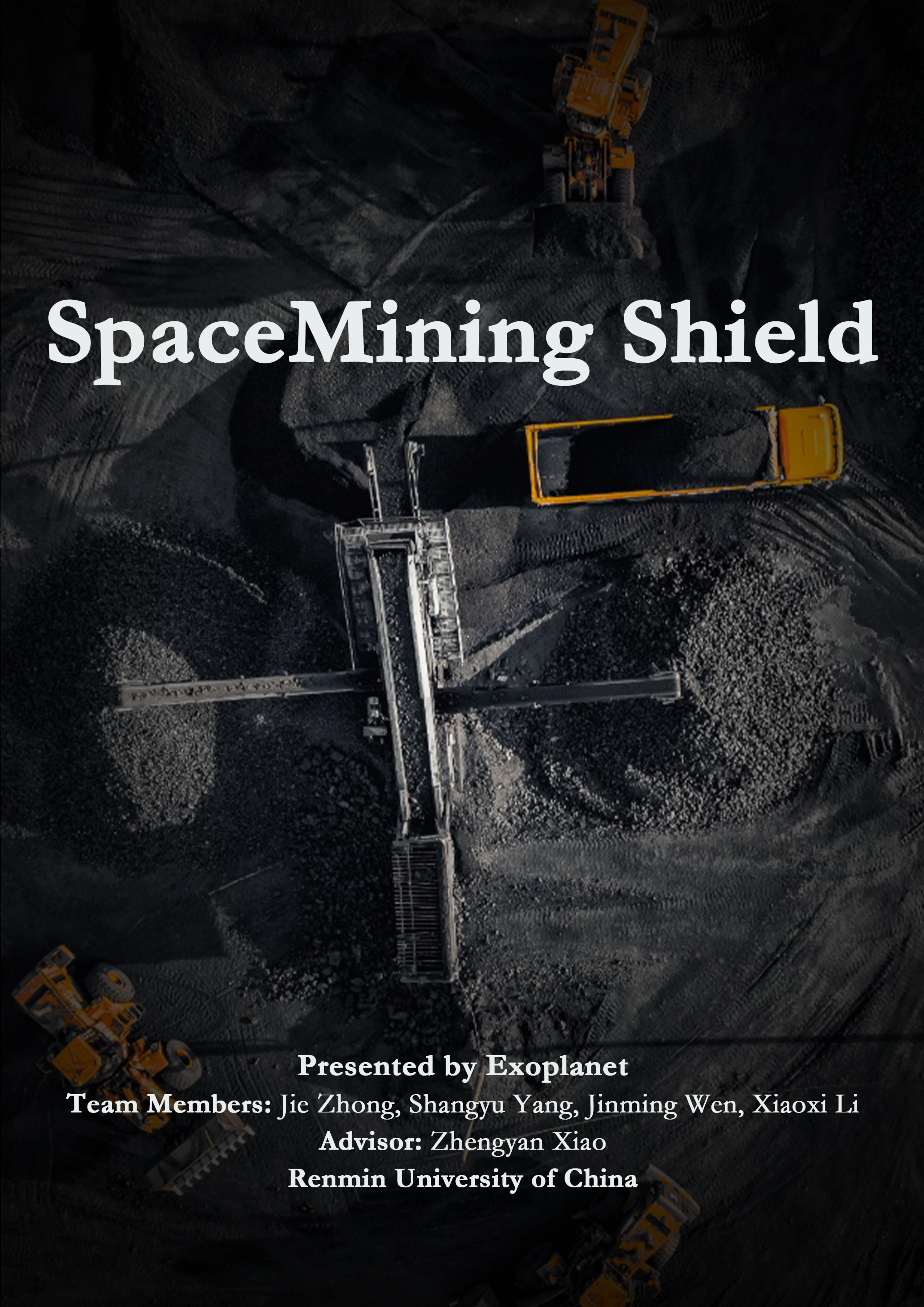


# SpaceMining Shield


**Presented by Exoplanet**

**Team Members:** Jie Zhong, Shangyu Yang, Jinming Wen, Xiaoxi Li

**Advisor:** Zhengyan Xiao

**Renmin University of China**

# Contents

# 1 Executive Summary

Based on a comprehensive review of Cosmic Quarry Mining Corporation's tender documents, our team recommends bundling the four core insurance products into an integrated Interstellar Mining Comprehensive Insurance Package **SpaceMining Shield**. The proposed solution demonstrates strong financial viability, with an aggregate **10-year expected NPV** of **Đ15.57 billion** and a **portfolio-level combined ratio** of **80.9%**, ensuring profitable underwriting performance while maintaining pricing competitiveness.

To address distinct environmental challenges, the product design incorporates system-specific trigger conditions: micro-debris collision frequency in Helionis, radiation peaks in Bayesia, and orbital shear indices and stellar flare activity in Oryn Delta. Pricing analysis revealed significant right-skewness in Business Interruption and Cargo Insurance, leading to targeted reinsurance structures that reduce their **99.5% VaR by 51.5% and 7.0%** respectively, and lower aggregate economic capital by **32.7%** (from Đ5.37B to Đ3.62B). Workers' Compensation and Equipment Failure, with lower volatility, are fully retained, achieving pre-tax RAROC of **30.5% and 30.1%**.

**Future-Ready Adaptability:** Recognizing the rapid technological evolution of interstellar mining, our solution utilizes a dynamically adaptive architecture. Integrated Orbital AI Nodes continuously ingest emerging hazard data to calibrate risk parameters in real time, ensuring coverage remains relevant as new threats emerge. The modular design allows seamless integration of new risk modules into existing policies, with parametric triggers automatically updated based on the latest scientific consensus. For frontier operations, the framework facilitates risk integration following expert assessments, utilizing credibility factors to calibrate historical data relevance across disparate galactic sectors. This scalability ensures the program remains robust as Cosmic Quarry expands to new systems.

**ERM Integration:** Our solution enhances Cosmic Quarry's enterprise risk management through real-time risk monitoring via Q-RISK System, enabling automated claims processing and tamper-proof verification. Specialized mining risk analysts will collaborate with internal teams to identify emerging threats and refine controls, while annual risk score disclosures and compliance audits ensure ongoing policy adherence.

**ESG Considerations:** Complementing this ERM framework, our products incorporate ESG pillars. Environmentally, the policy offers premium discounts for clean energy technologies and full indemnity for green recovery practices. Socially, it provides enhanced coverage for space-related occupational diseases, dedicated mental health support for isolation trauma, and genomic stability restoration for radiation exposure. Governance features include transparent underwriting protocols and automated claims handling, ensuring ethical risk management across all three solar systems.

# 2 Product Design

The **SpaceMining Shield** is a comprehensive insurance solution built specifically for deep-space mining operations. It covers four critical areas: **Equipment Failure, Business Interruption, Cargo Loss, and Workers' Compensation**. Powered by our **Q-RISK Engine** and **Orbital AI Node**, the program creates a fully automated system—from risk assessment and trigger verification to claims settlement—ensuring fast, accurate, and transparent protection for Cosmic Quarry's interstellar operations.

## 2.1 Distinct Design for each Solar System

Each solar system presents **unique environmental challenges**. To ensure that coverage aligns precisely with actual risk exposure, the **SpaceMining Shield** incorporates **system-specific trigger conditions and compliance requirements**:

Table 1. Distinct design of each solar system

| Insurance Section | Galaxy-Specific Design Elements |
|---|---|
| **Equipment Failure** | • **Bayesia:** Radiation shielding mandatory (Claims will be declined if not implemented).<br>• **Helionis:** Optional debris-cloud/communication interruption endorsement. |
| **Business Interruption** | **Parametric triggers**: Radiation thresholds (Bayesia); Orbital shear/solar flares (Oryn Delta); Prolonged communication blackouts (Helionis). |
| **Cargo Loss** | **Mandatory protective measures** : Gravity buffer packaging (Bayesia); Magnetic stabilization (Oryn Delta); Active debris avoidance (Helionis). |
| **Workers' Compensation** | • **Bayesia:** Coverage includes genomic stability restoration for radiation exposure and treatment for high-gravity-induced physical degeneration.<br>• **Oryn:** Enhanced mental health support for "Dark-Space" isolation trauma. |

*Note: Non-compliance with galaxy-specific requirements voids coverage for related losses.*

## 2.2 Performance-Based Rating and Incentive Program

- **Dynamic Experience Rating:** Premiums are adjusted annually based on **historical loss ratios, ESG Ratings, and Orbital AI Safety Scores**. Environmental penalties incurred during the policy period will result in a premium surcharge in the following year.
- **Data Sharing Incentives:** New operations may qualify for **Research and Development tax credits** in exchange for anonymized data sharing.
- **Safety Performance Incentives:** Ongoing safety performance—demonstrated through data sharing, claim-free records, and implementation of injury prevention projects—can earn premium credits and subsidies.
- **Green Recovery Bonus:** Losses restored to environmentally sound standards qualify for **full indemnity**, encouraging sustainable recovery practices.
- **Compliance Requirement:** The Insured is required to maintain **safety training and equipment protection measures** that meet or exceed a minimum specified standard.

## 2.3 Core Coverage Architecture

### 2.3.1 Equipment Failure Insurance

- ***Benefit Structure***: Compensatory property insurance settled on a Reinstatement Basis. Coverage includes transport, installation, and recalibration costs.
- ***Coverage Triggers***: A Dual-Trigger Mechanism activates coverage only when both a Defined Peril and a predefined State-Based Trigger are met. State-Based Triggers include measurable conditions such as Structural Integrity, Functional Stability, and Parametric thresholds.
- ***Key Exclusions***: Coverage does not apply to gradual deterioration, known design defects, failure to follow maintenance manuals, deliberate acts, or failure to implement required radiation shielding (e.g., Bayesia), etc.

### 2.3.2 Business Interruption Insurance

- ***Benefit Structure***: Covers Loss of Gross Profit, Increased Cost of Working, Wage Loss (key personnel), Audit and Expert Fees.
- ***Coverage Triggers***:
  - **Material Damage Trigger**: Activated following an insured Equipment Failure, subject to a 7-day waiting period.
  - **Parametric Non-Damage Trigger**: Triggered by a mandatory operational halt due to predefined environmental thresholds.
- ***Key Exclusions***: Losses arising from market price fluctuations, loss of goodwill, planned maintenance, failure to comply with Q-RISK safety directives, or use of non-compliant equipment, etc.

### 2.3.3 Cargo Loss Insurance

- ***Benefit Structure***: Indemnifies loss of minerals or goods during transit, with settlement based on reasonable market value at the time and place of loss. A value declaration is required for shipments involving precious metals or rare earth elements.
- ***Coverage Triggers***: Loss or damage caused by collision, crash, or disappearance of the carrying craft; gravitational anomalies; cosmic radiation bursts; or magnetic flux instability.
- ***Key Exclusions***: Losses arising from consignor's fault, inherent vice or nature of the goods, delay or loss of market, insufficient or unsuitable packing, or failure to activate galaxy-specific protection systems, etc.

### 2.3.4 Workers' Compensation Insurance

- ***Benefit Structure***: Covers employee's occupational injury/disease/death, including medical/rehabilitation (unlimited necessary expenses), disablement (lump sum, monthly allowance, nursing care), death benefits (funeral subsidy, dependents' allowance), and specialized support.
- ***Coverage Triggers***: Occupational injuries/diseases from immediate trauma (physical impacts/radiation bursts/gravity anomalies), sub-acute injuries from prolonged extreme environment exposure, and certified occupational mental disorders.
- ***Key Exclusions***: Losses arising from intentional self-injury, substance abuse, willful violation of safety protocols, or lack of required safety training, etc.

We recommend that Cosmic Quarry Mining Corporation opt for our comprehensive insurance, which not only provides broader risk coverage but also offers a 3% rate discount compared to buying individual policies. For detailed terms, conditions, exclusions, and technical warranties pertaining to each insurance section, please refer to Appendix C.

# 3 Summary of Pricing and Capital Modeling

## 3.1 Aggregate Loss Distributions

A consistent frequency-severity approach is applied across all four hazard coverages. For each product, expected losses are derived as the product of claim frequency and claim severity, stratified by key risk drivers specific to each line of business. Frequency is modeled using count distributions (e.g., Poisson, Negative Binomial), while severity is fitted with continuous distributions (e.g., Gamma, Lognormal) based on historical claims data. The detailed calibration of the risk factors for each coverage is documented in Appendix B. The net premiums are then calculated by adding expense loads, risk margins, and profit provisions to the discounted expected losses, incorporating macroeconomic projections for inflation and interest rates.

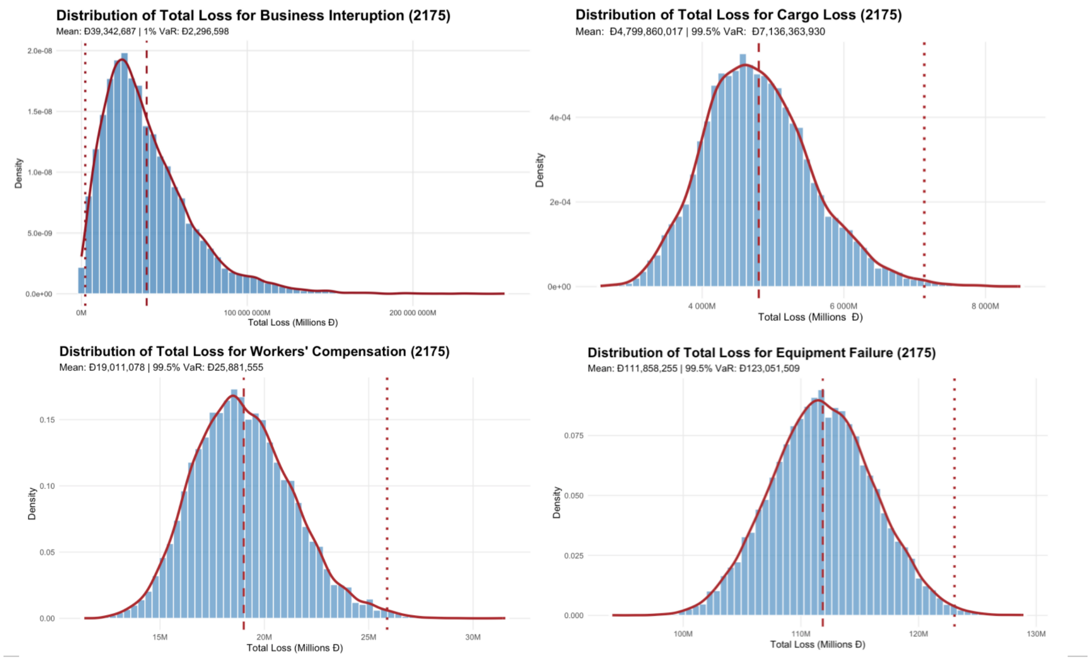



Figure 1: Distribution of Total Loss

In the stochastic modeling phase, we evaluated the **aggregate loss distributions** across the four primary insurance lines. Our analysis identified significant **right-skewness** and **high volatility** within the Business Interruption (BI) and Cargo Loss portfolios, indicating a **high propensity for catastrophic tail events**. To stabilize the portfolio and optimize capital allocation, we designed targeted **non-proportional reinsurance structures** for these two high-risk lines.

