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Päivi Pasanen

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Knowledge patterns as indicators of cause-and-effect relations in the domain of maritime safety

Päivi Pasanen
Department of Modern Languages, Faculty of Arts, University of Helsinki
Finland

Correspondence to: paivi.pasanen@helsinki.fi

Abstract. In recent years, a number of researchers in fields such as terminology and computer science have worked on developing methods for the automatic or semi-automatic extraction of terminological information from texts. Terminological information is information on terms and concept relations or characteristics. One method used to extract of terminological information is based on the utilization of terminological markers, also called knowledge patterns.

This paper discusses some theoretical and practical issues that arise in the process of extracting terminological information from texts in the domain of maritime safety. In my earlier study I argued that terms and other terminological information must be extracted together, and consequently, a combined model was proposed. In the domain of maritime safety, knowledge patterns proved to be especially productive when searching for associative concept relations, particularly for causal relations.

In this paper, I will show how knowledge patterns can be used for the semi-automatic extraction of terminological information from texts. The textual archive used for the experiment is a collection of maritime accident investigation reports available on the Marine Accident Investigation Branch (MAIB) website.[1] A technique combining the use of seed terms, knowledge patterns, and a corpus tool will be presented.

Keywords. Cause-and-effect relations, knowledge patterns, languages for special purposes, maritime English, maritime safety, terminological information, terminology.

1. Introduction

The methods applied in descriptive terminology work have developed rapidly, and new methods for semi-automatically extracting terminological information from texts have been introduced. Researchers of the semi-automatic extraction of terminological information have had different goals. For terminology work or terminography, the goal may be to assist with domain knowledge acquisition or to construct ontologies (Marshman 2008: 127). To achieve these goals, the extraction focuses on knowledge-rich contexts expressing terminological information, i.e. information on terms and concept relations or characteristics (see e.g. Meyer 2001).

In the field of terminology and computer science, for example, researchers have tried to automatize the extraction of knowledge-rich contexts and terminological information from texts by using terminological markers, also called knowledge probes (Ahmad & Fulford 1992) or nowadays more often knowledge patterns (e.g. Meyer 2001). The studies on knowledge patterns originate from the observation that authors use certain words or phrases to emphasize terminological information. These are linguistic phrases, punctuation marks, or typographic means which indicate terminological information in texts. This paper discusses the identification of a certain kind of terminological information, namely causal concept relations, from texts by utilizing knowledge patterns.

Terms and other terminological information have been recommended to be extracted together, and one combined model for this purpose was proposed in Pasanen (2009). This study aims, firstly, to experiment with this model using a technique which combines the use of seed terms, knowledge patterns, and a corpus tool for the semi-automatic extraction of terminological information from texts. Secondly, a basis will be formed for a further improvement of the methods currently

used for the extraction of terminologically relevant information, and furthermore, a concept system will be drafted that includes some central maritime safety concepts (cf. Aussenac-Gilles & Jacques 2008: 49).

The improvement of maritime safety is at concern of the entire maritime community worldwide. One way to prevent future accidents and incidents is to report and investigate those which have already happened. However, according to Vepsäläinen and Lappalainen (2010: 31, 40), no guidelines are mutually accepted for investigating and reporting, and the information produced by the parties involved is scattered in different databases. In the future, improvement is expected because the European Marine Casualty Information Platform (EMCIP) has started to collect information from EU Member States. Still, before the platform can fully function, the essential challenge is the question of shared taxonomy and terminology. Vepsäläinen and Lappalainen express the problem in the following way:

> Maritime safety has obviously the essential problem of broad terminology, which has not yet been standardized. This inconsistency can have a negative impact on reporting, because if one does not know, for example, what is meant by a near-miss, it is hard to report such an occasion. […] Furthermore, the inconsistent and situation-specific usage of terms causes a fundamental problem when trying to compare different researches and statistics made on safety management. (Vepsäläinen & Lappalainen 2010: 16)

Causal relations are typical of the field of maritime safety and have been the focus of research for decades. The research is mainly based on mathematical models of risk assessment, such as Reason's "Swiss cheese" model and the Bayesian Network (BN) model (see e.g. Ren, Jenkinson, Wang, Xu & Yang 2008). Bayesian networks are graphical representations of factors and the links between these factors. The relationships between network nodes and their parent nodes are quantified with probabilities. It can be asked, though, how reliable the models and probabilities are if the conceptual base is not concise. Clearly, the field of maritime safety has a strong need for a thorough concept analysis. This paper is an attempt to provide tools for this essential task.

