Problems of Decision Making in Subject Domain “Electric Vehicle”

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Abstract
In this paper we consider world`s and Ukrainian market of electric cars, international and state initiatives, manufacturers and official representatives of manufacturers, we analyze types of electric cars in relation to their main elements - battery and engine, business infrastructure. The directions of further development of mathematical support for decision making tasks in the subject area "Electric Vehicle" are determined. The ontology for the subject area "Electric Vehicle" is constructed. Based on the provided analysis, the problem of choosing the types of charging stations and their location in Ukraine was studied. Software that visualizes the map of charging stations in Ukraine and allows you to test the efficiency of use of electric vehicles on the introduced highway has been developed, for example, time data spent on a specific path.

Keywords [1]
electric vehicles, electric cars, ontology of subject area, charging types, EV brands, governmental green initiatives, system optimization methodology, decision support system.

1. Introduction

The worldwide market of electric vehicles (EV´s) is gaining momentum. Given that in the early 2000s the EV business was not considered as promising, today we can state with confidence that the future lies within electric vehicles domain [1]–[2]. Due to the large amount of smog, the relevance of EV´s is growing faster every day. Recently, electric vehicles (EVs) with low gas emission and environment protection have attracted much attention and have been widely applied in some countries when harsh environment problems are exposed in the world, such as energy shortage, air pollution, and the greenhouse effect [3–5]. It is already clear at the governmental level how much the introduction of electric cars can help solving the environmental situation, so countries are actively creating governmental initiatives. There is currently a legislative initiative on the introduction of electric vehicles (EVI): a common policy of different countries to accelerate the production and adaptation of electric vehicles around the world. Currently, EVI includes such regions as Africa, Asia, Europe and North America, namely 14 countries: Canada, India, Germany, France, Finland, China and others. Unfortunately, Ukraine is not on this list, but the country is implementing measures to increase demand for electric vehicles. For example, the import of an electric car with purely electric

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motor is duty free. However, this is not enough. Ukraine does not have its own capacity to manufacture electric vehicles, and foreign manufacturers are in no hurry to enter Ukrainian market [1]. For example, the manufacturer Renault entered Ukrainian market only in 2018 and only from the second attempt. After all, at the stage of checking Ukraine's readiness to accept electric cars, it turned out that even large Ukrainian cities do not have the proper infrastructure of charging stations. This situation is not limited to Renault. That is why in this article the task of the analysis on the choice of types of charging stations for Ukraine is set. Most of electric cars in Ukraine are used, either purchased abroad and imported by the owners or sold in the country by dealers. According to data of June 2018, the following electric cars are the most popular in Ukraine: Nissan Leaf - 1621 units, BMW i3 - 182 units, Tesla Model S - 123 units, Mercedes-Benz B-Class Electric Drive - 78 units, Smart For two Electric Drive - 69 units, Tesla Model X - 57 units, KIA Soul EV - 53 units, Volkswagen e-Golf - 52 units, Toyota RAV4 EV - 46 units, Fiat 500e - 37 units. Additionally, ThunderPower EV, Audi e-Tron Quattro, Renault Zoe, Renault Kangoo ZE , Kia Soul EV, Hyundai Ioniq Electric, which also potentially plan to enter Ukrainian market.

Let's move on to the task of analysis and selection of types of charging stations for Ukraine. The difficulty of solving it is that each electric car has its own characteristics and can be charged with a certain type of charging, depending on its connector and type of charging station. The solution to this problem is based on the construction of ontology for the subject area "Electric Vehicle".