Specifically, for Business Interruption, we designed a **two-layer structure** comprising a **per-location excess-of-loss layer** (Đ25M retention, Đ100M limit, 90% placement) and an **annual aggregate layer** (Đ60M retention, Đ80M limit, 95% placement) to protect against both individual large claims and severe loss years. For Cargo Insurance, a **three-layer excess-of-loss structure** was implemented: **Layer 1 (Đ200M–Đ400M)** with a marginal rate of 1.2×, **Layer 2 (Đ400M–Đ600M)** with a marginal rate of 1.5×, and **Layer 3 (above Đ600M)** with a marginal rate of 1.8×, reflecting the **non-linear risk growth** with shipment value.

To capture dependencies across perils and solar systems in our joint loss modeling, we employed an **event-driven Gumbel copula approach**. Three **global events** (Communication Relay Failure, Capital Market Volatility, Interstellar Supply Interruption) capture **systemic risks** affecting multiple systems simultaneously, while **system-specific internal events** (Asteroid Belt Collision, Electromagnetic Storm, Asteroid Ring Shear) reflect **localized catastrophes**. **Baseline correlations** are calibrated to reflect business logic during normal years: EF-BI 0.45 (physical causality), EF-CL 0.20, EF-WC 0.25, WC-BI 0.12, CL-BI 0.15, with cross-system correlations at 0.02. During disaster years, correlations increase to **0.35** to reflect heightened synchrony while maintaining realistic dependency levels. The Gumbel copula parameters are set at $\theta_{\text{normal}} = 1.3$ ($\tau \approx 0.23$) and $\theta_{\text{disaster}} = 1.8$ ($\tau \approx 0.44$) to capture upper-tail dependence appropriately..

Simulation results demonstrated that the proposed reinsurance programs effectively truncated **aggregate joint loss tail risks**—reducing the **99.5% VaR by 20.2%** and lowering overall **economic capital requirements by approximately 32.7%**, thereby enhancing **portfolio stability** and **solvency**. For more details about aggregate joint loss and economic capital modeling please refer to Appendix E.

## 3.2 Pricing Migration Across Solar Systems

Given that our historical claims data covers only the Helionis Cluster, Epsilon, and Zeta systems, we developed a **structured pricing migration approach** to extend coverage to the new Bayesia System and Oryn Delta.

First, we fitted **generalized linear models (GLMs)** to quantify the relative impact of each existing solar system on claim frequency and severity, establishing **adjustment factors** for pure risk premiums. For the new systems, we conducted **qualitative risk assessments** based on environmental factors—such as gravitational conditions, asteroid density, and solar activity levels—to determine their **risk rankings** relative to systems with observable data.

For exposure modeling (e.g., Cargo Insurance), we calibrated the distribution of key risk characteristics, such as route risk and debris density—to reflect each new system's **unique operating environment**.

To account for the **data limitations** associated with these new systems, we applied **higher risk margins** compared to the Helionis Cluster (e.g., 15% vs. 10%). In addition, our **economic capital modeling** incorporates **system-specific catastrophe exposures** to ensure sufficient solvency buffers.

This migration framework ensures that our pricing remains **risk-reflective** while maintaining consistency with the underlying statistical models—allowing us to underwrite new systems with confidence, even where historical data is limited.

## 3.3 Stress Testing

We subjected each product line to severe shocks across key risk drivers, evaluating shifts in expected loss, standard deviation, 95% VaR, and 99% TVaR. The results revealed distinct portfolio vulnerabilities: Equipment Failure deteriorated most under **Extreme Aging** conditions, Cargo Loss spiked significantly under **Worst-Case Route** hazards, Business Interruption suffered cascading disruptions from **Deferred Maintenance**, and Workers' Compensation proved highly sensitive to **Safety Training Deficiencies**. Ultimately, these findings not only validate the adequacy of our proposed reinsurance structures but also pinpoint critical risk drivers, enabling management to prioritize targeted mitigation strategies.(See Appendix G)

# 4 Financial Results: Pricing, Capital, and Stress Testing

To assess the viability of the proposed portfolio, we evaluate both the immediate underwriting profitability and the 10-year capital accumulation trajectory. Tables 2 and 3 summarize the pricing adequacy (via Expected Loss Ratios), short-term tail risk (99.5% VaR), and long-term value creation (10-Year Expected NPV) for each product. Aggregate loss distributions and Q-Q plots assessing tail fatness are detailed in Appendix A.

Table 2. 1-Year Financial and Risk Profile by Product Line (in Millions)

| Product | Gross Premium | Expected Revenue | Expected Loss Ratio | 99.5% VaR Gross LR | 99.5% VaR Net LR | RAROC |
|---|---|---|---|---|---|---|
| **Cargo Loss** | 8206.88 | 1696.00 | 59.3% | 87.0% | 80.9% | 33.75% |
| **Equipment Failure** | 162.52 | 15.13 | 68.8% | 75.8% | – | 30.09% |
| **Business Interruption** | 60.55 | 6.03 | 64.3% | 241.5% | 117.0% | 14.07% |
| **Workers' Comp.** | 36.89 | 3.55 | 68.5% | 88.6% | – | 30.52% |

*Note: Equipment Failure and Workers' Comp. assume no reinsurance.*

Table 3. 10-Year Long-Term Capital and Value Creation (in Millions)

| Product | Expected PV of Net Cash Flow | 5% VaR of Net Cash Flow | 95% VaR of Net Cash Flow |
|---|---|---|---|
| **Cargo Loss** | 15179.99 | 11817.57 | 18528.49 |
| **Equipment Failure** | 282.09 | 249.95 | 314.27 |
| **Business Interruption** | 80.13 | -14.7 | 174.91 |
| **Workers' Compensation** | 29.06 | 7.41 | 49.61 |

*Note: Expected PV of Net Cash Flow is discounted to 2175 via our simulated Actuarial ESG yield curve.*

Priced near a 65% target loss ratio, the portfolio ensures robust profitability, driven by Cargo Loss (15.1B 10-year NPV). Reinsurance effectively halves Business Interruption's 99.5% VaR (241.5% Gross to 117.0% Net), while predictable lines like Equipment Failure and Workers' Compensation (VaR <90%) are fully retained to maximize RAROC. This optimized structure, validated by 1-in-100-year stress testing (Table 4), ensures long-term capital accumulation and ERM resilience against systemic interstellar shocks.

Table 4. Stress Testing: Impact Multiples of Extreme Scenarios (Relative to Baseline)

| Product | Worst-Case Stress Scenario | Impact on Expected Net Loss | Impact on Net 99.5% VaR |
|---|---|---|---|
| **Cargo Loss** | Route Risk Level 5 | 1.42x | 1.37x |
| **Equipment Failure** | Extreme Aging | 2.57x | 2.53x |
| **Business Interruption** | No Maintenance | 1.06x | 1.01x |
| **Workers' Compensation** | Safety Training Deficiency | 2.81x | 2.92x |

*Note: Multiples reflect the post-reinsurance (Net) impact. A value of 1.45x indicates a 45% increase compared to the baseline simulation. Full stress testing methodologies are provided in Appendix G.*

# 5 Risk Assessment

## 5.1 Risk identification

Accurate risk assessment requires understanding each system's unique pressures. Table 5 shows how their diverse conditions shape this complex landscape.

Table 5. Matrix of Environmental Stressors and Associated Operational Hazards

| Solar System | Equipment Failure | Cargo Loss | Workers' Compensation | Business Interruption |
|---|---|---|---|---|
| **Bayesia System** | **Medium:** Radiation spikes induce logic bit-flips; high-gravity accelerates structural wear. | **Low:** Heavily mapped, stable asteroid belt (standardized transit corridor). | **Extreme:** High-gravity physical strain; radiation-induced long-term physiological risks. | **High:** Mandatory preventive shutdowns necessitated by electromagnetic radiation storms. |
| **Oryn Delta** | **High:** Fluctuating gravitational gradients exert physical torque, causing structural fatigue. | **Extreme:** Faint luminosity and rapid orbital shear elevate catastrophic collision risks. | **Med-High:** Low-visibility, isolated habitats trigger severe psychological stressors. | **Extreme:** 240 AU spatial distance amplifies logistical lag and repair latency. |
| **Helionis Cluster** | **Low-Med:** Shifting debris clouds cause high-frequency, low-severity micro-collisions. | **Medium:** Erratic drift patterns and gravitational resonances create a "moving maze" for navigation. | **Low:** Temperate terrestrial conditions; risks primarily stem from routine human/system error. | **Low-Med:** Spatial cluttering causes signal flickering, leading to intermittent operational pauses. |

*Note: This assessment delineates the environmental heterogeneities dictating underwriting strategy:* ***Bayesia*** *is dominated by radiological and gravitational strain;* ***Oryn Delta*** *by extreme navigational and logistical latency; and* ***Helionis*** *by high-frequency but low-severity attritional hazards.*

## 5.2 Correlated Risk Scenarios & Scenario Stress Testing

Based on the distinct environmental characteristics of the three solar systems, we identified three correlated risk scenarios where global events could simultaneously impact multiple systems:

- **Communication Relay Failure**: A failure of the primary relay satellite between Helionis and Bayesia would disrupt navigation and coordination, increasing equipment failure, cargo loss, and business interruption risks across both systems, with Oryn also affected due to communication dependencies.
- **Interstellar Supply Interruption**: A shutdown of Earth Central Logistics Hub would delay critical spare parts supply, with impacts escalating by distance—Oryn Delta, as the most distant system, experiences the greatest disruption to equipment maintenance and cargo operations.
- **Capital Market Volatility**: A liquidity crisis at the Intergalactic Stock Exchange would force reductions in preventive maintenance and safety investments, increasing equipment failure in Helionis, workers' compensation in Bayesia, and cargo loss in Oryn.

These scenarios were selected based on the unique vulnerabilities of each solar system, capturing both systemic interdependencies (shared communication infrastructure, common supply chains) and localized risk factors. In our joint loss modeling, these global events are integrated alongside system-specific internal events—such as Helionis's asteroid belt collisions, Bayesia's electromagnetic storms, and Oryn's asteroid ring shear—to construct a comprehensive **event-driven Gumbel copula** framework that captures the full spectrum of correlated risks across all perils and systems. The resulting joint distribution forms the basis for our scenario stress testing.

Table 6. Scenario Testing Results (Pre-Reinsurance)

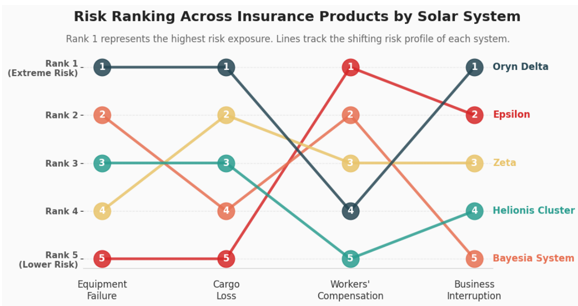
| Scenario | Total Loss (M Đ) | Accounting Profit (M Đ) | RAROC (%) |
|---|---|---|---|
| Best-case (5%) | 3,557.9 | 3,282.2 | 65.4 |
| Moderate-case (50%) | 5,585.8 | 1,052.4 | 23.8 |
| Worst-case (95%) | 7,100.9 | -614.2 | -7.2 |
| Extreme-case (99.5%) | 9,237.1 | -2,964.0 | -51.0 |

Table 7. Scenario Testing Results (Post-Reinsurance)

| Scenario | Total Loss (M Đ) | Accounting Profit (M Đ) | RAROC (%) |
|---|---|---|---|
| Best-case (5%) | 3,473.9 | 2,800.4 | 81.7 |
| Moderate-case (50%) | 5,151.1 | 955.5 | 30.6 |
| Worst-case (95%) | 6,180.3 | -176.6 | -0.7 |
| Extreme-case (99.5%) | 7638.8 | -1781.0 | -45.0 |

The scenario testing results demonstrate robust portfolio performance, with profitability maintained across 95% of scenarios (up to the 95th percentile). This loss profile confirms the effectiveness of our proposed reinsurance structure in protecting against catastrophic events while preserving upside potential in the vast majority of scenarios.

## 5.3 Threat Ranking




Due to distinct astrochemical and physical environments, risk profiles vary significantly across systems. For example, owing to its low luminosity and rapid orbital shear within the asymmetric asteroid ring, the Oryn Delta presents the highest risk exposure in Equipment Failure, Cargo Loss, and Business Interruption. However, direct physiological threats to personnel remain relatively moderate. This heterogeneity enables **optimal risk-spreading**: balancing volatile asset risks in the Oryn Delta against more stable systems ensures **overall portfolio robustness**. Risk shifts are illustrated in the chart above; for detailed hazard profiles per system, see Appendix F.

## 5.4 ESG & Technical Solvency

Our underwriting approach combines actuarial rigor with **ESG governance** for long-term resilience. Given Cosmic Quarry's history, we imposed strict orbital debris controls and addressed crew psychological risks—through defined safety roles, equipment standards, and counseling—which supported a favorable risk rating. For the target systems' diverse exposures, we developed tailored **pricing factors** (see Appendix B) to reflect actual risk drivers. We also added stability via higher **deductibles** for frequent small claims and **reinsurance** for catastrophic losses. This keeps even uncertain frontiers within our risk tolerance.

# 6 Assumptions

Table 8. Key Assumptions

| Assumption | Selected value | Rationale |
|---|---|---|
| **Pricing and Capital Assumptions** | | |
| Expense Loadings | Underwriting: 15%<br>Claims: 10% | Based on historical averages and industry benchmarks for underwriting operations. |
| Target Loss Ratio | 65.0% | Implies a 35% combined expense and profit margin, balancing market competitiveness with solvency requirements. |
| **Economic and Financial Assumptions** | | |
| Inflation | Workers' Comp: 5% annual;<br>Others: historical/macro | WC reflects interplanetary medical cost trends and wage adjustments; other perils derived from Project Data macroeconomic forecasts. |
| Discount Rates | Spot yield curves | Separate discount factors for premium income (policy inception) and loss payments (year-end), derived from provided macroeconomic data. |
| Exposure Growth | Helionis/Bayesia: 2.26%,<br>Oryn: 1.41% | Based on expansion plans outlined in the Online Encyclopedia, reflecting differential growth across solar systems. |
| **Reinsurance Assumptions** | | |
| Layer Pricing | Commercial loadings: cargo 1.2–1.8×, BI per-location 1.7×, BI aggregate 1.4× | Reinsurance premiums calculated as expected layer losses multiplied by market-consistent loadings. |
| Ceding Commission | 10.0% | Assumed for all reinsurance placements, representing acquisition cost savings passed to reinsurers. |
| **Dependence and Correlation Assumptions** | | |
| Copula Selection | Gumbel: $\theta_{\text{normal}} = 1.3$, $\theta_{\text{disaster}} = 1.8$ | Captures upper-tail dependence essential for insurance risk, with parameters increasing in disaster years to reflect heightened synchrony (Kendall's $\tau$: 0.23 normal, 0.44 disaster). |
| Normal Year Dependence | EF–BI: 0.45; EF–CL: 0.20; EF–WC: 0.25; WC–BI: 0.12; CL–BI: 0.15; cross-system: 0.02 | Correlations calibrated to business logic: equipment failures directly impact business interruption, moderately affect cargo and worker safety, while cross-system risks remain largely independent. |
| Disaster Year Dependence | Three systemic events (2%, 5%, 1% annual probability); correlations increase to 0.35; Gumbel $\theta$ increases to 1.8 | Communication failure, capital market volatility, and supply chain disruption trigger multiplicative loss increases across specific system-peril combinations, with EF and WC exposures deliberately enhanced to reflect their vulnerability to systemic shocks. |

*Note:* EF = Equipment Failure, BI = Business Interruption, WC = Workers' Compensation. Systemic events in disaster years affect specific system-peril combinations. Additional assumptions are detailed in Appendix H.

