Office for Product
Safety & Standards

A causal Bayesian network approach for consumer product safety and risk assessment

Research Summary Report: 2021/035

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Introduction and Background

This is a report for the Office for Product Safety and Standards (OPSS) by Joshua Hunte, Martin Neil and Norman Fenton from Queen Mary University London.

The views expressed in this report are those of the authors, not necessarily those of the Office for Product Safety and Standards or the Department for Business, Energy & Industrial Strategy (nor do they reflect Government policy).

Introduction

Every year there are many non-food products available on the UK and EU markets that pose a serious risk to the health and safety of consumers. In fact, since 2012, UK and EU regulators have identified approximately 2000 products each year, including electrical appliances and toys posing serious risks such as fire and physical injury (European Commission, 2020). It is essential that the products we use in our homes are acceptably safe. To ensure our safety, regulators perform product risk assessment which is the overall process of determining whether a product is safe for consumers to use. There are several methods of product risk assessment, including RAPEX, which is the primary method used in the UK and EU. (European Commission, 2015, 2018). Despite its widespread use, we identified several limitations of RAPEX. Most importantly, its approach to handling uncertainty is limited, and it cannot properly assess the risk of novel products or products with limited or no historical data. We propose a systematic method of product risk assessment that complements methods like RAPEX but resolves these issues. It is based on causal Bayesian networks, an increasingly widely accepted method for combining data and knowledge.

The research summarised in this report is part of the PhD project titled “Strategic Decision-Making using Bayesian Networks for Product Safety and Standards” at the Queen Mary University of London done by Mr Joshua Levi Hunte (PhD student) under the supervision of Professor Norman Fenton and Professor Martin Neil. It is supported by the Office for Product Safety and Standards.

Background: RAPEX and its Limitations

RAPEX Overview

RAPEX is a system that allows the rapid exchange of information between the Member States of the EU and the UK concerning non-food products that pose a serious risk to the health and safety of consumers (European Commission, 2015, 2018). An essential component of the RAPEX system is product risk assessment which is the overall process of determining whether a product is safe for consumers to use. It entails identifying and categorising the level of risk associated with a particular (product) hazard (a hazard is a potential source of harm). In RAPEX, the risk of a product is quantified as:

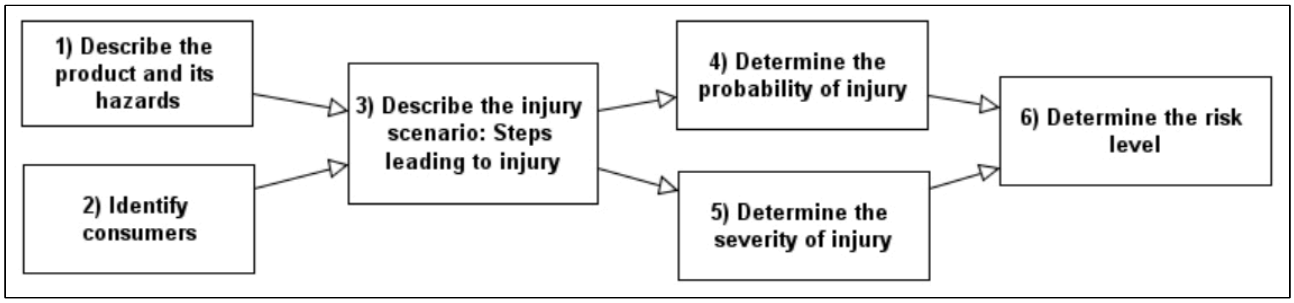
$$\textit{Risk} = \textit{Probability of Injury} \times \textit{Severity of Injury}$$

- *Risk*: This is the risk of the product (4 levels ranging from ‘low’ to ‘serious’).
- *Probability of Injury*: This is the probability that the identified product hazard cause injury to the user or consumer.

- *Severity of Injury*: This is the severity of the injury to the user caused by the product hazard (4 levels ranging from 'first aid treatment' to 'fatal').

The overall risk assessment process consists of several steps, including identifying product hazards and identifying consumers. A schematic describing the RAPEX risk assessment process is shown in Figure 1.

Figure 1. Schematic of the RAPEX risk assessment process adapted from (European Commission, 2015, 2018).



RAPEX Limitations

Despite its widespread use for product risk assessment, we identified several limitations of RAPEX (Hunte, Neil, & Fenton, 2020). They include:

1. A limited approach to handling uncertainty.
2. Cannot be applied to products with little or no historical data.
3. Does not include causal explanations for using and interpreting the data.
4. Does not differentiate between different types of users – i.e., their usage profile and risk tolerability.
5. Does not consider different product combinations and interactions with different classes of users when estimating product risk.
6. Does not consider the user exposure to the hazard when estimating the probability of injury.
7. Cannot assess the risk of products with unknown hazards or unknown product usage information.

