation**. This is the lowest projected revenue scenario using the historical max and min values from the dataset.

	Max interest (5.54%)	Min interest (0.15%)
Max inflation (7.08%)	Cost: \$4.133 B	Cost: \$4.341 B
	Returns: 9.513%	Returns: 3.920%
	Net revenue: \$393 M	Net revenue: \$170 M
Min inflation (0.22%)	Cost: \$4.401 B	Cost: \$4.638 B
	Returns: 17.009%	Returns: 11.034%
	Net revenue: \$749 M	Net revenue: \$512 M

Sensitivity Analysis was conducted with a deductible of 40%, policy limit of 90%, and a coinsurance of 80%. The base cost is 4.655 billion, the base return is 10.39% (calculated with inflation adjusted interest and target profit margin 10%), and the base net revenue is 483 million.

Stress Testing

Evaluating resilience of simulated aggregate loss distribution:

- **Inflation shock** - 30% severity increase (American Academy of Actuaries, 2013)
- **Equipment failure** - 20% aggregate losses increase (Workers Compensation Research Institute, 2025)
- **Environmental catastrophe** - 50% largest simulated losses increase (Swiss Re Institute, 2025)

Scenario	Mean Loss	95% VaR	99% VaR	TVaR (99%)
Baseline	10.37B	19.48B	29.78B	34.46B
Inflation Shock	13.49B	25.33B	38.71B	46.10B
Equipment Failure	12.45B	23.38B	35.73B	42.56B
Environmental Catastrophe	11.02B	19.97B	44.67B	53.20B

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Questions?

