

A Semi-Automatic Methodology for Making FMEA Surveys

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Abstract

This paper proposes a semi-automatic methodology to assist the user in creating surveys about FMEA and Risk Analysis, based on a customized use of the tools for semantic analysis and in particular a home-developed syntactic parser called Kompat Cognitive. The core of this work has been the analysis of the specific FMEA-related jargon and its common modalities of description within scientific papers and patents in order to systematize the linguistic analysis of the reference documents within the proposed step-divided procedure. The main goals of the methodology are to assist not skilled in the art users about FMEA during the analysis of generic and specific features, by considering large moles of contributions in restricted amounts of time. The methodology has then been tested on the same pool of 286 documents, divided between 177 and 109 patents, manually analyzed in our previous survey, in order to replicate part of its classifications through the proposed new modality. In this way we evaluated the abilities of the methodology both to automatically suggesting the main features of interest and to classify the documents according to them.

Keywords- FMEA, Risk analysis, Patents, Parsing, Semantic

1. Introduction

Since its introduction in 1949, FMEA had a great following both in industrial and scientific community as testified by the vast multitude of related documents from scientific and patent literature: to date, we have more than 3600 papers only in Scopus DB and 146 patents in Espacenet DB, just looking for one single keyword “FMEA”, without synonyms, with a trend of constant growth over the years. The great majority of these contributions deals with FMEA modifications involving the procedure and the integrations with new methods and tools in order to enlarge the field of application and to improve the efficiency of the analysis, e.g. by reducing the required time, by finding more results, etc.

In order to be able to orientate among the many contributions the surveys proposed in literature can play a fundamental role, even if they are limited in the number of considered documents by never exciding one hundred of only scientific papers from journals. Bouti and Kadi (1994) analyzed within scientific papers about FMEA, the description and review of its basic principles, the types, the improvements, the computer automation codes, the combination with other techniques and specific applications. Sutrisno and Lee (2011) analyzed, through a literature survey, the FMEA applications for enhancing service reliability, by determining how FMEA is focused on profit and supply chain-oriented service business practices and FMEA research opportunities are related to enhancement in Risk Priority Number (RPN), reprioritization, versatility of its application in

service supply chain framework and non-profit service sector as well as combination with other quality control tools are proposed for further investigations. Tixier et al. (2002) studied 62 methodologies about Risk Analysis by separating them into three different phases (identification, evaluation and hierarchisation) and by studying their inputs (plan or diagram, process and reaction, products, probability and frequency, policy, environment, text, and historical knowledge), the implemented techniques for analyze risk (qualitative, quantitative, deterministic and probabilistic) and their output (management, list, probabilistic and hierarchisation). Liu et al. (2013) analyzed the innovative proposed approaches to overcome the limitations of the conventional RPN method within 75 FMEA papers published between 1992 and 2012 by identifying which shortcomings attract the most attention, which approaches are the most popular and the inadequacy of the approaches. Other authors focused on analyzing specific kinds of application of FMEA approach. Dale and Shaw (1990) studied how 78 companies of the United Kingdom motor industry apply FMEA by identifying some common difficulties such as time constraints, poor organizational understanding of the importance of FMEA, inadequate training and lack of management commitment.

An attempt to overcome this limitation has been made by our previous surveys (Spreafico et al., 2017; Spreafico and Russo, 2019a), where we analyzed a representative pool of scientific papers (220) and patents (109), by classifying them into four groups of common improvements dealing with the applicability of the method, representation of the cause and effect chain, risk analysis and integration with the problem-solving phase. Each group has a series of subclasses about the sub-goals and the integration (methods and tools).

A common limitation for all these surveys regards their reference time period and the onerousness of execution and updating. To deal with such problems, automatic tools and techniques for text mining can be considered, which can help for different purposes: knowledge source both for papers (e.g. Google Scholar, Scopus) and for patents (e.g. Espacenet), bibliographic search tools implementing different techniques (e.g. Boolean or Semantic logics), tools for managing the documents (e.g. Mendeley), tools for text summarization and topics extraction, software for data representation (e.g. D3.js, Google Charts). However, an automatic methodology to assist the researcher to organize and manage documents about FMEA and Risk Analysis is still missing in literature.

2. The Procedure of Analysis

In order to overcome the open problems from the previous survey, we retain that a semi-automatic methodology based on semantic analysis could be a possibility as recently demonstrated for other fields of application, e.g. Sentiment analysis social media monitoring, E-discovery for legal literature and GoPubMed for biomedical texts.

In our case, starting from the same pool of documents from our previous survey (Spreafico et al., 2017), we analyzed them through a home-built software, called Kompat Cognitive (Russo et al., 2018), and we compared the linguistic rules for the linguistic analysis (e.g. logical analysis), with the specific FMEA terminology. Kompat Cognitive is an advanced version of the our previous Kompat, a syntactic Parser that allows to easily set up a sequence of terms and to automatically extract the list of terms linked to it by selecting the semantic relations. This tool has previously been used also in other fields, such as circular economy (Spreafico et al., 2019) and the investigation of the market potential of a product (Russo et al., 2019).

Through this work we collected some common linguistic forms used to describe FMEA improvements within papers and patents at different levels of detail: pursued goals, specific strategies of intervention and proposed integrations with methods and tools. We have then classified the results within a series of specific steps in order to define a systematic methodology to be automatized.

In the following, the proposed methodology is presented in detail.

