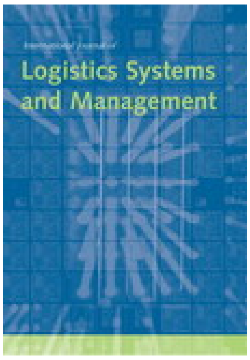

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Assisted discovery of optimal solution for logistics problems using ontology modelling

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Abstract: The logistics processes conjointly execute various physical and logical tasks. The physical tasks may concern the elements such as goods to be transported, vehicles, and human resources. Whereas, the logical tasks are generally accomplished by software units that can be fully automatic or interactive such as optimisation methods or event management, etc. The logistics problems are often complex np-hard combinatorial optimisation problems. In this paper, we define the shared conceptual vocabulary concerning the logistics problems and inherent optimisation solutions. The result of the work is a knowledge base system, which is formalised and implemented as a set of ontologies. These have been used as key components of a tool that may assist the logistics expert to identify the related optimisation methods to solve the concerned problem and eventually list the available corresponding web-services implementing them.

Keywords: optimisation ontology; transportation optimisation; automated transportation; optimisation methods; decision support systems; logistics ontology; vehicle routing problems; VRPs.

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1 Introduction

Logistics expert may seek the most cost-effective solutions in a given situation. For instance, she could ask, what is the optimal cost in terms of time or load for a dispatcher during a transportation? Would she transport her goods directly from one destination to the other or could she consolidate them somewhere to gain more benefit? Her choice must not rely solely on chance or some general considerations. Instead it should be optimised in some way. While the optimisation objectives may differ; she could opt for minimising cost, minimising time, or minimising environmental impacts, etc.

Logistics and transportation problems are well established for the past several decades (Ansari et al., 2018; Speranza, 2018; Dong et al., 2021). Among others, the *vehicle routing problem (VRP)* (Toth et al., 2014) prominently presents a significant challenge along with the evolving technologies. It attempts to determine the optimal set of routes to be adopted by a fleet of vehicles in order to serve a given set of customers constrained by some objective functions. A recent literature review (Chanchaichujit et al., 2019) identifies the modelling approaches and mathematical techniques to solve industrial supply chain problems. It employs the existing mathematical tools and techniques to exploit the mathematical modelling approaches with an industry focus to achieve sustainable supply chain management. Some of the contemporary research work proposes to adapt the ontological approach (Hitzler, 2021) over the generic models. It may respond to the additional constraints such as legal restrictions or specific usages to evaluate the suitability of evolutionary algorithms in order to effectively respond to a logistics problem. Yet, the research literature lacks a mapped evaluation of logistics problems and optimisation solutions. In fact, we assume that such tasks are mainly performed by logistics experts who are not necessarily software experts. The logistics experts express their requirements by means of some logistics concepts like *vehicle*, *warehouse*, *tour*, and *order*. The choice of an optimal combination of such concepts to achieve some common objective of a logistics process may imply the understanding of both the logistics and optimisation domains. In this context, we believe that ontology definitions for shared knowledge domain of logistics and optimisation can bridge the gap to better specify logistics problems. Therefore, we attempt to exploit the logistics process building or improvement to intend a semi-automatic assistance during the selection of an optimal software unit in order to resolve the encountered logistics problem. In this regard, we percept a layered approach, as follows:

1. The core of our work is composed of the logistics ontology which is intended to semantically model all the concepts dealing with optimisation processes in the context of logistics and transportations.
2. The superficial layer is composed of a reasoning-based system that combines the use of queries and reasoning engines to explore the ontology.

We use the description logic formalisms (Baader et al., 2017) such as TBox (assertions on concepts) and the ABox (assertions on individuals) to analyse and define the vocabulary of logistics, transportation, and optimisation domains. We use the web semantic languages such as RDF (Banane and Belangour, 2018), OWL (Hendler et al., 2020), and SPARQL (Kiselev and Yakutenko, 2020) to implement the ontologies and associated tools. Later on, we extract the knowledge from the developed reasoning system with the help of user interactions, developed using Java Enterprise Edition technologies (Parsons, 2020). In our previous work (Bouneffa et al., 2018), we analysed and defined the general concepts of transportation and optimisation. In the current work, we exploit these concepts for a continuous development of the reasoning system to solve the *VRP* and its variants (Braekers et al., 2016).

The rest of the paper is organised as follows: Section 2 briefly reviews the related literature. Section 3 presents the transportation ontology in general. We then specifically argue the conceptualisation of the *VRPs* in Section 4. We provide the conceptual base of optimisation ontologies in Section 5, which help us to better understand the conceptualisation of the *VRP* solutions, as detailed in Section 6. We further extend this conceptual representation in Section 7 to attempt an exhaustive expressiveness of our proposed mathematical formulations. These formulations are later on realised with the help of ontologies to cope with the problem domain. Section 8 describes the working model of our approach to detail the knowledge acquisition from the interaction of defined ontologies. We argue the automation of the optimal solution discovery in Section 9 by qualitative evaluations of chosen web-services. Finally, in Section 10, we conclude the contents and narrate the possible prospects of the work presented in this paper.

