How to understand better "smart vehicle"? Knowledge Extraction for the Automotive Sector Using Web of Things

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Abstract. How to understand better the knowledge provided by Google results to build future "smart vehicle-centric" applications? What is the knowledge expertise required to build a smart vehicle application (e.g., driver assistance system)?

Automotive companies (e.g., Toyota, BMW, Renault) are employing Internet of Things (IoT) and Semantic Web technologies to model the automotive sector. We aggregate this "common sense knowledge" in an automotive dataset which comprises 42 semantics-based projects between 2005 and 2019. The knowledge is already encoded with knowledge representation languages (e.g., RDF, RDFS, and OWL) and supported by the World Wide Web Consortium (W3C). However, only a subset of those projects share their expertise by publishing their ontologies online. For this reason, at the current time of writing, only 16 ontologies are processable.

Our innovative Knowledge Extraction for the Automotive Sector (KEAS) methodology analyzes what are the most popular terms required to build a smart car, it provides: 1) a set of keyphrase that are synonyms to smart cars to find domain-specific knowledge, 2) synonyms are used to build a corpus of scientific publications to train the k-means machine learning algorithm, 3) a dataset of smart car ontologies that we collected, is analyzed by the k-means algorithm, and 4) the extraction of the most common terms from the ontology dataset for the automotive sector.

Our KEAS findings can be used as a starting point for further domain-specific investigations (e.g., Volvo willing to integrate semantic web) and for future information extraction from structured knowledge.

Keywords: Internet of Things (IoT), Knowledge Directory Service, Semantic Ontology Interoperability, Ontology Validation, Reusability, Semantic Web of Things (SWoT), Semantic Web Technologies, Reusable Knowledge.

1 Highlights

– Reusing knowledge already designed for knowledge-based smart car projects.
– Automatic knowledge extraction for the automotive sector based using the k-mean machine learning algorithm.

2 Introduction

How to understand better the results provided by Google to build the future "smart vehicle-centric" applications? What is the knowledge expertise required to build a smart vehicle application such as the driver assistance system? According to PC magazine[5], a **smart car** is an automobile with advanced electronics. Microprocessors have been used in car engines since the late 1960s and have steadily increased in usage throughout the engine and drivetrain to improve stability, braking and general comfort. According to Gartner's 2018 prediction[6], "IoT platforms","Autonomous Driving Level 4", and "Knowledge Graphs" are the next challenges for the coming 5-10 years or even beyond.

Automotive companies (e.g., **Toyota**[7] [1], **BMW** [2] [3] [4] [5], **Renault** [6]) are already employing Internet of Things (IoT) and Semantic Web technologies. BMW Autonomous Driving in the Internet of Cars Summer School[8] demonstrates interest in IoT technologies and even Semantic Web technologies [3]. BMW is designing the Vehicle Signal and Attribute (VSSO) ontology[9] [2] and the Vehicle Driving Context (VDC) ontology[10]. **auto.schema.org**[11] defines 4 types, 20 properties and 3 enumeration values (in December 2018) which clearly shows that the knowledge could be extended. Volvo is investigating the integration of semantic web technologies (RDF, Linked Data, ontologies) for automomous cars[12].

Acquiring knowledge about automotive (e.g., technological survey, reading scientific publications and staying updating with the latest progresses) is a time-consuming approach. The survey about transportation ontologies [7], published in 2018, can be easily enriched with numerous ontologies that we collected within the LOV4IoT ontology catalog for IoT and transport[13] that we designed. The survey [7] compares 11 ontologies according to 7 criteria: 1) Precision (relationship diversity, axiom complexity), 2) Evaluation, 3) Knowledge management services, 4) Generality, 5) Granularity, 6) Competence, and 7) Span.

We designed the "semantic-based IoT smart vehicle" LOV4IoT dataset thats collects common sense knowledge for the automative sector. We classified 42

[5] http://bit.ly/2xMZQDv
[6] https://gtnr.it/2SgUvOi
[7] http://bit.ly/2Y3A1xL
[8] http://www.bmwsummerschool.com/
[9] http://automotive.eurecom.fr/vsso
[10] http://automotive.eurecom.fr/vdc
[11] https://auto.schema.org/
[12] https://twitter.com/olafhartig/status/1121539105924550661
[13] http://lov4iot.appspot.com/?p=lov4iot-transport

projects between 2005 and 2019 since they claim that the knowledge is already encoded with knowledge representation languages (e.g., RDF, RDFS, and OWL) and supported by the World Wide Web Consortium (W3C). However, only a subset of those projects share their expertise by publishing their ontologies online. For this reason, at the current time or writing, our dataset comprises only 16 processable ontologies.

Motivation are as follows:

- M1: Why cannot we find the entire PhD thesis, entitled "Using Ontologies and Intelligent Systems for Traffic Accident Assistance in Vehicular Environments" [8] published in 2014 relevant for smart car on the first page of Google results? It is provided on the third page on Google[14] whereas years of research and expertise are explained in the thesis.
- M2: How to find more knowledge than Google for a specific domain (e.g, smart vehicle)?
- M3: Why does the Google Knowledge Graph cannot provide results to handle the synonyms used for the automotive domain (e.g., smart car, smart vehicle, smart mobility)?