2.1 STEP 1 – Building the Electronic Pool of Documents

The first step of the proposed methodology regards the digitalization of the documents, where the required output files are related to the used tools, both as regard the format, the syntactic and the organization of the content within specific text tags. In our case, we opted for the definition of a single textual file (i.e. XML) for each document, which must to be named with a univocal ID name, in order to allow the user to go trace back the document containing a determined content. The content of the electronic document is instead organized through text fields, including specific parts of the documents (e.g. introduction, state of the art and proposal), so as to allow the analysis of some parts. In this way during the enumerations of the specific proposed contributions we can avoid redundancies present within the state of the art of the considered documents. A limitation of these files concerns the impossibility to process images, tables and graphs but only the semantic relations within the sentences.

2.2 STEP 2 – Query Definition

Once the electronic pool has been defined it has to upload on the server and can be processed by Parser tool, in response to a query, consisting of a single keyword (e.g. name, verb, adjective) defined by the user, provides the main linguistic relations between the keyword and other terms (e.g. subjects, verbs, objects). These relations are identified within the single sentences of the processed documents and they also include the relations with modifiers of the keyword (e.g. synonyms, meronyms, hypernyms) that are identified on the basis of statistical patterns based on the considered pool. The kinds of identified relations by the Parser are different depending on the linguistic nature of the used keyword.

If we use a substantive (e.g. FMEA), the software provides: (1) the modifiers, or the adjectives or the substantives acting as adjectives (e.g. Design FMEA, Economic-Based FMEA), (2) the nouns and verbs modified by the keyword (e.g. FMEA template), (3) verbs using the keyword used as object (e.g. perform FMEA), (4) verbs with the keyword used as subject (e.g. FMEA is ..., FMEA generates ...), (5) substantives linked to the keyword through AND/OR relations (e.g. FMEA and TRIZ – Spreafico and Russo, 2019b) and (6) prepositional phrases (e.g. ... of FMEA, ... through FMEA). While, when we use a verb as keyword, we can instead identify: (1) the modifiers (e.g. effectively improve), (2) the objects (e.g. ... improve quality, ... improve design), (3) the subjects (e.g. TRIZ improves ...) and (4) other particles (i.e. prepositions and adverbs) used before or after the verb (e.g. determine AND select). Thus, each provided linguistic relation can be manually checked by the user: by selecting it, the tool provides the list of the sentences of the documents of the pool, which contain it. In this way, we can verify their adherence in relation to the purposes and the context of the research.

However, although the qualitative level (precision) of the analysis along with the quantity of the provided results (recall) achieved through the Parser proved to be more than acceptable in several applications from different fields, some considerations about this specific case, and in particular

regarding FMEA jargon, in order to systematize and automatize the approach.

Our main focus was then to identify the common linguistic ways along with the specific terminology used within FMEA related documents to declare interesting concepts (e.g. goal, strategies and tools). The first step regarded the definition of the terminology. Among them, we identified generic verbs (e.g. Improve, Ameliorate, Reduce) that are generally used to introduce the goals of the proposed interventions, which in turn are expressed by generic terms (e.g. costs, time, production), or strategies for improving FMEA tasks, which are instead expressed through FMEA-related terms (e.g. Failure, Modes, Effects).

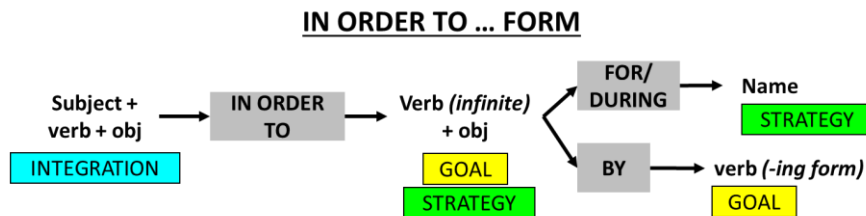
Table 1 summarizes the main terms that can be used as keywords to start the analysis, which have been enriched with synonyms and other terms that iteratively emerged during the analysis as explained in the following (Step 3).

Table 1. Initial keywords used to search the queries.

Generic terms		FMEA terms
Nouns	Verbs	
FMEA, Human, Approach, Design, Production, Maintenance, Time, Costs, Problem	Improve, Anticipate, Ameliorate, Automatize, Analyze, Reduce, Eliminate, Solve	Failures, Modes, Effects, Cause, Risk, Solving, Decision making

Then, we searched for the common linguistic constructions, involving prepositions (e.g. by, for), more articulated constructs (e.g. with the aim to) and the identified terms (verbs and nouns), and we analyzed their ways of use within the documents (e.g. introduce a tool, a goal, a strategy or relate these terms among them). As result, some common forms have been identified.

The construct “In order to” (see Figure 1) is generally used to explain the reason why a determined integration, e.g. a method or a tool, has been introduced to improve FMEA: to achieve a generic goal (e.g. reduce the required time for the application of the method) or to pursue a strategy (e.g. Determine More Failures through schematic representation). We noted that both of them are expressed through a verb with infinite form and an object. In addition, “In order to” can be followed by the particles “for” or “by”, respectively coupled with a name or a verb in “-ing” form to introduce another strategy or another goal.