2 Theoretical and empirical background of logistics ontologies

The ontologies have been used to establish the common vocabulary for heterogeneous information sources, in order to integrate the knowledge domain to the leading domain experts (Staab and Studer, 2010). In the literature, some individual ontologies concerning the semantic knowledge of logistics concepts exist. Most of them having primary focus on the design, simulation, and modelling research areas are dominant (Miller et al., 2004). Leukel and Kirn (2008) define a logistics ontology based on a taxonomy of processes. They consider five process types (*plan*, *source*, *make*, *deliver* and *return*) and then accordingly they define relationships of these process types among companies and goods.

Kowalski et al. (2012) introduce a case-based reasoning system to measure the similarity of logistics knowledge collections written in natural language. They attempt an intelligent collection of reusable knowledge with the help of ontological definitions from the experience of finished logistics projects. Their proposed system is based on an ontology concerning the linguistic aspects of the logistics area. This ontology defines physical and abstract logistic objects. The physical objects may represent the transportation means and goods whereas the abstract objects represent things like key performance indicators (KPI), etc.

Hoxha et al. (2010) discuss the semantic representation of various logistic data and service functionalities. They define the top level concepts of the logistics ontology including processes, services, resources, and KPI. Their framework enables automated and intelligent techniques for discovery and classification of services into logistics processes. The use of ontology is demonstrated with the help of web-services that simulate the management of the train transportation tickets.

Anand et al. (2012) define an ontology to formalise the knowledge for the domain of city logistics, to facilitate agent-based modelling. It addresses the urban freight transport management. In this regard, the ontology may help to conceptualise a city from a logistic point of view to permit an ontology-based data access.

Solanki and Brewster (2016) present 'OntoPedigree', which specialises and extends the domain specific traceability of logistics artifacts as they move along the supply chain. It is a content ontology design pattern to encapsulate the event-based traceability of linked pedigrees – interlinked datasets defined in RDF as they move among various trading partners.

Likewise, there are other ontologies allowing the semantic modelling of the well-known optimisation problems such as GOO (Moussas et al., 2013), ONTOP (Witherell et al., 2007), and SoPT (Han et al., 2011).

General optimisation ontology (GOO) (Moussas et al., 2013) is particularly interesting as it is designed and structured with the main focus on the optimisation. The authors develop the basic concepts common to all optimisation problems that are required by the core part of the ontology. The primary objective has been to support automatic selection of the appropriate optimisation tool.

Ontology for optimisation (ONTOP) (Witherell et al., 2007) has been developed to facilitate engineering problems. The preliminary work began with the development of a finite element model (FEM) knowledge-capturing tool. ONTOP's structure provides a means to identify feasible optimisation techniques, for a given design optimisation problem.

SoPT (Han et al., 2011), the ontology for simulation optimisation includes concepts from both conventional/mathematical programming and optimisation simulation. It is yet unclear to consider these ontologies for complex logistics problems such as logistics optimisation.

Hong and Jeong (2019) develop a goal programming model with multi-objective functions and considers each result as a decision making unit. They attempt to evaluate the impact of emergency relief facilities and the distribution channels between these facilities concerning the performance.

The problem we deal with, in this paper, mainly concerns the responsiveness of organisations dealing with logistics activities. The enterprises responsiveness has yet been defined as their ability to rapidly and cost effectively react to the frequent changes affecting them and/or their technological and socio-economic environments (Alsafi and Vyatkin, 2010; Koren and Shpitalni, 2010). The information technology (IT) systems of such enterprises must then be designed and deployed as a set of modules. Modularity is in fact recognised as an attribute of the systems changeability or re-configurability. In this context, numerous works have highlighted the interest of the use of ontologies for a flexible implementation of the production systems and in particular the corresponding logistic chains (Dallari et al., 2009; De Koster et al., 2007; Goetschalckx and Ashayeri, 1989; Marchet et al., 2011, 2015). Negri et al. (2017) drew up a state concerning the use of ontologies in the logistics area. They highlight, in particular, the different uses of ontologies in the field of production and manufacturing classified into five categories:

1 Support for re-configuration of manufacturing systems (Alsafi and Vyatkin, 2010; Fumagalli et al., 2014; Garetti et al., 2013; Loskyll et al., 2011).

2 Integrated modelling of manufacturing systems (Colledani et al., 2008; Giovannini et al., 2012; Lee et al., 2012; Usman et al., 2010).

3 Inter-and intra-company interoperability (Ameri et al., 2012; Cai et al., 2011; Lin and Harding, 2007; Jardim-Goncalves et al., 2011, 2014; Panetto et al., 2012a, 2012b; Vernadat, 2010).

4 Sharing and reuse of knowledge (Chungoora et al., 2013; Imran and Young, 2013; Kiritsis, 2011; Matsokis and Kiritsis, 2011; Legat et al., 2014; Lin et al., 2011; Long, 2010; Verhagen and Curran, 2011).