# 7 Data and Data Limitations

## 7.1 Data Sources and Constraints

This report draws on four primary data sources: (i) Galaxy General Insurance Company's historical claims database; (ii) RFP from Cosmic Quarry; (iii) Encyclopedia and public databases; and (iv) specialized literature in space physics and mining engineering, together with existing insurer policy wordings and pricing practices. While these sources provide a useful analytical foundation, several data limitations remain:

- **Limited data for new systems**: Bayesia and Oryn Delta lack historical claims experience and standardized environmental benchmarks. Pricing relies on qualitative judgment and approximated parameters from comparable systems.
- **Extreme event exposure**: Historical data may not include rare astrophysical events (e.g., major solar flares). Such events could produce losses beyond the modeled range.
- **Operational data gaps**: Tender materials lack detailed information on supply chains, terrain, and orbital conditions. Pricing assumes average operational parameters rather than site-specific risk-adjusted values.
- **Expert judgment reliance**: Event probabilities and impact factors for novel perils are based on expert opinion and historical analogs, which may not predict actual outcomes.
- **Small sample uncertainty**: Several risk subgroups have limited historical observations, increasing parameter uncertainty despite statistical adjustments.
- **Tail risk estimation**: GPD-based tail estimates are sensitive to distributional assumptions; heavier true tails could lead to understated extreme losses.
- **Dependency structure**: The model uses a Gumbel copula, which imposes a specific dependency pattern. Alternative copula choices could produce different correlation and aggregation results.
- **Outlier influence**: Historical claims contain several outliers. Adjustments were applied to retain sample size, but this introduces some estimation uncertainty.
- **Spatial independence assumption**: Due to lack of spatial interaction data, risks are modeled as independent across sites. Unmodeled correlations could affect portfolio-level results.
- **Macroeconomic projection uncertainty**: Inflation, interest rate, and business expansion assumptions are simplified and may not capture long-term economic or operational developments. Premium calibration may require refinement based on actual business mix.

## 7.2 AI and LLM Disclosure Statement

AI and LLM tools were used in preparing this report solely for text polishing, structural optimization, and translation.All core actuarial analyses, pricing models, and risk assessment recommendations are the original work of this Team. We further confirm that no part of this submission materially relies on unverified AI-generated content.

# Appendix

## Appendix A Exploratory Data Analysis

Missing values were detected across multiple fields in the raw dataset. Additional issues included redundant suffixes in string fields, negative or out-of-range values in numerical fields, unexpected decimals in integer fields, and categorical entries falling outside predefined classes.

To ensure data integrity, a five-stage governance pipeline was implemented. First, a **primary key audit** was conducted on the *frequency* dataset to verify the unique identification of exposure units. Second, **missing values** were partially imputed by cross-referencing corresponding fields between the *frequency* and *severity* tables after removing records with missing `policy_id`. Third, the remaining missing observations were deleted due to their small proportion. Fourth, string fields were cleaned using regex filters, while numerical anomalies—including negative values, out-of-range entries, and unexpected decimals—were corrected or truncated. Finally, a structural reconciliation audit was performed by removing any `worker_id` whose `claim_count` in the *frequency* table did not match the number of verified cost records in the *severity* subset, resulting in a fully harmonized dataset.

It is noteworthy that the *Data Dictionary* specifies a range of **28K–1,426K** for Business Interruption claims; however, more than **50%** of observations exceed this upper bound, with a maximum of approximately **142,583K**. Compared with the *Cargo Insurance* dataset (maximum around ~680,000K), the dictionary limit appears economically inconsistent with mining station exposure. Since the observed data follow a plausible Log-Normal pattern, we interpret the discrepancy as a documentation error (likely unit scaling) and proceed with modeling the **full dataset** to avoid underestimating tail risk.

### Appendix A.1 Business Interruption

In the *frequency* dataset, there were originally 99,923 observations. A total of 1,886 records were eliminated because they fell outside the range specified in the Data Dictionary, resulting in a retention rate of 98.11%.

In the *severity* dataset, there were originally 10,055 observations. A total of 101 records were removed because they were either outside the dictionary range or mismatched with the *frequency* dataset, leaving 99% of the data retained.

The graphs reveal a monotonically increasing relationship between loss frequency and the supply chain index, whereas average claim severity shows a declining trend.

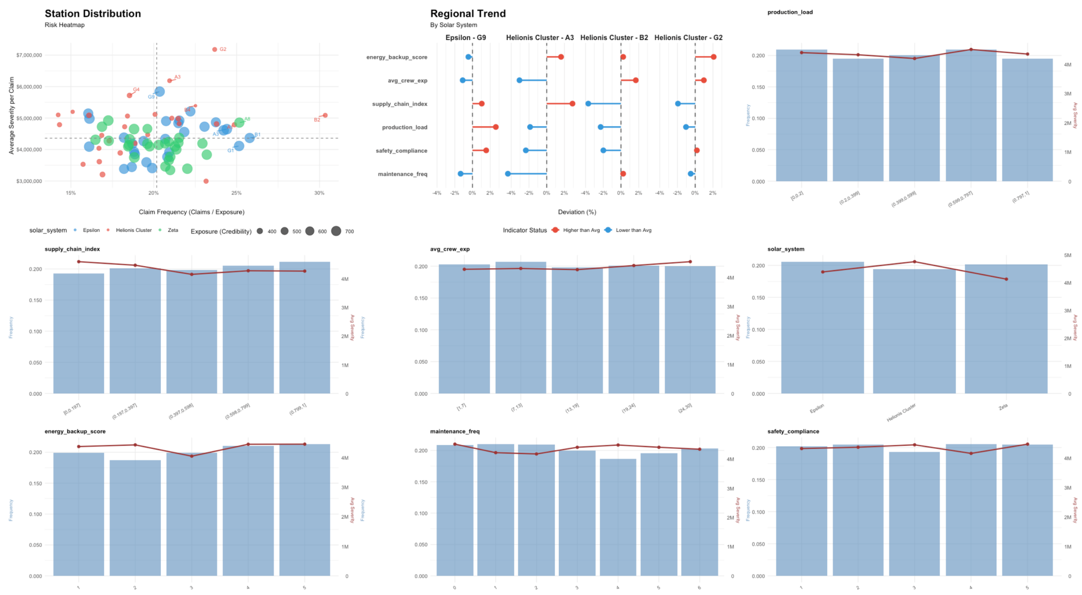



Figure 2: EDA of Business Interruption

Further cross-analysis with star systems shows that the Zeta Solar system, possibly due to chaotic outer orbits and higher navigation risks, exhibits the most pronounced monotonic increase in frequency with rising supply chain index. Meanwhile, the Helionis Solar system displays a notable pattern of ”low frequency but high severity” when the supply chain index reaches the fourth level. This suggests the possible presence of typical semi-self-sufficient heavy-asset mining stations in this region, which rely on imported critical components or specific fuels. Operational halts in such stations could lead to substantial business interruption losses.

## Appendix A.2 Equipment Failure

In the *frequency* dataset, there were originally 95,062 observations. A total of 1,615 records were eliminated because they were outside the range specified in the Data Dictionary, resulting in a retention rate of 98.27%.

In the *severity* dataset, there were originally 8,272 observations. A total of 85 records were removed because they were either outside the dictionary range or mismatched with the *frequency* dataset, leaving 98.97% of the data retained.

The solar system variable exhibits strong discriminatory power: Helionis Cluster shows the highest claim frequency yet the lowest claim severity, while Zeta demonstrates the lowest claim frequency but the highest claim severity. Equipment type varies significantly across categories, confirming its appropriateness as a classification variable for ratemaking.

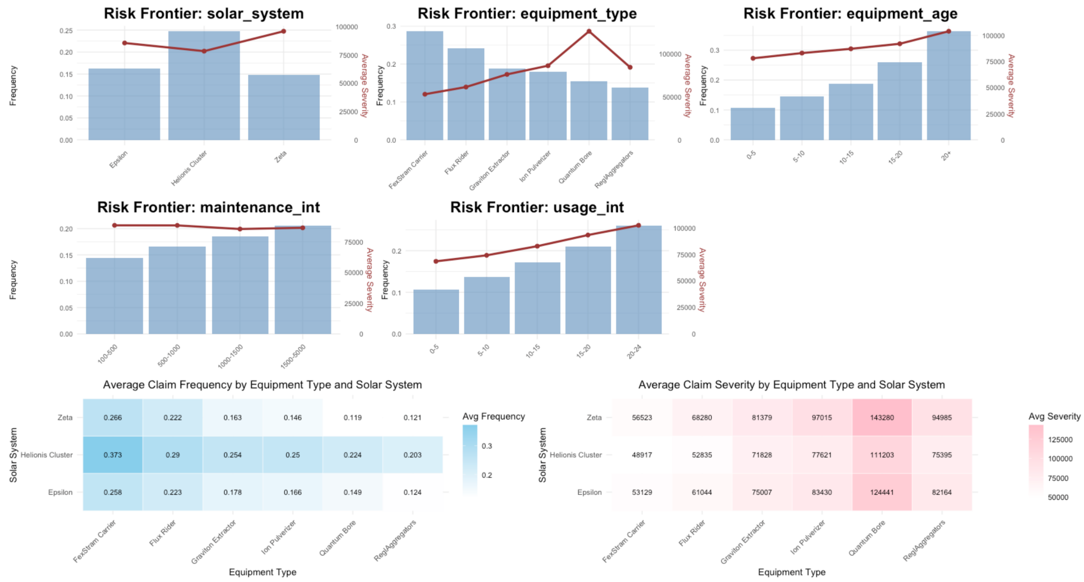



Figure 3: EDA of Equipment Failure

A clear pattern emerges when comparing the two charts: Helionis Cluster stands out with high claim frequency but low severity—indicating frequent, small-scale incidents. Zeta presents the opposite profile: low frequency yet high severity, pointing to rare but costly claims. Meanwhile, FexStram Carrier leads in claim frequency, while Quantum Bore tops the chart in claim severity. These contrasting risk profiles are critical for more nuanced pricing and effective risk segmentation.

## Appendix A.3 Workers' Compensation

In the *frequency* dataset, there were originally 134,947 observations. Among them, 624 records contained negative values, and 2,943 records were eliminated because they fell outside the range specified in the Data Dictionary, resulting in a retention rate of 97.82%.

In the *severity* dataset, there were originally 1,917 observations. Ten records contained negative values, and 57 records were removed because they were either outside the dictionary range or mismatched with the *frequency* dataset, leaving 97.03% of the data retained.

The Helionis Cluster has the highest average claim amount, while Zeta exhibits the highest claim frequency (Panel 1 & 2). A significant escalation in both claim frequency and severity is observed when the `gravity_level` exceeds 1.1g. However, as gravity continues to increase, claim severity shows a declining trend.

Occupationally, Drill Operators exhibit the highest risk loading, consistent with the high-energy mechanical environments in which they operate, while Executives show the highest claim severity. Both claim frequency and severity vary across different occupations (Panel 4).

Risks remain relatively stable up to 25 hours per week (Panel 9), but a significant spike in both frequency and severity occurs at the 25–30 hour mark. Panel 10 indicates that claim frequency increases progressively from stress levels 1 to 4.

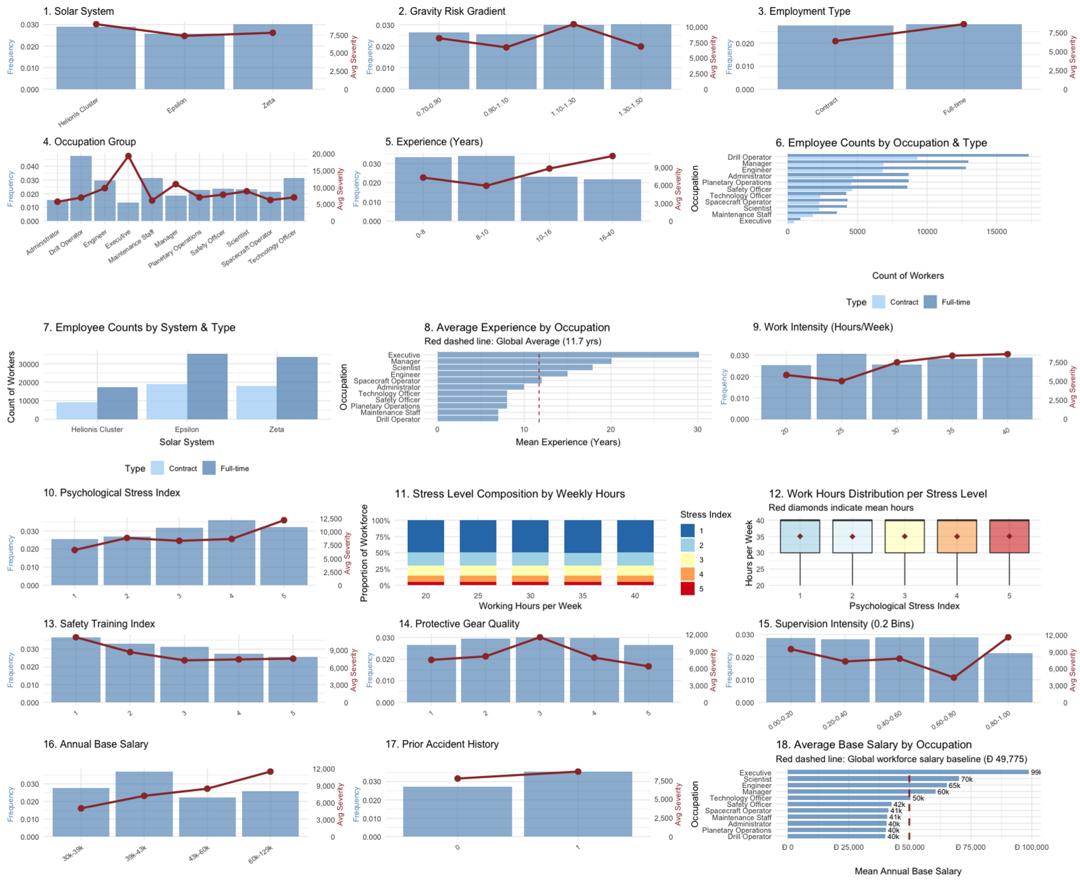



Figure 4: EDA of Workers' Compensation

As the **Safety Training Index** (Panel 13) increases, both claim frequency and claim severity show a clear downward trend. In contrast, for **Protective Gear Quality** (Panel 14), both frequency and severity exhibit an inverted U-shaped pattern: they increase initially and then decline. Both metrics reach their peak at a moderate level (index = 3), while at index = 5, claim frequency and severity fall to their lowest levels.

It is also observed that as the base salary increases, claim severity shows a clear upward trend, while claim frequency tends to decline. This may be because employees with higher salaries are more likely to work in relatively safer environments (Panel 18).

Finally, employees with a history of prior claims exhibit significantly higher claim frequency and claim severity compared with those with no previous claims (Panel 17).

## Appendix A.4 Cargo Loss

In the *frequency* dataset, there were originally 124,982 observations. A total of 514 records contained negative values, and 531 records were eliminated because they were outside the range specified in the Data Dictionary, leaving 124,451 observations retained.

In the *severity* dataset, there were originally 30,650 observations. A total of 2,023 records contained negative values. The *severity* dataset was subsequently merged with the *frequency* dataset using `policy_id` and `claim_id`.