2. Preliminaries

A subject area is a fragment of objective or virtual reality, with a set of concepts (entities) that belong to it. Decision-making tasks are formulated on a disciplinary basis and can be mono-disciplinary or multi-disciplinary, depending on the number of disciplines or areas under consideration. In the problem under study, we have a single subject area - "Electric Vehicle". The decision-making process is presented in the form of a multilevel hierarchical system, which consists of a set of tasks that are at different levels of the hierarchy and are responsible for a particular function or activity. Each task for the corresponding activity can have subtasks. Different types of interaction are possible between different subsystems, problems (subprblems), models. Such interaction can be realized on the basis of relations of direct subordination; of information exchange; of functional subordination, consistency and coordination [6–7]. This determines the priorities of interaction between the relevant objects, which are described by the hierarchy or execution time. The presence in the decision-making tasks of their own goals and priorities of interaction leads to different situations of interaction between the respective tasks. It is necessary to consider various aspects of decision-making. These can be, for example, the behavioral aspect (describes the decision-making situations and the order in which tasks are considered), the organizational aspect (describes the structure of the decision-making environment) and the information aspect (describes the information used in decision-making, how it is presented and how it can be applied).

3. Construction of the ontology of subject area "Electric Vehicle"

Now we will build a mathematical model of the ontology of a complexly structured subject area Electric vehicle. The term “ontology” first appeared in the works of T. Gruber [8–9], in which various aspects of the interaction of information systems with each other and with a person were considered. The review [10–11] presents research results achieved in a new field of knowledge dealing with the development and application of ontologies. The papers describe different approaches to the notion of ontology and discuss various classifications of ontologies. In [10] gives a general description of automatic techniques of ontology development. Ontologies are a computer form of presenting knowledge about problem areas in the form of semantic information-logical networks of interconnected objects, where the main elements are concepts with their properties and the relationship between them. Instead of concepts, the main elements can still be classes of objects, problem areas with their properties and relationships. As a rule, the computer ontology of the subject area means a triplet:

$O = < X, R, F >$, where $X = \{x_1, x_2, \ldots, x_i, \ldots, x_n\}$ − a finite set of concepts of a given subject area; $R = \{r_1, \ldots, r_k, \ldots, r_n\}, R : x_1 \times x_2 \ldots \times x_n$ − a finite number of semantically significant relationships between the concepts of the subject area; $F = X \times R$ − a finite set of interpretation functions defined on a set of concepts and / or relations. A partial case of the task of a set of interpretation functions is a glossary, which is compiled for a set of concepts X .

In this manner, ontology is a system that describes the structure of a particular problem area and consists of many classes of concepts related to relationships and their definitions.

Let's build such a system for the specified subject area.

Special programming languages are usually used to build ontologies. In this task we used OWL (Web Ontology Language - a language that allows you to describe classes and relationships between objects in them). Implementation was carried out in Protégé 5.2. This is a special environment created by the Stanford Center for Biomedical Informatics Research to build a knowledge base. The Protégé platform supports two main ways of modeling ontologies using Protégé-Frames and Protégé-OWL editors [12] – [13]. For usage, it can be either downloaded from the official website https://protege.stanford.edu/ or used online on the same website. This platform is free to use. When downloaded to your computer, it will run from the terminal of your folder with the command. /run.sh.

For further work it is necessary to open the Classes window. This is done through the top panel as follows: go to Window View Window $\longrightarrow$View $\longrightarrow$Classviews $\longrightarrow$Classhierarchy.

Afterwards, we place a window of classes where it is convenient for us. Now we have a yellow window of the Protegé 5.2 class. Now you can create classes. To do this, right-click on owl: *Thing* is a constructor class, and a list of actions will open. Choose *AddSubclass* or *AddSubclasses*. In the popup window, enter the name (s) of the classes. Thus, we obtain the following list (Fig. 1).