Research questions are as follows:

- RQ1: How to automatically analyze structured knowledge (e.g., ontologies) from existing projects? We found that numerous projects designed ontologies that are also explained within scientific publications can be analyzed.
- RQ2: What are the most used entities (e.g, concepts, instances) within those ontologies? Statistical methods can help to achieve this task.

Contributions are as follows: Our innovative Knowledge Extraction for the Automotive Sector (KEAS) methodology understands the "common sense knowledge" required to build smart vehicle applications which provides:

1. C1: A set of keyphrase synonyms for the smart vehicle domain to find domain-specific knowledge in past or current projects that published their results within scientific publications,
2. C2: Synonyms are used to build a corpus of scientific publications to train the k-means machine learning algorithm,
3. C3: A dataset of smart car ontologies is built and analyzed by the k-means algorithm to cluster knowledge, and,
4. C4: The extraction of the most common knowledge for the automotive sector. We refined a previous methodology [9] that we applied to the smart vehicle domain in this book chapter.

Structure of the Paper: Section 3 introduces the related work. Section 4 explains our Knowledge Extraction for the Automotive Sector (KEAS) methodology to find the relevant knowledge already implemented within ontologies. Section 5 evaluates our proposed approach. Section 6 concludes the paper and provides future work.

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[14] "Smart car ontology" search on Google, December 2018

3 Background and Related Work

Toyota Motor Europe (TME)[15] uses auto.schema.org in their web site to describe cars to sell. For instance, 7000 URLs including the type "Car" from the TME web site have been encoded and indexed by Google.

auto.schema.org[16] defines 4 types (BusOrCoach, CarUsageType, Motorcycle, MotorizedBicycle), 20 properties (accelerationTime, acrissCode, bodyType, emissionsCO2, engineDisplacement, enginePower, engineType, fuelCapacity, meetsEmissionStandard, modelDate, payload, roofLoad, seatingCapacity, speed, tongueWeight, torque, trailerWeight, vehicleSpecialUsage, weightTotal, wheelbase) and 3 enumeration values (DrivingSchoolVehicleUsage, RentalVehicleUsage, TaxiVehicleUsage) (in December 2018). It clearly shows the the knowledge could be extended.

OpenSensingCity[17] references 12 ontology URLs relevant to mobility: Transport, travel domain, transportation networks, transport disruption, soft mobility, PASSIM, location concept for travel support system, route, ASK-IT, road, transit.

SAREF4AUTO is being specified and supported by the ETSI standard; the ontology code and specification cannot be found yet, only those slides can be investigated [10] at the time of this writing.

Conclusion: Ontology-based projects are introduced in Table 1 when ontologies are publicly available, that we analyze thanks to the KEAS methodology in Section 4.2. Other projects related to the topic that cannot be used since ontologies are not shared (as depicted in Table 2). Although scientific publications were really interesting, those ontologies have been discarded since we cannot find their ontology online (see Table 2).

4 Knowledge Extraction for the Automotive Sector (KEAS) Methodology

The long-term vision of the Knowledge Extraction from IoT-related ontologies project is depicted in Figure 1. In this paper, we are focused on the *Ontology code extraction algorithm* and the *Ontology Dataset* components applied to the smart vehicle domain.

4.1 Survey methodology to collect ontologies for smart vehicles

Scientific Publication Corpus and Ontology Dataset. We collected a total of 42 projects from 2005 to 2018 more or less related to smart vehicles. However, the aggregation of knowledge has been done since several years. The methodology

[15] `http://bit.ly/2Y3A1xL`
[16] `https://auto.schema.org/`
[17] `http://ci.emse.fr/opensensingcity/ns/result/domain/transportation/`

Authors	Year	Expertise	OA	Reasoning
Klotz et al. [2] [4] [5]	2018	BMW: Vehicle Signal and Attribute	✓	✓OWL restriction
OpenSensingCity	2018	Parking Scenario Bike Scenario	✓ ✓	✗ ✗
CityPulse [11] [12]	2016	Traffic Analysis Scenario	✓	-
Gyrard et al. [3] BMW Summer School	2014	Transport Ontology	✓	✓Jena rules
Morignot et al. [13]	2013	Autonomous Vehicle Assistance	✓	✓foggy -> mode manual
Zhao et al. [14] [15] [16] [17] [1]	2017-2014	Toyota: Safe Autonomous Driving	✓	✓SWRL
Lecue et al. [18]	2014	STAR-CITY: Transport Ontology	✓	-
Ruta et al. [19] [20] [21]	2017	iDriveSafe Ontology Mafalda projet (3 ontologies)	✓ ✓	✓OWL restrictions
Maarala [22]	2017	Traffic Ontology	✓	✓16 rules, OWL restrictions
Bermejo et al. [23]	2013	Road Traffic Management Ontology	✓	✓77 rules/actions (SWRL DLSafe rule in the ontology)
Dardailler et al.	2012	W3C Road Accident Ontology	✓	✗
Corsar et al. [24]	2015	Transport Disruption Ontology	✓	✓OWL restriction
Codescu et al. [25]	2011	Open Street Map and Route Planning	✓	✗
Grausberg, Fuchs et al. [26] [27]	2008	Driver Assistance System Ontology	✓	✓OWL restriction (rule speed max min)
Hepp et al.	-	W3C Vehicle Sales Ontology	✓	✗No owl:Restriction

