Operational risk assessment of chemical industries by exploiting accident databases

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Abstract


Classical statistical approaches are ineffective for low frequency, high consequence events because of their rarity. Given this information limitation, this paper uses Bayesian theory to forecast incident frequencies, their relevant causes, equipment involved, and their consequences, in specific chemical plants. Systematic analyses of the databases also help to avoid future accidents, thereby reducing the risk.

More specifically, this paper presents dynamic analyses of incidents in the NRC database. The NRC database is exploited to model the rate of occurrence of incidents in various chemical and petrochemical companies using Bayesian theory. Probability density distributions are formulated for their causes (e.g., equipment failures, operator errors, etc.), and associated equipment items utilized within a particular industry. Bayesian techniques provide posterior estimates of the cause and equipment-failure probabilities. Cross-validation techniques are used for checking the modeling, validation, and prediction accuracies. Differences in the plant- and chemical-specific predictions with the overall predictions are demonstrated. Furthermore, extreme value theory is used for consequence modeling of rare events by formulating distributions for events over a threshold value. Finally, the fast-Fourier transform is used to estimate the capital at risk within an industry utilizing the frequency and loss-severity distributions.

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Abbreviations:
Companies A, B, C, D, E, F, G—A, B, C, D, E, F, G; Basic indicator approach, BIA; Capital at risk, CaR; Center for Chemical Process Safety (AIChE), CCPS; Equipment failure, EF; Environmental Protection Agency, EPA; Extreme value theory, EVT; Fast-Fourier transform, FFT; Heat transfer units, HT; Identically and independently distributed, iid; Inverse fast-Fourier transform, IFFT; Internal measurement approach, IMA; Loss distribution approach, LDA; Markov-chain Monte Carlo, MCMC; Major Accident Reporting System, MARS; National Response Center, NRC; Others, O; Operator error, OE; Occupational Safety and Health Administration, OSHA; Process Safety Incident Database, PSID; Process safety management, PSM; Process units, PU; Process vessels, PV; Quantile-quantile, Q-Q; Risk Management Plan, RMP; Standardized approach, SA; Storage vessel, SV; Transfer line, TL

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### Nomenclature

- \(a, b\) parameters of Beta prior probability distribution
- \(a_i, b_i\) parameters of prior probability distribution of cause \(i\) for an incident
- \(d_1, d_2, d_3\) cumulative number of incidents of causes EF, OE, and O at the end of each year
- \(e_i\) probability of involvement of equipment type \(i\)
- \(E(\mu|\text{Data})\) expected posterior mean of \(\mu\)
- \(E(q|\text{Data})\) expected posterior mean of \(q\)
- \(E[y_i|y_{-i}]\) expected value of number of incidents in a year \(i\) based on incidents in \(y_{-i}\)
- \(f(e_i)\) prior probability distribution of involvement of equipment \(i\) for an incident
- \(f(x_i|\text{Data})\) posterior probability distribution of involvement of equipment \(i\) conditional upon \(\text{Data}\)
- \(f(x_i)\) prior probability distribution of cause \(i\) for an incident
- \(f(x_i|\text{Data})\) posterior probability distribution of cause \(i\) conditional upon \(\text{Data}\)
- \(f_1\) discrete loss-severity distribution function
- \(f_2(Z)\) discrete probability distribution function of total loss
- \(F_l(y)\) cumulative probability distribution for distribution of losses, \(l\), over threshold \(u\)
- \(G(l)\) Generalized Pareto distribution of losses
- \(l\) loss associated with an incident
- \(M_i + N_i + O_i\) cumulative number of incidents associated with equipment \(i\) at the end of each year
- \(n_p\) number of points desired in total loss distribution
- \(N_{C/P}\) number of incidents associated with compressors and pumps
- \(N_d\) amount of damage, $
- \(N_e\) number of evacuations
- \(N_{EF}\) number of incidents associated with equipment failures
- \(N_f\) number of fatalities
- \(N_h\) number of hospitalizations
- \(N_{HT}\) number of incidents associated with heat-transfer equipment items
- \(N_i\) number of injuries
- \(N_{OE}\) number of incidents associated with operator errors
- \(N_{PU}\) number of incidents associated with process units
- \(N_{SV}\) number of incidents associated with storage vessels
- \(N_t\) number of years
- \(N_{TL}\) number of incidents associated with transfer-line equipment
- \(N_{total}\) total number of incidents
- \(N_U\) number of incidents associated with unknown causes
- \(p(\lambda)\) prior distribution of \(\lambda\)
- \(p(\lambda|\text{Data})\) posterior distribution of \(\lambda\) given \(\text{Data}\)
- \(p(q|\text{Data})\) marginal posterior distribution of \(q\) given \(\text{Data}\)
- \(p(\mu|\text{Data})\) marginal posterior distribution of \(\mu\) given \(\text{Data}\)
- \(P_N\) probability generating function of the frequency of events, \(N\)
- \(p_i, q_i\) parameters of prior probability distribution of involvement of equipment \(i\) in an incident
- \(q\) parameter of the Negative Binomial distribution
- \(s\) total number of incidents in \(N_i\) years
- \(u\) threshold value of \(l\) for loss-severity distribution
- \(V(y)\) variance of number of incidents per year
- \(w_d\) dimensionless damage measure
- \(w_e\) dollar amount per evacuation, $
- \(w_f\) dollar amount per fatality, $
- \(w_h\) dollar amount per hospitalization, $
- \(w_i\) dollar amount per injury, $
- x_1, x_2, x_3\) probabilities of causes EF, OE, and O for an incident
- \(y_i\) number of incidents in year \(i\)
- \(z_i\) predictive score for incidents in year \(i\)
- \(Z\) total annual loss for a company

### Greek

- \(\alpha, \beta\) parameters for Gamma density distribution function
- \(\text{Beta}(\alpha, b)\) Beta density distribution with parameters \(\alpha\) and \(b\)
- \(\phi_l\) characteristic function of the loss-severity distribution
- \(\phi_Z\) characteristic function of total loss distribution
- \(\lambda\) average annual number of incidents
- \(\lambda_B\) average annual number of incidents for company B with losses greater than \(u\)
- \(\lambda_F\) average annual number of incidents for company F with losses greater than \(u\)
- \(\mu\) parameter of the Negative Binomial distribution
- \(\xi, \beta\) parameters of the generalized Pareto distribution

### Subscript

- \(i\) year counter
- \(n\) year vector
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