Analyzing system changes with importance measure pairs: Risk increase factor and Fussell-Vesely compared to Birnbaum and failure probability

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Introduction

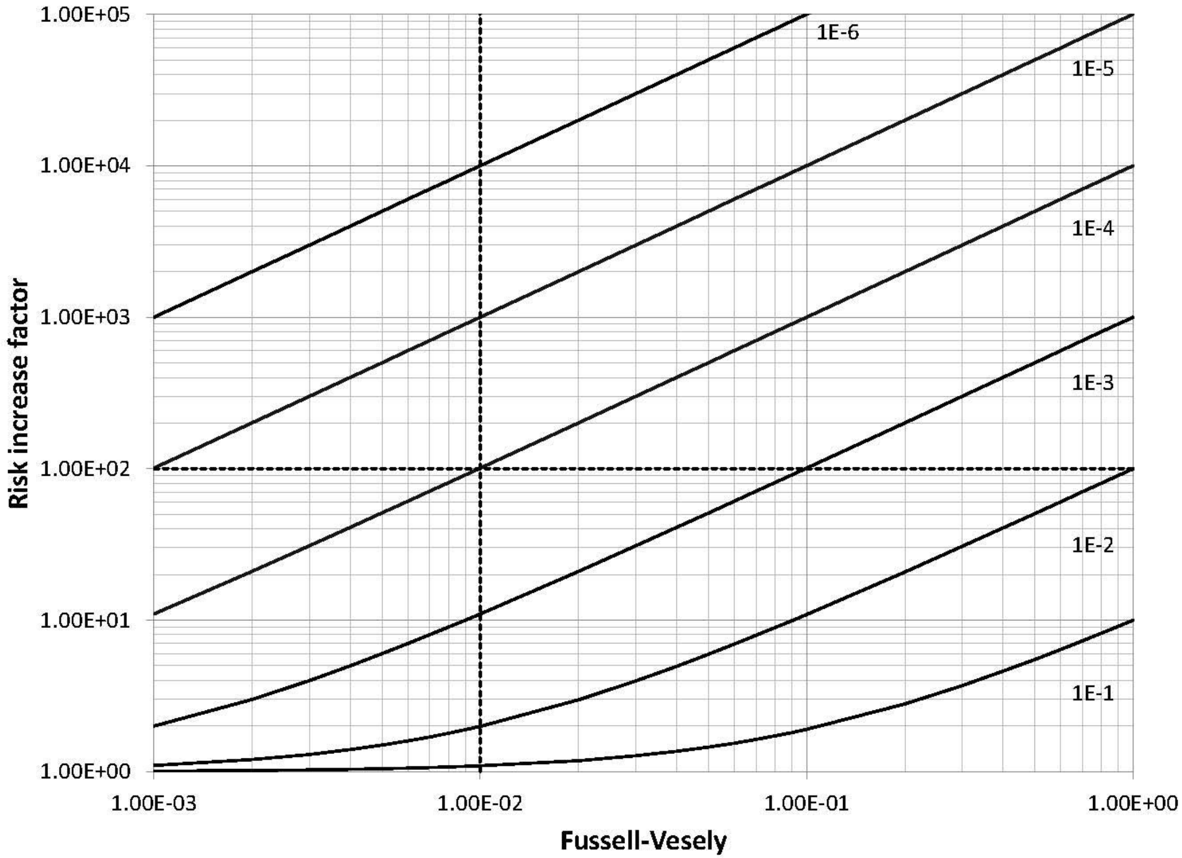
- Importance measures are used to rank components according to a selected criterion depending on the decision problem
  - e.g. finding system vulnerabilities or targeting maintenance and inspections

- Sometimes more than one importance measure may be used, e.g., **risk increase factor, RIF,** (i.e. risk achievement worth, RAW) and **Fussell-Vesely, FV,** (risk reduction worth: RRW = 1/(1-FV))

- This approach is **compared to** an alternative method which utilizes **Birnbaum** importance measure and **the failure probability X_i** of a basic event

