How to Choose the Greenest Delivery Plan: A Framework to Measure Key Performance Indicators for Sustainable Urban Logistics

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How to choose the greenest delivery plan: a framework to measure Key Performance Indicators for sustainable urban logistics

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Abstract. The sustainability of urban logistics is an important issue for rapidly growing cities worldwide. Although many cities and research works have developed strategies to move people more efficiently and safely within the urban environment, much less attention has been paid to the importance of optimizing the delivery of goods to people at work and home taking into account sustainable goals. In this work we propose a framework that aids to register and measure a set of sustainable Key Performance Indicators (KPIs) for delivery routes and plans in urban zones. The approach is general and based on a set of well defined KPIs from the specialized research field.

Keywords: Urban Logistics, Green Supply Chains, KPIs

1 Introduction

Urban logistics [1] is essential to the functioning of modern urban economies. Cities are places of consumption relying on frequent deliveries of groceries and retail goods, express deliveries to businesses, and a fast-growing home delivery market. European cities (as most of worldwide cities) are forced to tackle a wide range of urban traffic problems: first of all the big challenge of reducing traffic congestions, CO2, pollutant emissions, and energy consumption. According to the European Environment Agency, cities emit 69% of Europe's CO2 and urban transport accounts for 70% of the pollutants and 40% of the greenhouse gas emissions from European road transport (European Environment Agency). On the other hand, cities have to guarantee to citizens not only the overall accessibility to the different city and transport services, but also an efficient urban logistic with respect to the economic and environmental factors. According to this, the Transport Policy White Paper[1] set up the CO2 free urban logistics as

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[1] https://www.eesc.europa.eu/sites/default/files/resources/docs/pp-white-paper-transport-may16-en.pdf

one of the 10 objectives to reach by the 2030. The EU guidelines for "Developing and Implementing a Sustainable Urban Mobility Plan", aims to provide realistic and simple guidelines for city stakeholders and technicians, for developing a Sustainable Urban Logistics Plan focused on the optimization of urban logistics processes in order to reduce the related energy consumption and environmental impacts yielding its economic sustainability.

There is today a considerably growing consensus on the idea that more sustainable urban logistic operations and significant benefits in terms of energy efficiency can be achieved by an appropriate mix of different measures such as: urban consolidation centres, optimized urban logistic transport and delivery plans, use of clean vehicles and low emission technologies, focused regulation framework, public incentive/qualification policies, last mile and value added services, integration of city logistics processes within the overall urban mobility planning and management. To aid in these measures and focusing mainly on delivery plans in this paper a framework for scoring sustainable plans is proposed. Our work is motivated on the need to register and measure Key Performance Indicators (KPIs) that can help stakeholders and practitioners to mark and select those urban logistic delivery plans that optimizes sustainable goals.

2 Sustainable Urban Logistic and how to measure its performance

Cities are places of consumption, production, and distribution of material goods. Urban logistics [1] includes all activities ensuring that the material demands of these activities are satisfied. It includes all goods movements generated by the economic needs of local businesses, that is, all deliveries and collection of supplies, materials, parts, consumables, mail and refuse that businesses require to operate [4]. As a city hosts a great number of different economic sectors, it is provisioned by hundreds of different supply chains, making urban logistics very complex and diverse. Over the past two decades delivering goods into cities has become a challenge with cities getting overly congested and traffic jams resulting in expensive logistics bottlenecks. Studies show that the cost of congestion now in terms of time wasted in traffic and fuel consumption is very high, almost 200% more than what it was in the 1980s. Pollution, lack of parking bays, and warehousing costs are all restraints that are contributing to the economic cost of urban logistics.

The concept of Sustainable Urban Logistic (or Sustainable Last Mile Logistic) is closely related with that of Sustainable Supply Chains. A Sustainable Supply Chain is one that performs well on both traditional measures of profit and loss as well as on an expanded conceptualization of performance that includes social and natural dimensions [8]. In the specialized literature a large number of works related with measuring the economic performance of logistics solutions can be found. Nevertheless, less works that mix all the aspects of sustainable logistics were reported. Among the few, but interesting, works found in the literature we base our study on the list of 21 indicators proposed by Morana in [6]. The list is

Table 1. Sustainable Urban Logistics' Key Performance Indicators [6]