5 Means of reasoning to infer new knowledge (Ferrándiz-Colmeiro et al., 2010).

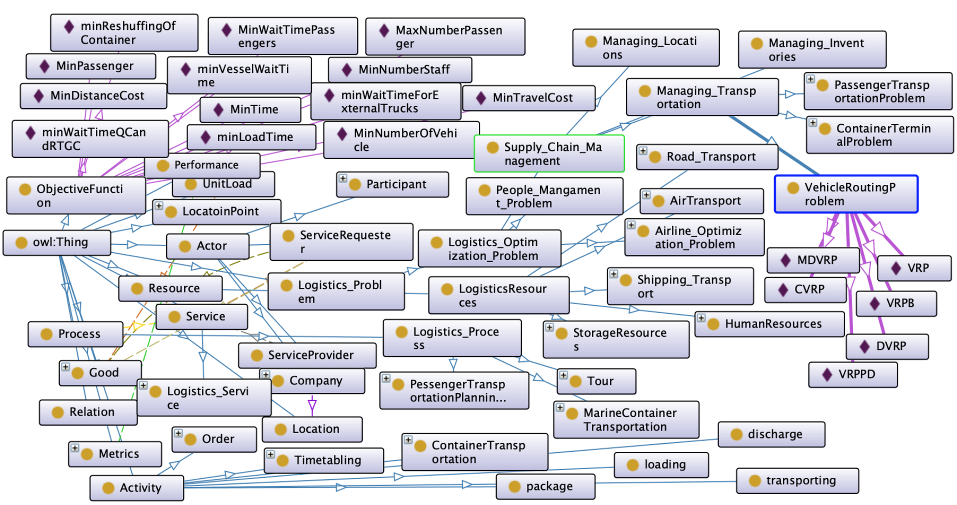
In this paper, we mainly try to answer the first question but consequently we also address the other questions. Our goal is to implement reasoning tools to build and deploy processes in the field of logistics by exploiting knowledge, formalised in terms of ontologies, on these processes but also on the tools and especially the methods of optimisation they use and on the computer modules implementing these tools. We start from the fact that the systems we consider are mainly designed according to a modular approach based on *service oriented architecture (SOA)*. This type of architectures makes it possible to consider several levels of abstraction from business activities and tasks to their deployment by encapsulated computer components in the form of services, etc. The adoption of the *SOA* approach and especially by first considering an IT system as a set of business processes makes it more easy for the logistics actors to effectively contribute to the implementation and the deployment of the system modules.

3 Logistics ontology

We define the logistics ontology to capture the conceptual domain of logistics. It incorporates the semantics among primitive logistics concepts (or classes) and their relations (or roles). We then define axioms to further model the inherent essence of logistics.

Figure 1 shows the general concepts of logistics ontology. The top level includes the classes such as `process`, `service`, `resource`, `performance`, `activity`, and `logistics problem`. These are further extended into subsidiary classes, e.g., `logistics process` is a sub-class of `process`, and the `logistics service` is a sub-class of `service`. It is equally important to define the inter-connections of these logistics concepts. Hence, we define some roles such as the `compose` role that connects the `process` concept and the `service` concept. The `uses` role connects the `service` concept and the `resource` concept. The `requestedBy` role connects the `order` concept and the `ServicesRequester` concept. The `containsGoods` role connects the `warehouse` concept and the `goods` concept, etc.

Figure 1 Concepts of logistics ontology (see online version for colours)



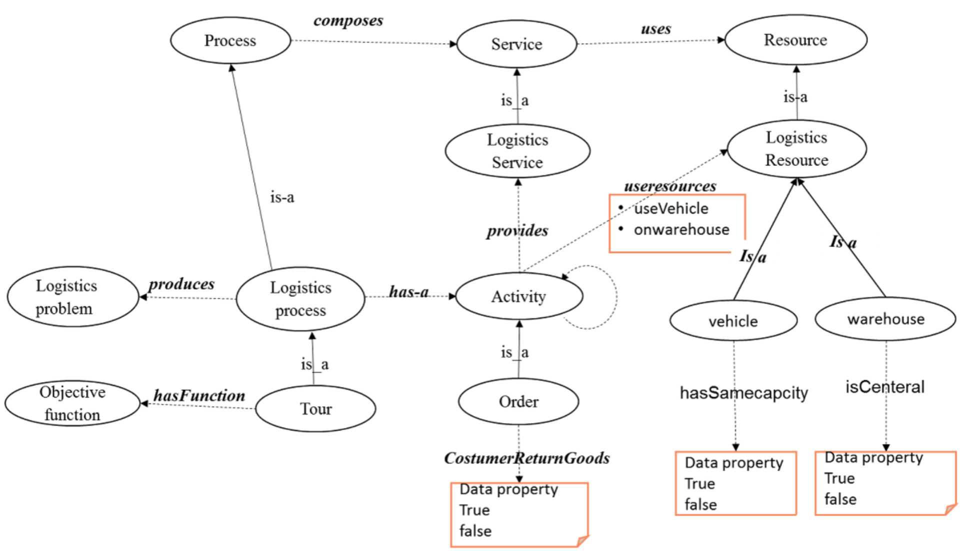
4 Conceptualisation of VRPs

A logistics process may combine various inter-connected elements emerging from the *human resource management*, *airline management*, or *supply chain management*. In the present work, we broadly discuss the *supply chain management* (Hugos, 2018) to illustrate the proposed approach intended to design the logistics systems. The supply chain management is a vast domain. It mainly covers the logistics problems related to the transport, location, inventories, vehicle routing, etc. Formally, the supply chain management can be modelled as follows:

$$SupplyChainManagement \equiv LocationManagement \cup TransportationManagement \cup InventoryManagement \quad (1)$$

The *VRP* is one of the transportation problems. Concretely, in this paper, we restrain our focus on *VRP* for the sake of better understanding of proposed approach. It is therefore, in this section, we discuss the basic concepts of *VRP*. Most often, an optimised solution of *VRP* depends on two main logistics resources which are *vehicle* and *warehouse*. The multiple objectives of *VRP* suggests to classify it into different variants (Braekers et al., 2016) for a simplified resolution in respect of concerned objective. Although, the major constraint of *VRP* is to ensure the minimum consumption of cost and time during the delivery of the *orders* to relevant costumers.

