A Hybrid Knowledge Graph and Bayesian Network Approach for Analyzing Supply Chain Resilience

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Abstract. Supply Chain Risk Management focuses on the identification, assessment and management of disruptive events that can affect companies, transport routes and resources involved in critical goods supply chains. Modern supply chains consist of interconnected components that can be complex and dynamic in nature. In this demo, we present our system for analysing the resilience of supply chains for crisis relevant products. A dependency Bayesian Network is automatically generated from relevant information about the supply chain maintained in a Knowledge Graph. The main objective of the proposed approach is the early identification of bottlenecks and timely prediction of the consequences of probable disruptions of the network.

Keywords: Supply chain resilience · Knowledge Graph · Bayesian Network · Crisis management · Automatic bottleneck identification

1 Context and motivation

Recent disruptive events like COVID-19 or the Suez canal obstruction in 2021 showed how vulnerable our society and economy are to unforeseen disruptions of supply chains [1]. Due to a strong globalisation, modern supply chains became very complex, spanning multiple countries or even continents, involving longer transport distances and globally distributed suppliers. They depend highly on interconnected and tightly synchronized networks of a dynamic nature. Disruptions from an event affecting one subnetwork of the system can have costly and sometimes disastrous cascading effects on the whole supply chain.

Together with critical public safety organisations, we are developing ResKriVer[1], a crisis management platform and services offering relevant, interconnected and high-quality information for a wide range of crisis scenarios. The main aim of the platform is to provide crisis teams with the best possible overview for assessing the current situation and communicating it to the population. The demonstrator "Supply with substitutable Goods and Resources" focuses on the reliability of supply networks for crisis relevant goods and resources. The central objective is the assessment and management of threats and events that can affect the network and the early identification of bottlenecks. The platform is constantly enriched with necessary information about supply chains of crisis goods, such as manufacturers, production capacities, importers and transport routes. If a

[1] reskriver.de

supply shortage is predicted by the system, suggestions for possible product substitutes, transport routes, or alternative manufacturers will be generated.

In ResKriVer knowledge is captured semantically based on an ontology we developed using a modular approach. As upper-level ontology we use the PROV Ontology (PROV-O) [3] and the Basic Formal Ontology (BFO) [2] and for the mid-level the Common Core Ontologies (CCO) [8], a suite of ontologies describing generic classes across all domains of interest. In addition to the knowledge graph (KG), we developed an extended Bayesian Network approach (BN) to analyze supply chain disruptions, this network is automatically generated from the KG. Bayesian Networks have proven to be a powerful tool to model and analyze supply chain disruptions under uncertainty conditions [5,6]. Approaches combining KGs and BNs have been proposed recently for Knowledge Graph inference [10,11] and collaborative recommendation [7]. In order to take advantages of both worlds, we propose a new approach and tool called ReSCA (Resilience of Supply Chain Analyzer) combining the flexibility of Knowledge Graphs with the computation power of Bayesian Networks. Our knowledge on supply network can be continuously extended and adapted by new findings through the KG, the Bayesian Network structure can then be extracted from the KG in order to make timely predictions.

2 ReSCA Knowledge Graph representation

A supply chain is the network of individuals, organizations, activities and resources involved in the production and transport of goods from a supplier to an end customer. A disruption will affect a specific supply chain if it affects one of the activities and components involved in it. Based on this definition, we consolidated a set of high-level entities and their relations for describing supply chains of crisis goods and their disruptions and shown in figure 1.

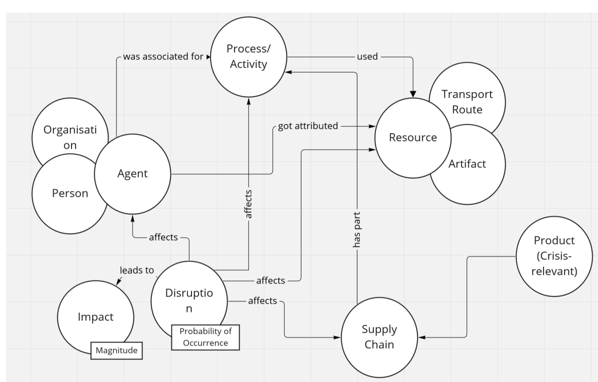


Fig. 1. High-level entities and relations for supply chains and their disruptions