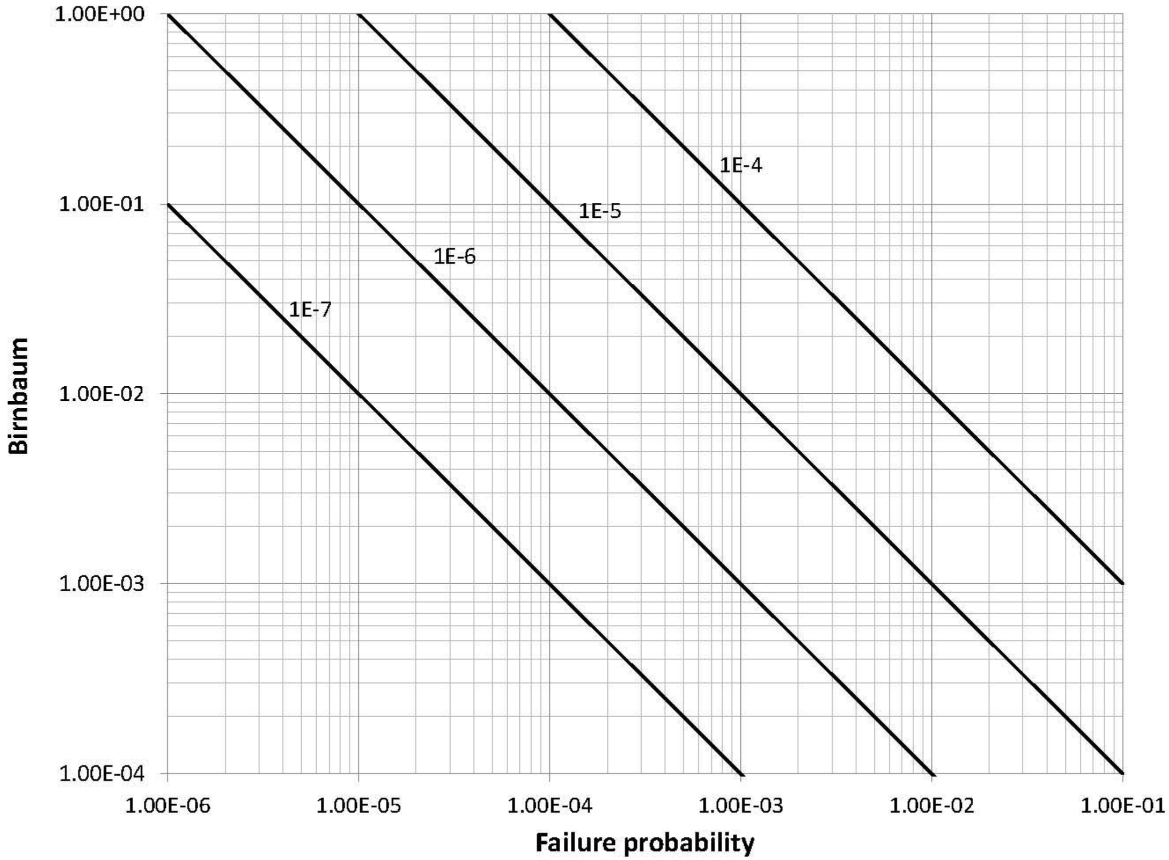
RIF and FV mapping

- RIF, FV and failure probability X_i are tied by $RIF = 1 + FV\left({}^{1}\!/_{X_i} - 1 \right)$
- These curves for different failure probabilities X_i are shown below
- **Basic event with failure probability X_i can only appear on the corresponding curve regardless of the system**



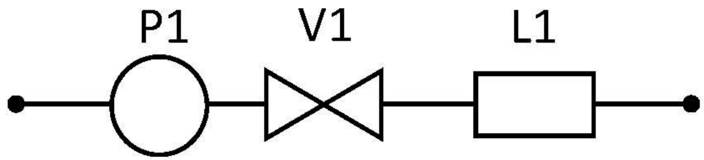
Birnbaum and failure probability mapping

- Birnbaum is dependent on the structure of the system and independent of the corresponding failure probability X_i
- Interpretation of the measures is simple
- Lines for equal risk (shown below) divide the space into risk zones