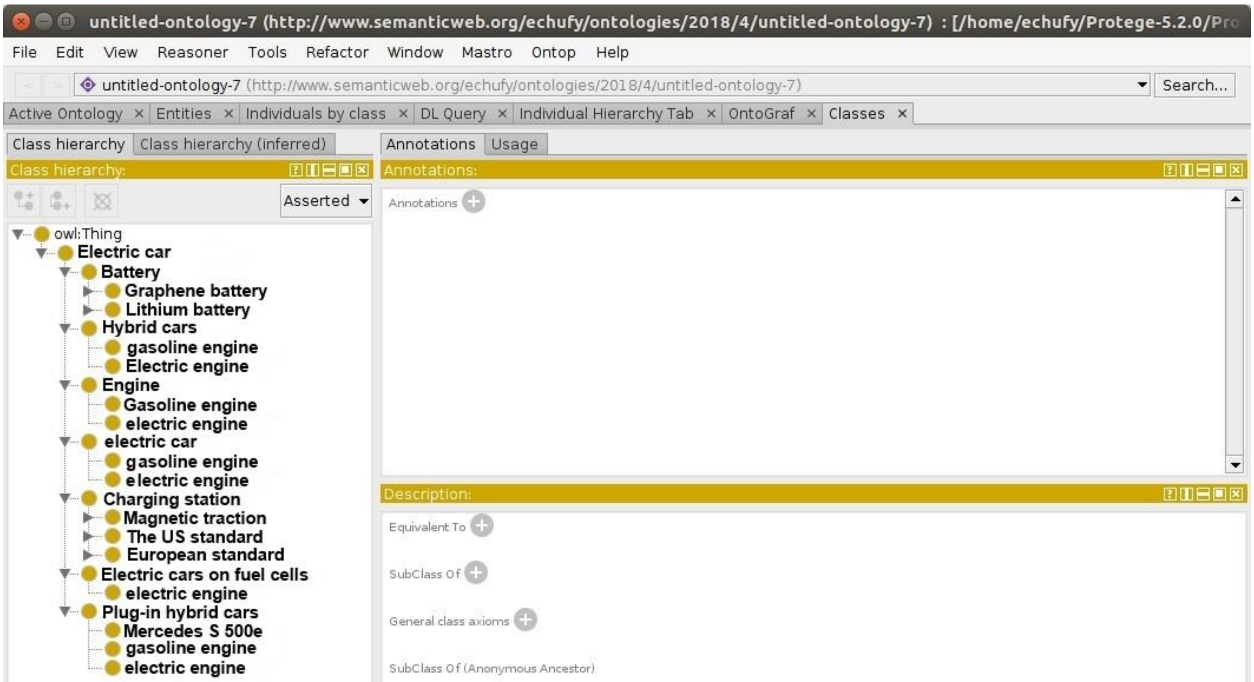

Figure 1: Creating classes in Protégé 5.2.

To the right, you can enter comments for a class / subclass in the Annotations field.

Let´s consider our subject area in detail to create its ontology. We formulate the set X . It will represent classes and subclasses in the ontology. Concepts such as «Electric car», «Hybrid cars», «Plug-in hybrid cars», «Electric cars on fuel cells», «Internal combustion engine», «Electric motor», «Battery», «Graphene battery», «Lithium battery», «Lithium Cobalt», «Magnesium Oxide», «Charging Stations», «Magnetic Thrust», «Nino», «US Standard», «Level 1», «Level 2», «CCS Type 1», «Level 3», «CCS Combo 1», «CHAdeMO», «Standard of Europe», «Mode 1», «Mode 2», «Mode 3», «SAE J1772», «Mennekes», «CCS Type 2», «Mode 4», «CCS Combo 2».

Since, according to the definition of computer ontology, one of its parts is a glossary (set *F*), and in this case we have:

Electric car (BEV - battery electric vehicles) - a car driven by one or more electric motors powered by batteries or cells, rather than an internal combustion engine.

Hybrid cars (HEV - hybrid electric vehicle) - highly economical cars that run in parallel using an electric motor powered by batteries and a gasoline engine. The gasoline engine receives fuel from the gas tank. Batteries cannot be charged from external sources, and mileage on electric traction is very limited.