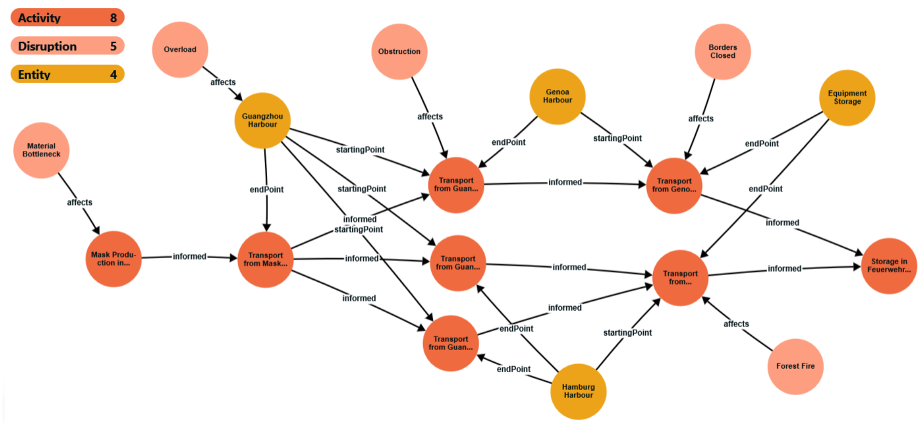


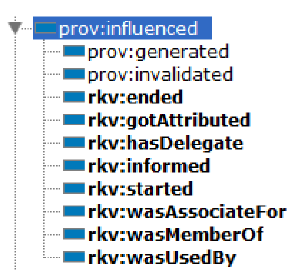
Fig. 2. A subset of the Knowledge Graph describing the supply chain of FFP2 masks

Our basis for the knowledge representation was the consolidated high-level entities and their counterpart PROV-O Starting Point classes: prov:Entity, prov:Activity and prov:Agent [3]. We mapped those through BFO to a useful set of the CCO ontologies, namely: the Event, the Agent and the Artifact ontologies. For the mapping, we extended the alignment between PROV-O and BFO proposed in [4] for core classes.

Figure 2 shows a subset of the Knowledge Graph describing activities and entities involved in the supply chain of the pandemic relevant product FFP2 mask. Disruptions can affect any element of the subgraph. For instance, a material bottleneck can affect a production activity and the closing of borders a transport one. We show in the next section how information from the KG can be used to generate the corresponding Bayesian Network.

3 Bayesian Network extraction and impact factor calculation

In order to enable a dynamic extraction of the Bayesian Network from the KG, we defined a set of object properties expressing the notion of dependency. We extended the PROV-O properties under prov:influenced as follows:



The Bayesian Network for the pandemic relevant product FFP2 mask is displayed in figure 3. We extract its basic structure automatically by querying the KG for all activities, agents and entities involved in the supply chain of a given crisis relevant product together with their dependency relationships.

Two impact factors are defined. These are the Bayesian Impact Factor (BIF) and the Node Failure Impact Factor (NFIF) [9]. BIF and NFIF are both ratios used to evaluate the impact of disruptions on system reliability. BIF measures how much a disruption affects a node's reliability by comparing its reliability with and without a disruption, while NFIF compares the system's reliability with and without the failure of a specific node. By analyzing BIF and NFIF results, we can identify critical nodes and bottlenecks that significantly reduce system reliability if they fail. Those are highlighted in the graph with a blue or orange frame based on the threshold exceeded as shown in figure 3. Node reliability reflects nodes ability to operate efficiently, regardless of other nodes in the network, while the probability of node failure is determined by internal failures, disruptions, and parent node failures. In the graph, the probability of the last node is the most important as it represents the probability of the entire system operating well. Node reliability is initially obtained from the knowledge graph, and the probability of disruptions is randomly generated within a range of 0.0 to 0.05.

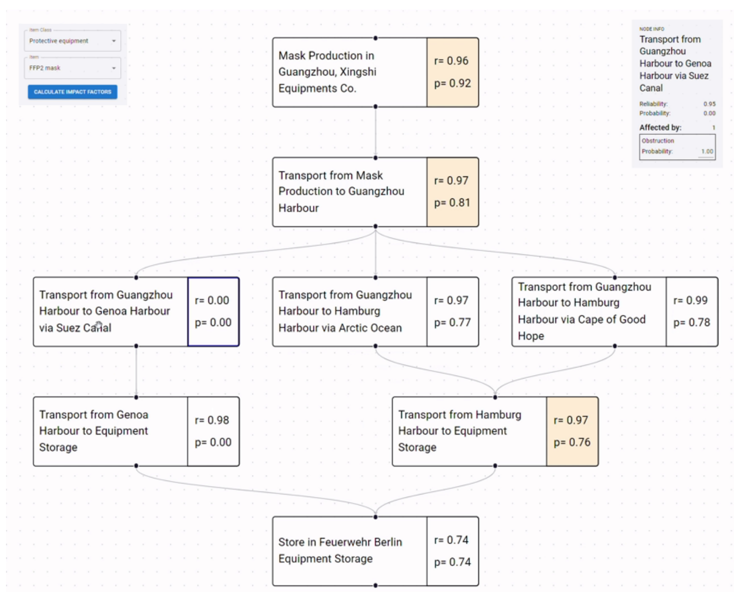


Fig. 3. Bayesian Network for the supply chain of the pandemic relevant product FFP2 mask

4 Demonstration

In this demonstration, visitors will be able to use the interface to enter disruptions, the system will compute the network's overall score and point out bottleneck nodes. We will provide guidance and example scenarios. A demo video can be found at: https://owncloud.fokus.fraunhofer.de/index.php/s/4ux8YvusxrA2gqx. For users interested in the models and RDF data behind the demo, we will provide access to the SPARQL endpoint and the Knowledge Graph visualisation.

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