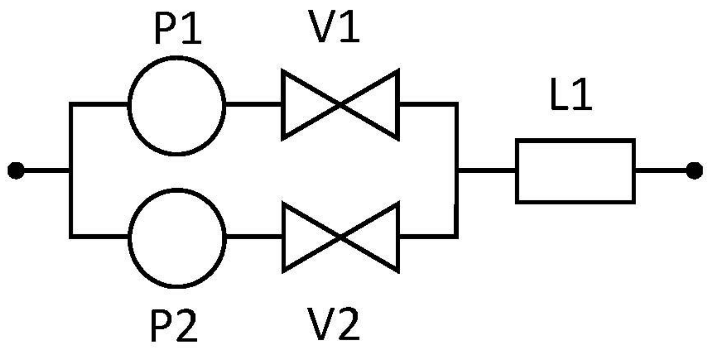
Illustrative example: pump line system

- Utilizing importance measure pair (FV, RIF) or (X_i, B) in analyzing system changes is compared with the following pump line system



TOP = L1 + V1 + P1
Pr(TOP) = 1.01E-2

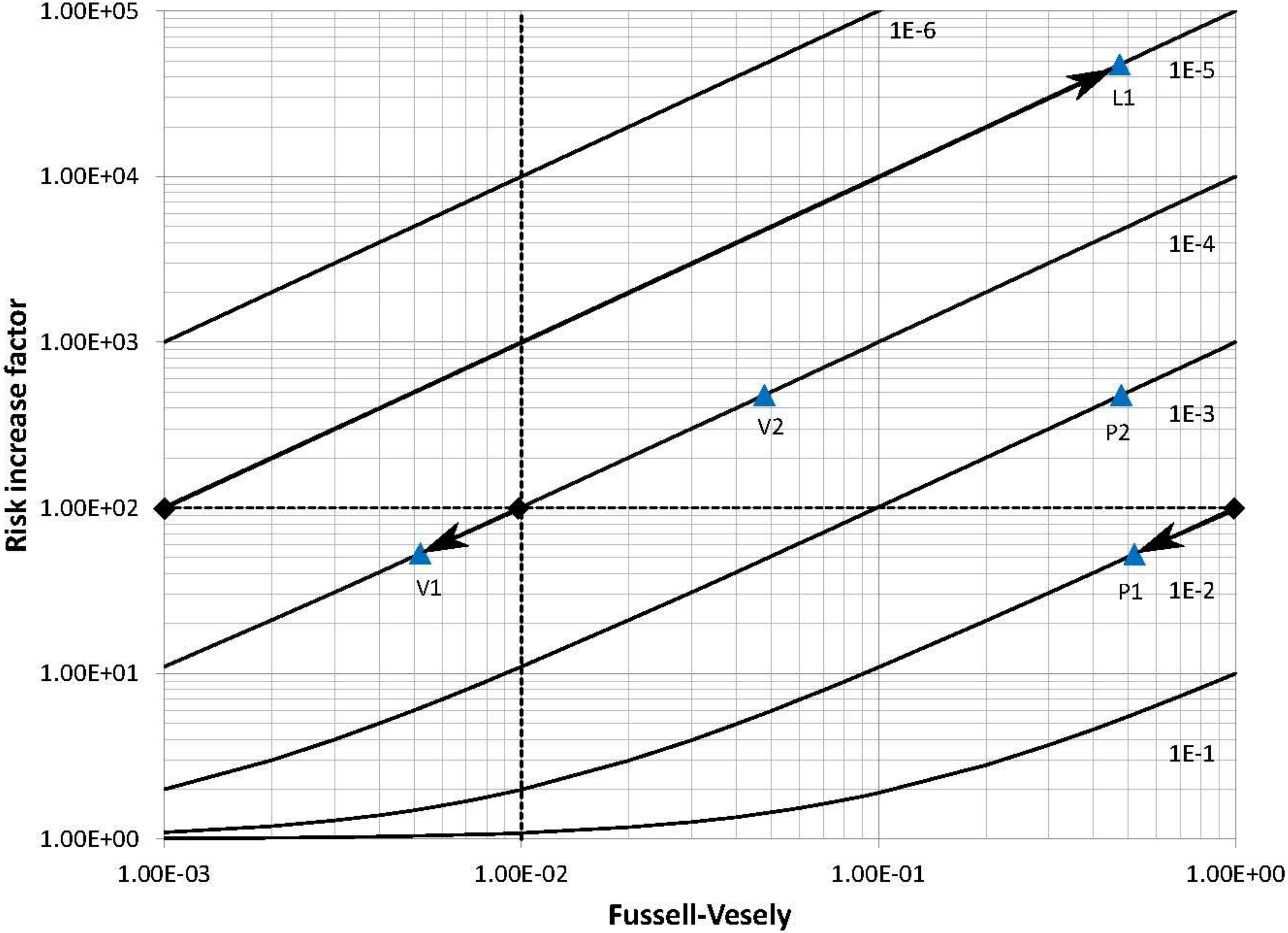
- Following changes to the system are considered:
  1. Redundant pump P2 and valve V2 installed