Plug-in hybrid electric vehicles (PHEV - plug-in hybrid electric vehicle) - cars which principle of work, as in traditional hybrids, is based on the joint work of electric and gasoline motors. The difference is that the main role here is played by the electric motor which drives the car. The petrol internal combustion engine is switched on when the accelerator pedal is pressed hard and the speed is sharply increased, even if the battery capacity is sufficient to continue the movement.

Fuel cell electric vehicles (FCEVs) are electric vehicles that convert hydrogen into electrical energy that causes the car to move. The required battery charge is provided by fuel cells that operate using hydrogen and oxygen. Oxygen is drawn by an electric car from the environment, and hydrogen is stored in a high-pressure tank under the cabin floor. The electricity produced as a result of the process feeds the electric motor and other systems of the car, and the battery pack is charged by recuperative energy.

Internal combustion engine - a type of engine in which the chemical energy of fuel that burns in the working area, is converted into mechanical work.

Electric motor - a type of motor that converts electrical energy into mechanical.

Battery (car acid battery) - a type of electric battery used in cars or motorcycles. Used as an auxiliary source of electricity in the onboard network when the engine is not running and to start the engine.

Graphene battery is a new generation rechargeable battery that allows you to charge an electric car in 8 minutes and travel up to 1000 kilometers. Two of the four German car companies have already tested such batteries.

Lithium battery is the most widely used battery. For such batteries, one of the most important characteristics is the age and number of charging cycles of the battery, i.e. how many times during its operation it can be charged.

Lithium cobalt is an anode of graphene and lithium batteries, which depends on the world's lithium reserves and is therefore much more expensive than potential graphene batteries.

Magnesium oxide is the anode of the graphene battery, which is proposed to replace lithium cobalt, which will greatly reduce the price of the battery, and thus the electric car.

Charging stations - stationary points of current from which you can charge your electric car. There are different types of stations, depending on alternating or direct current, its power, and so on.

Magnetic traction is a completely new type of charging, which is now being introduced by leading automotive industries. It is a non-contact charging that consists of a transmitter and a receiver of energy.

Nino is a bus that is the first from all modes of transport to have a magnetic resonance-type charger, which provides a contactless way of charging. That means, it is charged by magnetic traction. The maximum distance that the bus can travel on one full charge is 89 km. Full energy recharge lasts 15 minutes. Manufacturer is the Japanese company Toshiba.

The US standard is insignificantly different from European standards. The names of the charging stations are different, but the characteristics are almost the same. They use their own stations and connectors.

Level 1 is the slowest AC charging up to 16A. For the US, 16A is loaded with 120 volts; is not safe, because there is no protection against short circuit and overheating of the cable; now rarely used, as at this speed any car can be charged without special infrastructure, simply by inserting the adapter into the socket; the car must have a charger that rectifies the current.

Level 2 is charging with alternating current up to 30A, loaded with 240 volts; the car must have a charger that rectifies the current.

CCS Type 1 is one of the standards of the connector for charging an electric car with alternating current. Is the predominant solution for North America.

Level 3 is the fastest DC charging up to 100A and 300-600 volts can charge the battery up to 80% in half an hour, after which the power is reduced or stopped so as not to damage the battery.

CCS Combo 1 is one of the connector standards for charging an electric car with direct current. Is the predominant solution for North America.

ChadeMo - one of the standards of the connector for charging an electric car with direct current, used worldwide, is a monopoly in Japan.

European standard - differs from US standards but insignificantly. The names of the charging stations are different, but the characteristics are almost the same.

Mode 1 - the slowest charging with alternating current up to 16A, loaded with 220-240 volts; is not safe, because there is no protection against short circuit and overheating of the cable; now rarely used, because at this speed any car can be charged without special infrastructure; the car must have a charger that rectifies the current.

Mode 2 - AC charging from the household network using a protection system inside the cable.

Mode 3 - single- or three-phase AC charging using a special connector, which implements a system of protection and control over the charging of the electric vehicle. With the help of these stations it is possible to charge cars with both single-phase and three-phase connectors.

