Data Article

Probabilistic model data of time-dependent accident scenarios for a mixing tank mechanical system

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A B S T R A C T

This article presents the risk assessment of a mixing tank mechanical system based on the failure probabilities of the components. Possible component failures can cause accidents which evolve over multiple time stages and can lead to system failure. The consequences of these accident scenarios are analyzed by quantifying the failure probabilities and severity of their outcomes. Illustrative costs and updated failure probabilities are provided to evaluate preventive safety measures. Data refers to the results of the Bayesian model presented in our research article (Mancuso et al., 2019).

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This article presents the probabilistic model data of the time-dependent accident scenarios for a mixing tank mechanical system. Specifically, we revisit the earlier analyses of the accident scenarios by Khakzad et al. [2] to illustrate the methodology presented in our research article [1]. One of such accident scenarios occurred on 14 June 2006 at Universal Form Clamp in Bellwood (Illinois, U.S.) through a vapor cloud ignition [3].

| Specifications table |
|-----------------------|
| Subject               | Safety, Risk, Reliability and Quality |
| Specific subject area | Portfolio optimization for risk mitigation |
| Type of data          | Tables |
| How data were acquired| Analysis of the numerical results of the Bayesian model [1] |
| Data format           | Analyzed data |
| Parameters for data collection | Journal reputation |
| Description of data collection | Literature review |
| Data source location  | Institution: Aalto University |
|                       | City: Helsinki |
|                       | Country: Finland |
| Data accessibility    | With the article |
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**Table 1** shows the failure probabilities of *Alarm* and *Sprinkler* for different ways of activating such components during an accident. In particular, the activation occurs if the vapor is ignited or if there is a specific amount of vapor concentration in the air, even though the vapor is not ignited.

Based on the analyses by Khakzad et al. [2], **Table 2** lists the system components and their failure probabilities. In addition, we assume that the activation of *Sprinkler* reduces the probability of delayed ignitions by 50%, as detailed in **Table 3** (last row, first and second columns). For this reason, the activation of the *Sprinkler* for a vapor concentration in the air could prevent delayed ignitions.

**Table 4** lists the nine possible outcomes of the accident scenarios where the state *Safe* represents the outcome following the non-occurrence of the system failure (*Vapor = Controlled*). The other outcomes are caused by malfunctions of some system components. Due to the activation of *Sprinkler*, accident consequences *C₁* and *C₂* are less severe than *C₃* and *C₄*, respectively. This information is helpful in eliciting the disutility functions to specify the ranking of the outcome severity. The last column of **Table 4** shows illustrative disutility values that quantify the severity of the outcomes.

Based on the failure probabilities in **Table 2**, the Bayesian model computes the occurrence probabilities of the outcomes of the accident scenarios, reported in **Table 5** for each time stage. The deployment of preventive safety measures on some selected components mitigates the risk of the negative outcomes. **Table 6** lists the alternative preventive safety measures (second column) that affect the occurrence of failures of specific components (first column). The last two columns of **Table 6** report illustrative costs and updated failure probabilities of the components. In particular, the preventive safety measure *Synergy* refers to a combination of *Calibration test* and *Sensor*: if both
Table 1
Conditional probabilities of Alarm and Sprinkler at $\tau = 0$ ($\tau$ refers to the time stage of the Bayesian model).

| Vapor  | Ignition | Controlled | Overflow |
|--------|----------|------------|----------|
|        |          | No spark   | Spark    | No spark | Spark    |
| Alarm  | Activation | 0          | 0        | 0.7750   | 0.9987   |
|        | No activation | 1          | 1        | 0.2250   | 0.0013   |
| Sprinkler | Activation | 0          | 0        | 0.70     | 0.96     |
|        | No activation | 1          | 1        | 0.30     | 0.04     |

Table 2
List of components and respective failure probability.

| Component                                      | Symbol | Failure probability |
|------------------------------------------------|--------|---------------------|
| Sensor                                         | Sensor | 0.0400              |
| Pneumatic unit                                 | P_unit | 0.2015              |
| Temperature control system                     | T_ctrl_sys | OR gate            |
| Operator                                       | Operator | 0.0200             |
| Infrared thermometer                           | Thermo | 0.0468              |
| Temperature measurement system                 | T_sys  | OR gate             |
| Manual steam valve                             | M_valve | 0.0243              |
| Automatic steam valve                          | A_valve | 0.0276              |
| Automatic temperature control system           | ATCS   | OR gate             |
| Manual temperature control system              | MTCS   | OR gate             |
| High temperature protection system             | HTPS   | AND gate            |
| Ventilation                                    | Vent   | 0.0150              |
| Fan                                            | Fan    | 0.0100              |
| Belt                                           | Belt   | 0.0500              |
| Duct                                           | Duct   | 0.0010              |
| Ventilation system                             | Vent_sys | OR gate           |
| Vapor overflow                                 | Vapor  | AND gate            |
| Ignition barrier                               | Ignition | 0.1000             |
| Water sprinkler system                         | Sprinkler | 0.0400, 0.3000    |
| Alarm system                                   | Alarm  | 0.0013, 0.2250      |