2. Knowledge patterns in the extraction of terminological information

Knowledge patterns have been studied by a number of researchers, mostly in English (e.g. Ahmad & Fulford 1992; Christensen 2000; Feliu 2004; Meyer 2001; Pearson 1998). According to Meyer (2001: 290), knowledge patterns can be of three types: lexical, grammatical, or paralinguistic. The most common type is the lexical knowledge pattern, which involves specific lexical items. A typical grammatical knowledge pattern consists of a noun and a verb. The use of grammatical knowledge patterns requires that the corpus is part-of-speech tagged. This fact restricts the choice of corpus or may mean extra work. Paralinguistic knowledge patterns are punctuation marks or typographic means, for example.

In its basic form, a pattern-based knowledge-rich context includes a term X, a term Y, and a linguistic unit expressing a semantic relation between the terms X and Y (Auger & Barriére 2008: 6). Prototypically, these patterns take the form X + marker + Y, as in the phrase *smoking causes cancer* (Marshman 2008: 125). Commonly, the marker is a verb. Besides verbs, some adverbs, adverb clauses, prepositional phrases, or conjunctions indicate causal relations. Tiranagari et al. (2010: 2) mention, for example, the adverbs *consequently, therefore, thus, so, as, since*; the adverb clauses *as a result, as a consequence*; the prepositional phrases *for this reason, for the reason that, because of, due to*; and the conjunction *because*. However, verbs are reckoned to be the most reliable form of knowledge patterns (Barrière 2001). Therefore, I decided to focus on verbs in this paper.

According to Auger and Barrière (2008: 3), pattern-based semantic relation extraction involves four steps: defining the semantic relation of interest, discovering the patterns which express the relation in the text, searching for instances, and structuring or modifying an ontology or a

terminological database. This model requires that at least one term or pattern must be known before the search. In my earlier study on Finnish and Russian knowledge patterns, I concluded that in the semi-automatic extraction of concept relations, patterns provide the best results when a term identified earlier is included in the search string, since knowledge probes usually occur in the vicinity of terms (Pasanen 2010: 12). One method is to start with a small number of seed terms and known patterns. The system WWW2Rel (Halskov & Barrière 2008), for example, discovers new relation instances using relation patterns with one argument instantiated and the other blank.

The principle of knowledge patterns is language independent even though the actual linguistic phrases depend on languages. The biggest challenge related to the use of knowledge patterns is the difficulty of formulating the search string due to the ambiguity of linguistic units. Quite often the patterns generate invalid instances, and not every knowledge-rich context contains a pattern. In addition, some of the patterns may indicate different kinds of relations in different contexts. Furthermore, patterns vary from one domain to another and from one author to another. (See e.g. Marsham, L'Homme & Surtees 2005: 168; Pasanen 2010: 6.) Halskov and Barrière (2008: 41) argue that some knowledge patterns tend to be domain specific. Meyer (2001: 296) has noted as well that every domain seems to have a number of domain specific patterns. In spite of the challenges, researchers in the field of terminology and computer science agree that the method of using knowledge patterns for the extraction of terminological information from texts is promising and that the results will improve with the development of information technology. In many specific fields, especially in the field of maritime safety, researchers have focused on the extraction of causal relations due to their importance in the field.

3. Knowledge patterns as indicators of causal relations

According to the ISO standard 704 (ISO 704:2009(E): 26), the concept relation between cause and effect is a kind of associative relation, but no exact definition is given. The standard ISO 1087-1 (ISO 1087-1: 2000 (E/F): 5) says that a causal relation is an associative relation involving cause and its effect. These definitions are not accurate enough for practical concept analysis. In contrast, classifications presented in research reports are compiled for research purposes and are, therefore, finely graded. For practical purposes, such as terminology work or concept analysis, a more general classification is often enough. For the purposes of this study a "middle-weighted" definition of a causal relation is used, based on my earlier study (Pasanen 2009). According to that definition, a causal relation between the concepts exists when there is an activity having a purpose and a result or an event having a cause and an effect (cf. Nuopponen 2008; Pilke 2000).

In reality, causal relations seldom are as simple as this; instead, more than one cause and effect often exist in the relation. Causes and effects may also be mutually exclusive. The complexity of the issue can be illustrated by a study by Ren et al. (2008: 8), who propose a framework for modelling causal relationships in offshore safety assessment focusing on human and organizational factors. The framework proposed uses a five-level structure to address latent failures within the causal sequence of events.