SAE J1772 - single-phase charging connectors for Mode 3, used in the US stations Level 1, Level 2.

"Mennekes" - connectors for three-phase charging, suitable for Mode 1, Mode 2, Mode 3.

CCS Type 2 - one of the connector standards for charging an electric car with single or three-phase charging, is the predominant solution for Europe, is also used in Australia, South America, Africa and Asia.

Mode 4 - fast DC charging, allowing 600 volts and up to 400 A.

CCS Combo 2 is one of the connector standards for charging an electric car with direct current. It is the predominant solution for Europe, but is also used in Australia, South America, Africa, Asia.

So, the *set of relations (set R)* consists of elements - {Whole-part, Genus-type, Contains, Requires, Class-subclass, Charging stations in Europe, Charging stations in the USA, Station-connector}.

Let's build an ontograph of a fragment of the subject area "Electric Vehicle".

Let's do it this way: to see the ontograph built by classes, go to Window →Tabs →Ontograf. The display shows the classes we built (Fig. 2). In this example, let's take a closer look at the components and connections of the "Electric Vehicle" subject area. Since there are different types of electric cars: electric car, hybrid car, plug-in hybrid car and car on fuel cells, each of them corresponds to a certain branch of the ontograph.

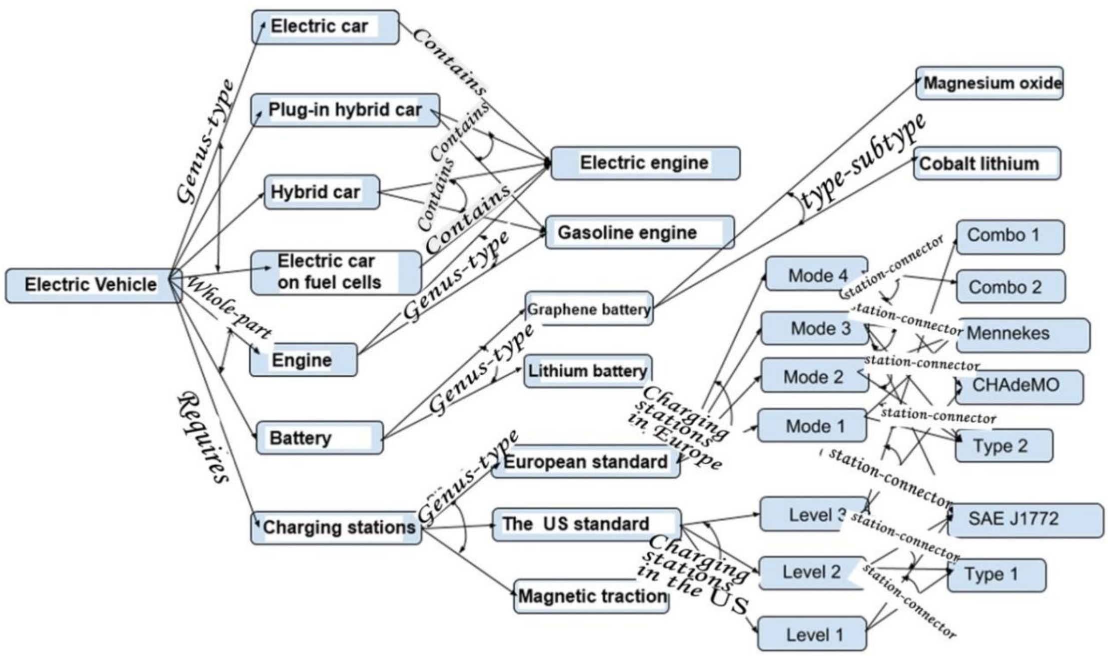

Figure 2: Ontograph of the subject area "Electric Vehicle".

The main elements of an electric car, as in any other car, are the battery and the engine.