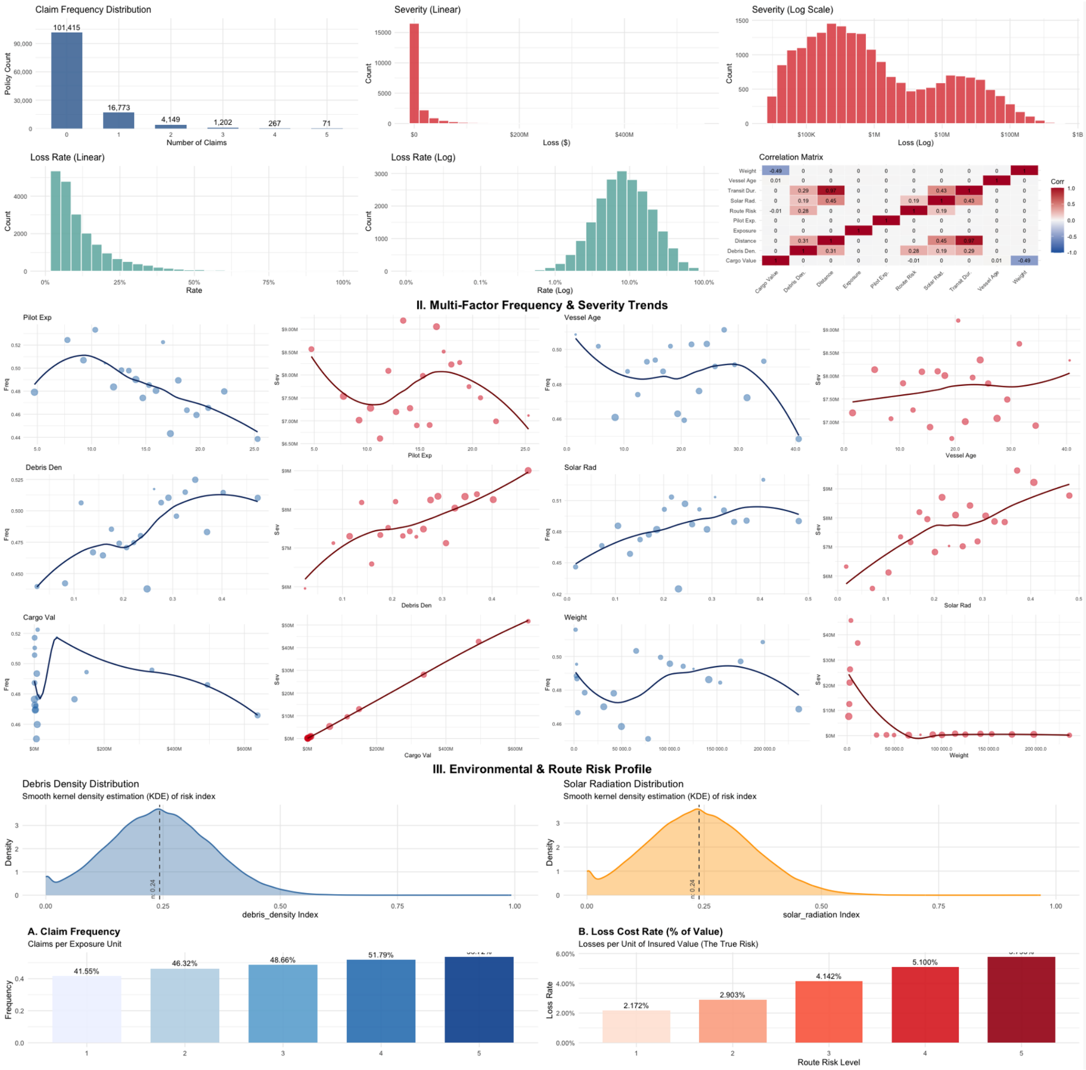



Figure 5: EDA of Cargo Loss

We began with data standardization and the filtration of zero-exposure records to ensure modeling integrity. Through distributional diagnostics, it identifies characteristic zero-inflation in claim frequency and extreme right-skewness in severity, justifying the application of log-link functions and Gamma-family distributions in subsequent GLM pricing. By integrating Spearman correlation matrices with exposure-weighted LOESS smoothing, the analysis quantifies non-linear trends across operational and environmental risk drivers, while the final stage of feature engineering—discretizing continuous variables and evaluating loss rates by route and container type—establishes a rigorous, data-driven foundation for risk segmentation and technical rating.

# Appendix B Model Specification

## Appendix B.1 Formula

To translate these expected losses into gross premiums, we established a dynamic, mathematically rigorous pricing framework. Recognizing that claim handling expenses ($CL$) scale with actual losses rather than overall premium, the total loading expense ($L$) is defined dynamically:

$$L = UW + (CL \times TLR) \tag{1}$$

Where $UW$ is the fixed underwriting expense and $TLR$ is the Target Loss Ratio. Based on the fundamental pricing identity ($100\% = TLR + L + Profit + Risk$), we can solve for the exact equilibrium $TLR$:

$$TLR = \frac{1 - UW - (Profit + Risk)}{1 + CL} \tag{2}$$

Applying our baseline portfolio parameters—Underwriting Expense ($15\%$), Claim Expense ($10\%$), and a combined Profit and Risk margin ($13.5\%$)—the formula dictates a strictly calibrated Target Loss Ratio of **65.0%** and a corresponding Loading Expense of 21.5%. The final Gross Rate is then derived by grossing up the risk-adjusted base rate:

$$\text{Gross Rate} = \frac{\text{Base Rate} \times (1 + \text{Risk Margin})}{1 - L - \text{Profit Margin}} \tag{3}$$

## Appendix B.2 Modeling

Table 9. Summary of Actuarial Model Selection and Distribution Fitting

| Insurance Line | Component | Selected Model | Selection Criteria & Rationale |
|---|---|---|---|
| **Business Interruption** | **Frequency** | Zero-Adjusted Negative Binomial | Handled 93% zero-inflation and extreme volatility; achieved superior AIC and standard normal randomized quantile residuals. |
| | **Severity** | Lognormal GLM | Best fit for attritional losses (<97.5th pct) based on Q-Q plots and AIC; accommodated inherent right-skewness without explicit truncation. |
| **Workers' Compensation** | **Frequency** | Negative Binomial (Log-link) | Accommodated 99% zero-claims. Vuong test confirmed zero-inflated alternatives offered no significant gain, satisfying the Principle of Parsimony. |
| | **Severity** | Inverse Gaussian GLM | EVT POT ($\xi = -0.17$) indicated a bounded tail. A unified IG model was chosen over spliced approaches due to superior AIC/MLE metrics. |
| **Equipment Failure** | **Frequency** | Negative Binomial | Outperformed Poisson, ZIP, and ZINB with the lowest AIC/BIC scores and near-perfect graphical alignment with empirical PMF/CDF. |
| | **Severity** | Lognormal | Demonstrated superior tracking across density comparisons, Q-Q plots, and CDFs against IG, Gamma, and Weibull alternatives. |
| **Cargo Loss** | **Frequency** | Logistic Regression (Binomial, logit) | Explicitly addressed highly zero-inflated interstellar maritime risks by modeling the absolute probability of a claim. |
| | **Severity** | Spliced Model (Weibull + GPD) | Weibull optimally fitted the attritional body (best AIC); EVT/GPD explicitly captured extreme tail risks exceeding the Đ200M threshold. |

## Appendix B.3 Rating Factor

Table 10. Equipment Failure Insurance Rating Factors

| Rating Variable | Freq. Rel | Sev. Rel | Selected Rel |
|---|---|---|---|
| **Solar System** | | | |
| Helionis Cluster | - | - | 1.000 |
| Bayesian System | - | - | 1.074 |
| Oryn Delta | - | - | 1.264 |
| **Equipment Type** | | | |
| ReglAggregators | 1.000 | 1.000 | 1.000 |
| Graviton Extractor | 1.366 | 0.909 | 1.241 |
| FexStram Carrier | 2.075 | 0.603 | 1.252 |
| Flux Rider | 1.731 | 0.725 | 1.254 |
| Ion Pulverizer | 1.296 | 1.033 | 1.340 |
| Quantum Bore | 1.121 | 1.517 | 1.701 |
| **Equipment Age** | | | |
| 0-5 | 1.000 | 1.000 | 1.000 |
| 5-10 | 1.356 | 1.070 | 1.450 |
| 10-15 | 1.749 | 1.139 | 1.992 |
| 15-20 | 2.396 | 1.219 | 2.920 |
| 20+ | 3.417 | 1.334 | 4.559 |
| **Usage Intensity** | | | |
| 0-5 | 1.000 | 1.000 | 1.000 |
| 5-10 | 1.292 | 1.109 | 1.432 |
| 10-15 | 1.609 | 1.243 | 1.999 |
| 15-20 | 1.962 | 1.386 | 2.718 |
| 20+ | 2.440 | 1.529 | 3.731 |
| **Maintenance Intensity** | | | |
| 100-500 | 1.000 | 1.000 | 1.000 |
| 500-1000 | 1.146 | 1.007 | 1.154 |
| 1000-1500 | 1.269 | 0.977 | 1.240 |
| 1500-5000 | 1.416 | 0.988 | 1.399 |

- Base Premium is set to Đ 3950.
- All values are rounded to three decimal places.

Table 11. Business Interruption Insurance Rating Factors

| Rating Variable | Freq. Rel | Sev. Rel | Selected Rel |
|---|---|---|---|
| **Solar System** | | | |
| Helionis Cluster | - | - | 1.000 |
| Bayesia System | - | - | 1.075 |
| Oryn Delta | - | - | 1.065 |
| **Maintenance Frequency** | | | |
| [0, 2) | 1.000 | 1.000 | 1.000 |
| (2, 3] | 0.944 | 1.000 | 0.944 |
| (3, 6] | 0.919 | 1.000 | 0.919 |
| **Production Load** | | | |
| [0, 0.2) | 1.000 | 1.000 | 1.000 |
| (0.2, 0.4] | 0.908 | 1.000 | 0.908 |
| (0.4, 0.6] | 0.942 | 1.000 | 0.942 |
| (0.6, 0.8] | 0.998 | 1.000 | 0.998 |
| (0.8, 1.0] | 0.933 | 1.000 | 0.933 |
| **Supply Chain Index** | | | |
| (0.2, 0.4] | 1.052 | 1.000 | 1.052 |
| (0.4, 0.6] | 1.022 | 1.000 | 1.022 |
| (0.6, 0.8] | 1.077 | 1.000 | 1.077 |
| (0.8, 1.0] | 1.084 | 1.000 | 1.084 |

- Base Premium is set to Đ1,392,290.
- **Actuarial Override Note:** Certain variables were excluded from the final rating model based on actuarial judgment due to statistical insignificance or counterintuitive directional impacts that would create misaligned incentives. The selected variables demonstrate both predictive power and consistency with sound underwriting principles across all three solar systems.
- All values are rounded to three decimal places.

Table 12. Cargo Loss Insurance Rating Factors

| Rating Variable | Freq. Rel | Sev. Rel | Selected Rel |
|---|---|---|---|
| **Cargo Type** | | | |
| gold | 1.000 | 1.000 | 1.000 |
| cobalt | 1.000 | 1.013 | 1.013 |
| platinum | 1.000 | 1.013 | 1.013 |
| lithium | 1.000 | 1.030 | 1.030 |
| rare earths | 1.000 | 1.063 | 1.063 |
| titanium | 1.000 | 1.208 | 1.208 |
| supplies | 1.000 | 1.403 | 1.403 |
| **Route Risk Level** | | | |
| 1 | 1.000 | 1.000 | 1.000 |
| 2 | 1.193 | 1.256 | 1.498 |
| 3 | 1.374 | 1.515 | 2.082 |
| 4 | 1.552 | 1.700 | 2.638 |
| 5 | 1.700 | 1.924 | 3.270 |
| **Debris Density Group** | | | |
| [0,0.2) | 1.000 | 1.000 | 1.000 |
| [0.2,0.3) | 1.026 | 1.040 | 1.067 |
| [0.3,1] | 1.074 | 1.065 | 1.143 |
| **Solar Radiation Group** | | | |
| [0,0.2) | 1.000 | 1.000 | 1.000 |
| [0.2,0.3) | 1.042 | 1.076 | 1.121 |
| [0.3,1] | 1.071 | 1.099 | 1.178 |
| **Pilot Experience Group** | | | |
| 0-5 Years | 1.000 | 1.000 | 1.000 |
| 5-10 Years | 0.934 | 1.000 | 0.934 |
| 10-15 Years | 0.880 | 1.000 | 0.880 |
| 15-20 Years | 0.823 | 1.000 | 0.823 |
| 20+ Years | 0.721 | 1.000 | 0.721 |

- Base Rate is set to 0.762%.
- Values are relative to the baseline level (Multipliers = 1.000).
- Frequency and Severity multipliers are derived independently prior to generating the Total Relativity.
- All values are strictly rounded to three decimal places.

Table 13. Tiered Marginal Surcharge Logic (ILF & Reinsurance Driven)

| Layer Range | Marginal Rate | Logic |
|---|---|---|
| \$0 – \$200M | 1.0 | Base Limit |
| \$200M – \$400M | 1.2 | Excess over \$200M |
| \$400M – \$600M | 1.5 | Excess over \$400M |
| > \$600M | 1.8 | Excess over \$600M |

**Formula:** Effective Surcharge Factor = ∑ (Layer Exposed Limit × Marginal Rate) / Total Cargo Value

**Calculation Example:** For a flagship vessel with a Total Cargo Value of \$500M, the surcharge is blended across three layers:

- *Layer 1 (\$0 – \$200M):* \$200M × 1.0 = \$200M
- *Layer 2 (\$200M – \$400M):* \$200M × 1.2 = \$240M
- *Layer 3 (\$400M – \$600M):* \$100M × 1.5 = \$150M
- **Effective Factor** = (\$200M + \$240M + \$150M) / \$500M = **1.180**

Table 14. Deductible Discount Factors (Based on LER)

| Deductible(% of Cargo) | Loss Eliminated Ratio (LER) | Multiplier |
|---|---|---|
| **0%** | 0.00% | 1.00 |
| **1%** | 8.47% | 0.95 |
| **2%** | 16.76% | 0.85 |
| **5%** | 38.27% | 0.65 |
| **10%** | 61.79% | 0.40 |

**Actuarial Note:**
While the Loss Elimination Ratio (LER) represents the theoretical proportion of ground-up losses absorbed by the deductible, the final selected **Multipliers** are manually smoothed and deliberately set higher than the theoretical (1 − LER) baseline. This actuarial selection ensures a necessary safety margin and accounts for fixed underwriting expenses that do not scale down proportionately with the deductible. Final multipliers are smoothed to two decimal places for administrative simplicity.