Knowledge patterns have been introduced for the automatic detection and extraction of causal relations in computational linguistics (see e.g. Girju 2003) and in terminology (see e.g. Bowker & Pearson 2002: 219; Grinsted 2000: 45–47). As a result of these studies, the English verbs and verbal phrases *to cause, is caused by, result from, result(s) in, lead to, produce*, and *produce by* have proved to be strong knowledge patterns indicating causal relations. Causal relations relate to activities and the phenomena involved in these activities. It is therefore natural that the knowledge patterns indicating this type of concept relations are verbs. Equally naturally, the influencing factor is connected to activities by verbs (*to affect, to improve, to reduce*). In this study, the focus is on the above-mentioned strong knowledge patterns, although it is commonly agreed that knowledge patterns tend to be domain specific (see Meyer 2001:296). The verbs and verbal knowledge patterns applied in this study are listed in Appendix 1.

4. Material and method

The textual archive used for the experiment reported in this paper is a collection of marine accident investigation reports available on the Marine Accident Investigation Branch (MAIB) website.[1] The MAIB examines and investigates all types of marine accidents that happened to or on board United Kingdom ships worldwide and other ships in UK territorial waters. All the reports cited in this study are available on the website.

On the website, the investigation reports are listed alphabetically. Moreover, the reports have been divided into three different categories: year, vessel category, and incident. The oldest reports on the web resource are from the year 1991. For the purposes of my experiment, I randomly chose the accident type of grounding and the 10-year period starting from the year 2003 and ending in the year 2012. Furthermore, I decided to concentrate on merchant vessels. This category contained 33 reports of grounding accidents. The length of the reports varies greatly. The shortest reports have only 16 pages, and the longest has 85 pages. The reports are written in natural language and have a common structure of a narrative, an analysis of the circumstances, and recommendations. The pdf files were saved as text files, and the 33 text files give a total word count of 348,292 words.

The method utilized follows the four steps of the pattern-based semantic relation extraction model proposed by Auger and Barrière (2008: 3; see section 2 of this article). In this study, the first step, the semantic relation of interest, is the cause-and-effect relation, and the second step, the patterns which express this relation, are those extracted in former studies. Since the scope of this study does not allow presenting the process in full and the aim of this study is to demonstrate the semi-automatic extraction of causal relations, I will focus on just one core concept, the effect concept, *grounding*, designating the incident type under investigation. The effect concept is also the core node in our concept system, which we adopted from Nuopponen's (2008) model. In the searches, the upper level concept *accident* is also applied since the authors of the investigation reports often use this designation to refer to the grounding accident under investigation.

The third step, searching for instances, was conducted using a corpus tool. In this study, the corpus tool used to produce concordance lists was WordSmith 4.0.[2] The software has an advanced search function with which the search can be focused by including additional search strings that are expected to occur in the near context of the main search string. The results of the searches are reported in Appendix 1. The wildcard * represents an omitted word or words.

In this study, the fourth step, structuring a concept system, was conducted utilizing Nuopponen's (2008) model for analysing causal concept systems. The model is based on her former studies on causality and the classification of concept relations. In her study, the focus is on terminological hand-crafting, but she adds that the results may be utilized when working with corpora. The model she suggests builds on a mind map similar to the satellite system model, in which one concept is taken as a core node and point of departure, and other concepts are satellites around the core node. Nuopponen (2008: 18) divides causes into causal agents, producing causes, and explanatory causes. A causal agent is a person or a phenomenon considered to have caused something. Causal concept systems also involve patients, which are concrete or abstract objects affected by the cause and in which the effects appear. Besides these, causal concept systems contain symptoms and consequences. Symptoms belong to the resulting event, product, or state itself as its characteristics or constituent parts. Consequences may follow from the sequence of the causal chain. One interesting part in Nuopponen's concept system is the concept of counteracting causes. These are factors that counteract the causation process. Next, I will report the results of the experiment on knowledge patterns in the field of maritime safety, using the effect concept *grounding* as a point of departure.