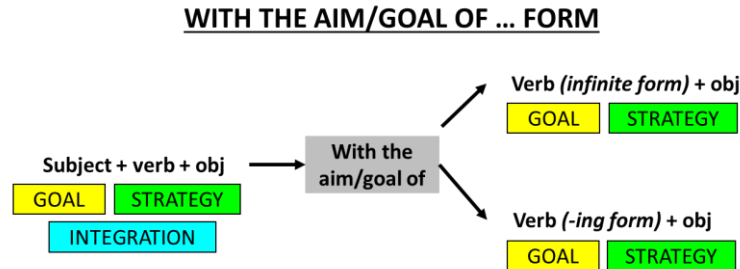


Examples:

- The proposed method integrates Fuzzy logic IN ORDER TO reduce user's subjectivity FOR risk analysis
- The proposed method integrates Fuzzy logic IN ORDER TO improve risk evaluation phase BY reducing user's subjectivity

Figure 1. Common uses of “in order to ...” form.

The constructs “With the aim of” and “With the goal of” (Figure 2) is also exploited for express the goals and the strategies related to a determined integration (methods and tools) and to relate a strategy with a goal or vice versa.

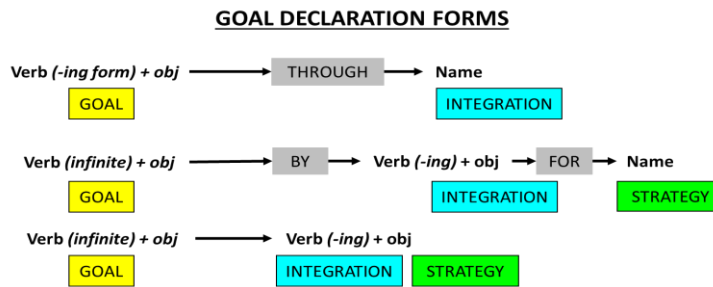


Examples:

- The proposed method integrates Fuzzy logic with the aim to reduce user’s subjectivity

Figure 2. Common uses of the constructs "With the aim of ..." and "With the goal of ...".

Other constructs are instead related to the declaration of the goals (Figure 3) of the proposed FMEA modifications. They are the prepositions “Through” and “By”, which are used after the declaration of the goal itself, expressed (through a verb and an object) to relate an integration or a strategy. Finally, the particle “For” has been used sometimes after the integration, preceded by the preposition “by”, to introduce the related strategy, in turn expressed through a name.



Examples:

- Reducing user’s subjectivity THROUGH Fuzzy logic
- Reduce user’s subjectivity BY introducing Fuzzy logic FOR risk evaluation
- Reduce user’s subjectivity calculating the risk...

Figure 3. Common linguistic forms identified for declaring the goals of the proposed FMEA modifications.

2.3 STEP 3 – Semantic Expansion and Counting of the Number

The activity carried constitutes the basis both to automatically identify the main interesting features of interest and to classify the documents according to them. However, in order to obtain a significant result regarding the document classification, the set of the identified terms has to be expanded by considering also the synonyms and other terms. In fact, the same concept can be

expressed within the documents in a multitude of different textual forms that generally increase if the investigated concept itself is more abstract.

Table 2 shows, as example, some of the combinations of verbs and objects used to express the concept “Solve problem”, found within the considered pool of documents.

Table 2. Synonyms of “Solve problem” found within the considered pool of documents.

Solve		
Eliminate	Overcome	Avoid
Deal with	Mitigate	Address
Prevent	Cause	...
Problem		
Issue	Drawback	Challenge
Trouble	Limitation	Deficiency
Disadvantage	Anomaly	...

Carrying out a linguistic expansion manually is undoubtedly a difficult and onerous task and some considerations must be taken into account. For what concern the expansion of generic terms, i.e. verbs (e.g. Solve) and common names (e.g. Interface, Design), a simple dictionary can be sufficient to achieve acceptable results, while for those specific nouns and concepts related to FMEA (e.g. Root Causes) and their integrations (e.g. Quality Function Deployment), the knowledge about the argument is required. This because they are often referred also through their multiple acronyms: e.g. TRIZ methods can be reported as “Theory of Inventive Problem Solving”, “TIPS”, “Theory of the resolution of invention-related tasks”. Moreover, there are also some variants of the methods that are typically used in different applications: table 3 reassumes some applications of Fuzzy logic, which have been identified by the Parser, by analysing the reference FMEA pool of documents.

Table 3. Examples of applications of “Fuzzy logic” found within the considered pool of documents.

Nouns and verbs modified by "fuzzy"	"fuzzy" and/or ...
Fuzzy Membership Function	Triangular Fuzzy Number
Fuzzy Analytic Hierarchy Process	Fuzzy Weighted Geometric Mean
Fuzzy Cognitive Map	Fuzzy linguistic terms
Fuzzy Decision Matrix	Fuzzy linear programming model
Fuzzy Group Fault	Trapezoidal fuzzy numbers
Fuzzy Set Theory	Fuzzy evidential reasoning

The main problem of the manual expansion of the synonyms of methods and tools is the excessive required amount of time, which typically increases when the analyst is less expert. In addition, if the process is carried out a priori can be useless, because the expansion of the synonyms, not knowing those effectively used within the pool, can digresses through extraneous terms. Fortunately, some of the available tools for semantic analysis, and the Parser, are able to automatically identify the modifiers of the used keywords within the considered pool, with a sufficient degree of accuracy. This functionality is also particularly useful to discriminate specific uses of the variants of the integrations in relation to the context of use.

Figure 4 shows how Fuzzy Logic and Fuzzy Membership Function have been related to different

goals by the Parser.