Table 15. Workers' Compensation Insurance Rating Factors

| Rating Variable | Freq. Rel | Sev. Rel | Selected Rel |
|---|---|---|---|
| **Solar System** | | | |
| Helionis Cluster | - | - | 1.000 |
| Bayesia System | - | - | 1.300 |
| Oryn Delta | - | - | 1.100 |
| **Occupation Class** | | | |
| Administrator | 1.000 | 1.000 | 1.000 |
| Executive | 1.000 | 1.000 | 1.000 |
| Manager | 1.000 | 1.000 | 1.000 |
| Spacecraft Operator | 1.398 | 1.000 | 1.398 |
| Planetary Operations | 1.495 | 1.000 | 1.495 |
| Scientist | 1.519 | 1.000 | 1.519 |
| Safety Officer | 1.550 | 1.000 | 1.550 |
| Engineer | 1.934 | 1.000 | 1.934 |
| Technology Officer | 2.042 | 1.000 | 2.042 |
| Maintenance Staff | 2.065 | 1.000 | 2.065 |
| Drill Operator | 3.102 | 1.000 | 3.102 |
| **Gravity Profile** | | | |
| [0.7,0.9) | 1.000 | 1.000 | 1.000 |
| [0.9,1.1) | 1.000 | 1.358 | 1.358 |
| [1.1,1.3) | 1.000 | 1.478 | 1.478 |
| [1.3,1.5) | 1.000 | 1.707 | 1.707 |
| **Annual Salary Band** | | | |
| [0,75K) | 1.000 | 1.000 | 1.000 |
| [75K,105K] | 1.000 | 1.923 | 1.923 |
| **Safety & Training Index** | | | |
| 1 & 2 & 3 | 1.000 | 1.000 | 1.000 |
| 4 | 0.746 | 0.622 | 0.464 |
| 5 | 0.700 | 0.460 | 0.322 |
| **Psychological Stress Index** | | | |
| 1 & 2 | 1.000 | 1.000 | 1.000 |
| 3 | 1.242 | 1.000 | 1.242 |
| 4 | 1.402 | 1.000 | 1.402 |
| 5 | 1.258 | 1.000 | 1.500 |
| **Loss History Factor** | | | |
| Prior Claim: No | 1.000 | 1.000 | 1.000 |
| Prior Claim: Yes | 1.294 | 1.000 | 1.294 |

- Base Premium is set to Đ 379.57.
- **Actuarial Override Note:** While the Combined Factor is primarily derived from the product of Frequency and Severity multipliers, actuarial judgment was applied to manually override specific levels
- Base classes (Relativity = 1.000) reflect the highest exposure volumes for baseline stability.
- All values are strictly rounded to three decimal places.

# Appendix C Product Design

## Appendix C.1 General Provisions

The Interstellar Mining Comprehensive Insurance program provides a structured indemnity framework across four primary sections: Equipment Failure, Business Interruption, Cargo Loss, and Workers' Compensation. This policy is underwritten and administered via the Q-RISK System and Orbital AI Node, facilitating a fully automated ecosystem for risk assessment, trigger validation, and claim adjustment.

**Conditions Precedent to Liability:** The Insurer's liability under the Business Interruption section is strictly conditional upon: (i) a loss has been admitted and a claim paid under the Equipment Failure section (Material Damage Proviso); or (ii) the occurrence of a verified Parameter-Based Event as defined in the Policy Schedule.

**Dynamic Experience Rating:** Premiums are subject to adjustment based on historical loss ratios, ESG Ratings, and Orbital AI Safety Scores. New operations may qualify for a Research and Development Credit in exchange for anonymized data-sharing.

**General Exclusions:** The Insurer shall not be liable for loss, destruction, or damage caused by (i) war, terrorism, or civil commotion; (ii) radioactive contamination or nuclear risks; (iii) cyber or data-related perils; (iv) any deliberate act, gross negligence, or intentional ecological violation by the Insured.

## Appendix C.2 Equipment Failure Insurance

### (a) Benefit Structures

This is a compensatory property insurance policy, indemnifying the Insured for direct material damage to core mining equipment caused by sudden physical damage or functional failure. Claims will be settled on a Reinstatement Basis, representing the cost of restoring the property to a condition substantially equal to, but not better than, its condition when new. Replacement must be with equipment of functionally equivalent or superior technical capability, with costs for any resulting technical upgrade being excluded. Reasonable interstellar transport, installation, and recalibration costs are covered (limited to 15% of the replacement cost for the OrynDelta system).

### (b) Coverage Triggers

This section utilizes a Dual-Trigger Mechanism combining Defined Perils and State-Based Triggers. Coverage is triggered when a Defined Peril (including inherent defects, human error, mechanical stress, electrical faults, external factors, communication failure, micro-debris collision, and any other unforeseen cause not excluded) results in any of the following observable states:

1. **Structural Integrity Trigger:** Physical damage including stress exceeding yield limits, crack propagation beyond safe tolerance, core module deformation, magnetic flux stability below threshold, or gravitational balance deviation exceeding 5%.
2. **Functional Stability Trigger:** Core operating parameters continuously exceeding 20% of manufacturer design thresholds for over six hours, with remote calibration unsuccessful.

3. **Parametric Trigger (External Environment):** When environmental monitoring data in specific galaxies reaches pre-defined critical thresholds (e.g., gravity index, radiation spikes in Bayesia; orbital shear index, stellar flares in OrynDelta; micro-collision frequency in Helionis Cluster) directly leading to equipment destruction, it is deemed an insured event. The Insured has a duty to implement immediate emergency shutdown upon receiving an environmental warning; failure to do so may result in no coverage for the aggravated loss.

**(c) Exclusions**

The Insurer shall not provide indemnity for loss or damage directly or indirectly caused by, arising from, or resulting from:

- **Gradual Deterioration:** Normal wear and tear, metal fatigue, or any form of progressive deterioration.
- **Design Manufacturing Issues:** Known design defects, inherent vice, latent defects, or matters subject to a manufacturer's recall.
- **Maintenance Failures:** Failure to maintain equipment in accordance with technical specifications or manufacturer manuals.
- **Deliberate Acts:** Intentional damage, fraud, or the deliberate tampering with or disabling of risk monitoring systems.
- **Operational Non-Compliance:** Operation by personnel lacking minimum safety certification; unauthorized prospecting activities.
- **Galaxy-Specific Perils:** In the Bayesia System, failure to implement required radiation shielding.

**(d) Other Features**

- **Optional Endorsement (Helionis Debris Cloud & Communication Interruption Extension):** Specifically for the Helionis Cluster, this extends coverage for losses directly caused by debris-cloud events leading to satellite destruction or communication interruption (exceeding 30 minutes), and emergency relay deployment costs. The indemnity per occurrence is limited to 15% of the main section sum insured, subject to a 15-minute waiting period (buyable).
- **Technical Warranties:** The Insured warrants that all equipment operates within certified parameters, is maintained per manufacturer manuals, and undergoes regular calibration. Specific equipment (e.g., Quantum Bores) has mandatory calibration intervals. Operations in Bayesia and Oryn Delta are subject to specific radiation hardening and navigation guarantees. Breach of warranty may suspend cover.

### Appendix C.3 Business Interruption Insurance

**(a) Benefit Structures**

This section indemnifies the Insured for loss directly resulting from an interruption of the mining business caused by an insured event.

1. **Loss of Gross Profit:** Indemnity = (Standard Output - Actual Output) × Gross Profit Rate - Saved Variable Costs during the indemnity period.

    - **Standard Output** is based on the pre-loss approved production plan and the sales contract price (or monthly average spot price) prevailing at the start of the indemnity period.
    - **Actual Output** is derived from the mill feed records using the same price basis.
    - **Gross Profit Rate** is taken from the last audited financial accounts.

2. **Increased Cost of Working:** Covers necessary and reasonable additional expenditure incurred to reduce the loss, limited to the amount of gross profit loss thereby avoided.

3. **Wage Loss:** To retain key personnel, the first 13 days of the indemnity period are covered at 100% of payroll cost, with the remainder at up to 50%, always net of any saved wages.

4. **Audit and Expert Fees:** Covers reasonable third-party professional service fees necessary to substantiate the claim, subject to a separate sub-limit.

**(b) Coverage Triggers**

Activation relies on a dual-trigger mechanism:

1. **Material Damage Trigger:** Must be consequent upon physical damage insured under the Equipment Failure section, as verified by Q-RISK sensors and Orbital AI. The indemnity period commences 7 days (waiting period) after the loss.

2. **Parametric Non-Damage Trigger:** An innovative response to space-specific perils. If environmental conditions reach pre-set thresholds forcing a mandatory operational halt, indemnity is payable even without physical damage. Examples include:

    - Helionis Cluster: Critical communication link signal strength at zero for over 7days.
    - Bayesia System: Radiation levels exceeding thresholds until official warning lifts.
    - Oryn Delta: Orbital shear index exceeding Level 5, or X-class stellar flare, sustained for a specified duration.

**(c) Waiting Period and Indemnity Period**

- **Waiting Period:** 7 days, during which no indemnity is payable.

- **Maximum Indemnity Period:** Up to 12 months from the date of the loss (can be extended to 18 months by special agreement).

**(d) Exclusions**

The Insurer shall not provide indemnity for loss or damage directly or indirectly caused by, arising from, or resulting from:

- **Market & Credit Risks:** Losses arising solely from market price fluctuation, exchange rate changes, or cancellation of sales contracts.
- **Consequential Losses:** Loss of goodwill, market share, or any other indirect or consequential loss of a similar nature.
- **Planned Activities:** Loss during planned maintenance, scheduled overhauls, or resulting from resource depletion.
- **Safety Non-Compliance:** Failure to comply with mandatory Q-RISK safety directives, including preventive shutdown instructions.
- **Non-Compliant Equipment:** Use of equipment not meeting specified protection standards or use of non-original parts.

**(e) Other Features**

- **Galaxy-Specific Operational Risk Adjustments:** Cover is conditional on the Insured's active management of specific risks. This includes using dynamic debris mapping in Helionis, adhering to radiation peak shutdown procedures in Bayesia, and selecting an adequate indemnity period for Oryn Delta's extended supply chain. Non-compliance may limit claims.
- **Incentives:** Includes premium credits for data sharing, safety performance-linked rating, green recovery bonus (full indemnity), community continuity allowance, and encouragement of responsible supply chains.

### Appendix C.4 Cargo Loss Insurance

**(a) Benefit Structures**

This insurance indemnifies the Insured for material loss or damage to mineral resources and related goods during interstellar transit caused by transit perils. Insured property includes precious metals/minerals, rare earth elements, essential supplies, and their packaging units.

- **Value Declaration:** For precious metals and rare earths, the Insured must declare the value at inception and provide proof. Failure to do so allows the Insurer to settle claims based on galactic standard benchmark values.
- **Basis of Settlement:** Indemnity is calculated based on the reasonable market value at the place and time of loss, in proportion to the loss. Constructive Total Loss applies if the cost of recovery and forwarding exceeds the insured value, or if the conveying craft is missing for 60 galactic days.

**(b) Transit Scope and Duration**

Coverage is provided on a Warehouse-to-Warehouse basis, attaching from the time the goods leave the warehouse at the place of dispatch and continuing during the ordinary course of transit, terminating on delivery to the consignee's final warehouse. Cover automatically terminates 30 days after completion of discharge at the final port of discharge if not delivered. If transit is delayed due to force majeure (e.g., orbital congestion), cover may be automatically extended for up to 90 days upon payment of a pro-rata additional premium.

**(c) Coverage Triggers & Exclusions**

Coverage Triggers include collision, crash, disappearance of the conveying craft, fire, explosion, jettison, loss due to gravitational anomalies, cosmic radiation bursts, and magnetic flux instability.

The Insurer shall not provide indemnity for loss or damage directly or indirectly caused by, arising from, or resulting from:

- **Consignor's Responsibility:** Loss arising from the fault or negligence of the consignor.
- **Pre-Existing Conditions:** Quality deterioration or quantity shortage existing prior to the attachment of risk.
- **Inherent Vice:** Natural wastage, ordinary leakage, loss of weight/volume, inherent vice, or inherent nature of the goods.
- **Delay & Market Loss:** Any loss caused by delay, loss of market, depreciation, or any consequential loss of any kind.
- **Packaging:** Insufficiency or unsuitability of packing or preparation of the goods.
- **Trade Disputes:** Loss arising from contract disputes or trade□□.
- **Technical Non-Compliance:** Failure to comply with the technical warranties and galaxy-specific requirements set forth in this policy.

**(d) Other Features**

- **Galaxy-Specific Risk Clauses:** In Bayesia, goods must use gravity buffer packaging systems. In Oryn Delta, dual-layer magnetic stabilization systems must be activated when orbital shear index exceeds Level 4. In Helionis, active debris avoidance systems must be operational. Non-compliance voids cover for related losses.
- **Transit Monitoring Obligation:** The Insured must maintain real-time connectivity of conveying craft with the risk monitoring system and retain data for at least five years.

## Appendix C.5 Workers' Compensation Insurance

**(a) Benefit Structures**

This is an employer's liability insurance, indemnifying the Insured (the employer) against liability for personal injury, disablement, or death sustained by employees arising out of and in the course of their interstellar mining employment.

- **Medical and Rehabilitation Benefits:** Unlimited coverage for necessary medical expenses (net of planetary health fund payments), rehabilitation costs directly paid by the Insurer, hospitalization allowances, travel expenses for medical, prosthetics and assistive devices (e.g., quantum neural interfaces), and a special Genomic Stability Restoration benefit for radiation-induced genetic damage.
- **Treatment during Suspension from Work:** During the period of suspension from work (typically up to 12 months), the employee's original wages and benefits remain payable by the employer.
- **Disablement Benefits:** After assessment of permanent disablement, benefits include:
  - Lump sum disablement benefit (scaled from 7 to 27 months' wages based on degree of disablement).
  - Monthly disablement allowance (60%-90% of wages for Grades 1-4; 60%-70% for Grades 5-6 paid by employer).
  - Nursing care allowance for those needing constant care (30%-50% of benchmark wage). This includes coverage for technological alternatives like AI nursing robots and the extra cost of gravity-stabilized wards.
  - One-off medical subsidy and employment subsidy for Grades 5-10 upon termination of contract.
  - Specialized vocational rehabilitation funding, including functional enhancement support, retraining allowance, and job placement subsidy.
- **Death Benefits:** Includes funeral subsidy, dependent's survivor's allowance (40% for spouse, 30% for each other eligible relative), and a lump sum death benefit.
- **Built-in Hospitalization Income Benefit:** Daily benefit calculated at 80% of (base_salary/30), subject to a 3-day deductible and a maximum of 60 days per incident.

**(b) Coverage Triggers**

Covers occupational injuries, diseases, and circumstances deemed equivalent to work-related injuries (e.g., death from sudden illness within 48 hours, injury during disaster relief, certified occupational mental disorders). Specific coverage is provided for immediate trauma from physical impacts, radiation bursts, gravity anomalies, and sub-acute injuries from prolonged exposure to extreme environments (e.g., Bayesia high-gravity induced degeneration).

**(c) Risk Management**

- **Premium Fluctuation Mechanism:** Base premium rates are categorized into eight industry risk classes (0.2%-1.9%). Premiums are adjusted annually based on the claims ratio (pay-out/paid premium), ranging from a 50% discount to a 150% surcharge.
- **Safety Incentives:** Includes premium discounts for achieving high safety training indices, application of coinsurance for PPE non-compliance, premium dividends for claim-free periods, and subsidies for injury prevention projects.

- **Compliance Warranty:** The Insured warrants maintaining a safety_training_index of at least Level 3.

**(d) Exclusions**

The Insurer shall not provide indemnity for loss or damage directly or indirectly caused by, arising from, or resulting from:

- **Intentional Acts:** Any injury arising from the insured person's intentional self-injury, suicide, or criminal act.
- **Substance Abuse:** Injury arising from the use of unauthorized bio-enhancers or illegal narcotics.
- **Non-Compliance:** Injury sustained while the employee is in willful violation of safety protocols, including failure to comply with a Grade-A Q-RISK safety mandate or a red alert evacuation instruction.
- **Unauthorized Activities:** Injury resulting from an employee entering a prohibited or restricted area without authorization, including specific zones in the Oryn Delta.
- **Personal Activities:** Injury sustained during a non-work-related personal activity while on an authorized absence from work premises.
- **Lack of Training:** Injury sustained by an employee who has not undergone any safety training.