Figure 2 The top-level concepts of *VRPs* (see online version for colours)



We, thus, infer in our ontology modelling that the `VehicleRoutingProblems` is a sub-class of `TransportationProblems` class. It can be shown using the descriptive logic notations, as follows:

$$VehicleRoutingProblems \subseteq TransportationProblems \quad (2)$$

Figure 2 shows the top-level concepts of `VRP` ontology. We define the classes of `VRP` such as `order` is an `activity`, `tour` is a `logistics process` which may have an `ObjectiveFunction`. Likewise, we define the relationships such as the `useVehicle` and `onWarehouse` roles which are sub-set of `useResource` role. Similarly, we also define the `hasFunction` role which connects `tour` and `ObjectiveFunction`.

5 Optimisation ontology

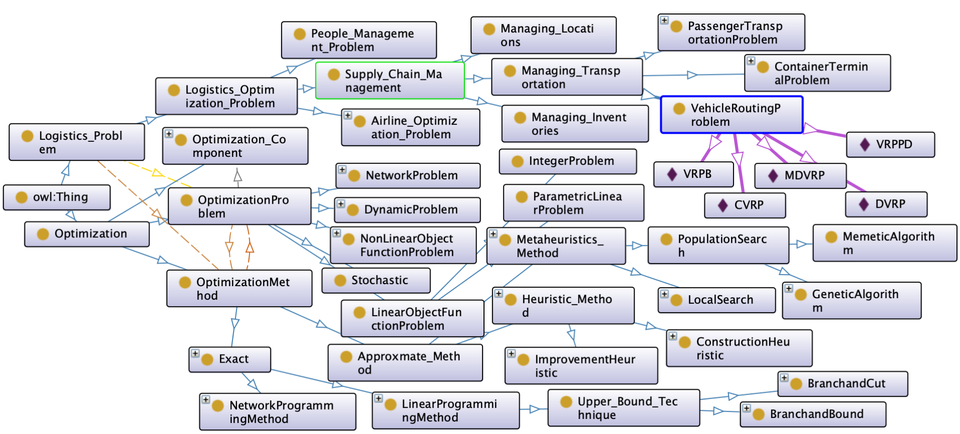
The essence of optimisation ontology is to define the typical optimisation problems along with the descriptions of the methods that can be applied to solve them (Golden et al., 2008; Uchoa et al., 2017). It is thence necessary that the basic structure of optimisation ontology should support optimisation processes. It should also focus on how to select and apply a suitable solution for the encountered optimisation problem. In this regard, a `logistics optimisation problem` (`LOP`) is a sub-class of `OptimisationProblem`. It may have multiple components and there exists an `OptimisationMethod` to solve the `LOP`. This can be formally described, as follows:

$$LOP \sqsubseteq OptimisationProblem \sqcap \exists solvedBy.OptimisationMethods \sqcap \exists hasComponent.OptimisationComponent \quad (3)$$

Figure 3 shows the general concepts of the optimisation ontology. The top-level contains the following concepts:

- The `OptimisationProblem` class represents the problem to be solved, e.g., the `VRP`.
- The `OptimisationMethod` class represents the method used to solve the problem.
- The `OptimisationComponent` class represents the various parameters of the optimisation problem.

Figure 3 Concepts of optimisation ontology (see online version for colours)



The `OptimisationMethod` class is further classified into the `ExactMethod` and `ApproximateMethod`. An `ApproximateMethod` can be either a `HeuristicMethod` or a Meta-heuristicMethod. Similarly, a HeuristicMethod can be either an ImprovementMethod or a ConstructionMethod. The above can be formalised as follows:

$$OptimisationMethod \equiv ExactMethod \cup ApproximateMethod \quad (4)$$

$$ApproximatedMethod \equiv HeuristicMethod \cup Meta\text{-}heuristicMethod \quad (5)$$

$$HeuristicMethod \equiv ImprovementMethod \cup ConstructionMethod \quad (6)$$

The ConstructionHeuristic class may include the Clarke and Wright saving algorithm, Fisher and Jaikumar algorithm, Petal algorithm, route first cluster second, and Sweep algorithm. The ImprovementHeuristic class is specialised by two sub-classes InterRoute and IntraRoute. The InterRoute may include the methods such as 2opt exchange, cross exchange, relocate operater, cyclic-K-transfer, ejection chain, exchange operator, and GENI Exchange. The IntraRoute may include two methods which are K-exchange and Or-exchange.

Likewise, the Meta-heuristicsMethod class is specialised by three sub-classes; learning-mechanisms class, LocalSearch class, and PopulationSearch class. The LearningMechanisms may include two sub-classes such as: The ant colony algorithms and neural network. Similarly, the LocalSearch may include the record to record travel, simulated annealing method, variable neighbourhoods search, and Tabu search. While the population search may include the genetic algorithms and mimetic algorithm.

6 Conceptualisation of VRP solutions

We specifically experiment the *VRP* and its variants. We define more than 95 classes, 33 roles, 83 individuals and 12 data properties in this regard. Eventually, we use these definitions to formulate the axioms in order to exploit the knowledge domain of logistics. A preview of some of the axioms is given below to further illustrate their formalism.