Consider the branch "Battery". Currently, most electric cars are made with a lithium engine, which is based on lithium. It is expensive because lithium is difficult to extract and its reserves are rapidly declining. Moreover, it is flammable, because in contact with water, such batteries are at risk of explosion. But there was no other alternative until some progress was made in the development of batteries: the creation of a new type of battery, based on graphene. Two types in which anode differs are currently being considered: cobalt lithium and magnesium oxide. With the latter, the battery is much cheaper (77% cheaper than its analogues) and safer. However, both allow you to charge the car in just 8 minutes and travel up to 1000 km, and charging time and power reserve are among the main criteria when choosing an electric car. So far, graphene batteries have been tested by two of the four German car companies, and they have not yet entered the general market.

Next, consider the branch "Engine". There are electric and gasoline engines, and depending on their type, the car will have either the first or both engines. For example, hybrid, hybrid-plug-in types have both engines, and electric cars and electric cars on fuel engines have only an electric one.

Charging stations in the world are divided according to standards. There are two main standards: European and American. Therefore, in the branch "Charging Stations", there is a division into subclasses "European Standards" and "US Standards". Despite the fact that the characteristics are almost similar, their names are different, "European Standards" branch on their characteristics to "Mode 1", "Mode 2", "Mode 3" and "Mode 4", and "US Standards" on their characteristics - on "Level 1", "Level 2" and "Level 3". The problem with charging stations is that not every electric car can be charged by every station. It all depends on the type of connectors that are installed during production. Moreover, American manufacturers prefer one type of connector, European - another. This is how the "Mennekes" and "Type 2" connectors are branched for European "Mode 1" and "Mode 2" standards; "Mode 3" connectors "Mennekes", "Type 2" and "SAE J1772"; for "Mode 4" connectors "CHAdeMo" and "Combo 2"; and for US standards: "Level 1" - "Type 1" and "SAE J1772"; "Level 2" - "Type 1" and "SAE J1772"; and "Level 3" - "CHAdeMo" and "Combo 1".

Also today there are achievements in the development of new wireless charging stations. They are also called magnetic traction charging. Japan has even launched a test bus, which is charged in this way. Therefore, in the branch "Charging Stations" there is a type of "Magnetic Thrust" as a type of charging. Later in the article, the decision-making area will be considered as a multi-level structure, which has four levels and includes a problem area, a model area, a method area and an implementation area.

The first (upper level) is a problem. It is a task characterized by the materiality, necessity, sufficiency of content, the plurality of possible solutions and the variability of results. The problem determines the formulation of the decision-making task, which is based on the semantic basis and determines the requirements for model development.

In this task, the problem is formulated as follows: using decision-making methods to consider the problems of electric vehicle infrastructure in Ukraine and propose solutions.

The second level - models. Models use a system of concepts and are formulated to represent a problem situation or task in a particular language. Models consist of operators that express the relationship between concepts or terms. In this paper, ontologies are used to represent models.

The third level - methods determining the decision-making processes based on the built model and provides the direction of solving the problem. To use the method you need to know how this method was built, for what purpose, where and when.

The fourth level - implementation determines how, by what means, in what environment models or methods can be implemented in DSS.

An ontological representation (OT) is designed to describe a hierarchy of tasks and the relationships between tasks that determine the order and conditions of their execution. OP describes the set of possible states and transitions from state to state.

Thus, the ontology for the presentation of problems and decision-making process will be understood as an interconnected set of ontologies, which is a multilevel associative structure of this kind [6]:

$O = < O_{meta}, O_{core}, O_{cntxt}, \{O_{DM}\}, O_R, O_{user}, Inf >$, where

O_{meta} – metaontology;

O_{core} – basic ontology;

O_{core} – contextual ontology;

$\{O_{DM}\}$ – a set of ontologies representing the decision-making process, which includes the presentation of problems and their solutions at the level of the problem area, the ontology of subject-formal and formal representation and implementation of this process;

O_R – implementation ontology, which includes a description of software to support decision making;

O_{user} – ontology of user representation and interaction with the user;

Inf – is a model of an output machine that is associated with the set of ontologies O.