Table 1. Ontology-based IoT automotive projects used in the dataset that we analyzed. Legend: Ontology Availability (OA)

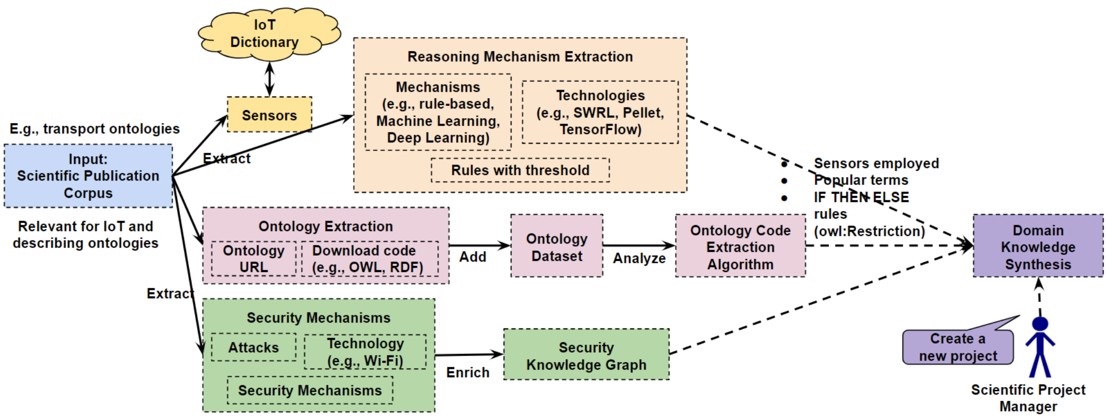

Fig. 1. Knowledge extraction from scientific publications and ontologies (Long-term vision)

Authors	Year	Expertise	OA	Reasoning
Wetterwald et al. [10]	2019	SAREF4AUTO	✗	✗
Katsumi et al. [7]	2018	Survey - 11 ontology referenced	✗	✗
Fernandez et al. [28]	2016	Automatic traffic lights settings	✗	✗
Armand et al. [6]	2014	Renault: Driving Assitance	✗	✓14 SWRL rules
Villalba et al. [8] [29] [30]	2014	VEACON: Vehicular Accident CAOVA: Car Accident for VANETs	✗ ✗	- -
Stocker et al. [31] [32]	2014	Road vehicle classification	✗	✓Rule-based inference (vehicle type)
Ebers et al. [33]	2013	VANETs ontology	✗	✗
Mnasser, De Oliveria, Houda, Zidi et al. [34] [35] [36] [37]	2013	Transportation ontology	✗	✓Jess engine for SWRL rules
Li et al. [38]	2012	Car ontology (in chinese)	✗	✗
Calavia et al. [39]	2012	Traffic ontology	✗	✓Semantic reasoning, SWRL rules
Madkour et al. [40]	2011	Ontology of transportation networks	✗	✗
Hamilton et al. [41]	2013	Ontology of transportation networks	✗	✓Pellet, SWRL, Jess
Feld, Muller et al. [42]	2011	Automative, distance between cars	✗	✗
Wang et al. [43]	2011	Traffic accident ontology	✗	✗
Hulsen et al. [44]	2011	Ontology for Driver Assistance	✗	✓RacerPro
Berdier et al. [45]	2011	Ontology for Urban mobility	✗	✗
Kannan et al. [46]	2010	Intelligent driver assistance system for vehicle	✗	✓Pellet reasoner (consistency)
Baumgartner et al. [47]	2010	Ontology for Situation Awareness	✗	✓10 rules
Liu et al. [48]	2010	Road surveillance system	✗	✓SWRL rules (inform, alert)
Niaraki et al. [49]	2009	personalized route planning	✗	✗
Yue et al. [50]	2009	Traffic accident	✗	✗
Zhai et al. [51]	2009	Traffic information	✗	✓(dryness, dampness)
Sun et al. [52]	2009	Smart car	✗	✗
Belhadef et al. [53]	2009	Urban geographical information system	✗	✗
Regele et al. [54]	2008	Autonomous Driving System: trajectory planning, traffic coordination	✗	✗
Mair, Eigner et al. [55]	2008	Collision avoidance in VANETs Ontology (in German)	✗	✗
Cheng et al. [56]	2008	Transportation	✗	✓Ontology-based reasoning (Racer) rule-based reasoning (Jess, LISP, SWRLJessTab)
Hu et al. [57]	2007	oil	✗	✗
Lorenz et al. [58]	2005	Ontology of transportation networks	✗	✗