5. Results

I started the experiment by producing concordance lists of contexts containing the knowledge

pattern under investigation without any seed term. This analysis produced a set of 1517 instances. These data are summarized in Appendix 1. The wildcard * represents an omitted letter or letters. Not all of the knowledge patterns were productive. The most productive were the verbs *to prevent, to reduce, to increase, to indicate, to result in*, and *to avoid*. Based on the results of this study, they clearly form the basis of the knowledge patterns which are typical for the domain of maritime safety. The next step was to produce concordance lists containing the most prominent knowledge patterns and the concept *grounding* designated by the term *grounding* or *accident* as its head. Each of these occurrences was then manually analysed to identify the validity of the information. In this paper I pay special attention to the relation between cause and effect as well as the relation between counteracting cause and effect. This categorization of causal relations is adopted from Nuopponen (2008: 22), in which the subcategories of the cause concept are producing causes, explanatory causes, and causal agents (see Appendix 2).

5.1. Producing causes, explanatory causes, and causal agents

In Nuopponen's conceptual model, a causal agent is a person or a phenomenon considered to have caused something (Nuopponen 2008: 18). The first obvious verb to be analysed is the verb *to cause*, even though the knowledge patterns including it were not the most productive. With the aim of searching for causal agents involved in grounding accidents, I applied the search strings *caus* the* and *caused by*, thus excluding the great number of instances containing the noun *a cause*, which was not under investigation in this study. The verb *to cause* was not as productive as expected. The search produced 58, instances and the following two information patterns were retrieved (the emphases in the examples are mine):

NP_1 + caused by + NP_2

(1) He fell asleep as a result of very high levels of *fatigue* **caused by** *the cumulative effect of this irregular working pattern*. (Jambo 2003: 1)

NP_1 + caused / causes + NP_2 + V(inf)

(2) *The contact with the seabed* lasted 16 seconds and **caused** *the vessel* to vibrate loudly (CSL Thames 2012: 3)

In 17 out of the 28 instances following the latter information pattern, the verb is in the past tense form *caused* or in another tense referring to the past. This is logical since the investigation reports examine grounding events which happened before the investigation. In 10 instances, the patient concept is the vessel, which is affected by an action or an event, as illustrated by example 2. The instances more often include explanatory causes than direct causes, as illustrated by example 1. Next, the search string including the core term *caused* + *grounding** was applied, firstly, to test the usefulness of including a term in the search and, secondly, to study whether the direct cause of the grounding accident could be retrieved from the text. The search produced eight instances, and the direct cause is indicated in only two instances. Example 3 is the only case in which the action of the master of the vessel is indicated to be the cause of the accident.

(3) **The grounding was caused by** the master electing to deviate from his planned route […] (Balmoral 2005: 17)

The knowledge patterns *caus* the* and *caused by* appeared to be productive when searching for producing or explanatory causes, in other words, actions or events as well as states, conditions, or properties which have contributed to grounding accidents. However, the patterns mentioned were not productive when searching for the causal agent, i.e. the person or phenomenon having caused the accident (cf. Nuopponen 2008: 18). The instances induced in the concordance search indicate that besides the core concept *grounding*, the upper level concept *accident* and the concept *damage* might also give fruitful results if they were included in the search string together with the verb forms.

The other verbs generally regarded to be good indicators of a causal relation are *to produce, to*

result (in), and *to lead (to)*. First, I conducted searches with the search strings *produce*, produced by*, and *producing.* The first two knowledge patterns were productive, but the instances did not give information related to the causal relation under investigation. The search employing the knowledge pattern *produc** and the core term *grounding* did not produce any hits. The collocates *chart, documentation, annual schedule, instructions*, and *signs* refer to navigational aids instead of causes, albeit navigational aids play an important role in maritime safety. The same holds for the knowledge patterns *result* in* and *result* from.* The first search was productive but did not give the kind of information which was expected. In one third of the instances the verb collocated with the noun *recommendations*, indicating that something has resulted in a recommendation. This indicates that many instances are related to the structure of the corpus instead of the expected causal relations. The search strings *leading up to* and *leading to* were not very productive, producing 26 and 36 instances respectively, but the information retrieved was closely connected with the core concept *grounding*.

The knowledge pattern *leading up to* produced 26 instances. In eight instances the pattern is the one illustrated in example 4:

(4) Events **leading up to** the grounding (Berit 2006: 4)

This similar pattern can be explained by the structure of investigation reports, in which the phrase is part of a title. It must be noted that the title implies that more than one event caused the grounding. Although in conceptual analyses an event is a concept without human involvement, in investigation reports the role of the human element is included in chapters with this title. For the purposes of the concept analyses these instances are only partly valid since the cause is hard to find in the context.