Given these limitations of RAPEX[1], we proposed an improved systematic method of product risk assessment based on causal Bayesian networks discussed in the next section.

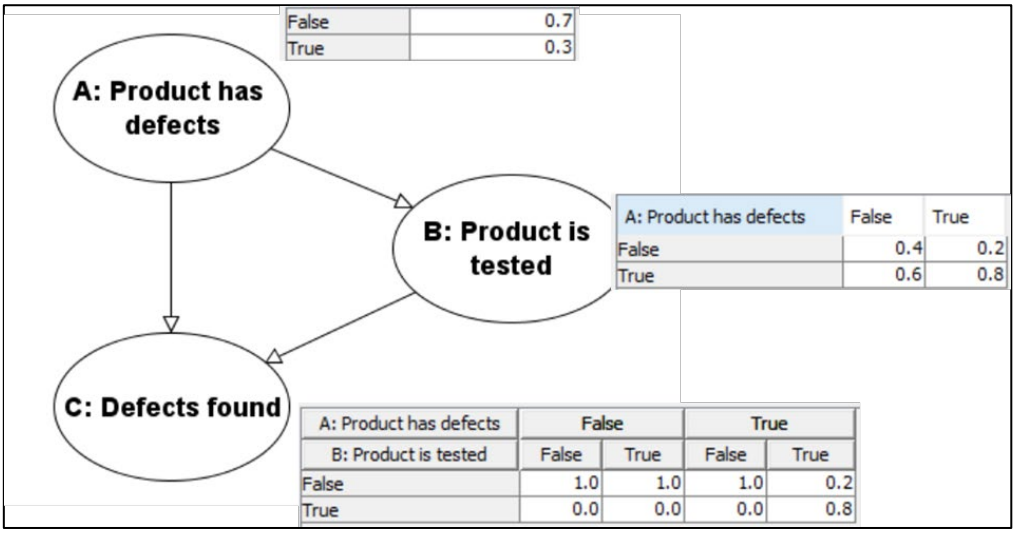
[1] For an in-depth review of RAPEX and its limitations please see our pre-print manuscript "Product Risk Assessment: a Bayesian Network Approach" on Arxiv (a pre-print server) https://arxiv.org/abs/2010.06698. A revised version is under review.

Bayesian Networks for Product Risk Assessment

Background: Bayesian Networks

A Bayesian network (BN) is a graphical method for visualising risk that enables us to model the 'cause and effect' relationships between risk factors and observed data (Fenton & Neil, 2018). It combines causal knowledge and data to make predictions or diagnoses. By incorporating causal knowledge, it is now a widely accepted standard method necessary to address the fundamental limitations of purely data-driven approaches as highlighted by Pearl & Mackenzie (2018).

Figure 2. A simple Bayesian network



Specifically, a BN such as the simple example shown in Figure 2, is a directed acyclic graph (DAG) that describes the causal relationship between a set of variables. It consists of qualitative and quantitative parts. The qualitative part consists of nodes and directed arcs. The nodes represent random variables (discrete or continuous) such as events or actions.

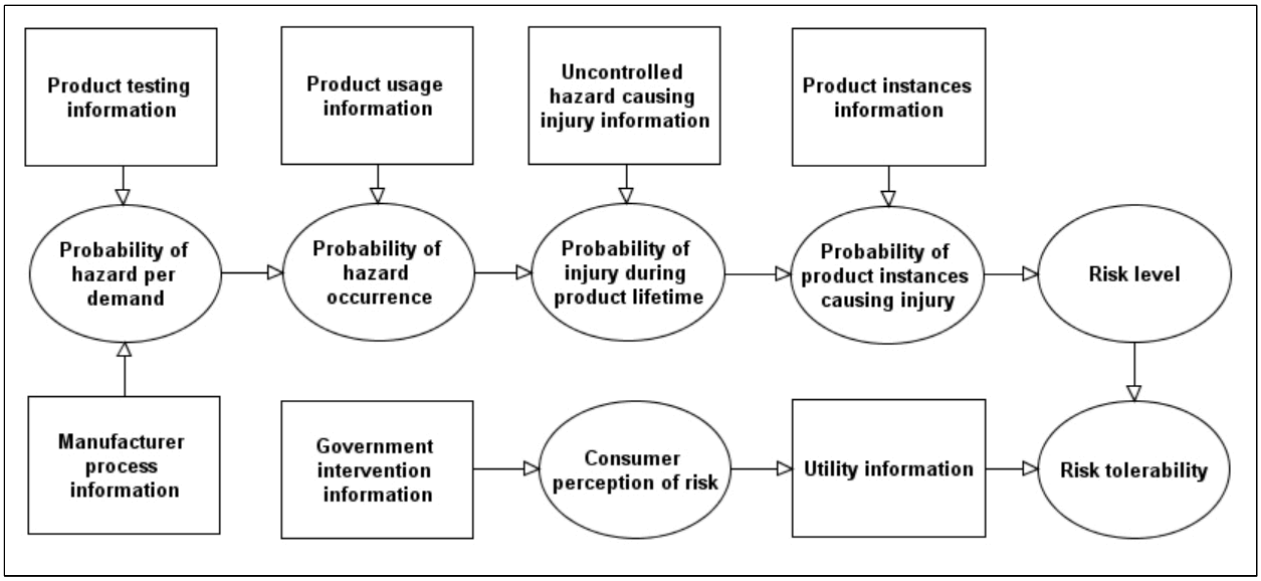
There is a directed arc from node *A* to node *B* if *A* has a direct causal or statistical influence on *B*. In this situation, *A* is called the parent of *B,* and we also say *B* is dependent on *A*. The quantitative part of the BN consists of probability tables associated with each node that describe the strength of the relationship between a node and its parents.