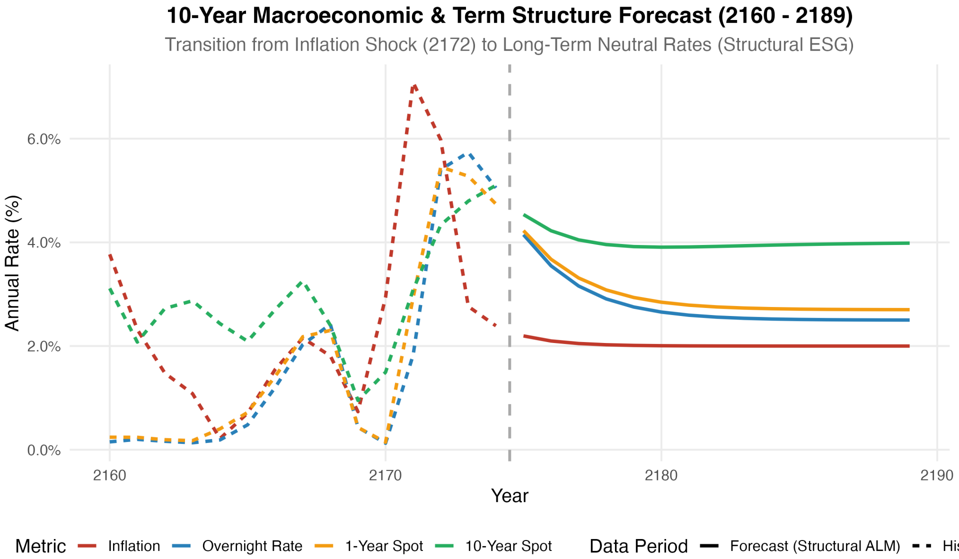
**(e) Additional Support & Special Protections**

In addition to the indemnity provided under this Section, the Insurer offers the following support and protections:

- **Medically Trained Rehabilitation Teams:** In the unfortunate event of serious injury to an employee, the Insurer provides access to medically trained rehabilitation teams. These specialists work directly with the injured employee, with the objective of facilitating recovery and enabling a safe and timely return to work.
- **Mental Health Support:** Coverage is extended to include access to professional mental health support services for employees experiencing psychological distress, including trauma resulting from prolonged "Dark-Space" isolation or other extreme operational conditions.

# Appendix D Financial Results

## Appendix D.1 Macro Finance




To support the long-term pricing and capital modeling of the proposed insurance products, we developed a forward-looking macroeconomic projection table for the period 2175–2189. The forecast employs a structural Actuarial ESG, modeling inflation via autoregressive mean reversion and driving short-term interest rates through a dynamic, smoothed Taylor Rule. This framework was selected over static historical averaging because it explicitly captures the normalization of inverted yield curves through time-varying term premiums. This table incorporates key financial assumptions—including projected inflation rates and the term structure of interest rates (overnight, 1-year spot, and 10-year spot rates)—that are essential for discounting future losses, estimating real returns, and assessing the scalability of coverage under evolving economic conditions.

Table 16. Projected Inflation and Interest Rate Term Structure

| Year | Inflation | Overnight | Spot 1Y | Spot 10Y |
|---|---|---|---|---|
| 2175 | 2.20% | 4.15% | 4.23% | 4.54% |
| 2176 | 2.10% | 3.55% | 3.67% | 4.22% |
| 2177 | 2.05% | 3.16% | 3.31% | 4.05% |
| 2178 | 2.02% | 2.91% | 3.08% | 3.96% |
| 2179 | 2.01% | 2.75% | 2.94% | 3.92% |
| 2180 | 2.01% | 2.66% | 2.85% | 3.91% |
| 2181 | 2.00% | 2.60% | 2.79% | 3.91% |
| 2182 | 2.00% | 2.56% | 2.75% | 3.92% |
| 2183 | 2.00% | 2.54% | 2.73% | 3.93% |
| 2184 | 2.00% | 2.52% | 2.72% | 3.95% |
| 2185 | 2.00% | 2.51% | 2.71% | 3.96% |
| 2186 | 2.00% | 2.51% | 2.71% | 3.97% |
| 2187 | 2.00% | 2.50% | 2.70% | 3.97% |
| 2188 | 2.00% | 2.50% | 2.70% | 3.98% |
| 2189 | 2.00% | 2.50% | 2.70% | 3.99% |

- Inflation and interest rates represent projected macroeconomic assumptions.
- All values are expressed as annual percentages.

## Appendix D.2 Business Interruption

Table 17. Business Interruption Portfolio Metrics by Solar System

| Solar System | Units | Gross Premium | Expected Loss | Loss VaR95 | Loss VaR99.5 | Loss TVaR99 | UW Expense | Claim Expense | Reinsurance Cost | Expected Net Revenue |
|---|---|---|---|---|---|---|---|---|---|---|
| Helionis Cluster | 15 | 32.99 | 17.98 | 45.50 | 57.43 | 57.78 | 5.94 | 1.98 | 3.76 | 3.33 |
| Bayesia System | 30 | 18.30 | 9.80 | 32.01 | 47.15 | 48.00 | 3.29 | 1.08 | 2.09 | 2.03 |
| Oryn Delta | 10 | 12.29 | 6.47 | 25.89 | 41.74 | 42.96 | 2.21 | 0.71 | 1.40 | 1.49 |

Table 18. Business Interruption Projected Cash Flow and Capital Metrics

| Year | Gross Prem | Ceded Prem | Net Prem | Exp Net Loss | VaR 99.5 Net | Expenses | Net Cash Flow | PV NCF |
|---|---|---|---|---|---|---|---|---|
| 2176 | 66.26 | 8.69 | 57.57 | 35.74 | 63.81 | 16.46 | 6.24 | 7.35 |
| 2177 | 69.04 | 9.12 | 59.92 | 37.14 | 65.14 | 17.15 | 6.54 | 7.30 |
| 2178 | 71.91 | 9.68 | 62.23 | 38.80 | 66.23 | 17.89 | 6.51 | 7.00 |
| 2179 | 74.89 | 9.92 | 64.98 | 39.95 | 67.82 | 18.57 | 7.44 | 7.58 |
| 2180 | 78.00 | 10.16 | 67.83 | 41.07 | 69.47 | 19.28 | 8.50 | 8.26 |
| 2181 | 81.23 | 10.56 | 70.67 | 42.34 | 70.68 | 20.03 | 9.36 | 8.74 |
| 2182 | 84.60 | 11.40 | 73.20 | 44.28 | 72.41 | 20.91 | 9.14 | 8.37 |
| 2183 | 88.10 | 12.00 | 76.10 | 45.63 | 73.88 | 21.73 | 9.93 | 8.78 |
| 2184 | 91.75 | 12.48 | 79.27 | 47.24 | 75.28 | 22.60 | 10.68 | 9.15 |
| 2185 | 95.55 | 13.42 | 82.13 | 48.71 | 77.06 | 23.52 | 11.24 | 9.35 |

## Appendix D.3 Cargo Loss

Table 19. Cargo Loss Portfolio Metrics by Solar System

| Solar System | Units | Gross Premium | Expected Loss | Loss VaR95 | Loss VaR99.5 | Loss TVaR99 | UW Expense | Claim Expense | Reinsurance Cost | Expected Net Revenue |
|---|---|---|---|---|---|---|---|---|---|---|
| Oryn Delta | 1078 | 2909.70 | 1648.58 | 2478.81 | 3131.40 | 3213.82 | 523.75 | 181.34 | – | 556.03 |
| Helionis Cluster | 1147 | 3212.88 | 1855.00 | 2756.93 | 3527.05 | 3615.65 | 578.32 | 204.05 | – | 575.51 |
| Bayesia System | 775 | 2183.91 | 1296.28 | 1935.49 | 2532.46 | 2591.63 | 393.10 | 142.59 | – | 351.94 |

Table 20. Cargo Loss Projected Cash Flow and Capital Metrics

| Year | Gross Prem | Ceded Prem | Net Prem | Exp Net Loss | VaR 99.5 Net | Expenses | Net Cash Flow | PV NCF |
|---|---|---|---|---|---|---|---|---|
| 2176 | 8469.22 | 682.34 | 7786.88 | 4652.63 | 6347.59 | 2025.23 | 1098.00 | 1307.59 |
| 2177 | 8825.25 | 710.93 | 8114.32 | 4846.00 | 6589.32 | 2065.21 | 1146.72 | 1282.87 |
| 2178 | 9187.40 | 740.02 | 8447.38 | 5043.29 | 6856.44 | 2105.83 | 1195.59 | 1272.45 |
| 2179 | 9559.87 | 769.92 | 8789.94 | 5235.51 | 7137.32 | 2146.10 | 1257.76 | 1282.25 |
| 2180 | 9944.67 | 800.82 | 9143.86 | 5459.65 | 7328.90 | 2189.66 | 1293.60 | 1274.60 |
| 2181 | 10344.11 | 832.88 | 9511.23 | 5670.42 | 7637.53 | 2231.91 | 1355.12 | 1291.26 |
| 2182 | 10759.77 | 866.24 | 9893.52 | 5917.81 | 7995.94 | 2277.76 | 1388.00 | 1285.65 |
| 2183 | 11191.20 | 900.87 | 10290.33 | 6134.53 | 8165.35 | 2320.72 | 1466.59 | 1316.66 |
| 2184 | 11640.11 | 936.89 | 10703.22 | 6388.77 | 8591.57 | 2367.23 | 1516.47 | 1325.01 |
| 2185 | 12107.21 | 974.37 | 11132.84 | 6638.19 | 8844.63 | 2413.32 | 1585.15 | 1346.80 |

## Appendix D.4 Workers' Compensation

Table 21. Workers' Compensation Portfolio Metrics by Solar System (in Millions)

| Solar System | Employees | Premium | Loss | VaR95 | VaR99.5 | TVaR99 | UW Exp | Claim Exp | Reins Cost | Net Profit |
|---|---|---|---|---|---|---|---|---|---|---|
| Helionis Cluster | 39105 | 20.04 | 14.04 | 17.46 | 20.03 | 20.25 | 3.01 | 1.40 | – | 1.59 |
| Bayesia System | 19470 | 9.33 | 6.21 | 8.58 | 10.38 | 10.55 | 1.40 | 0.62 | – | 1.10 |
| Oryn Delta | 13043 | 7.52 | 5.03 | 6.95 | 8.25 | 8.42 | 1.13 | 0.50 | – | 0.86 |

Table 22. Workers' Compensation: 10-Year Financial Projections (in Millions, No Reinsurance)

| Year | Gross Premium | Exp Total Loss | 99.5% Loss VaR | Economic Capital | Total Expenses | Net Cash Flow | PV of NCF |
|---|---|---|---|---|---|---|---|
| 2176 | 41.52 | 28.44 | 36.93 | 9.81 | 10.52 | 2.56 | 2.46 |
| 2177 | 44.50 | 30.48 | 39.67 | 10.78 | 11.28 | 2.74 | 2.54 |
| 2178 | 47.70 | 32.69 | 42.68 | 11.65 | 12.09 | 2.92 | 2.61 |
| 2179 | 51.13 | 35.09 | 45.96 | 12.82 | 12.97 | 3.07 | 2.67 |
| 2180 | 54.81 | 37.47 | 49.48 | 13.78 | 13.89 | 3.46 | 2.92 |
| 2181 | 58.75 | 40.29 | 53.71 | 15.24 | 14.90 | 3.56 | 2.92 |
| 2182 | 62.98 | 43.16 | 57.20 | 16.36 | 15.97 | 3.86 | 3.08 |
| 2183 | 67.51 | 46.44 | 61.99 | 17.74 | 17.13 | 3.94 | 3.07 |
| 2184 | 72.37 | 49.65 | 66.36 | 19.31 | 18.35 | 4.37 | 3.30 |
| 2185 | 77.58 | 53.17 | 71.86 | 21.48 | 19.67 | 4.74 | 3.49 |

## Appendix D.5 Equipment Failure

Table 23. Equipment Failure Portfolio Metrics by Solar System

| Solar System | Units | Gross Premium | Expected Loss | Loss VaR95 | Loss VaR99.5 | Loss TVaR99 | UW Expense | Claim Expense | Reinsurance Cost | Expected Net Revenue |
|---|---|---|---|---|---|---|---|---|---|---|
| Helionis Cluster | 1290 | 107.60 | 71.69 | 77.50 | 81.01 | 81.44 | 19.37 | 7.89 | – | 8.66 |
| Bayesian System | 2580 | 43.95 | 27.98 | 31.55 | 33.66 | 33.92 | 7.91 | 3.08 | – | 4.98 |
| Oryn Delta | 860 | 19.09 | 12.16 | 14.48 | 15.87 | 16.06 | 3.44 | 1.34 | – | 2.16 |

Table 24. Workers' Compensation Projected Cash Flow and Capital Metrics (Scenario A)

| Year | Gross Prem | Ceded Prem | Net Prem | Exp Net Loss | VaR 99.5 Net | Expenses | Net Cash Flow | PV NCF |
|---|---|---|---|---|---|---|---|---|
| 2176 | 191.22 | 0 | 191.22 | 125.35 | 137.86 | 34.42 | 17.66 | 16.23 |
| 2177 | 212.46 | 0 | 212.46 | 139.23 | 152.89 | 38.24 | 19.67 | 23.75 |
| 2178 | 234.22 | 0 | 234.22 | 153.42 | 167.66 | 42.16 | 21.76 | 25.07 |
| 2179 | 257.30 | 0 | 257.30 | 168.70 | 184.42 | 46.31 | 23.72 | 26.33 |
| 2180 | 280.97 | 0 | 280.97 | 184.11 | 200.98 | 50.57 | 26.03 | 27.89 |
| 2181 | 313.11 | 0 | 313.11 | 205.04 | 223.57 | 56.36 | 29.15 | 30.23 |
| 2182 | 346.87 | 0 | 346.87 | 227.30 | 246.97 | 62.44 | 32.13 | 32.36 |
| 2183 | 381.75 | 0 | 381.75 | 250.01 | 271.76 | 68.71 | 35.53 | 34.75 |
| 2184 | 418.14 | 0 | 418.14 | 273.87 | 296.83 | 75.26 | 38.87 | 37.00 |
| 2185 | 455.78 | 0 | 455.78 | 298.53 | 322.33 | 82.04 | 42.38 | 39.24 |