Urban Logistics KPIs		
Economic Dimension	**Environmental Dimension**	**Social/Societal Dimensions**
Service rate	Greenhouse gas emission rate	Inhabitants satisfaction rates
Logistics costs	Energy consumption	Employment creation rates
Customers' satisfaction rate	Congestion	Reclamation rate
Number of vehicles	Noise level	
Delivery times		
Economic viability rates		
Number of deliveries		
Economic savings		
Number of delivery platforms		
Delay rates		
Vehicles' loading rates		
Maintenance rates		
Number of ruptures of charge		
Time delay due to congestion		

in turn built from two other works [3] and [2]. The concrete details on why are these concrete KPIs included in the list can be found in [6], nevertheless it is important to point out that the proposed list was built based on an in-depth study on urban logistics experts, practitioners and stakeholders. The Morana list, see Table 1 includes three types of measurement that reflect the three dimensions of sustainable development, that is economic, environment and social/societal. Despite the usefulness of these KPIs there is a lack of a conceptual model (ontology) that can aid the stakeholders to register all the information relevant to measure these KPIs in order to facilitate working with them and better integrate into transportation models.

In this work we propose a framework that allows to capture these KPIs into an ontology for Intelligent Transportation Systems providing in this way an easy to use approach to measure them and using these KPIs in applications that want to find optimized sustainable urban delivery plans.

3 An ontology to capture sustainable KPIs in Urban Logistics

The Intelligent Transportation System Ontology (ITSO) we propose is based on the work of [7]. Nevertheless, other works such as [10] that proposes two ontologies for way-finding with multiple transportation modes, and [5] in which a system is proposed based on public transportation ontology, were also taken into account for the ontology definition. The ITSO is complete in terms of the six dimensions defined in [7] and extended with the sustainable specific attributes and/or relationships that are key in order to register the sustainable KPIs of Table 1 and to realize the optimized movement of materials in the city. Moreover, it is ready to use and provided as an XML description file easy to read and process by any type of software application. Following the ontology is described with special focus on its original elements.

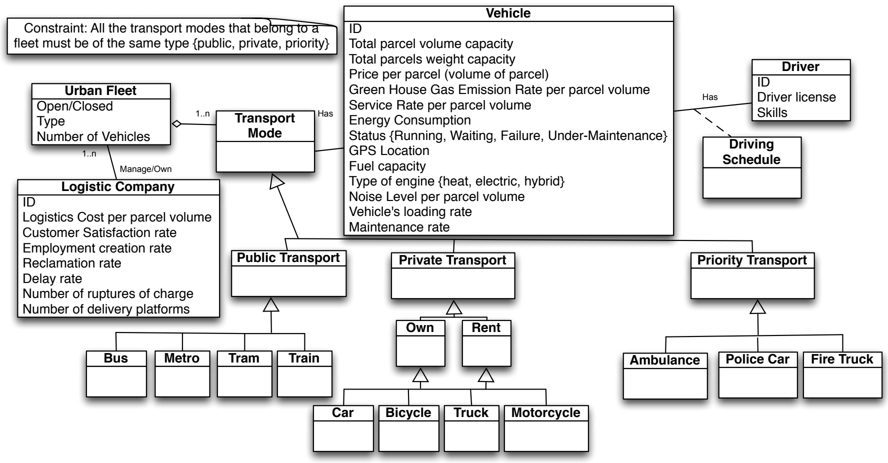

Fig. 1. Main ontology concepts of the Intelligent Transportation System Ontology

Figure 1 shows the different ontology concepts that built up the model and deal specifically with the transportation multi-modality or transportation mode and the sustainable KPIs related with the Vehicles definition and the Logistic Company characterization. The three dimension KPIs of Table 1 are included for vehicles and logistic company. In the proposed ontology there are three modes. (i) Public to which pertain the modes that are provided by transportation operators, with transportation lines running in a transportation network following a schedule (see Figure 2 for a detailed view). This mode is included in order to allow logistic deliveries using the public transportation system in urban areas. (ii) Private to which pertain Cars, Bicycles, Trucks (the particular features of the trucks are registered in the class Truck, in this way different type of trucks are allowed depending on the fleet requirements for LMD), and Motorcycle that can again be Owned or Rented by citizens/users. (iii) Priority to which pertain special type of transports such as: Ambulance, Police Car and Fire Truck. This last transportation mode is included in order to provide a complete transportation model, but this mode cannot be used by Logistic Companies for delivery purposes.