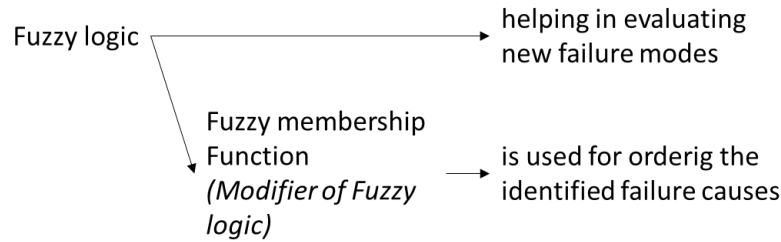


Figure 4. Identification of different goals from FMEA integrations with “Fuzzy logic” and “Fuzzy Membership Function”.

3. Case Study

In order to test the efficacy of the proposed methodology, we replied the manual classification of the solutions (i.e. strategies) to improve FMEA, from our previous survey (Spreafico et al., 2017) by comparing the obtained results. That previous survey was made on a pool constituted by 286 documents, 177 scientific papers (165 from academia and 12 from industry) and 109 patents (23 from academia and 86 from industry), collected from scientific DBs (i.e. SCOPUS) and international patents DBs (i.e. Espacenet).

Table 4 presents the considered classification about the main problems (Applicability, Cause and Effects Chain representation, Risk Analysis and Problem Solving) and the solutions to improve them identified from literature, with the total number of documents related to each of them.

Table 4. Main problems and solutions to improve FMEA, from Spreafico et al. (2017).

Problems	Solutions	Number of citations in papers/patents		
		Accad.	Ind.	Total
Applicability	Anticipate the analysis: Integrate FMEA with design methods in order to anticipate it during design phase (Liu et al., 2011)	54	18	72
	More automation (Price and Taylor, 1998)	34	19	53
	Info management: Improve management of the information through matrix and graphical representations	38	10	48
	Guidelines: Introduce new guidelines to explain the sequence of application and the single steps.	28	12	40
	Complex systems: Introduce criteria to approach complex systems by analysing all the components.	16	5	21
	User interface: Ameliorate user interface by providing data filing template (Price, 1996)	10	9	19
	New criteria: Introduce criteria to approach complex systems by reduce the number of ITEMS to be analysed (Regazzoni and Russo, 2011)	3	2	5

Table 4 continued ...

Cause and effects representation	New methods for Failure Modes identification (Lee, 2001a)	35	30	65
	New methods for Failure Effects: increase the number of determined Failure Effects (Xiao et al., 2011)	30	13	43
	Combine multiple Failures Effects , studying the result and the possible synergies (Price and Taylor, 1998)	18	8	26
	New methods for Failure Causes: Increase the number of the determined Failure Cause, including root causes (Yang et al., 2010)	10	5	15
Risk analysis	Statistical methods: quantify statistically and logically the probability of the faults	68	10	78
	Requirements-based criteria: New measure to evaluate the risks based on the analysis of the requirements	25	6	31
	Economic criteria: quantify the potential faults according to economic criteria (Rhee and Ishii, 2003)	13	3	16
	Historical data: quantify the potential faults according to historical data (Garcia and Gilabert, 2011)	9	5	14
	Qualitative criteria: Analyse qualitatively the risk, using personal judgments and impressions instead of aseptic measurements and numerical ratings (Kara-Zaitri et al., 1991)	1	4	5
Problem solving	Results representation: Improve presentation of the results by changing the interface of presentation.	27	7	34
	New methods to be integrated into FMEA (TRIZ, Maintenance management tools, etc.) (Liu et al., 2011)	19	10	29
	Use FMEA for other purposes (i.e. robust design)	3	5	8
Total		441	181	622

In order to make an objective evaluation, we applied the proposed methodology on the same pool of documents of our previous survey. So, we executed two different tests: TEST 1 aimed to investigate the ability of the proposed methodology to automatically identify the features of interest for the analysis (TEST 1) and TEST 2 to evaluate ability of the methodology in classify the documents according to the features.

3.1 Results

3.1.1 TEST 1. Identifying the Features

During this first test, we used simple generic keywords consisting of common nouns (e.g. FMEA, Failures, Guidelines) and we considered only one semantic structure where the keywords are used as object in relation to the verbs automatically provided by the Parser. The test is considered positive if the Parser is able to suggest relations referred to the features (Problems) of the previous survey. As further confirmation, we manually checked the sentences of the documents provided by the Parser for each relation in order to verify their adherence with the relative feature.

Table 5 collects, for each previously determined feature, the used keywords, the considered relations and the pertinent sentences. As first confirmation of the goodness of the methodology, from the table, we can see that for each feature, one pertinent sentence has been determined.

Table 5. Investigated solutions, used queries and obtained sentences.