Table 2. Other Ontology-based IoT automotive projects that cannot be employed since ontologies are not available (even upon request). Legend: Ontology Availability (OA)

has been search on Google and Google Scholar a set of specific keywords, as an example those keyphrases: 1) start with ontology-based, 2) finished with ontology, or 3) start with semantic-based. Keyphrases are as follows:

- Automotive, Automated vehicle, Autonomous vehicle, Car, Cars, Vehicle, Vehicles, Smart car.
- Transportation, Transportation networks, Transport, Public transportation.
- Road Traffic Management, Roads, Road system, Traffic Jam Avoidance.
- Personalized Route Planning, Route Planning.
- Car Driving Assistance, Driver Assistance Systems, Advanced Driver Assistance, Intelligent Driver Assistance System.
- Vehicular Ad Hoc Networks (VANETs), Wireless Vehicular Networks (VANETs), Vehicle-to-Vehicle (V2V), Vehicle-to-Vehicle Networks, Vehicular Networks.
- Road Accident, Vehicular Accident, Traffic Accidents, Road Safety, Car Accident Prevention, Accident Rescue Mission.
- Intersection Assistance.
- Vehicle Context-aware Services.
- Pedestrian Detection.
- Car Pooling Recommendation System.

For the set of scientific publications, we focused on the following criteria:

- Are ontology URLs available within the scientific article? Frequently, URLs are missing. Authors have been contacted to retrieve ontology code and we enriched the dataset when receiving positive answers. 1 summarizes the 16 ontologies that share their ontologies online, which is the smart vehicle ontology dataset later analyzed. Other ontology-based projects are referenced in Table 2, unfortunately, the ontologies cannot be processed yet since they are not accessible.
- Are sensors mentioned within the paper?
- Are there reasoning mechanisms and already defined rules to interpret data generated by the smart vehicle applications?
- Is the reference section provide more resources to investigate? We enrich our scientific publication dataset accordingly (e.g., LOV4IoT-transport knowledge repository).

The main difference between our survey and the existing ones, is that our survey is the result of a continuous enrichment of the LOV4IoT ontology catalog since 2012 and we provide tools to support the reuse of the survey outcome (e.g., dump of ontology code). Meanwhile, we are aware of Systematic Literature Review (SLR) guidelines such as [59] [60] [61].

4.2 Building the corpus of knowledge for the transportation domain

To train the dataset, we need to build a corpora of knowledge for the transportation domain. word2vec helps in transforming texts from either scientific publications or ontologies into vectors that can be processable by machine learning algorithms. **word2vec** performs the training of the term embeddings and the process of building a word2vec model for all identified unique words. The word2vec algorithm is based on neural networks and builds a vocabulary from a pre-training text model and attaches the vector representations to each word. Around 20 of the terms were not part of the pre-trained model thus we removed those terms from the list of words. The output of this step is the word embedding vector space representation. The genism python library is used to implement word2vec.

Transport Ontology Dataset: We have collected 16 ontologies that can be downloaded and analyzed (as depicted in Table 1): 2 ontologies are excluded since they were in Chinese or German. We released the list of ontology URLs within an online table[18]. For the convenience of the developers, we created a tutorial web page (`http://lov4iot.appspot.com/?p=queryTransportOntologiesWS`) to either use the web service or easily download the dump of the ontology code that we collected.

For instance, the developer can query the web service `http://lov4iot.appspot.com/perfectoOnto/getOntoDomain/?domain=Transportation` which returns the list of the projects relevant for the smart car domain that we collected within the LOV4IoT ontology catalog for transport[19], it includes: the name of the project and the ontology, the ontology URL, and additional information such as the scientific publication describing the ontology (see Figure 2). The web service is more up-to-date with latest ontologies collected, compared to the dump file. However, when the projects are not maintained anymore, the URLs can become dead links, which is the reason we store the ontology code within dump files.

5 Evaluation

Planned Evaluation: To identify the most popular concepts from smart car ontologies, the proposed KEAS methodology is evaluated in an empirical study which includes an analysis that gives a complete overview of the performance of the descriptiveness of the most popular concepts (in the same way it has been done in our Knowledge Extraction for the Web of Things (KE4WoT) work [62]). The objective of this experiment is to identify if the keywords provided by KE4WoT can sufficiently describe existing ontologies.

Ontology Selection: 16 smart car ontologies are collected from LOV4IoT for evaluation purposes (Table 1). The most important ontologies in each domain have been selected according to the following criteria:

- Citations of the scientific publications describing the ontology (e.g., the SSN ontology v1 [63] has more than 1000 citations): higher is the number, better the ontology might be. However, this criteria cannot be applied to recent publications.