An Urban Fleet (see Figure 1) is defined as a group of transports in which all the transports belong to the same Transportation Mode. It can be Open or Close. An Open Urban Fleet is one that can change dynamically, i.e. a transport owner can decide to enter or exit the fleet at any time. A Close Urban Fleet is one in which no new transport owners can decide to enter the fleet in a dynamic fashion. A Logistic Company manages or owns one or many Urban Fleets. Its associated features for the KPIs registry are Logistics Cost per parcel volume, Customer Satisfaction rate, Employment creation rate, Reclamation rate, Delay rate and Number of ruptures of charge. The values for these features

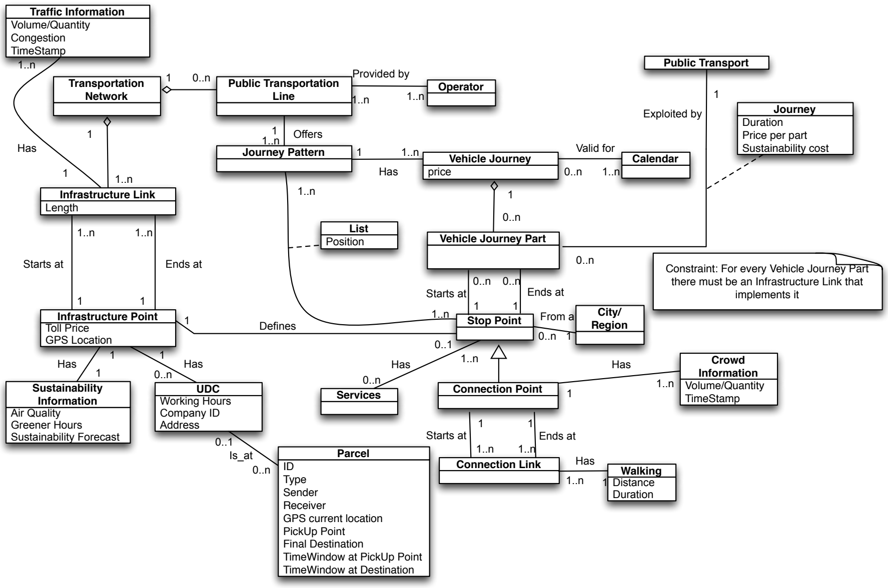

Fig. 2. Ontology definition of the Transportation Network

can be calculated and/or measured using different mechanism depending on the concrete application that uses the ITSO. For example the Customer Satisfaction rate can be measured by means of customer polls.

Figure 2 presents the Transportation Network ontology. It is defined by the set of Infrastructure Links that defines the transportation infrastructure itself and the set of Public Transportation Lines that runs in the network. An Infrastructure Links connects Infrastructure Points. Every Infrastructure Link has a Traffic Information associated that is used in order to infer recommendations to the users about timing issues when intending to move trough the given Infrastructure Link, the Congestion KPI is registered using this concept. Moreover, every Infrastructure Point is associated with Sustainability Information about Air Quality, "Greener" Hours to navigate the point, and Sustainability Forecast (mainly about CO2 data). The Sustainability Information is intended to be taken into account by for example a recommender model when analyzing the sustainability cost for the overall system for the given itinerary (a route made up of connected Infrastructure Links).

Finally Figure 3 shows the specification for the Deliveries. The rest of the KPIs associated with the concrete material/parcel that is being delivered are included as attributes of the Delivery and DeliveryPath concepts.

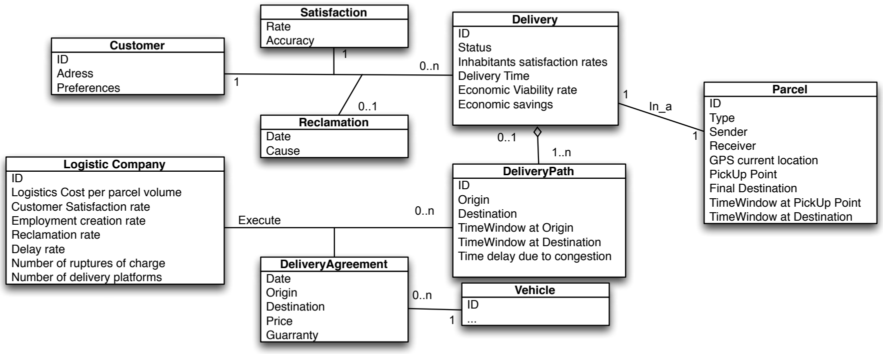

Fig. 3. Users, Deliveries and parcels

4 Measuring KPIs

In this section we describe the measurement module of the framework in order to complete the ITSO with a complete definition of its measuring methods. The methods we describe in this section are those for measuring the KPIs from the delivery plans (a set of DeliveryPaths, see Figure 3) provided by Logistic Companies. These methods are appropriate for applications seeking to optimize delivery plans (in Section 5 a case study is presented).

From Figure 3 a Delivery Plan $Plan(P)$ for a Parcel P is an ordered non-empty set of DeliveryPaths $DPath$.