TOP = L1 + (V1 + P1) (V2 + P2)
Pr(TOP) = 2.11E-5
Failure probabilities:
Pr(L1) = 1E-5
Pr(V1) = Pr(V2) = 1E-4
Pr(P1) = 1E-2, Pr(P2) = 1E-3

  2. Failure probability Pr(L1) changed from 1E-5 to 1E-6
  3. Failure probability Pr(P2) changed from 1E-3 to 1E-4

(FV, RIF)-map: #1 installing P2 and V2



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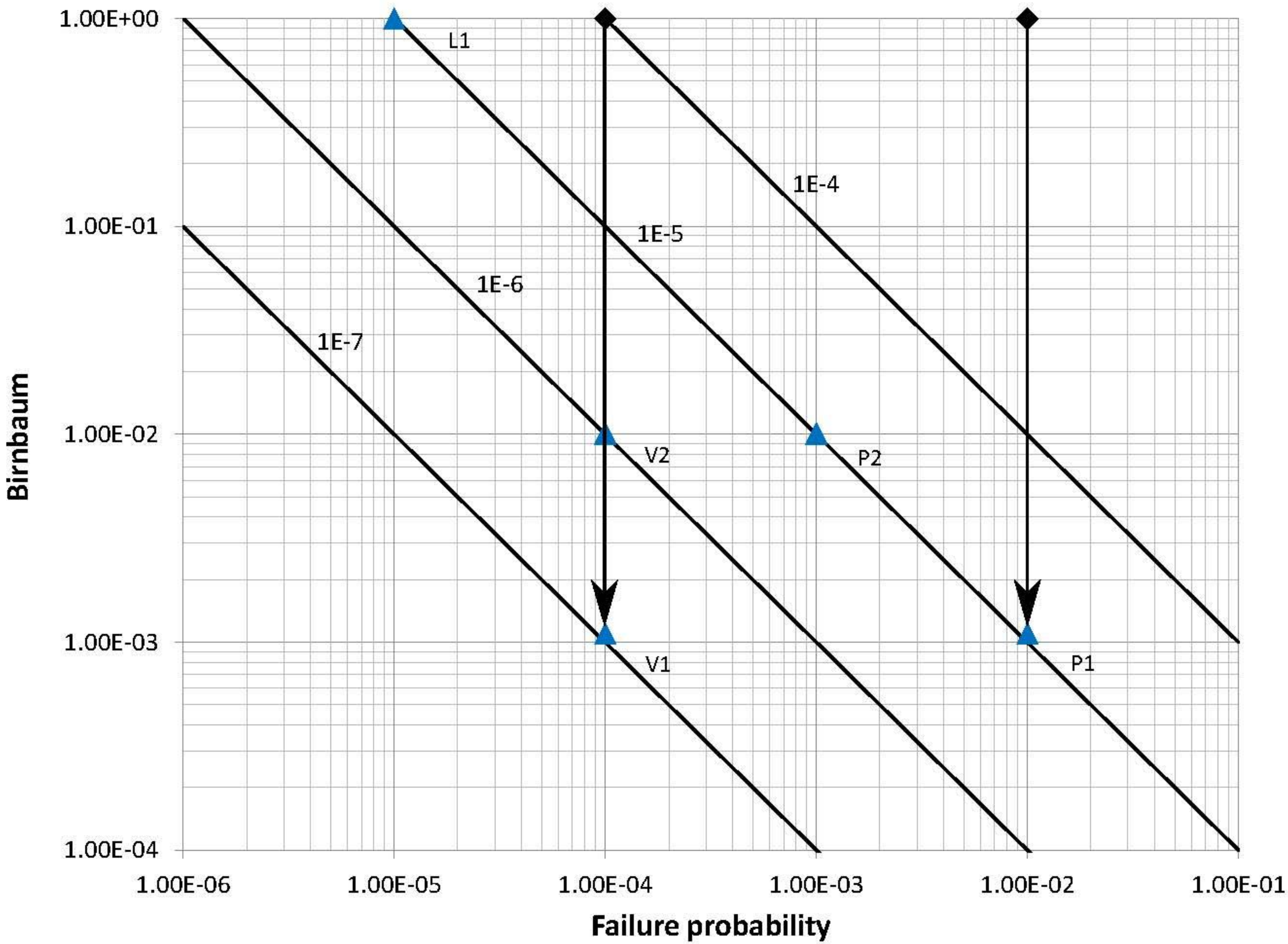
$(X_i$, B)-map: #1 installing P2 and V2