Let's consider each ontology from the set in more detail and build them for our subject area.

Metaontology O_{meta} is considered as an integrating component. Since decision-making uses knowledge from different subject areas, one of the tasks of meta-ontology is interdisciplinary integration as a basis for finding a rational and adequate solution to the problem of decision-making. The essences of the metaontology are such concepts as object, attribute, meaning, relation, etc.

Current task uses knowledge from a single subject area "Electric Vehicle", so interdisciplinary integration is not required.The purpose of *the fundamental (basic) ontology* O_{core} is to provide key concepts and constructions in order to define, understand, structure and present the basic principles of the field of decision-making, within which the solution of the problem is realized. For the task in the role of a fundamental ontology, we can consider the ontology of the subject area, because it already presents the key concepts and structures for the field of decision making. A contextual system helps to recognize, understand and present relevant elements of decision-making within contexts. Context is any information that can be used or characterizes a relevant problem area.

Contextual ontology O_{cntxt} is based on the results includes component ontologies: context ontology, layer ontology and point of view ontology.

The context ontology defines the following context areas: goal / outcome area, actor area (human or software), process / action area, object area, environment area, capability area, means area, presentation area, location area, and time area. The layer ontology supports the decision-making structure and describes the relationship at the general level of decision-making components and their implementation at the appropriate levels: problem, model, method and implementation within the results system, object system, use system and management system. The ontology of points of view supports many specific aspects of consideration for a concrete presentation of the decision-making process and structuring the perception of the components of decision-making, in particular from a systemic, conceptual, functional, informational and implementation point of view.

We will present *a set of ontologies* $\{O_{DM}\}$ for presenting the decision-making process as a multilevel system of ontologies. Such a system of ontologies will include the presentation of problems of the subject area (formulation of the problem and, accordingly, its model, definition of the scheme / scenario / method of solution), ontology of subject-formal and formal representation (transformation of models into a formal record, definition of scenario, method and algorithm for solving) and implementation of this process.

The level of the problem area is represented by the ontology of the problem area as a component that describes the concepts, terms, objects, processes of the problem area. This ontology describes the specific mechanisms, methods, technologies of decision-making in this problem area. To represent the level of the problem area, we construct a new ontology (Fig. 3) based on the ontology of the subject area. Analyzing it, we can understand which problems the "Ukrainian electric car market" has and how it differs from the "World car market". On the branch "World Electric Vehicle Market" you can see that there are many manufacturers of electric vehicles. Moreover, international initiatives involving a large number of leading countries are used for their development. Infrastructure for electric vehicles is developed. Charging stations are mostly installed in public places and at the owner's home. Considering the branch "Ukrainian market of electric cars" we can conclude that there are very few representatives or manufacturers of electric cars in Ukraine, relative to the total number of manufacturers. However, Ukraine has already created a state initiative and stimulates demand for electric cars by lowering taxes on their purchase. When placing gas stations for public use, you should pay attention to where exactly to install them. The most rational thing to do is to do it on the world market, that is, to place it where people will spend a certain amount of their time, because cars need to be recharged.