Once the DAG and probability tables are specified, we can perform different probabilistic inferences such as predictive and diagnostic inferences using Bayes Theorem. Bayes Theorem revises our prior belief called the prior probability given new evidence. Our revised belief is called the posterior probability. For example, in the BN shown in Figure 2, if no defects are found, the posterior probability that the product has defects drops from 30% to 13%. These Bayesian inference calculations are performed automatically in tools such as AgenaRisk (Agena Ltd, 2021).

A causal Bayesian Network approach for Product Risk Assessment

Bayesian networks are suitable for developing an improved systematic method for product risk assessment since they are a normative method for modelling uncertainty. In fact, they have been used for risk assessment in several domains including finance (Neil, Häger, & Andersen, 2009), system reliability (Weber et al., 2012) and health (Li et al., 2019). There is also limited previous research on using them for product risk assessment (Berchialla et al., 2010; Suh, 2017). A generic causal BN model for product risk assessment that resolves the limitations of RAPEX is shown in Figure 3.

Figure 3. Schematic of product risk assessment BN model adapted from (Hunte et al., 2020)



The proposed causal BN model was developed using expert knowledge and BN idioms (small reusable BN fragments). It combines factors affecting product risk such as manufacturer process information, product usage information (i.e., number of times product is used and years in use), product testing information and product instances information in a causal manner to determine product risk. It also provides information on risk tolerability, utility, and the effect of government interventions on the consumer risk perception which are critical for informing risk management decisions. All model development was done using AgenaRisk software (Agena Ltd, 2021).

The causal BN model for product risk assessment was tested and compared to RAPEX by assessing the risk of products that a) were already being sold and for which relevant data were available; and b) were new and uncertified with little or no relevant data**Error! Bookmark not defined.**. The results showed that the BN model produces similar results as RAPEX for products with relevant data. Unlike RAPEX, the BN model produces auditable assessments for products with little or no relevant data. In both scenarios, the BN model produces fully quantified insights and explanations for the final recommendation that are not available when using RAPEX. Hence, the BN approach resolves the identified limitations with RAPEX and provides an improved systematic method for product risk assessment that can complement traditional risk assessment methods.

Recommendations and Future Work

The causal BN approach can be used in the interim to validate traditional methods like RAPEX since it uses additional factors such as product usage information to determine product risk. In situations where relevant data is unavailable, the causal BN approach

should be used for product risk assessment since it can produce auditable, quantifiable assessments with limited or no data. Future work includes using consumer behavioural surveys to understand the change in consumer risk perception given government interventions. This will inform and improve model estimates.

Conclusion

The research summarised in this report is part of the PhD project titled “Strategic Decision-Making using Bayesian Networks for Product Safety and Standards” at the Queen Mary University of London done by Mr Joshua Levi Hunte (PhD student) under the supervision of Professor Norman Fenton and Professor Martin Neil. It proposes a novel method of consumer product safety and risk assessment based on causal Bayesian networks.

The research shows that, despite the widespread use of RAPEX, it has several limitations such as a limited approach to handling uncertainty. Given the limitations of RAPEX, the research proposes a causal Bayesian network approach for product risk assessment. This approach resolves the identified limitations with RAPEX and is more suitable for product risk assessment than traditional methods like RAPEX since it can provide auditable, quantifiable risk assessments with limited or no relevant data; handles uncertainty and include all of the relevant factors that affect product risk in a causal manner.

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This research summary report was produced by Mr Joshua L. Hunte, Professor Martin Neil and Professor Norman Fenton. The views expressed in this report are those of the authors, not necessarily those of the Office for Product Safety and Standards or the Department for Business, Energy & Industrial Strategy.

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