6.1 Axiom of warehouse

The warehouse is a sub-class of LogisticsResource and there exists a relationship containsGoods (has-a role) with the goods class. It can be shown as follows:

$$Warehouse \subseteq LogisticsResource \cap \exists containsGoods.Goods \quad (7)$$

6.2 Axiom of order

The order is a sub-class of activity class. Every order has a requestedBy role in relation to the ServicesRequester class. While, the ServicesRequester is a sub-class of actor class with request role referring to some order. This can be shown as follows:

$$Order \subseteq Activity \cap \exists requestedBy.ServicesRequester \quad (8)$$

$$ServicesRequester \subseteq Actor \cap \exists request.Order \quad (9)$$

6.3 Axiom of tour

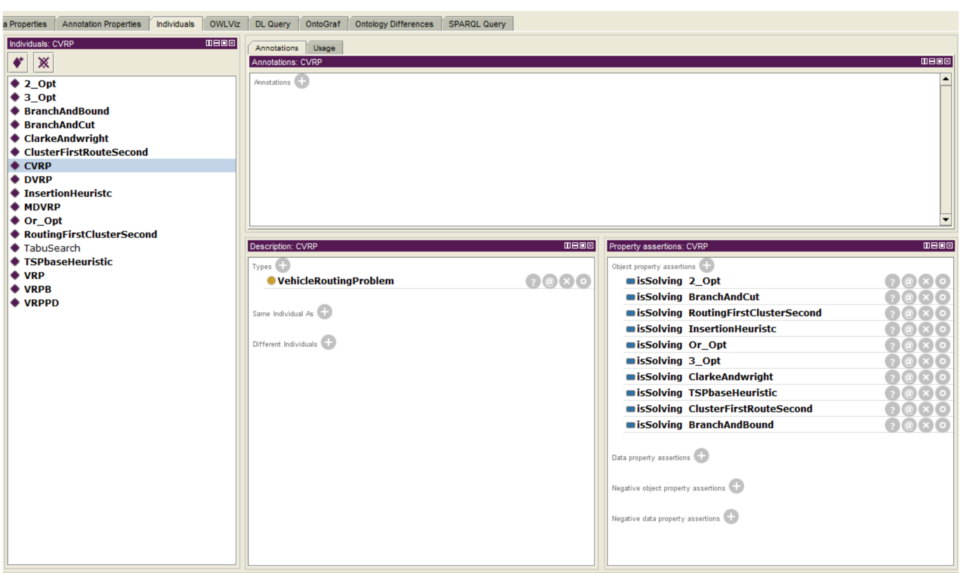
The `tour` class is a sub-class of `LogisticsProcess` class. Each `tour` has a role `has-order` referring to some `order` and it also refers to a role `hasObjectiveFunction` of class `ObjectiveFunction` along with a role `produce` refers to a collection of `LogisticsOptimisationProblems`. It can be shown as follows:

$$\begin{aligned} Tour \sqsubseteq\ & LogisticProcess \sqcap \exists hasOrder.Order \\ & \sqcap \exists hasObjectiveFunction.ObjectiveFunction \\ & \sqcap \exists produce.LogisticsOptimisationProblems \end{aligned} \tag{10}$$

7 Conceptualisation of VRP variants and their solutions

Likewise, we define some data properties in order to define the variants of the *VRP* such as: the `isCentral` property that denotes a warehouse either as central or not (i.e., whether only one warehouse is used or not). And the `sameCapacity` property is used to consider whether some vehicles have the same capacity or not. Finally, the `CustomerReturnGoods` property is associated to the `order` class, which allows to consider the fact whether the customers can return goods along the delivery order or not.

Figure 4 An example of solution method for *capacity VRP* (see online version for colours)



In the following, we continue to formulate the axioms to further define the variants of the *VRP*.

7.1 Axiom of CLVRP

The classical vehicle routing problem (CLVRP) is a VehicleRoutingProblem produced by the tour process class. The tour has some order and an ObjectiveFunction (i.e., to minimise the cumulative distance) where each order uses a vehicle and a central warehouse. It can be shown as follows:

$$\begin{aligned} CLVRP \subseteq\ & VehicleRoutingProblem \\ & \cap \exists producedBy.(Tour \cap \exists hasOrder.(Order \\ & \cap \exists useVehicle.Vehicle \\ & \cap \exists onWarehouse.(Warehouse \cap isCentral.\tau)) \\ & \cap \exists hasObjectiveFunction.minDistance) \end{aligned} \tag{11}$$

7.2 Axiom of CVRP

The capacity vehicle routing problem (CVRP) is a VehicleRoutingProblem having the same characteristics as the classical VRP with an additional constraint concerning the two or more vehicles which must have the same capacity. It can be shown as follows:

$$\begin{aligned} CVRP \subseteq\ & VehicleRoutingProblem \cap \exists producedBy.(Tour \\ & \cap \exists hasOrder.(Order \cap \exists useVehicle.(Vehicle \\ & \cap\ hassameCapacity.\tau) \cap \exists onWarehouse.(Warehouse \\ & \cap\ isCentral.\tau)) \cap \exists hasObjectiveFunction.minDistance) \end{aligned} \tag{12}$$

7.3 Axiom of VRPPD

The vehicle routing problem pickup and delivery (VRPPD) is a CVRP that includes orders which may allow customers to return some goods. It can be shown as follows:

$$VRPPD \subseteq CVRP \cap \exists hasOrder.(Order \cap \exists customerReturnGoods.\tau) \tag{13}$$