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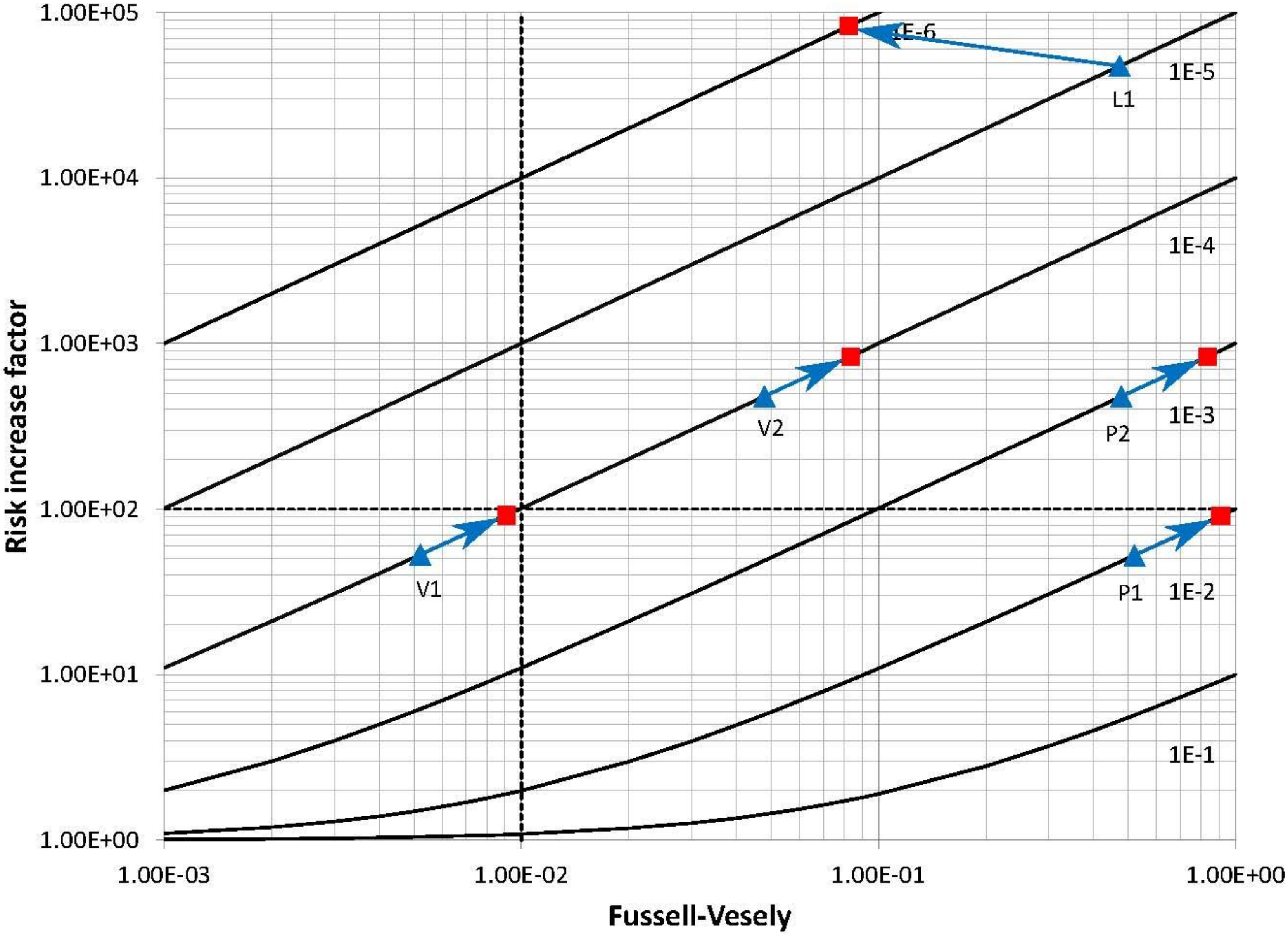