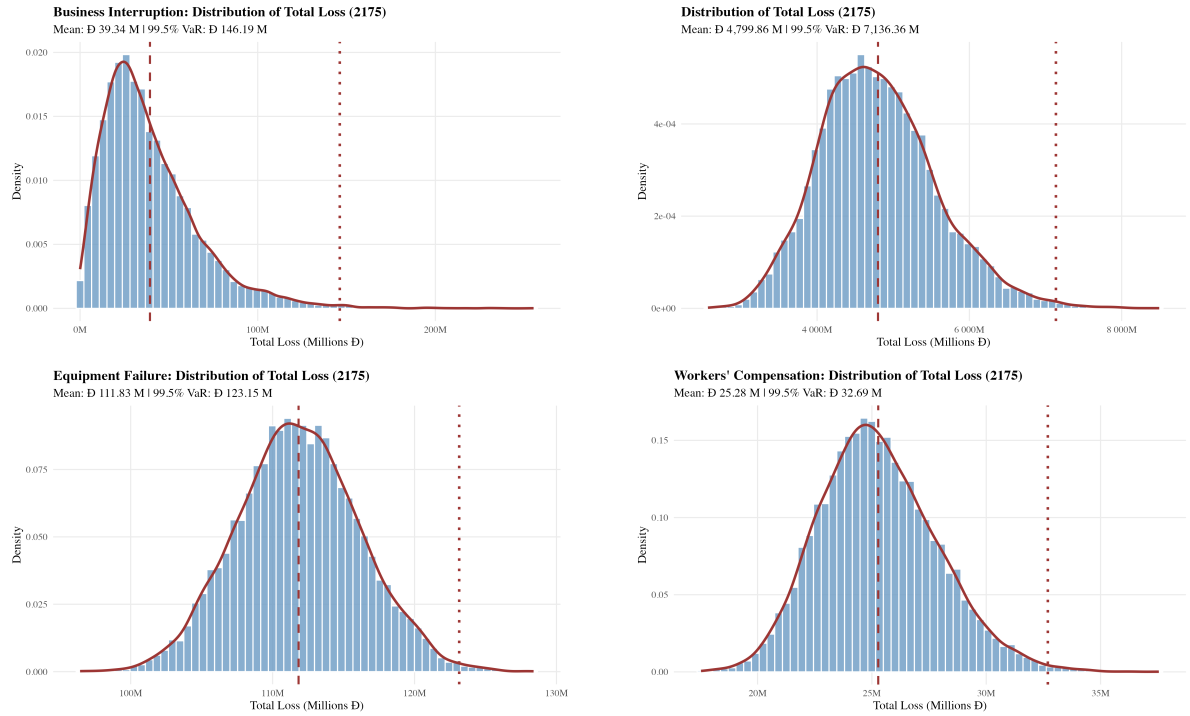



Figure 6: Total Loss Distribution

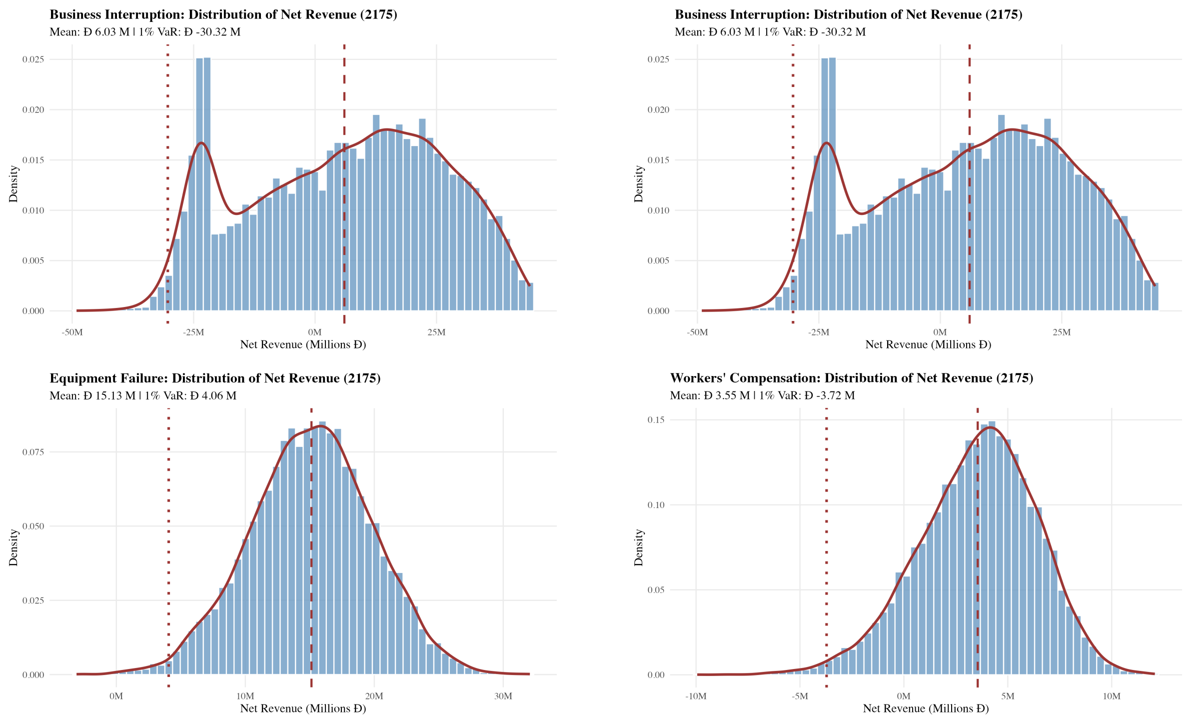



Figure 7: Net Revenue Distribution

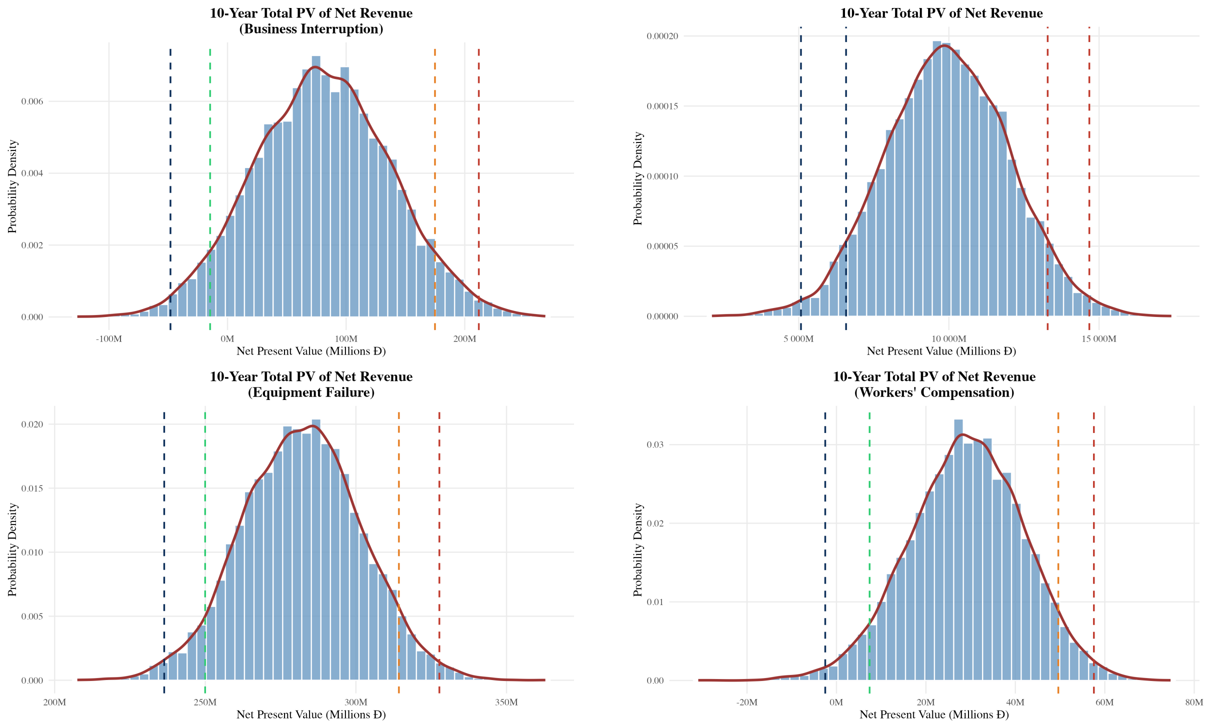



Figure 8: 10-Year NPV Histogram

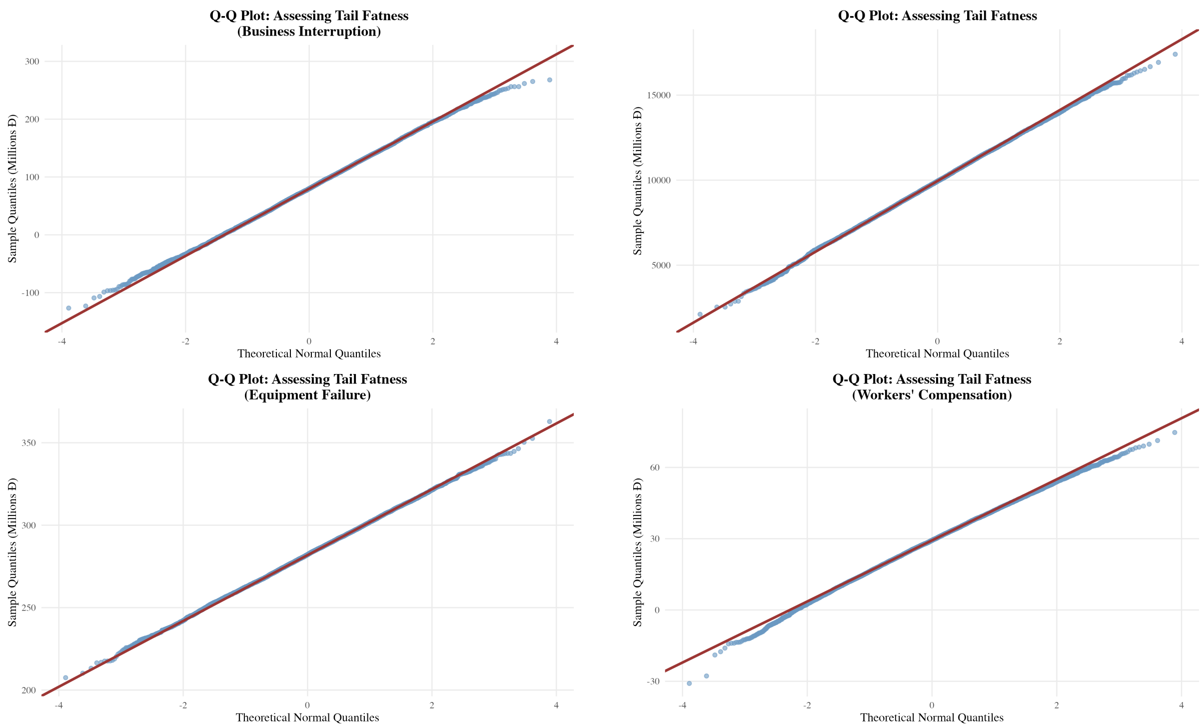



Figure 9: 10-Year NPV Q-Q Plot

# Appendix E Joint Loss Modeling and Economic Capital

## Appendix E.1 Overview of Joint Loss Modeling

To accurately capture dependencies across perils and solar systems, we employed an event-driven hybrid model combined with a Gumbel copula. This approach distinguishes between normal years and disaster years, where global events trigger simultaneous losses across multiple risk units. The Gumbel copula was selected for its upper-tail dependence property, which is essential for modeling joint extreme losses while avoiding unnecessary lower-tail dependence.

## Appendix E.2 Correlation Structure

Two correlation matrices were constructed to reflect normal and disaster years, calibrated to the environmental characteristics of each solar system.

**Normal Year Correlation Matrix $R_{\mathbf{normal}}$** The normal year correlation matrix reflects baseline dependencies with moderate correlations that align with business logic:

- **EF-BI correlation**: Set to 0.45 within each solar system, reflecting the physical causality where equipment failures directly lead to business interruption.
- **EF-CL correlation**: Set to 0.20, recognizing that equipment failures may impact cargo loading and unloading operations.
- **EF-WC correlation**: Set to 0.25, capturing the relationship between equipment failures and potential workplace injuries.
- **WC-CL correlation**: Set to 0.08, reflecting the weak linkage between workplace injuries and cargo transport.
- **WC-BI correlation**: Set to 0.12, acknowledging that severe injuries may cause temporary business interruption.
- **CL-BI correlation**: Set to 0.15, recognizing that cargo losses can lead to business disruption.
- **Cross-system correlations**: Set to 0.02, reflecting the environmental independence across different solar systems.

**Disaster Year Correlation Matrix $R_{\mathbf{disaster}}$** During disaster years, correlations across all risk units increase to 0.35, reflecting heightened synchrony during extreme events while maintaining realistic dependency levels.

All correlation matrices were adjusted to positive definiteness using the `nearPD` function to ensure suitability for copula modeling.

## Appendix E.3 Event Parameters

Based on Galaxy General's proprietary risk assessment of the three solar systems' operating environments, we identified three global events and three system-specific internal events.

**Global Events Event A: Communication Relay Failure** (Probability: 2%)

Failure of the primary communication relay satellite between Helionis and Bayesia, affecting navigation and coordination capabilities. This event increases expected losses by:

- Helionis: Equipment Failure +35%, Cargo Loss +20%, Business Interruption +20%
- Bayesia: Equipment Failure +30%, Cargo Loss +20%, Workers' Compensation +30%, Business Interruption +25%
- Oryn: Equipment Failure +40%, Cargo Loss +25%, Business Interruption +15%

**Event B: Capital Market Volatility** (Probability: 5%)

Liquidity crisis at the Intergalactic Stock Exchange leading to reduced preventive maintenance budgets and safety investments. This event increases expected losses by:

- Helionis: Equipment Failure +40%, Workers' Compensation +30%
- Bayesia: Equipment Failure +30%, Workers' Compensation +45%
- Oryn: Equipment Failure +35%, Cargo Loss +15%, Workers' Compensation +35%

**Event C: Interstellar Supply Interruption** (Probability: 1%)

Earth Central Logistics Hub shutdown causing delays in critical spare parts supply, extending repair times and amplifying operational disruptions. This event increases expected losses by:

- Helionis: Equipment Failure +45%, Business Interruption +20%, Workers' Compensation +30%
- Bayesia: Equipment Failure +40%, Business Interruption +25%, Workers' Compensation +35%
- Oryn: Equipment Failure +50%, Cargo Loss +20%, Business Interruption +20%, Workers' Compensation +40%

**Internal Events Helionis Internal Event: Asteroid Belt Collision** (Probability: 1.5%)

Collisions in the dense asteroid belt causing damage to equipment and transport vessels. Expected loss increases:

- Equipment Failure +60%
- Cargo Loss +30%
- Workers' Compensation +40%
- Business Interruption +20%

**Bayesia Internal Event: Electromagnetic Storm** (Probability: 1.5%)

Sharp spikes of electromagnetic radiation from the binary star system affecting electronics and communications. Expected loss increases:

- Equipment Failure +55%
- Cargo Loss +10%
- Workers' Compensation +50%
- Business Interruption +20%

**Oryn Internal Event: Asteroid Ring Shear** (Probability: 1.5%)

Sudden gravitational shifts in the asymmetric asteroid ring disrupting transport routes and operations. Expected loss increases:

- Equipment Failure +45%
- Cargo Loss +25%
- Workers' Compensation +45%
- Business Interruption +20%

All events are assumed to be independent. If multiple events occur in the same year, their loss impacts are multiplicative.

### Appendix E.4 Gumbel Copula Parameters

The Gumbel copula parameter $\theta$ relates to Kendall's $\tau$ as $\tau = 1 - 1/\theta$:

- Normal years: $\theta_{\text{normal}} = 1.3$ ($\tau \approx 0.23$), reflecting moderate dependence
- Disaster years: $\theta_{\text{disaster}} = 1.8$ ($\tau \approx 0.44$), reflecting stronger upper-tail dependence

This choice ensures appropriate correlation during normal years while allowing for increased tail dependence during disaster years, which aligns with insurance risk characteristics.