Features (“Solutions” from previous survey)	Query (used keywords)	Identified relation (verb + keyword)	Identified sentence
Anticipate the analysis	Design	Improve design	"conventional design FMEA is often performed by the design team" (Kmenta and Ishii, 2004) "in producing the parts and to simplify and improve the design" (Teng and Ho, 1996)
More automation	FMEA	Automate FMEA	"proposed a concept for automated FMEA employing qualitative reasoning" (Kmenta and Ishii, 1998)
Info management	Information	Manage information	"systemically manage the FMECA information of each part" (Lee, 2001b)
Guidelines	Guidelines	Provide guidelines	"The method of this invention provides a few innovative guidelines to the implementation of a DFMEA technique" (Cutuli et al., 2001; U.S. Patent No. 10,330,485)
Complex systems	Systems	Analyze complex systems	"The framework has been applied to model and analyze a complex industrial system from a paper mill" (Sharma et al., 2008)
User interface	User	Provide user interface	"this methodology and provide a user interface to combine all the methods used in it" (Hassan et al., 2010)
New criteria	Criteria	Propose criteria	"Table VIII reports the pairwise comparisons given by the maintenance staff in terms of the four criteria proposed for the failure cause analysis problem" (Boggarapu et al., 2001; U.S. Patent No. 13,113,593)
New methods for Failure Modes	Failures	Identify failure modes	"The proposed method uses behavior modeling to map control functions to physical entities and identifies failure modes" (Kmenta and Ishii, 1998)
New methods for Failure Effects	Failures	Determine failure effects	"to determine the failure effects of the underlying component failure modes by means of the fault simulation analysis method; finally, the redundancy is solved by the hazard analysis method which takes into account the effects of multiple faults Inaccurate system analysis" (Chen et al., 2013; Chinese patent No. CN 10632162 (A))
Combine multiples Failure Effects	Failures	Consider multiple failures	"The new procedure allows for the consideration of multiple failures while retaining all the characteristics of FMEA" (Pickard et al., 2005)
New methods for Failure Causes	Failures	Identify failure causes	"It is a methodological tool which allows identifying and describing the failures scenarios for a given product or service. At the same time, ..., identifies the causes" (Laaroussi et al., 2007)
Statistical methods	Method	Approach statistical methods	"Failure prognostics has been approached via a variety of techniques ranging from probabilistic / statistical methods" (Abbas and Vachtsevanos, 2009)
Requirements-based criteria	Requirements	Identify requirements	"The first starts by identifying functional requirements and continues with performing a safety analysis, such as a Fault Tree Analysis, in order to identify non-expected system behavior" (Guo and Liggesmeyer, 2013; U.S. Patent No. 13,181,681)
Economic criteria	Costs	Analyze costs	"exemplary graphical user display showing cost analyzed and prioritized failure modes using the data" (Conchieri et al., 2009; U.S. Patent No. 11,859,199)
Historical data	Data	Are historical data	"The information used can be historical data, theoretical analysis, expert opinions and the attitude of interested parties" (Petrovic et al., 2014)
Qualitative criteria	Analysis	Perform qualitative analysis	"performing a sequence based qualitative risk analysis to identify a plurality of safety critical" (Guo and Liggesmeyer, 2013; U.S. Patent No. 13,181,681)
Results representation	Failures	Improve failures representation	"The purpose of scenario-based FMEA is to improve the representation of failures" (Kmenta and Ishii, 2000)
New methods	Method	Adopt TRIZ method	"To solve contradiction in order to improve service quality, we can adopt TRIZ method" (Wirawan and Ayu, 2014)
Use FMEA for other purposes	FMEA	Use FMEA for ...	"Using FMEA for early robustness analysis of Web-based systems" (Zhou et al., 2012)

3.1.2 TEST 2: Counting the Results

During the second test, we evaluate the ability of the methodology in classifying the documents according to the determined features. In order to check this functionality, we used specific keywords for each feature and we manually checked the sentences provided for the main linguistic relations between the keywords and their modifiers with other terms. For each sentence that has been considered pertinent with a certain feature, we traced back the corresponding document through its univocal ID. For instance, in order to identifying those documents dealing with the feature “Anticipate the analysis”, we used the keyword “Anticipate”, we analyzed the relations “Anticipate DURING ...”, “Anticipate AND/OR prevent ...” etc., and we checked the identified sentences from the documents that, for the sake of brevity, in the table are reported with an associated number that can be found in the legend.

Table 6 collects the achieved results: the features, with the number of related components from previous survey, the used keywords, the selected linguistic relations, the pertinent documents (references and total number) for each feature and the index of efficacy (expressed in percentage).

Table 6. Investigated solutions, used queries and identified documents.

Features (“Solutions” from previous survey)	Total number of documents (from previous survey)	Query	Related documents (only selected papers)	Total number of documents identified through the proposed methodology	Efficacy Index
Anticipate the analysis	72	<p>anticipate: * during, * failures, *mode, *scenario, * problem, * AND/OR evaluate, * AND/OR eliminate, *AND/OR prevent</p> <p>design: * FMEA, product *, * product, * reliability, * system, * part, * measure, * AND/OR implement, * AND/OR manufacturing, * FOR ..., * INTO ..., * IN ..., * OF ..., * WITH ..., * TO ..., improve *</p> <p>manufacturing: * process, * design</p>	Almannai et al. (2008), Arcidiacono and Campatelli (2004), Bertelli and Loureiro (2015), Bowles and Pelaez (1995), Braglia et al. (2007), Bell et al. (1992), David et al. (2010), Deshpande and Modak (2002), Dominguez-Garcia et al. (2006), Ebrahimipour et al. (2010), Eubanks et al. (1997), Eubanks et al. (1996), Hassan et al. (2010), Kim et al. (2013), Kimura et al. (2002), Kmenta et al. (1999), Kmenta and Ishii (2000), Kmenta and Ishii (2004), Kmenta et al. (2003), Ku et al. (2008), Lopez et al. (2010), Mader et al. (2013), Neghab et al. (2011), Wang et al. (2009), Regazzoni and Russo (2011), Rhee and Ishii (2003), Russomanno et al. (1994), Sharma et al. (2007), Sharma et al. (2005), Ming Tan (2003), Tay and Lim (2010), Teng and Ho (1996), Teoh and Case (2004), Vahdani et al. (2015), Wang (2011), Wang and Elhag (2007), Wang et al. (2004), Wirawan and Ayu (2014), Wirth et al. (1996), Zeng et al. (2015), Zhao and Zhu (2010), Zhao et al. (2009), Foster (2012)	73	+1%

Table 6 continued ...