[18] `shorturl.at/jEIQ7`

[19] `http://lov4iot.appspot.com/?p=lov4iot-transport`

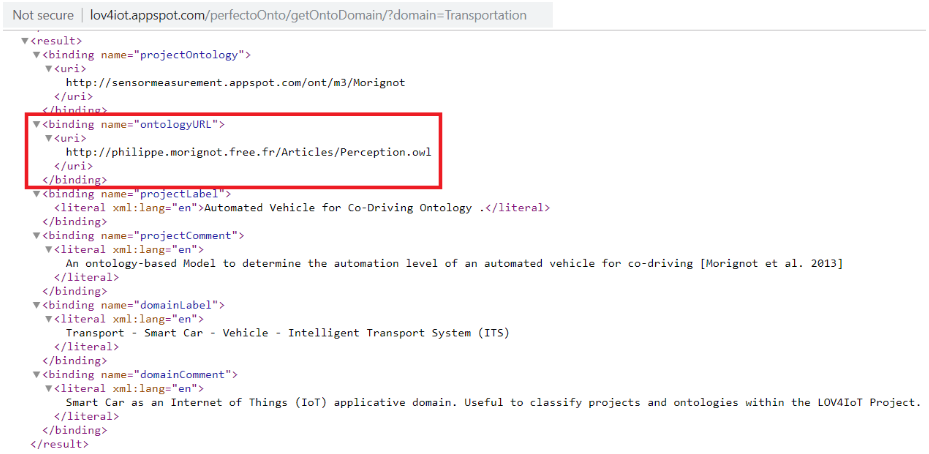

Fig. 2. Web service example to automatically retrieve ontology-based projects for the smart car domain: ontology URLs and scientic publications

- Journal impact factor and conference ranking: higher the ranking is, better would be the ontologies. Within the references section, the ranking is added for publications cited and classified within Table 1 and Table 2.
- Recent publications increase the chance to have the authors maintaining the ontology and integrating previous ontologies.
- Ontologies disseminated in standardizations (e.g., W3C Web of Things ontology[20], W3C SSN/SOSA ontology [64], ETSI M2M SAREF ontology [65]) can be considered as more reliable.
- Industrial partners involved, the project is considered more impactful, and the implementation is more reliable.
- Domain experts involved (not computer scientists) since they share their human expertise.
- Ontology code that can be downloaded, because, in science, the experiments should be replicable, following the FAIR (Findability, Accessibility, Interoperability, and Reuse) principles.

Ground Truth Dataset Design: Domain experts can participate in the questionnaire to design the ground truth (a similar questionnaire for smart cities, weather, and smart home is available online[21], see [62]) for detailed information). Experts were either involved in developing smart car ontologies or are an open audience having the domain expertise **to describe each ontology using three keywords**. The participants' level of expertise in the automotive domain and knowledge engineering, is asked in a Likert scale of five levels, from 'totally

[20] `https://www.w3.org/TR/wot-thing-description/`

[21] `https://bildungsportal.sachsen.de/survey/limesurvey/index.php/716626/lang-en`

disagree' to 'totally agree'. The experts are given the list of ontologies (through a series of figures from the ontology classes in Protege) in different domains to select the top three keywords that best describes that ontology in relation to the keywords that were obtained from the main concepts in the generated clusters. Domain experts chose keywords among a total number of keywords in our evaluation form.

6 Conclusion and Future Work

The Systematic Literature Survey (SLS) in any research topics is a time-consuming approach. Finding knowledge returned by Google results still require a huge work on learning, classification and summarizing. To ease this time-consuming task, we built a "common sense knowledge" dataset for the automotive sector comprising 42 projects between 2005 and 2019. However, only 16 ontologies are processable and published online with knowledge representation standards. Our innovative Knowledge Extraction for the Automotive Sector (KEAS) methodology aims to analyze the most popular knowledge required to build smart vehicle applications by applying the k-means machine learning algorithm to a dataset of 16 ontologies that we collected.

This work highly encourages researchers to share their reproduceable experiments by publishing online their smart vehicle ontologies. As a future work, we would like to re-generate an ontology to aggregate and unify the knowledge from existing ontologies. Furthermore, we would like to automatically recognize the sensors mentioned within ontologies and scientific publications to maintain our IoT dictionnary, and reasoning mechanisms used to detect abnormal sensor data and execute actions.