7.4 Axiom of MDVRP

The multiple depot vehicle routing problem (MDVRP) is a VehicleRoutingProblem produced by the tour process class. Where, the tour class has some order and an Objective-Function (i.e., to minimise the distances). Also, each order uses vehicle and warehouse. It can be shown as follows:

$$\begin{aligned} MDVRP \subseteq\ & VehicleRoutingProblem \\ & \cap \exists producedBy.(Tour \cap \exists hasOrder.(Order \\ & \cap \exists useVehicle.Vehicle \cap \exists onWarehouse.Warehouse) \\ & \cap \exists hasObjectiveFunction.minDistance) \end{aligned} \tag{14}$$

We continue to formulate the axioms to further define the solution methods. We define the ontologies along with the integration of constraints depending upon the logistics problem and their solution methods, which have been defined so far as individual ontologies.

For instance, there exist multiple methods to solve the `CVRP` (Ewbank et al., 2019; Uchoa et al., 2017) such as `branch and cut method`, `three-opt-based simulated annealing algorithm`, `genetics algorithms`, `cluster first route second method`, etc. We define the ontology classes along with roles to associate them accordingly, as shown in Figure 4.

Moreover, the `MDVRP` is linked to `exact methods`, `heuristics methods` and `meta-heuristics genetic algorithms`, etc.

We enhance the knowledge-base by integrating the solution methods to other variants of *VRP*; such that for the `VRPPD` problem, it contains `meta-heuristics`, `Tabu search`, and `heuristics methods`.

In the similar way, we integrate in the knowledge-base, the VRP with backhauls (`VRPB`) which contains `exact methods` and `heuristics methods` and `meta-heuristics memetic algorithm`.

Likewise, to seek the optimal solution for the VRP with time windows (`VRPTW`), we associate it with `memetic algorithm` and `meta-heuristics` in the knowledge-base. In this context, we further define, additional more than 70 classes, 5 roles, and more than 35 individuals to build a comprehensive knowledge-base for variants of *VRP*.

8 Knowledge acquisition from logistics and optimisation ontologies

In this section, we discuss the working scenario of the reasoning engine. This operates in several steps, as shown in Figure 5. Initially, it exploits the logistics ontology to formalise the general concepts of a logistics problem and later on refines them to identify the particular variant of the problem. The sub-sequent optimisation ontology may then help to find the associated optimisation methods. Which are linked with the concerned software units (optimal web-services) that implement the found method to solve the identified logistics problem. We illustrate the working scenario in more detail in the sections below with the help of an example.

8.1 Logistics problem identification

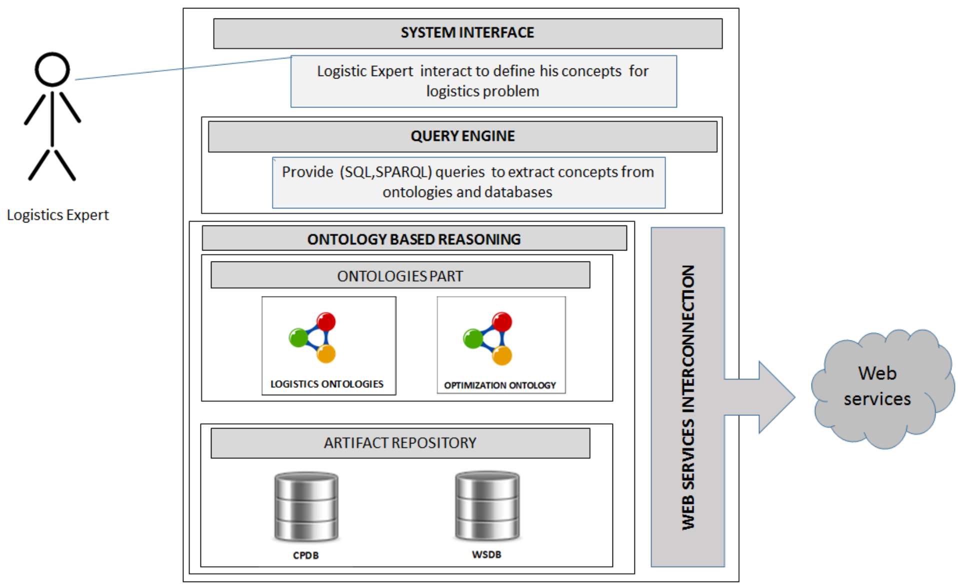
A logistics expert explores her resource concepts (RC), which are exploited by the reasoning engine to acquire the linked resource concept paths (RCP). In this context the reasoning engine inherently use the SPARQL queries to explore the logistics resources. The reasoning system extract the RCPs by following the inter-linking roles between RCs and eventually determines the logistics problem. To further illustrate this extraction, let us consider a problem involving `vehicle` and `warehouse` (RCs). The reasoning system explores all possible RCPs in logistics ontology and infer the similar concepts along with their inter-linkings to determine the general type of logistics problem. It devises the similar concept path groups on the basis of common concepts of the RCPs. For instance, the case where a problem involves `vehicle` and `warehouse` concepts. The reasoning system would list all the RCPs involving `vehicle` and `warehouse`. On this basis, it would propose at least two RCPs, with most common concepts, such as follows:

$$RCP : Vehicle \xrightarrow{\text{useVehicle}} Order \xrightarrow{\text{hasOrder}} Tour \xrightarrow{\text{produces}} VRP \tag{15}$$

$$RCP : Warehouse \xrightarrow{\text{onWarehouse}} Order \xrightarrow{\text{hasOrder}} Tour \xrightarrow{\text{produces}} VRP \tag{16}$$

Hence, it suggests that the combination of such concepts would be probably linked to *VRPs*.