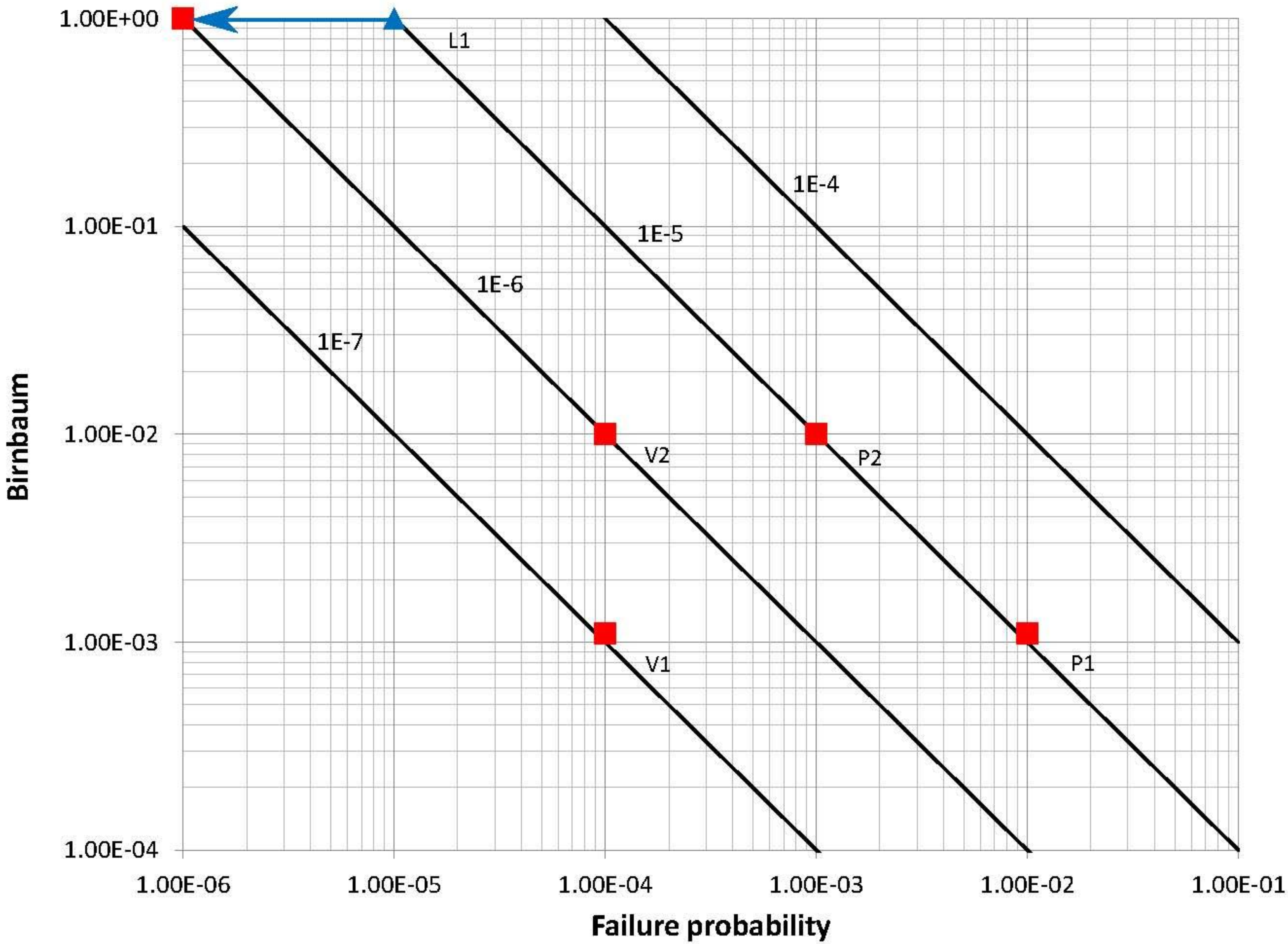
(FV, RIF)-map: #2 Pr(L1) changed from 1E-5 to 1E-6