### Appendix E.5 Economic Capital Results

Economic capital is defined as $EC = TVaR_{99.5\%} - \mathbb{E}[S]$, with TVaR chosen over VaR to better capture the shape of tail losses.

**Aggregate Economic Capital** Based on 10,000 joint simulations:

**Pre-reinsurance:**

$$\begin{aligned} \mathbb{E}[S] &= 5,035.45 \text{ M} \\ VaR_{99.5\%} &= 9,237.10 \text{ M} \\ TVaR_{99.5\%} &= 10,406.76 \text{ M} \\ EC_{\text{gross}} &= 5,371.30 \text{ M} \end{aligned}$$

**Post-reinsurance:**

$$\begin{aligned} \mathbb{E}[S] &= 4,685.87 \text{ M} \\ VaR_{99.5\%} &= 7,638.81 \text{ M} \\ TVaR_{99.5\%} &= 8,302.56 \text{ M} \\ EC_{\text{net}} &= 3,616.68 \text{ M} \end{aligned}$$

Reinsurance reduces economic capital by approximately 32.7%.

Table 25. Economic Capital Allocation by Risk Unit (M Đ)

| Risk Unit | System | Pre-Reinsurance | Post-Reinsurance |
|---|---|---|---|
| Hel_EF | Helionis Cluster | 42.16 | 36.48 |
| Hel_CL | Helionis Cluster | 1,973.19 | 1,311.80 |
| Hel_WC | Helionis Cluster | 8.94 | 7.73 |
| Hel_BI | Helionis Cluster | 62.77 | 26.33 |
| Bay_EF | Bayesia System | 17.77 | 15.38 |
| Bay_CL | Bayesia System | 1,377.71 | 973.86 |
| Bay_WC | Bayesia System | 3.51 | 3.04 |
| Bay_BI | Bayesia System | 51.14 | 21.61 |
| Ory_EF | Oryn Delta | 7.68 | 6.64 |
| Ory_CL | Oryn Delta | 1,781.82 | 1,192.58 |
| Ory_WC | Oryn Delta | 3.16 | 2.73 |
| Ory_BI | Oryn Delta | 41.46 | 18.48 |

**Economic Capital Allocation by Risk Unit**

**Economic Capital Allocation by Peril**

**Economic Capital Allocation by Solar System**

## Appendix E.6 Risk-Adjusted Return on Capital (RAROC)

Based on post-reinsurance economic capital and expected net income, RAROC was calculated for each peril:

Table 26. Economic Capital Allocation by Peril (Post-Reinsurance)

| **Peril** | **Economic Capital (M Đ)** | **Percentage** |
|---|---|---|
| Business Interruption | 66.43 | 1.84% |
| Cargo Loss | 3,478.24 | 96.17% |
| Equipment Failure | 58.50 | 1.62% |
| Workers' Compensation | 13.50 | 0.37% |
| **Total** | **3,616.68** | **100%** |

Table 27. Economic Capital Allocation by Solar System (Post-Reinsurance)

| **System** | **Economic Capital (M Đ)** | **Percentage** |
|---|---|---|
| Helionis Cluster | 1,382.36 | 38.22% |
| Bayesia System | 1,013.89 | 28.03% |
| Oryn Delta | 1,220.44 | 33.75% |
| **Total** | **3,616.68** | **100%** |

Table 28. RAROC Analysis by Peril (Post-Reinsurance)

| **Peril** | **Economic Capital** | **Net Income** | **Investment Income** | **Total Return** | **RAROC%** |
|---|---|---|---|---|---|
| Business Interruption | 66.43 | 6.54 | 2.81 | 9.35 | 14.07% |
| Cargo Loss | 3,478.24 | 1,026.69 | 147.13 | 1,173.82 | 33.75% |
| Equipment Failure | 58.50 | 15.13 | 2.47 | 17.60 | 30.09% |
| Workers' Compensation | 13.50 | 3.55 | 0.57 | 4.12 | 30.52% |

# Appendix F Risk Details

Table 29. Per-System Hazard Coverage Analysis Matrix

| Solar System | Stellar Hazards | Navigational Hazards | Planetary Hazards | Communication |
|---|---|---|---|---|
| **Helionis Cluster** | Low flare activity; predictable solar wind. | Gravitational resonance in outer asteroid clusters creating irregularly drifting **debris clouds**. | Temperate terrestrial and cold rocky planets; geologically stable. | Vulnerable to **spatial cluttering** from micro-collisions in debris clouds. |
| **Bayesia System** | Tight binary star pair; periodic **extreme EM and particle radiation spikes**. | Broad, heavily mapped asteroid belt with highly stable orbits. | **High-gravity environment**; thin magnetosphere, temperature extremes. | High clarity; supported by established orbital stations. |
| **Oryn Delta** | Dim M3 dwarf star; potential for unpredictable sporadic flares. | Asymmetric asteroid ring; localized rapid **orbital shear and fluctuating gravity gradients**. | Rugged terrain, deep tectonic scars, thin atmosphere. | **Extremely low visibility**, furthest distance (240 AU), heavily reliant on beacons. |

**Matrix Implication Note:**

The hazard profiles outlined above serve as the foundational parameters for proxy pricing. Each environmental extreme directly dictates the baseline exposure levels across the four primary operational insurance lines: *Equipment Failure*, *Cargo Loss*, *Workers' Compensation*, and *Business Interruption*.

## Appendix G Stress Testing Result

Stress tests were conducted for each insurance line by applying severe shocks to key risk drivers. For each scenario, we measured the impact on expected loss, standard deviation, 99.5% VaR, and 99% TVaR. The tables below present the results for all four perils, with Business Interruption and Cargo Insurance shown both before and after reinsurance to illustrate the risk-mitigating effect of the proposed reinsurance structures.

### Appendix G.1 Equipment Failure Insurance

Table 30. Equipment Failure Insurance Stress Testing Results (in Million Đ)

| Scenario | Expected Loss | Std Dev | VaR (99.5%) | TVaR (99%) |
|---|---|---|---|---|
| **Baseline Scenario** | **111.8 (Base)** | **4.3 (Base)** | **123.1 (Base)** | **123.6 (Base)** |
| **P1: Extreme Aging (All 20+ Years)** | 287.6 (+157%) | 8.8 (+105%) | 311.6 (+153%) | 311.7 (+152%) |
| **P2: Poor Maintenance (All 1500-5000 hrs)** | 134.6 (+20%) | 4.9 (+14%) | 147.6 (+20%) | 148.0 (+20%) |
| **P3: Over-utilization (All 20-24 hrs/day)** | 146.2 (+31%) | 5.3 (+23%) | 160.2 (+30%) | 160.7 (+30%) |

### Appendix G.2 Cargo Loss Insurance

Table 31. Cargo Loss Insurance Stress Testing Results – Before Reinsurance (in Million Đ)

| Scenario | Expected Loss | Std Dev | VaR (99.5%) | TVaR (99%) |
|---|---|---|---|---|
| **Baseline** | **4797.3 (Base)** | **767.4 (Base)** | **7090.0 (Base)** | **7258.0 (Base)** |
| **P1: Extreme Debris (All High)** | 5090.9 (+6%) | 801.3 (+4%) | 7518.3 (+6%) | 7654.9 (+5%) |
| **P2: Solar Radiation (All High)** | 5091.9 (+6%) | 805.1 (+5%) | 7400.5 (+4%) | 7578.6 (+4%) |
| **P3: All Gold Cargo** | 5377.8 (+12%) | 803.1 (+5%) | 7756.9 (+9%) | 7876.6 (+9%) |
| **P4: Route Risk Level 5** | 6945.5 (+45%) | 997.4 (+30%) | 9981.2 (+41%) | 10096.6 (+39%) |

Table 32. Cargo Loss Insurance Stress Testing Results – After Reinsurance (in Million Đ)

| Scenario | Expected Loss | Std Dev | VaR (99.5%) | TVaR (99%) |
|---|---|---|---|---|
| **Baseline** | **4463.4 (Base)** | **592.5 (Base)** | **6054.2 (Base)** | **6167.3 (Base)** |
| **P1: Extreme Debris (All High)** | 4716.5 (+6%) | 614.4 (+4%) | 6413.6 (+6%) | 6466.6 (+5%) |
| **P2: Solar Radiation (All High)** | 4724.7 (+6%) | 623.4 (+5%) | 6383.8 (+5%) | 6514.5 (+6%) |
| **P3: All Gold Cargo** | 5005.9 (+12%) | 625.4 (+6%) | 6774.6 (+12%) | 6839.1 (+11%) |
| **P4: Route Risk Level 5** | 6335.4 (+42%) | 741.7 (+25%) | 8279.9 (+37%) | 8379.3 (+36%) |

### Appendix G.3 Workers' Compensation Insurance

Table 33. Workers' Compensation Insurance Stress Testing Results (in Million Đ)

| Scenario | Mean Loss | Std Dev | VaR (99.5%) | TVaR (99%) |
|---|---|---|---|---|
| **Baseline Scenario** | **25.3 (Base)** | **2.6 (Base)** | **32.7 (Base)** | **33.1 (Base)** |
| **P1: Safety Training Deficiency** | 71.0 (+181%) | 8.1 (+214%) | 95.4 (+192%) | 96.3 (+191%) |
| **P2: Extreme Gravity** | 25.8 (+2%) | 2.6 (+2%) | 33.7 (+3%) | 34.0 (+3%) |
| **P3: Psychological Stress Peak** | 26.2 (+4%) | 2.6 (+3%) | 34.0 (+4%) | 34.5 (+4%) |
| **P4: Prior Claims History** | 45.6 (+80%) | 4.8 (+86%) | 59.2 (+81%) | 59.6 (+80%) |

### Appendix G.4 Business Interruption Insurance

Table 34. Business Interruption Insurance Stress Testing Results – Before Reinsurance (in Million Đ)

| Scenario | Expected Loss | Std Dev | VaR (99.5%) | TVaR (99%) |
|---|---|---|---|---|
| **Baseline** | **40.0 (Base)** | **27.0 (Base)** | **145.6 (Base)** | **152.9 (Base)** |
| **P1: Full Production Load (0.8-1)** | 39.1 (-2%) | 27.0 (+0%) | 145.9 (+0%) | 152.8 (-0%) |
| **P2: Supply Chain Disruption (0-0.2)** | 38.8 (-3%) | 27.1 (+0%) | 148.6 (+2%) | 156.1 (+2%) |
| **P3: No Maintenance (0-2)** | 43.2 (+8%) | 28.9 (+7%) | 155.9 (+7%) | 165.1 (+8%) |

Table 35. Business Interruption Insurance Stress Testing Results – After Reinsurance (in Million Đ)

| Scenario | Expected Loss | Std Dev | VaR (99.5%) | TVaR (99%) |
|---|---|---|---|---|
| **Baseline** | **34.8 (Base)** | **17.2 (Base)** | **62.4 (Base)** | **63.3 (Base)** |
| **P1: Full Production Load (0.8-1)** | 34.1 (-2%) | 17.4 (+41%) | 62.3 (0%) | 62.6 (-1%) |
| **P2: Supply Chain Disruption (0-0.2)** | 33.8 (-3%) | 17.4 (+41%) | 62.3 (0%) | 62.7 (+1%) |
| **P3: No Maintenance (0-2)** | 36.8 (+6%) | 17.4 (+41%) | 62.9 (+1%) | 63.8 (+1%) |

## Appendix H Additional Assumptions

Table 36. Additional Assumptions

| Assumption | Selected value | Supporting Evidence & Rationale |
|---|---|---|
| **Part I: Global Macroeconomic & Modeling Assumptions** | | |
| **Macroeconomic Inflation** | AR(1) Mean-reverting to 2.0% ($\kappa = 0.5$) | Modeled via a structural autoregressive ESG framework. Prevents unrealistic deflationary tail-scenarios and mirrors long-term central bank monetary targets over the projection horizon. |
| **Discount & Risk-Free Rates** | Dynamic Taylor Rule | Baseline rates link dynamically to inflation. Time-varying term premiums are incorporated to gradually recover from yield curve inversions, accurately modeling the long-term cost of capital. |
| **GLM Structure** | Freq/Sev Independence | A standard Actuarial assumption allowing the likelihood of an event and the distribution of claim sizes to be modeled separately via a multiplicative combined factor approach. |
| **Part II: Cargo & Spacecraft Insurance (CL)** | | |
| **Reinsurance Retention** | Đ200M per Vessel | Exposures exceeding this capital appetite trigger tiered marginal GLM surcharges (+20% to +80%) to directly fund Excess of Loss (XoL) reinsurance premiums. |
| **Fleet Capacity & System Allocation** | Empirical Cargo Census | Simulated cargo policies were strictly calibrated against the official vessel census. Cargo volumes and geographic exposures are distributed to perfectly match the empirical fleet capacity constraints and the exact operational deployment across the Helionis, Bayesia, and Oryn systems. |
| **Part III: Equipment Failure Insurance (EF)** | | |
| **Asset Growth & Aging** | Linear Growth & Deterministic (+1 Yr/CY) | New equipment influx is uniform and strictly discrete. Machinery age advances deterministically by calendar year to drive dynamic degradation multipliers. |

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*Table 36 – Continued from previous page*

| Assumption | Selected value | Supporting Evidence & Rationale |
|---|---|---|
| **Replacement Cost Trend** | Indexed to Macro Inflation | Base values dynamically link to ESG inflation forecasts, inherently capturing the escalating costs of interstellar manufacturing and future repair parts. |
| **Part IV: Workers' Compensation (WC)** | | |
| **Medical Claims Inflation** | 5.00% (Annual) | Includes a premium over base inflation to account for the rapidly escalating costs of advanced deep-space medical tech and specialized biological treatments. |
| **Synthetic Portfolio & Geography** | 35,809 Units & 30:15:10 Ratio | Summary census data was "uncounted" into granular units and geographically stratified. This creates a definitive, individual-level exposure base for Monte Carlo simulations. |
| **Workforce Growth & Mapping** | Smooth CAGR & Historical Parity | Workforce scales smoothly (avoiding unnatural step-jumps), while 2175 roles are assumed to maintain hazard profiles structurally consistent with historical proxy occupations. |
| **Part V: Dependency & Risk Measurement Assumptions** | | |
| **Loss Distribution Stability** | Stationary Marginal Distributions | Marginal distributions for each peril were calibrated to historical data and assumed to remain stable over the entire projection period, ensuring no unexpected regime shifts in baseline peril behavior. |
| **Event Independence** | Independence Assumption with Multiplicative Impacts | Global and internal events are modeled as independent; when multiple events co-occur, their impacts are combined multiplicatively rather than additively to capture compound tail risks. |
| **Copula Parameter Stability** | Static Gumbel Copula | Gumbel copula parameters are held constant over the projection horizon, preserving the calibrated tail-dependence structure between perils without temporal drift. |

*Continued on next page...*

*Table 36 – Continued from previous page*

| Assumption | Selected value | Supporting Evidence & Rationale |
|---|---|---|
| **Confidence Level** | 99.5% TVaR | Tail Value-at-Risk at the 99.5% confidence level was selected as the primary risk metric, ensuring regulatory consistency with Solvency II capital adequacy frameworks. |
| **Reinsurance Credit Risk** | Full Collateralization / Zero Counterparty Risk | All reinsurance programs are assumed to be fully collateralized, eliminating counterparty default risk from the tail-risk assessment and isolating underwriting risk. |

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