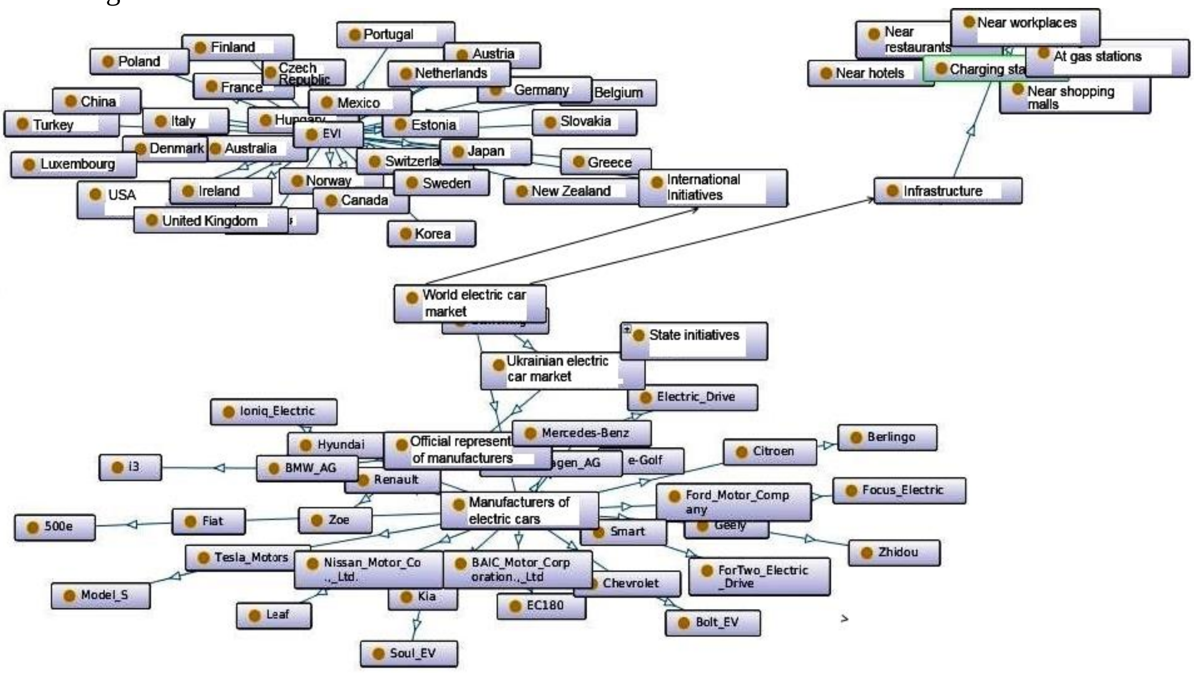

Figure 3: Ontology of the problem area.

The level of subject-formal and formal representation is realized through a formalized ontology as components that implement informational, mathematical, logical models, methods, algorithms and their interaction in the decision-making process. Formalized ontology or ontology of formal methods and algorithms contains scenarios, methods, algorithms for implementation and analysis of mathematical, informational, logical models. Description of realized methods, algorithms represents the level of implementation. Ontology implements the description, processing and use of existing software and algorithms, which allow completing computer support for the implementation of appropriate decision-making processes, models, methods and algorithms. As optimization methods, the methodologies of bi-level and system optimization, as well as the application of the game theory and theory of fuzzy sets, are used [14]−[19]. The use of intelligent modeling systems that allow explaining the results of computation programs in terms of various subject areas provides additional opportunities for specialists in these areas in comparison with systems of other classes [20]−[21]. The presence of a formally described area that defines an unambiguous interpretation of the terminology used makes it possible to create intelligent modeling systems that integrate knowledge and data from the sections of this area, as well as software systems for solving applied problems.

4. Conclusions

In the present work the ontology for the subject area "Electric Vehicle" is constructed. Protégé 5.2 development environment was used to build ontologies. It is assumed that such a model will be used to create intelligent systems that integrate ontologies, knowledge, data in the specified area, as well as software systems designed to solve applied problems (including using the software systems used).

This presentation gives the opportunity to assess the system-analytical problem area, to understand how to operate it in its best way. It is necessary to improve the business infrastructure for representatives of electric car manufacturers in Ukraine. Based on the analysis of the obtained data and constructed ontologies, investigated the problem of choosing types of charging stations and its location in Ukraine. Software has been developed that visualizes the map of charging stations in Ukraine and allows you to test the efficiency of use of electric vehicles on the given highway.

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