The knowledge pattern *increas** was productive with 191 instances, including a number of instances which include the state, condition, or property necessary for the final event, thus giving explanatory causes to the effect concept of grounding. The search can be narrowed by including the noun *risk* in the search, since it is often connected with the verb:

(5) That the turning basin was not made available to Dieppe, has avoidably **increased the risk** to the vessel when departing Newhaven. (Sardinia Vera 2005: 36)

The nouns *speed, wind, fatigue*, and *distance* also collocate with the verb *to increase*. The verbal knowledge patterns investigated were productive when searching for explanatory causes but not for direct causes. This can be explained by the fact that in most cases not just one but a number of states, conditions, events, or actions can be named to have caused the accident. Besides producing causes, explanatory causes, and causing agents, counteracting causes are also important for the concept analysis of maritime safety concepts.

5.2. Counteracting causes

Counteracting causes may be actors, actions, events, or circumstances, in other words, almost any kind of concept which counteracts the process (Nuopponen 2008: 21). The verb form *avoided* proved to be a strong knowledge pattern indicating the relation between a counteracting cause and the effect concept *grounding*. The search string *avoided* produced 31 instances, which are all valid. Seventeen of them have one of the following information patterns:

NP + would/could have been avoided + if ACTION or

if ACTION + NP + would/could have been avoided

Example 6 illustrates the latter pattern. The NP refers to the core concept *grounding*, which is sometimes indicated by the words *accident* or *situation*.

(6) Had the original plan been followed, *this accident* **would have been avoided**. (Balmoral 2005: 14)

It should be noted that this pattern is misleading since the counteracting cause did not actually occur. The effect concept would not have happened had the counteracting cause been realized. Still, for the future and for better maritime safety, it is important to know how similar incidents can be avoided. In the rest of the instances the verb takes the form *is to be avoided, to be avoided*, or *should be avoided.* These instances look forward, suggesting actions to be avoided to prevent similar incidents from happening.

Besides the verb *to avoid*, the verb *to prevent* is a natural candidate for the knowledge pattern for the causal relation between the counteracting cause and the effect. I first produced a concordance list with the search string *to prevent*. The knowledge pattern candidate was productive, producing 90 instances. However, due to the nature of the corpus used, in 30 instances this search matched a typical sentence employed in the analysis section of investigation reports, as illustrated by example 7:

(7) The purpose of the analysis is to determine the contributory causes and circumstances of the accident as a basis for making recommendations **to prevent** similar accidents occurring in the future. (e.g. Berit 2006: 19)

Surprisingly, the knowledge pattern *to prevent* produced information about actions directed towards preventing explanatory and productive causes from happening (see example 8). This information is valuable, since presumably it is easier to affect the causes than the grounding event.

(8) Riverdance's anchors could have been used to attempt **to prevent** the vessel being carried closer to shore on the still rising tide, [...] (Riverdance 2009: 51)

The verb *to increase* is a knowledge pattern for the cause concept. Likewise, the verbs *to decrease* and *to reduce* are knowledge pattern candidates for the counteracting cause concepts. The corpus search with the search strings *reduce*, reduced*, and *reducing* produced 201 instances, the past tense verb form being the most productive.

6. Conclusions

The method suggested here for the semi-automatic retrieval of conceptual information from untagged texts using knowledge patterns, seed terms, and a corpus tool was developed as a method for conceptual analysis. A technique combining the use of knowledge patterns and a concept model was shown to be well applicable when building concept systems or ontologies in the field of maritime safety. However, a technique combining the use of knowledge patterns and seed terms was not as productive as expected. In this aspect, more research is needed. In some respects the results were biased due to the corpus used. Firstly, the size of the corpus was not large enough to produce a sufficient number of valid instances. Normally, precise knowledge patterns which produce solely valid instances are not productive. Therefore, a large corpus is needed for their effective use. In addition, the features of the software could not be fully utilized, for example, cluster lists were not always produced. Secondly, the structure of the investigation reports and the titles follow well-established patterns, which are demonstrated in the concordance lists. In spite of these shortcuts, the method can give a new perspective on maritime safety concepts.

The results of the study give no support to the claim that accidents are often attributed to single causes in investigation reports. Only in rare cases were direct single causes given. Instead, explanatory causes were most often mentioned. This implies that accidents are caused by a series of errors or a combination of them. Regrettably, the method is not able to reveal the chains of actions or responsible parties semi-automatically, which is the interest of researchers in the field.