More automation	53	<p>automate: * FMEA, * XMEA, * generation, * prediction, * process, * mode, * OF ..., * simulation, design *, process *, * OF ..., in order to *</p> <p>automatic: * generation, * module, * extraction, * validation, * way, * update, * learning</p> <p>automating: by *</p> <p>simulate: simulate + system, * in ..., * and analyze, * or test, * how ...</p>	Augustine et al. (2009), Braglia et al. (2003), Carmignani (2009), Chin et al. (2008), David et al. (2010), Elmqvist and Nadjm-Tehreani (2008), Eubanks et al. (1997), Hunt et al. (1993), Kmenta et al. (2003), Kmenta and Ishii (1998), Lopez et al. (2010), Mader et al. (2013), Abbas and Vachtsevanos (2009), Montgomery and Marko (1997), Montgomery et al. (1996), Ormsby et al. (1991), Pelaez and Bowles (1995), Palumbo (1994), Park et al. (2009), Wang et al. (2009), Pillay and Wang (2003), Price and Taylor (1998), Price (1996), Price et al. (1995), Tay and Lim (2010), Teoh and Case (2004), Throop et al. (2001), Vernez et al. (2004), Wang et al. (2009), Wang et al. (2004), Wirth et al. (1996), Xiao et al. (2011), Yang et al. (2010), Foster (2012), Yasko et al. (2016)	55	+4%
Info management	48	<p>manage: * information, * requirement, * document, * risk, sistematically *, database *es, method *es, *d by database, * in database</p> <p>information: maintenance *, history *, diagnostic *, content *, collected *, update *, * represents, represent *</p>	Bertolini et al. (2006), Bell et al. (1992), Deshpande and Modak (2002), Granström (2008), Kmenta and Ishii (2004), Kumar and Chaturvedhi (2011), Liu et al. (2010), Pujawan and Geraldin (2009), Tay and Lim (2010), Teng and Ho (1996), Wirawan and Ayu (2014), Yang et al. (2010)	49	+2%
Guidelines	40	<p>guidelines: design *, methodological *, include *, * are ..., * for ..., ... as *</p> <p>through: * guidelines</p>	Arcidiacono and Campatelli (2004), Bevilacqua et al. (2000), Braglia et al. (2003), David et al. (2010), Hassan et al. (2010), Kara-Zaitri et al. (1991), Mandal and Maiti (2014), Neghab et al. (2011), Niu et al. (2011), Petrovic et al. (2014), Wang et al. (2009), Shahin (2004), Tay and Lim (2010), Wang and Elhag (2007), Wang et al. (2009), Wang et al. (2004), Wardani and Pharmatrisanti (2011), Wirth et al. (1996), Zafiroopoulos and Dyalinas (2005)	31	-22%
Complex systems	21	<p>complex: * system</p>	Bevilacqua et al. (2000), Braglia et al. (2003), David et al. (2010), Dominguez-Garcia et al. (2006), Eubanks et al. (1997), Garcia and Schirru (2005), Liu et al. (2012), Liu et al. (2010), Mader et al. (2013), Rhee and Ishii (2003), Sharma and Sharma (2010), Sharma et al. (2008), Vernez et al. (2004), Xiao et al. (2011)	35	+67%
User Interface	19	<p>through: * user interface</p> <p>user: * interface</p>	Chin et al. (2008), Hassan et al. (2010), Al-Humaidi and Tan (2012)	21	+11%
New criteria	5	<p>reduce: * number, * the amount of information</p>	Catelani et al. (2015)	3	-40%

Table 6 continued ...