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7 Appendix

7.1 Clustering Results

```
- [assessment, viewpoint, analysis, classification, investigation, survey]
- [course, begins, advance, back, go, last, step, put, forward, ahead, end, initial, first, start, meeting, date, point]
- [new, several, multiple, relevant, previous, following, involved, additional, interest, number]
- [making, made, make, driven, maker, trees]
- [manually, add, rule, search, update, meta, validity, observable, valid, static, match, set, inference, predefined]
- [asset, recovery, upgrading, installation, improvement, reconstruction, evacuation, progress, preventative, cleaning, cycle, preparation, plan, repair, maintenance, planning, inspection, construction, operation]
- [held, manager, play, played, reports, participant, board, report]
- [articulated, autonomous, automation, robot, navigation, adas, assistance, platooning, automated, driving, cruise, cooperative]
- [blizzard, ssn, record, sampling, reading, observation, description, measurement, weather]
- [aid, main, dedicated, common, includes, created, inter, based, shared, communications, built, general, technical, communication, sharing, works, connected, establishment, open, extension, involving, working, address, work, related, active]
- [declares, org, info, title, uri, doi]
- [publisher, guest, pub, ski, books, cert, email, comments, photo, fi, signed, creator]
- [access, using, usage, offer, store, delivers, availability, storage, collection, delivered, users, avail, used, use, available, consumption]
- [checks, sender, message, check, massage]
- [build, economy, urban, buildings, spaces, community, security, mobility, environment, city, environmental, network, smart, transport, transportation, management, public, building, infrastructure]
- [history, attraction, adult, birth, young, currency, age]
- [layout, riot, parameters, execute, steps, hardware, details, software, module, model, execution, run, mode, configuration, version, setup, running]
- [order, dealing, involves, problem, human, language, also, tools, parts, since, part, possibility, kind]
- [rescue, customs, prohibited, bank, reserve, administrative, airport, court, insurer, company, owned, authority, agency, organization, rights, insurance, post, engaged, police, site, facility]
```

Fig. 3. Cluster Results Part I

```
- [decision, stand, turn, u, action, right, left, drive, v]
- [done, specified, meets, fitness, standard, defined, selected, zone, modified]
- [note, minor, attributed, remaining, major, recognized, indirect, associated, subject, primary, secondary, cause, contributor]
- [registration, manual, fee, household]
- [school, office, informal, town, college, bureau, arts, chair, arena, turkish, department, theme, university, senior, tcs, greek, spanish, french, italian, official, centre, siemens]
- [relationship, belongs, vocabulary, element, named, property, document, attribute, relation, entity, item, restriction, operator, feature, object, category, class, event, name, agent, type]
- [strings, obj, slots, atomic, sequence, datatype, columns, rows, row, equivalence, matrix, timestamp, tree, block]
- [willingness, owners, owner, owns, man, people, child, person, contact, place, thing, body]
- [hard, carrying, restrict, protected, regular, covered, maintain, closure, allowed, 'yes', non, pre, internal, temporary, local, free, direct, short, long]
- [library, identification, barcode, label, rfid, image, code, qr, bar, card, tagging, id]
- [reliability, performance, accuracy, uptime, precision, quality, visibility, success]
- [black, white, color, box, style]
- [attack, leak, anti, detection, fault]
- [march, demonstration, campaign, regional, spur, national, program, catalyst]
- [impossible, unknown, deviated, weigh, witness, disruptive, wrong, even, bad, behind, abnormal]
- [experience, behavior, situation, nature, dynamic, ability, self, phenomenon, pattern, characteristics, changing, behaviour, game, activity, conditions, context, term, perception, condition]
- [convenience, walking, outdoor, infotainment, occupant, occupants, motorized, pedestrian, disabled, health, living, care, pedestrians, safety, emergency]
- [spacial, descent, variant, fourier, sax, symbolic, wavelet, cosine, piecewise, hybrid, derivation, blinding, gauss, lm, var, approximation, linear, discrete, dimensionless]
- [crowd, music, mobile, video, remote, obd, media, multimedia, cctv, biometric, smartphone, touch, nfc, phone, computer, tv, electronic, machine, text, telephone, voice]
```