$Plan(P) = \{DPath_1, ..., DPath_n\}$, where $n >= 1$

Each $DPath$ has an associated DeliveryAgreement that links the Logistic Company and the Vehicle that transport the Parcel in the given DeliveryPath. This connection of concepts must be navigated in order to measure, for example, the Green Gas Emission rate KPI (GGER-KPI) for a given Delivery Plan and, in this way, compare different plans in order to choose the greenest one.

$GGER - KPI(Plan(P)) =$
$\sum_{i=1}^{n} DPath_i.DeliveryAgreement.Vehicle.GreenHouseGasEmissionRate$

On the other hand, if the goal is to measure the Customers' Satisfaction rate KPI (CSR-KPI) for a given Logistic Company, the following formula must be calculated.

$CSR - KPI(LogisticCompany) =$
$\sum_{i=1}^{m}((LogisticCompany.Plan_i.Satisfaction.Rate)*$
$(LogisticCompany.Plan_i.Satisfaction.Accuracy))$, where $m >= 1$
and represents all the deliveries executed by the given Logistic Company.

The Energy consumption KPI (EC-KPI) is calculated as follows
$EC - KPI(Plan(P)) =$
$\sum_{i=1}^{n} DPath_i.DeliveryAgreement.Vehicle.EnergyConsumption$

The Congestion KPI (C-KPI) is measured with the following formula
$C - KPI(Plan(P)) =$
$\sum_{i=1}^{n} < DPath_i.Origin, DPath_i.Destination > .TrafficInform.Congestion$
The tuple $< DPath_i.Origin, DPath_i.Destination >$ defines an InfrastructureLink, see Figure 2, and helps to retrieve the Traffic Information.

Due to space limitation in this paper not all the formulas for all the KPIs are described, but the process to build them is easy and similar to those described in this section.

5 A Case Study: Last Mile Delivery a crowd logistic approach

In this section we shortly describe an application that uses the ITSO presented in this paper in order to implement a crowdsourcing approach for Last Mile Delivery. Crowd Shipping, these two words together form an increasingly familiar and emerging concept among those interested in transportation, logistics and urban mobility. In the spirit of collaborative economics, the idea behind crowdshipping is using ordinary citizens - on foot, by bicycle or by any means of transportation available to them - to make deliveries. Entrepreneurs, couriers, and consumers simply need to sign up in an application to connect. Crowdshipping can complement truck deliveries with lighter, easier-to-maneuver vehicles, as more and more cities impose restrictions on truck traffic. Crowdshipping can save companies money - as they no longer need to set up a carrier structure - and can be a new source of income for many people. Our approach is named *CALMeD SURF* [9] and is based on crowdsourcing, taking advantage of the movements of the citizens in the urban area, that move for their own needs. This application is addressed as a mobile phone app for: customers that want to deliver a parcel, and users that want to serve as occasional deliverers in an urban area. The main idea is that the users register in the application (as customer or deliverer), and *CALMeD SURF* will locate them in the city on real-time. In this way, when there is a parcel delivery request, the system uses a graph, that is dynamically generated from the active users and the instantiated ITSO, where each node is either a user (a potential deliverer, and/or customer) or a delivery center/office. The system proposes optimized parcels delivery paths (measuring the associated KPIs of previous sections) to the crowd of potential deliverers (those who are closest to the calculated delivery path) to participate. If some of the potential deliverers rejects the proposal, it calculates an alternative path (i.e. a new path and a new set of potential deliverers) in order to achieve the parcel delivery goal. The calculated path may include several deliverers that may pass the parcel from one to another (connecting sub-paths). One of the optimization criteria used by the system, closely related with the goal of minimizing the harm to the environment, is to minimize the deviation of the deliverers from the path to their own destinations and to maximize the use of sustainable transportation modes (mainly bicycles). Trying in this way to minimize new emissions originated by movements that are solely used for parcel deliveries. This case study is a successful example of the usefulness of ITSO in optimized delivery plans for sustainability goals, achieving an optimization of 30% in the Green House Gas Emission rate KPI and reducing by 35% the Service rate KPI.

6 Conclusion and Future Works

In this paper a framework that aids to register and measure a set of sustainable Key Performance Indicators (KPIs) for delivery routes and plans in urban zones was proposed. The approach is general and based on a set of 21 well defined KPIs from the specialized research field. Moreover a case study was also presented illustrating the usefulness of the proposed approach when building optimized delivery plan solutions for sustainable goals. As ongoing work we are tuning the measuring mechanism for the proposed KPIs (mainly in terms of fast search algorithms) and implementing a library of optimized SW approaches that can take into account multiple KPIs into different domains. A complete validation phase is also devised as future work.

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