Figure 5 The global architecture of ontology-based reasoning system (see online version for colours)



8.2 Determine the exact type of logistics problem

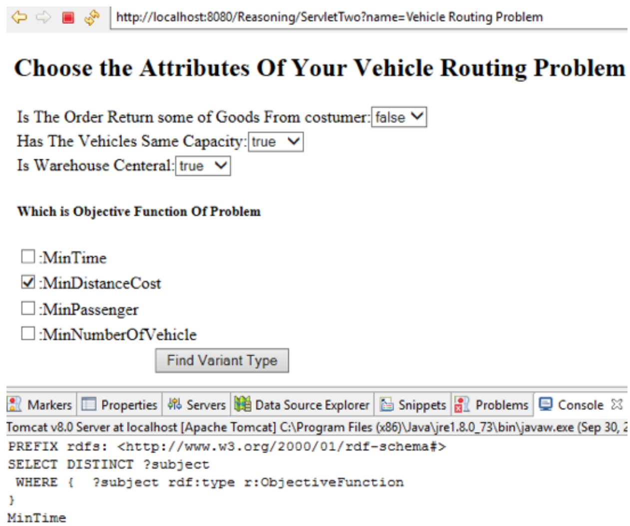
The identified similar RCPs are compared with the further attributes, interactively specified by the logistics expert to further determine the exact type of the problem. For the sake of illustration, let us once again consider the problem involving `Vehicle` and `Warehouse` concepts. The logistics expert may specify the data properties linked to these concepts, such as `isCentral = true`, `CustomerReturnGoods = false`, `has_sameCapacity = true` and `Objective-Function = minDistanceCost`, as shown in Figure 6. The reasoning system uses Algorithm 1 to determine the exact type of logistics problem, which in this case is *CVRP*.

Algorithm 1 Determine exact type of logistics problem

```
Procedure Type−VRP(returnGood, CapacityVehicle, WarehouseCent,
                    ObjectiveFunction)
      Connect to logisticsOntology;
      Launch query = SELECT ?problem
            WHERE {?tour r:hasOrder ?order.
                  ?order:useVehicle ?vehicle;
                  :onWarehouse ?warehouse;
                  :CustomerReturnGoods ''returnGood''
                  ?warehouse:isCentral ''WarehouseCent''.
                  ?vehicle:hassamecapacity ''CapacityVechile''.
```

```
                    ?tour r:produces ?problem;
                    :hasFunction ''ObjectiveFunction''};
        typeProblem := execute(query);
        Return typeProblem;
End procedure
```

Figure 6 Specification of data properties to find exact type of logistics problem



8.3 *Mapping the optimisation method*

Continuously, the results from logistics ontology may allow to further exploit the optimisation ontology to find the corresponding optimisation methods in order to solve the identified logistics problem, as shown in Algorithm 2.

Algorithm 2 Find optimisation method

```
Procedure TypeOfMethod(typeProblem)
        Connect to optimisationOntology;
        replace := Mapping(typeProblem);
        Launch query = SELECT ?method
                WHERE {:''replace'':isSolving ?method.
                    ?method rdf:type ?class.
                    ?class rdf:subClassOf ?class1};
        Methods[] := execute(query);
        Return Methods[];
End procedure
```

8.4 *Integration of web-services*

The proposed system also provides a means to execute the linked existing web-services which implement the selected optimisation method. We observe a lot of diversity in available web-services on internet. Each one may respond to a different objective function. Similarly, some web-services are commercial, while some are open source.

The *VRP solution* is an open source web-service developed for experimentation proposes. It uses the hybrid optimisation methods. It uses local search to arrange the *orders*, at the initial stage, and then it uses *first order split methods* to calculate the routes. It serves to solve *CLVRP* and *travelling salesman problem*. It has one objective function which is to minimise the distance.

Figure 7 Selection of web-services to solve the particular optimisation problem (see online version for colours)

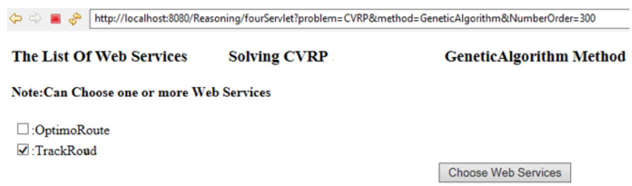


Figure 8 Results obtained from the TrackRoad web-service (see online version for colours)