Table 3
Conditional probabilities of Ignition at $\tau > 0$ ($\tau$ refers to the time stage of the Bayesian model).

| Ignition $[\tau - 1]$ | No spark | Spark |
|------------------------|----------|-------|
|                        |          |       |
| Sprinkler $[\tau - 1]$ |          |       |
| No spark               | 0.95     | 0     |
| Spark                  | 0.05     | 1     |

Table 4
List of accident outcomes ($C$ refers to the accident consequences, numbered based on increasing severity).

| Outcome                                      | Symbol | Disutility |
|----------------------------------------------|--------|------------|
| Controlled vapor                             | Safe   | 0          |
| Safe evacuation                              | $c_1$  | 10         |
| Wet vapor cloud near the ground              | $c_2$  | 15         |
| Safe evacuation with possibility of delayed ignition | $c_3$  | 30         |
| Vapor cloud with possibility of delayed ignition | $c_4$  | 40         |
| Fire, moderate property damage, low death toll | $c_5$  | 60         |
| Fire, high property damage, low death toll   | $c_6$  | 80         |
| Fire, moderate property damage, high death toll | $c_7$  | 90         |
| Fire, high property damage, high death toll  | $c_8$  | 100        |
measures are installed, this synergy effect yields more benefits than installing independent measures. The updated failure probabilities of Sprinkler and Alarm refer to the two different failure scenarios detailed in Table 1.

2. Experimental design, materials, and methods

The failure probabilities of the components in Table 2 are provided by the article by Khakzad et al. [2]. Gates represents logic structures of the Bayesian model in our research article [1]. The failure probabilities in Table 6 have been obtained by reducing the initial failure probability of the components, based on a specific reduction rate for each preventive safety measure. These values illustrate the viability of the Bayesian model [1], but do not represent any actual system. The occurrence probabilities of the outcomes of the accident scenarios have been computed by GeNiE Modeler [4] through the Dynamic Bayesian Network presented in our research article [1]. Finally, the severity of the outcomes has been quantified through the trade-off weighing approach SWING [5].

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Table 5

| Outcome | $\tau = 0$ | $\tau = 1$ | $\tau = 2$ | $\tau = 3$ | $\tau = 4$ | $\tau = 5$ |
|---------|------------|------------|------------|------------|------------|------------|
| Safe    | 0.998319   | 0.998319   | 0.998319   | 0.998319   | 0.998319   | 0.998319   |
| $C_1$   | 0.000820   | 0.001226   | 0.001289   | 0.001256   | 0.001202   | 0.001144   |
| $C_2$   | 0.000238   | 6.539252e-05 | 1.485681e-05 | 3.229053e-06 | 6.934547e-07 | 1.484231e-07 |
| $C_3$   | 0.000352   | 3.270228e-05 | 8.908458e-06 | 2.410073e-06 | 6.510108e-07 |
| $C_4$   | 0.000102   | 6.202325e-06 | 3.767917e-07 | 2.289007e-08 | 1.390572e-09 | 8.447723e-11 |
| $C_5$   | 0.000161   | 0.000264   | 0.000343   | 0.000411   | 0.000475   | 0.000536   |
| $C_6$   | 6.713624e-06 | 2.083401e-06 | 5.733853e-07 | 1.552510e-07 | 4.193539e-08 | 1.132327e-08 |
| $C_7$   | 2.097377e-07 | 2.850967e-08 | 5.062283e-09 | 1.019337e-09 | 2.140727e-10 | 4.552654e-11 |
| $C_8$   | 8.739072e-09 | 5.313530e-10 | 3.227972e-11 | 1.960993e-12 | 1.191303e-13 | 7.237167e-15 |

Table 6

| Component | Preventive safety measure | Cost [k$\text{V}$] | Failure probability |
|-----------|---------------------------|-------------------|---------------------|
| P_unit    | Inspection plan           | 60                | 0.1500              |
|           | Duplicates                | 80                | 0.100               |
| M_valve   | Calibration test          | 30                | 0.0200              |
|           | Sensor                    | 40                | 0.0150              |
|           | Synergy                   | 60                | 0.0100              |
| A_valve   | Calibration test          | 30                | 0.0200              |
|           | Sensor                    | 40                | 0.0150              |
|           | Synergy                   | 60                | 0.0100              |
| Belt      | Periodic test             | 40                | 0.0300              |
| Ignition  | Tank blanketing           | 100               | 0.0100              |
|           | Inerting systems          | 100               | 0.0800              |
|           | Hypoxic air technology    | 150               | 0.0400              |
| Sprinkler | Standard response         | 40                | 0.0300, 0.2000      |
|           | Quick response            | 80                | 0.0100, 0.1000      |
| Alarm     | Semi-conductor sensor     | 60                | 0.0013, 0.2000      |
|           | Catalytic gas sensor      | 80                | 0.0013, 0.1500      |
|           | Electrochemical cells     | 100               | 0.0013, 0.1000      |
Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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