The experiment also raised the question of the uncertainty connected to information extracted using knowledge patterns. The importance of this phenomenon has been noted in the processing of cause-effect relations in particular (see Marshman 2008). The ultimate usefulness of

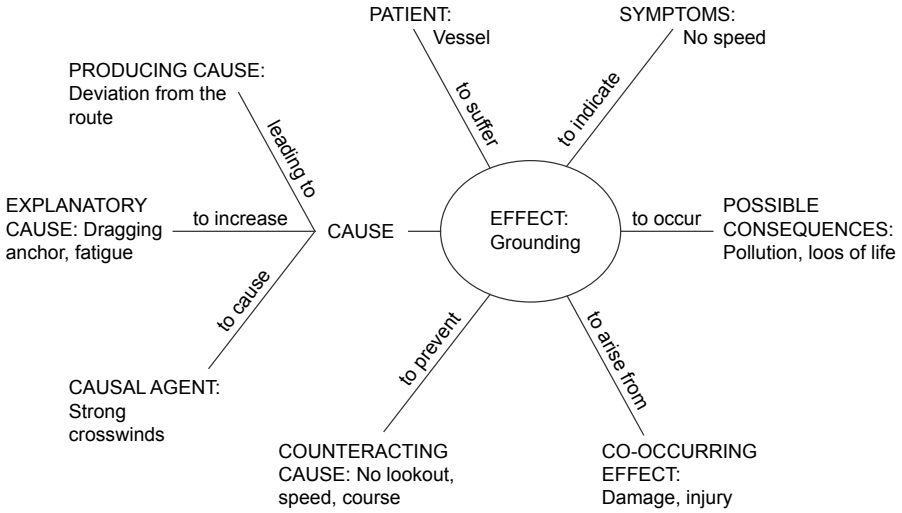
information may be indicated by textual elements such as the quantification of items linked in a relation, lexical indicators of hedging, modal verbs, or the negation of a potential relation. Some sentences in the corpus had textual elements indicating uncertainty, and undoubtedly, this phenomenon should be further studied.

7. Appendices

Appendix 1: Knowledge patterns investigated.

Search string	Frequency	Collocates	Clusters
affect*	45	safe, ability, navigation	not affected the
to avoid / avoiding / avoided avoid* + grounding*	49 / 10 / 31 16	action, grounding, accident	could / would have been avoided, action to avoid
cause* the / caused by caused + grounding*	28 / 30 8	vessel	caused the vessel
contribut* to the	40	accident, directly, safety, issues, fatigue	safety issues directly contributing to the accident
decreas*	19	depth, manoeuvrability, risk, wind, speed	
improve / improving / improved	30 / 24 / 19	safety	with the aim of improving the safety of
to increase / increases / increased / increasing increase* + risk	21 / 5 / 101 / 25 12	speed, risk, wind, fatigue, distance, vessel, master, knots	an increased risk of
indicate* / indicating	152 / 14	vessel, master, chart, fatigue, evidence, lack, need, data	to indicate / indicated / indicates that the
leading up to / leading to / can lead to /did not lead to leading (up) to + grounding* / accident	26 / 36 / 8 / 1 21 / 8	during the period, throughout the period, the latter stages	leading up to the grounding, leading up to the accident, leading up to the events, leading to the grounding, leading to recommendations
occur / occurs / occurred / occurring	17 / 3 / 98 / 41	accident(s), prevent, grounding, similar, future	to prevent similar accidents occurring in the future
to prevent / prevented / preventing prevent* + grounding*	90 / 38 / 21 19	accidents, similar, regulations, occurring, future, pollution	to prevent similar accidents, could have been prevented
produce* / produced by / producing	76 / 15 / 6	chart, documentation, annual schedule, instructions, signs	locally produced charts
reduce* / reduced / reducing reducing / reduced + risk	46 / 123 / 32 7 / 7	speed, risk, visibility, depth	had reduced to, speed was reduced
result* in / result* from	128 / 15	accident, recommendations, investigation, vessel	not resulted in
suffer* / suffer* from	46 / 8	fatigue, damage, master	suffering from fatigue, suffered damage

Appendix 2: Concept model of the concept *grounding* (adopted from Nuopponen 2008: 22).



8. Notes

[1] www.maib.gov.uk

[2] http://www.lexically.net/wordsmith/

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