<p>New methods for Failure Modes</p>	<p>65</p>	<p>mode: determine *, failure * entry, potential failure * identify: identify *</p>	<p>Bertolini et al. (2006), Bell et al. (1992), Chang and Wen (2010), Dominguez-Garcia et al. (2006), Eubanks et al. (1997), Garcia and Gilabert (2011), Garcia and Schirru (2005), Goble and Brombacher (1999), Hassan et al. (2010), Jee et al. (2015), Jeon et al. (2007), Jong et al. (2013), Kmenta and Ishii (2000), Kmenta and Ishii (1998), Ku et al. (2008), Kutlu and Ekmekcioglu (2012), Liu et al. (2010), Liu et al. (2014), Liu et al. (2011), Lopez et al. (2010), Mader et al. (2013), Mathew et al. (2012), Montgomery and Marko (1997), Montgomery et al. (1996), Pillay and Wang (2003), Regazzoni and Russo (2011), Rhee and Ishii (2003), Sharma and Sharma (2010), Sharma et al. (2008), Ming Tan (2003), Teng and Ho (1996), Al-Humaidi and Tan (2012), Vahdani et al. (2015), Zafiroopoulos and Dyalinas (2005), Tingdi et al. (2004), Foster (2012), Abdelgawad and Fayek (2010)</p>	<p>67</p>	<p>+3%</p>
<p>New methods for Failure Effects</p>	<p>43</p>	<p>effect: identify * determine: * effects identify: * effects define: * effects</p>	<p>Bas (2011), Braglia et al. (2007), Braglia et al. (2003), Elmqvist and Nadjm-Tehreani (2008), Eubanks et al. (1997), Eubanks et al. (1996), Gandhi and Agrawal (1992), Jee et al. (2015), Kimura et al. (2002), Kmenta and Ishii (2000), Liu et al. (2014), Liu et al. (2011), Lopez et al. (2010), Abbas and Vachtsevanos (2009), Neghab et al. (2011), Ozarin (2008), Pelaez and Bowles (1995), Regazzoni and Russo (2011), Sharma et al. (2008), Suddle (2009), Teng and Ho (1996), Vahdani et al. (2015), Wang et al. (2009), Wirth et al. (1996), Yang et al. (2010), Zafiroopoulos and Dyalinas (2005), Zhou et al. (2012)</p>	<p>45</p>	<p>+5%</p>
<p>Combine multiple Failures Effects</p>	<p>26</p>	<p>effect: * relationship, * combination multiple: * failures, * effects, * fault, * propagation, * failure scenario combination: failure *, cause and effect *, possible *</p>	<p>David et al. (2010), Kmenta and Ishii (2004), Ku et al. (2008), Liu et al. (2010), Lopez et al. (2010), Palumbo (1994), Price and Taylor (1998), Rhee and Ishii (2002), Rhee and Ishii (2003), Seyed-Hosseini et al. (2006), Suddle (2009), Thurnes et al. (2015), Xiao et al. (2011)</p>	<p>27</p>	<p>+4%</p>
<p>New methods for Failure Causes</p>	<p>15</p>	<p>identify: * mode, * cause find: * cause</p>	<p>Augustine et al. (2009), Denson et al. (2014), Jee et al. (2015), Kara-Zaitri et al. (1991), Kmenta et al. (1999), Kmenta and Ishii (2000), Kmenta and Ishii (2004), Kmenta and Ishii (1998), Ku et al. (2008), Kumar and Chaturvedhy (2011), Laaroussi et al. (2007), Regazzoni and Russo (2011), Sharma et al. (2008), Yadav et al. (2006)</p>	<p>20</p>	<p>+33%</p>

Table 6 continued ...

<p>Statistical methods</p>	<p>78</p>	<p>statistic: * risk, * fault, * class probability: occurrence *, failure *, severity *, fuzzy *, * value, estimate *, conditional *, estimated * evaluate risk with: * risk with fuzzy * risk of: * risk of fuzzy asses: * probability determine: * probability estimate: * probability compute: * probability associate: * probability evaluate: * probability through: * probability</p>	<p>Bas (2011), Bevilacqua et al. (2000), Bowles and Pelaez (1995), Chin et al. (2008), David et al. (2010), Dominguez-Garcia et al. (2006), Van Bossuyt et al. (2012), Elmqvist and Nadjm-Tehreani (2008), Garcia and Gilabert (2011), Garcia and Schirru (2005), Jenab et al. (2015), Kerk et al. (2017), Kim et al. (2013), Kmenta and Ishii (2000), Kmenta and Ishii (2004), Kmenta et al. (2003), Kmenta and Ishii (1998), Ku et al. (2008), Kumar and Chaturvedhy (2011), Lee (2001b), Liu et al. (2011), Liu et al. (2010), Mandal and Maiti (2014), Mandal et al. (2015), Niu et al. (2011), Pillay and Wang (2002), Pillay and Wang (2003), Pujawan and Geraldin (2009), Sharma and Sharma (2010), Sharma et al. (2008), Sharma et al. (2007), Sharma et al. (2005), Suddle (2009), Suganthi and Kumar (2010), Tang et al. (2015), Thurnes et al. (2015), Vahdani et al. (2015), Wang et al. (2004), Xiao et al. (2011), Yang et al. (2010), Zafiroopoulos and Dyalinas (2005), Yang et al. (2009), Zambrano et al. (2007), Foster (2012)</p>	<p>80</p>	<p>+3%</p>
<p>Requirements-based criteria</p>	<p>31</p>	<p>requirement: * is ..., * is not ..., * is feedback, verify *, maintain *, enhance *, meeting reliability *, reliability * analysis, * associated with ...</p>	<p>David et al. (2010), Mader et al. (2013), Teng and Ho (1996), Wang and Elhag (2007), Yadav et al. (2006), Zafiroopoulos and Dyalinas (2005)</p>	<p>24</p>	<p>-23%</p>
<p>Economic criteria</p>	<p>16</p>	<p>evaluate risk in: * risk in economic terms risk: cost *, cost * evaluation, monetary * evaluation, measure * in term of, business *, economical * determine: * financial risk cost: evaluation * through: * economic criteria economic: * consideration, * decision making</p>	<p>Braglia et al. (2003), Carmignani (2009), Van Bossuyt et al. (2012), Hassan et al. (2010), Kmenta and Ishii (2000), Rhee and Ishii (2002), Rhee and Ishii (2003), Sharma and Sharma (2010), Sharma et al. (2008), Su et al. (2014), Suddle (2009)</p>	<p>17</p>	<p>+6%</p>
<p>Historical data</p>	<p>14</p>	<p>historical: * datum</p>	<p>Chang and Wen (2010), Kimura et al. (2002), Liu et al. (2011), Liu et al. (2012), Lopez et al. (2010), Petrovic et al. (2014), Regazzoni and Russo (2011), Tay and Lim (2010), Teoh and Case (2004), Vahdani et al. (2015), Abdelgawad and Fayek (2010)</p>	<p>27</p>	<p>+93%</p>

Table 6 continued ...