Fig. 4. Cluster Results Part II

```
[xvalue, eclipse, juridical, vip, mopeds, bull, dop, timespan, van, cartography,
topo, routier, stationery, pizza, butcher, bunker, hostel, flightpath, waterfall,
baptist, hindu, burg, jain, basket, hut, aerodrome, disused, burger, christian,
dentist, cave, jewelry, drama, jewish, heath, casino, bakery, kindergarten, marsh,
orthodox, catholic, pier, fountain, chemist, cliff, desc, ascent, alt, kmeans, moto,
aux, artist, wiping, wmi, tps, drivetrain, ucum, lumber, album, bomb, unspecified,
slush, derivable, wheelbase, vin, storey, athletics, caravan, thai, landuse, wayside,
denomination, bic, comedy, arabic, pascal, doa, milliliter, freezer, diastolic,
insufficiently, hydrophone, milliliter, milliampere, okta, gsr, cupboard, crosswind,
lx, candela, lumen, farad, hg, unclassified, horn, clutch, args, tennis, ruins,
commanded, mil, tournament, cuisine, rab, radian, milliwatt, unsigned, osc, vehicule,
microgram, sens]
[spot, orientation, ego, moment, movement, trajectory, occupancy, along, segment,
heading, tracks, proximity, moving, track, current, line, area, space, field, status,
location, distance, direction, position, state]
[parade, exhibition, concert, demolition, marathon, festival, rugby, cricket, flyover,
archaeological, beach, beauty, motel, dog, memorial, pharmacy, dance, hiking, lockers,
climbing, worship, hall, marina, boulevard, zoo, theatre, airfield, naval, cinema,
skiing, mall, fortress, mexican, soccer, veterinary, camp, cafe, playground, courthouse,
museum, stadium, monument, avenue, rearview, basketball, baseball, football, picnic,
garden, bpm, hood, lorry, gallery, golf, castle]
[directed, stationary, force, normal]
[diversion, agricultural, metering, plant, drinking, wastewater, irrigation, forecasting,
agriculture, underground, monitoring, hvac, water]
[maximum, limit, range, full, wind, level]
[obstructing, insects, ill, gusty, assault, fight, viaduct, procession, occasion,
tongue, bicyclist, volcano, grave, halt, defensive, scrub, skating, woman, infant,
tired, pregnant, declined, refuel, hockey, seafood, religion, smoking, emotion,
tailwind, careless, overspeed, dusk, bolster, convoy, overturned, snowy, foggy,
race]
[squad, snowploughs, rolling, helicopter, aircraft, lorries, petrol, watercraft,
ship, cargo, sailing, rickshaw, valet, yard, taxi, parked, tow, cabin, ambulance,
abandoned, subway, ferry, taxis, docking, gates, clearance, rental, shop, tram,
bicycles, truck, boat]
```

Fig. 5. Cluster Results Part III

```
[trade, japanese, opera, american, electronics, maritime, civil, international,
asian, nuclear, german, chinese, indian, european, military]
[cancellation, jumping, swing, overnight, cleared, rush, sweeping, jam, sunset,
fell, idle, stuck, fallen, shake, busy, night, sunny, stands]
[pipe, anchors, wall, pipeline, branch, sewer, concrete]
[cultural, gardening, commercial, hospital, fishing, shelter, hotel, recreation,
toilets, residential, leisure, swimming, amenity, tertiary, sport, historic, tourism,
places, park, food, sports, restaurant]
[herd, swarms, flower, clothes, musical, fish, laundry, shoes, supermarket, toys,
doctors, beverages, worn, fridge, washing, pedometer, manifold, animal, heart, animals,
coffee]
[de, g, n, e]
[raid, flash, slam, transformer, miniature, pet, antilock, vac, anpr, dish, rrc,
airbag, latch, ignition, gearbox, wiper, glove, esp, volt, abs, restraint, coolant]
[avoidance, violation, reverse, warning, brakes, decelerate, signs, drives, drivers,
counter, timing, maneuver, overtaking, alarm, braking, belt, accelerator, pedal,
beat, steering, alert, seat, brake, sign, throttle, wheel, collision, driver]
[storeys, millibar, tonne, celsius, kilo, kg, pound, ug, lo, fahrenheit, centimeter,
centimetre, kelvin, mmol, ampere, kilogram, rpm, maf, watt, litre, liter, gram,
milligram, cubic]
[entry, detour, origin, trip, path, journey, destination, alternate, departure,
arrival, route, stop, travel]
[damaging, theft, sabotage, terrorist, destruction, vulnerable, explosion, protection,
aggressive, soft, natural, excessive, dangerous, serious, wear, spillage, hazardous,
reactive, damaged]
[horse, motorcycles, gears, coach, automobile, chassis, tesla, revolutions, hertz,
trailer, motorcycle, licence, comment, brand, motor, license, gear]
[shoulder, strike, contraflow, narrow, widening, adjacent, sight, guard, exit, gate,
shadow, footway, ballet, pole, runway, ends, plane, roll, mirrors, curb, roadway,
blind, windshield, carriageway, ramp, marking, bridge, tunnel, broken, head, obstruction,
obstacle, front, rear, side, crossing, crosswalk, lane]
[esc, ecg, glucose, photosynthetically, gyrometer, coulomb, orp, ohm, voc, capacitance,
luminosity, lux, electrocardiogram, cholesterol, chill, wetness, luminous, decibel,
ion]
```