http://localhost:8080/Reasoning/ServletSeven

NoLocation	Novehicle	Time	StopNumber	address	Distance
0	V0	325	1	Street:68 rue van grutten,City:calais,State:,PostalCode:62100,Country:france	2.7513
1	0	183	Stop 19	Street:Boulevard du 8 Mai,City:calais,State:,PostalCode:62100 ,Country:france	1.3906
2	0	7	Stop 17	Street:17 Place d'Armes,City:calais,State:,PostalCode:62100 ,Country:france	0.052
3	0	0	Stop 6	Street:31 Place d'Armes\n,City:calais,State:,PostalCode:62100 ,Country:france	0.0
4	0	5	Stop 21	Street:31 Place d'Armes,City:calais,State:,PostalCode:62100 ,Country:france	0.0401
5	0	5	Stop 16	Street:43 Place d'Armes,City:calais,State:,PostalCode:62100 ,Country:france	0.0342
6	0	46	Stop 12	Street:63 Place d'Armes,City:calais,State:,PostalCode:62100 ,Country:france	0.3336
7	V1	0	1	Street:68 rue van grutten,City:calais,State:,PostalCode:62100,Country:france	0.0
8	0	0	Stop 11	Street:Rue van Grutten,City:calais,State:,PostalCode:62100 ,Country:france	0.0
9	0	91	Stop 1	Street:rue van grutten,City:calais,State:,PostalCode:62100,Country:france	0.5052
10	0	61	Stop 15	Street:6 Boulevard Gambetta,City:calais,State:,PostalCode:62100 ,Country:france	0.4275
11	0	55	Stop 33	Street:Rue du 29 Juillet ,City:calais,State:,PostalCode:62100,Country:france	0.4071
12	0	82	Stop 4	Street:Rue des Fontinettes,,City:calais,State:,PostalCode:62100 ,Country:france	0.4721
13	0	96	Stop 31	Street:Rue Leavers,City:calais,State:,PostalCode:62100 ,Country:france	0.7152
14	0	73	Stop 9	Street:Rue Babinet,City:calais,State:,PostalCode:62100 ,Country:france	0.7037
15	0	80	Stop 20	Street:27 Boulevard Jacquard,City:calais,State:,PostalCode:62100 ,Country:france	0.7375
16	V2	136	1	Street:68 rue van grutten,City:calais,State:,PostalCode:62100,Country:france	0.9585

The reasoning system proposes two web-services which are *OptimoRoute* (https://optimoroute.com/) and *TrackRoad* (http://doc.trackroad.com/) to resolve the example problem identified in above section, as shown in Figure 7. Both of these are commercial web-services. These suggest the allocation of *orders* to vehicle driver on the basis of the road network. These may additionally solve the problem with added constraints such as driver work time and vehicle loading capacity, hence propose to solve the *CVRP*, *VRPPD*, *VRPB* and *VRPTW*. The objective function addressed by them can be summed as follows:

$$Objective function = \{minimumdistance, maximumloadingcapacity, \\ managedrivertime\}$$

9 Performance evaluation of web-services

We attempt to compare the execution of *OptimoRoute* and *TrackRoad* to verify their performance, as both offer to solve the same set of problem types. Hence, we experiment the same data (involving multiple *orders*) on both web-services. Figure 8 summarises some results obtained from *TrackRoad*. Each web-service uses a different optimisation method. Obviously, we obtain differing results according to the capability of the web-service to solve the given logistics problem. The developed platform provides a means to store the user experience for verification purposes. As a result of this experiment, the *OptimoRoute* responds in 22,670 milliseconds to compute the total distance of 26.145 km whereas the *TrackRoad* spent 2,170 milliseconds to compute the total distance of 17.727 km.

10 Conclusions

The work presented in this paper deals with the development of an approach and a platform intended to assist human experts in precisely identifying both the logistics problems they are faced to, the optimisation methods solving such a problem and the software units implementing these methods. Since we assume that concerned information systems are deployed following the *service-oriented architecture*, we especially consider the software units encapsulated by means of web services. In fact, one of our main objective is to make the considered information systems more responsive, consequently they are able to integrate the various changes with minimal costs and time. Our approach is mainly based on the use of a knowledge-based system containing sufficient knowledge that makes possible the implementation of an assistance process guiding the human experts from the expression of their problems by means of a set of concepts (RCs) to a set of web services implementing the solution of the initial problem. In this way, the interference of technical issues with the logistics problem can be avoided. It enables the expert to focus more on the problem but not on the optimisation methods and their technical details.

Our approach is mainly based on the use of a knowledge base formalised and implemented by ontologies. We define an ontology that conceptualises knowledge concerning the logistics processes. We particularly consider the *supply chain management* processes. We also focus on a transportation problem that is the *VRPs* and its variants. The second ontology, that we define and implement, concerns the various optimisation methods dealing with the resolution of the *VRP* problem and its variants. The final ontology concerns the web services implementing the methods.

Based on the above ontologies, we implement a platform accessed as a web application that is deployed using the Java Enterprise Edition technologies. The platform is also based on the semantic web technologies including the OWL language to implement ontologies and the SPARQL language to explore the various data representing the logistics artifacts along with their semantic annotations.

We are currently considering the use of the platform by users that are business experts associated at the Port of Calais, France. Actually, the imposed problem of these experts is to explore the means to better deal with the amount of changes induced by the BREXIT. The problem is more complex since it concerns a large variety of logistics and transportation processes mainly concerning the various security controls, the introduction of customs formalities, etc.

We are also experimenting the approach for other problems concerning the Industry 4.0 features. The goal is to assist the manufacturing actors to deal with the various and numerous changes affecting their environments. In this work, we assume that the software units interoperate by adopting some standards like ISO 16100-300 (Basson et al., 2019). The major goal is to be able to implement the changes affecting the manufacturing processes by combining the right software units that are identified and localised by exploring a distributed knowledge base built by means of ontologies.

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