Qualitative criteria	5	risk: qualitative * evaluation qualitative: * analysis, * evaluation, * assessment	Bowles and Pelaez (1995), Braglia et al. (2007), Chin et al. (2008), Demichela et al. (2004), Dominguez-Garcia et al. (2006), Kim et al. (2013), Sharma et al. (2008), Zafiroopoulos and Dyalinas (2005), Abdelgawad and Fayek (2010)	13	+160%
Results representation	34	result: represent *, present * representation: provide * by: * providing results representation	Bas (2011), Carmignani (2009), Chai et al. (2016), Chang and Wen (2010), Kmenta and Ishii (2004), Kumar and Chaturvedhy (2011), Kutlu and Ekmekcioglu (2011), Lindahl (1999), Liu et al. (2010), Mandal and Maiti (2014), Mandal et al. (2015), Petrovic et al. (2014), Seyed-Hosseini et al. (2006), Sharma et al. (2005), Zhao and Zhu (2010)	37	+9%
New methods	29	integrate: * technique, * tool, * method, * problem, * with ...	Arcidiacono and Campatelli (2004), Braglia (2000), Braglia et al. (2007), David et al. (2010), Elmqvist and Nadjm-Tehreani (2008), Hu et al. (2014), Kutlu and Ekmekcioglu (2011), Laaroussi et al. (2007), Lee (2001b), Lolli et al. (2015), Neghab et al. (2011), Regazzoni and Russo (2011), Thurnes et al. (2015), Yang et al. (2010), Yu et al. (2011), Zafiroopoulos and Dyalinas (2005), Emovon et al. (2014)	32	+10%
Use FMEA for other purposes	8	use: * FMEA for ... apply: * FMEA for ...	Chin et al. (2008), Kerk et al. (2017), Kmenta et al. (1999), Kmenta and Ishii (2004), Zhou et al. (2012)	12	+50%

3.2 Discussion of the Results

Both the tests achieved positive results by confirming the validity of the proposed methodology both in identifying the features and in classifying the documents according to them.

During the first test, all the features of the previous survey have been identified by using simple generic keywords not requiring a specific knowledge about FMEA. While, the results arising from the second test are encouraging even if with different levels of efficacy of the queries depending on the cases: for some of them (e.g. Historical data) the keyword “Historical” in relation to the word “Datum” has been sufficient to determine many more documents compared to the previous survey (+ 93%), while in other cases (e.g. Economic Criteria) we did not obtain the same success.

Only for specific searches, the knowledge about FMEA had been required: e.g. to collect all the documents dealing with FMEA anticipation, the network of relations generated from the more obvious keyword (i.e. “Anticipate”) has not been sufficient, so we had also to use the keywords “Design” and “Manufacturing” which represent the two main phases during which FMEA can be anticipated. This strategy can be considered for searching the more abstract features underlying a wider interpretation and expressed through different textual forms; e.g. to identify the documents dealing with the integrations with “Statistical methods”, the keyword “probability” proved to be much more useful than the more obvious “statistic”. Consequently, the choice of the most suitable features of analysis can influence the efficacy of the proposed methodology: the “better ones” are able to easily suggest a great number of possible lexical declinations to be used as keywords to increase the recall of the results.

A disadvantage of the proposed methodology regards the electronic format of the analyzed inputs, which are limited to the pure textual information, by excluding other contents (e.g. images, graphs and tables). As consequence, through the experiments emerged that some information can be lost, and this aspect is more accentuated in papers rather than in patents, which authors are generally used to more accurately describe the content of not-textual elements within the text.

Anyway, the undoubted advantage of the methodology is the strong reduction of the time required to perform the analysis, quantifiable in the executed tests in 5 days instead of in more than 6 weeks for the manual analysis.

Among the expected future developments there are the automation of the definition of the electronic pool and the research for the integrations with tools for the management of the bibliography (e.g. Scopus and Mendeley).

4. Conclusions

In this paper, a semi-automatic methodology to build FMEA surveys involving a home-built syntactic Parser has been introduced and the results of its test on a pool of 286 documents, divided between 177 and 109 patents, replying a previous manual work of analysis, have been reported. As result from the tests, the proposed methodology proved to be useful both to automatically determine the main features of interest to be analyzed within the pool and to classify the documents according to them, while saving a consistent amount of time.

Furthermore, the qualitative level achieved by the analysis (recall) can be in most cases higher than that manually obtained even if the knowledge about FMEA of the executioner can be crucial especially for checking possible misunderstanding related to the specific jargon. However, this fact seems do not preclude novices from using the methodology by reaching good results.

In particular, the use of the methodology to identify new features can increase the depth of the level of the analysis also in addition to those manually pre-determined for particular exigencies. While, the automatic classify the documents can be instead a useful tool especially for not expert users, since the major part of the results (> 60%) has been achieved by using generic and easy conceivable keywords, even if a supervised selection of homogenous and alternative features for the analysis can increase the precision of the analysis.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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