Fig. 6. Cluster Results Part IV

```
- [patches, pavements, spray, chippings, gritting, carriageways, gantry, cables, film,
  laying, resurfacing, litter, blasting, spun, packed, ball, seating, navigable, curbs,
  rails, rocks, bowls, wash, ditch, wood, apron, drain, stone, cable, bench, hydrant,
  furniture, cycleway, old, pad, pavement, grass, cutting, rock, beds, leafs, sloped,
  drained, gravel, dome, collapsed, loose, holes, pulling, mud, sand, asphalt, washer,
  cushion, trunk, fill]
- [sensitivity, derived, index, ratio, relative, absolute, intensity, indicator, degree,
  weight]
- [axles, foot, axle, mm, miles, inch, kilometers, kilometres, diameter, travelled,
  odometer, millimeter, millimetre, kilometre, kilometer, square, metre]
- [delivery, offering, business, platform, marketplace, services, connection, cloud,
  service]
- [deceleration, speeds, drag, stress, traction, bending, burst, displacement, friction,
  pitch, angular, vertical, torque, tension, rotational, velocity, instantaneous,
  motion, longitudinal, lateral, sound, angle, acceleration, speed]
- [fully, single, sub, scale, multi, tire, preferred, micro, second]
- [min, dtc, evap, ref, ra, dist, temp, max, avg, dew]
- [market, difficulty, barrier, political, obstacles, potential, barriers, gap]
- [c, b, w, k]
- [permanently, slide, roof, doors, outside, entrance, chamber, house, kiosk, closed,
  opening, rooms, room, refrigerator, empty, curtain, locked, container, lock, door]
- [cross, stability, boundary]
- [sleet, flooding, tornadoes, storms, slippery, intermittent, floods, avalanches,
  showers, overflow, weighing, thunderstorms, hurricane, smog, gusts, blowing, disturbance,
  salting, frost, hail, shower, icy, storm, rainy, smoke, fire, heavy, dust, rain]
- [earthquake, impacts, events, crash, landslips, damages, insured, severity, severe,
  roadworks, extreme, risk, injury, closures, incident, damage, hazard, failure, accident,
  danger]
- [odometry, localization, compass, barometer, gyro, positioning, speedometer, yaw,
  laser, microwave, seismometer, radar, optical, magnetometer, ultrasonic, gyroscope,
  accelerometer, magnetic, clock, tilt, camera, gps, mirror, beam, detector, thermometer]
- [diesel, production, fossil, recycling, renewable, goods, ethanol, gross, billion,
  million, chains, oil, waste, fuel]
- [undefined, leaves, sink, flux, leaf, stream, fog, source]
```

Fig. 7. Cluster Results Part V

```
- [glare, taxiway, shed, photovoltaic, illuminance, dimming, lighting, solar, window,
  lamp, shade, sun, lights, light]
- [pylon, sensors, deployed, sensing, monitor, actuation, information, data, actuating,
  device, sensor]
- [controlled, loops, carries, actuated, diagnostic, signals, terminal, appliance,
  controller, command, actuator, engine, control, switch, system, meter]
- [mountain, alpine, bay, glacier, rink, grassland, geological, valley, coastline,
  river, canal, reef, dam, wetland, forest, waterway, pan, delta]
- [duration, peak, hours, millisecond, instant, interval, year, times, day, volume,
  mileage, minute, hour, unit, time, per]
- [generator, generated, input, variable, interface]
- [dense, moderate, large, localized, isolated, clear, near, around, fair, poorly,
  medium, weak, strong, poor, presence, high, low]
- [deep, pool]
- [buses, transit, intersections, bikes, bike, vehicles, motorway, signalling, lanes,
  street, toll, highway, roadside, train, rail, passenger, railway, congestion, bicycle,
  car, bus, station, parking, traffic, road, vehicle]
- [noise, pollutant, co, emission, pollution, carbon, gas, energy]
- [difference, mean, equivalent, inflation, altitude, median, percent, elevation,
  density, variation, slope, height, error, width, length, values, average, value,
  rate, count]
- [oxide, monoxide, dioxide]
- [cold, avalanche, drifts, vegetation, patchy, subsidence, spring, uneven, freeze,
  warmer, snowfall, dry, rainfall, land, falling, melting, fall, cloudy, winds, cloudiness,
  cover, winter, wet, ground, ice, freezing, soil, precipitation, snow, surface]
- [heat, moisture, salinity, resistance, conductance, skin, ph, conductivity, ambient,
  blood, humidity, pressure, temperature]
- [toxic, fumes, fresh, coal, hydro, radioactive, methane, mg, oxidation, calcium,
  nitrate, ppm, gaseous, ammonium, salt, sodium, potassium, ammonia, combustion, ozone,
  oxygen, sulphur, alcohol, volatile, organic, nitrogen, concentration]
- [big, fast, pace, accelerate, smooth, transform, backward, slow]
- [artwork, points, coordinates, map, spatial, latitude, longitude, reference]
- [tidal, barometric, global, atm, radiation, atmospheric]
```

Fig. 8. Cluster Results Part VI

```
- [exhaust, injection, lift, chiller, conditioner, boiler, drop, cooler, conditioning,
  recirculation, tower, fan, ventilation, intake, heater, heating, fluid, tank, flow,
  air]
- [overhead, queuing, latency, cons, delay, throughput, handover]
- [filter, materials, particle, aggregate, particles, compound, material, mass, chemical,
  quantity]
- [charging, cell, backup, charge, electrical, capacity, battery, voltage, load, electric,
  power]
- [payload, cc, timer, pulse, wi, par, pc, packet, transmission, uplink, frequency,
  downlink, signal, link, mhz]
- [impact, reduced, influence, depends, result, increase, decrease, ect, distribution,
  negative, reduction, loss, change, total, show]
```

Fig. 9. Cluster Results Part VII