$(X_i$, B)-map: #2 Pr(L1) changed from 1E-5 to 1E-6



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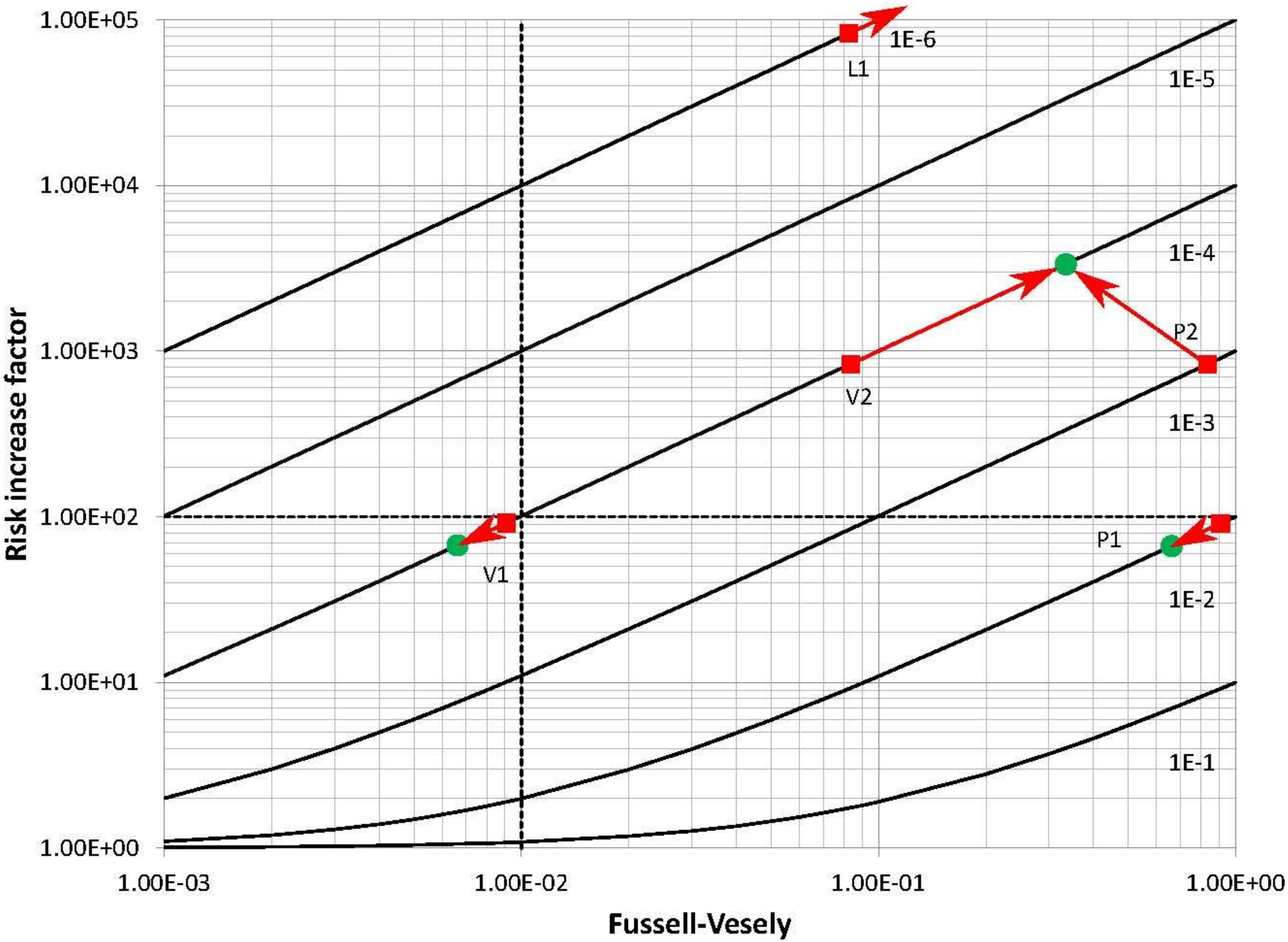
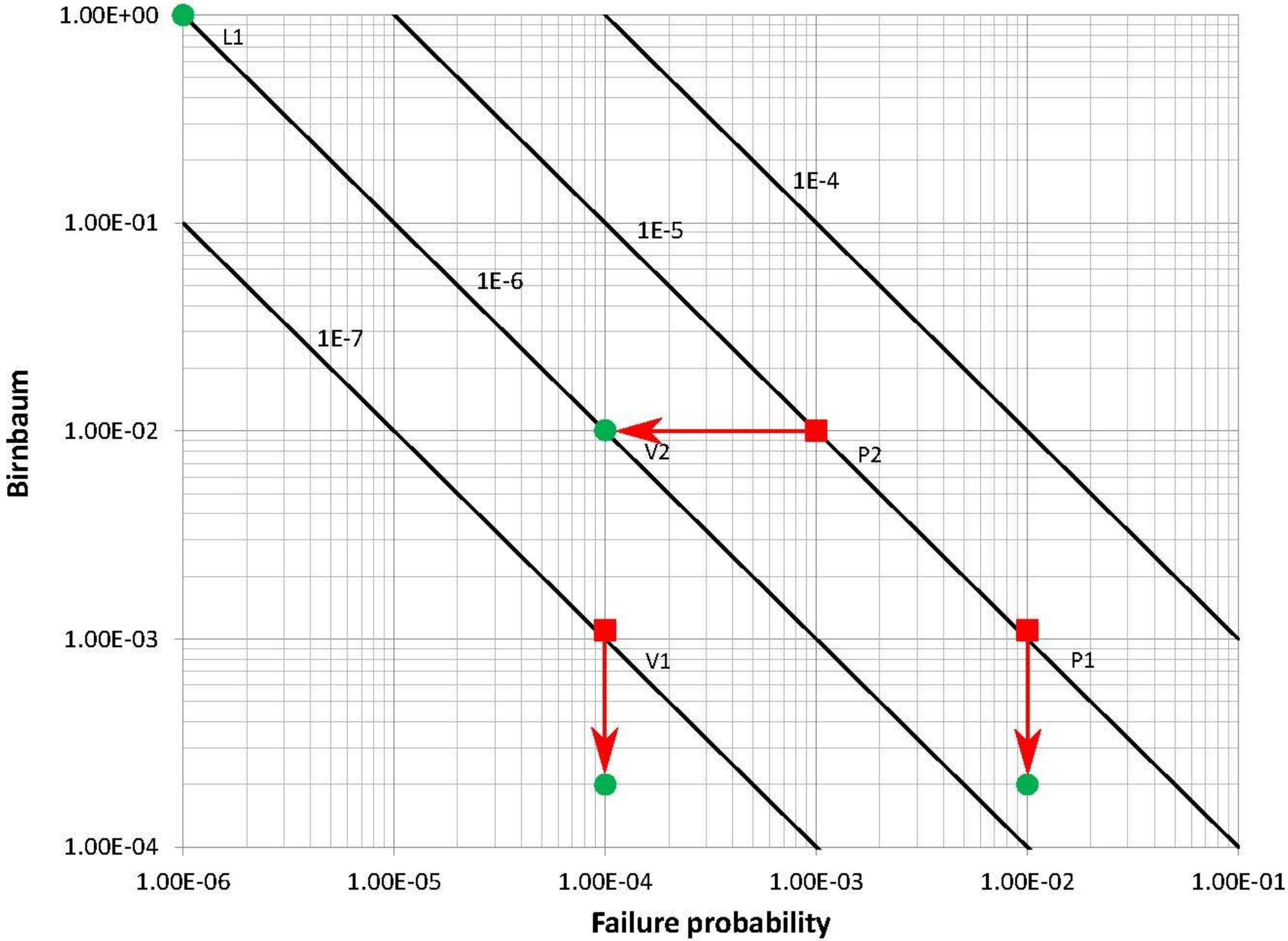
(FV, RIF)-map: #3 Pr(P2) changed from 1E-3 to 1E-4



$(X_i$, B)-map: #3 Pr(P2) changed from 1E-3 to 1E-4



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Conclusions

- Using failure probability and Birnbaum in analyzing system changes was found to have several advantages compared to Fussell-Vesely and risk increase factor:
  1. **Failure probability and Birnbaum are independent** on each other and therefore can be illustrated orthogonally
  2. **The measures are absolute** which means that comparison of different system configurations is evident. Another consequence of absoluteness is that the **change on basic event importances expresses real change** and only those basic events move on the graphical illustration that are really affected by the modification
  3. The axes of the graphical illustration have **clear interpretations, failure probability and safety margin**, so understanding the location of the basic events is straightforward