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INNOVATIVE SCHEME FOR EFFICIENT FREIGHT MOVEMENT AND SUSTAINABLE EMISSIONS MANAGEMENT

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This paper presents and analyses an innovative integrated scheme that aims to rationalize and improve the efficiency of urban freight transport as well as to promote reduced GHG emissions and traffic flows. Emissions management has become critical concern for modern companies and public authorities seeking to reduce carbon emissions and energy consumption from private and commercial heavy vehicle fleets, in line with the political targets of COP21 to COP23. The proposed scheme aims to utilize the current technological advances for efficient transport and logistics operations that regional authorities and companies can use and afford in order to provide competitive traffic management decisions as well as improvements in terms of pollutant emissions reduction. Both public and private stakeholders could interact to monitor and evaluate the impact of traffic policies and measures over time as well as the level of success of their routing strategies. Computational results on different scenarios of an experimental simulation model illustrate the competitiveness of the proposed scheme in an effort to quantify its effect.

Keywords: GHG emissions; transport environmental management; logistics

1. Introduction

The transport sector is expected to be the largest source of CO2 emissions in EU within forty years (2010 – 2050) and it is the major sector where greenhouse gas (GHG) emissions are still rising. It currently accounts for 30% of the CO2 emissions while this share reaches the 40% in urban areas (European Commission, 2009). In particular, road freight transport still consumes significantly more energy than rail or ship freight transport (European Environment Agency, 2013) and contributes to 33% of total transport emissions (Faberi *et al*., 2015) including city logistics. As such, the political target of COP21 to COP23 is to achieve a reduction up to 80-85% for the freight transport GHG emissions with both operational and technical interventions.

In the dynamic environment of urban transport logistics, innovative technology and tools are able to provide accurate real-time traffic information and fuel consumption data for trucks and other commercial vehicles (Bell *et al*., 2013) allowing flexible freight demand management and operational changes. Freight demand management is one of the core activities performed by transport authorities aiming to promote transport policy goals associated with traffic efficiency as well as with environmental aspects. In order to achieve these goals, traffic authorities implement various operational and behavioural measures such as dedicated HOV lanes, off-hour and night deliveries, off-street delivery areas and access control based on traffic/emissions zones. Towards to this direction, industry also makes significant efforts in reducing the environmental impacts of freight distribution and relevant activities revealing their increased interest for achieving reduced emissions profiles (mostly due to the impending taxation measures). Monitoring and evaluating the level of success and the impact of such strategies over time is an essential factor for promoting the quality of decision making processes (Joumard *et al*., 2008).

Considering urban transport logistics, the wide range of modern technology services make available accurate real-time traffic information, roadway conditions, location of facilities, and other data, for trucks and commercial vehicles. Special equipment and infrastructure provide fleet composition, traffic data and historical information about traffic volumes. Sensors can also provide detailed information on the performance and operations of a truck, including fuel consumption, speed and acceleration/deceleration. A large amount of data is thus continuously collected and may complement the geographic features data of a certain region, which includes spatial and attribute information. The value of these data is to support traffic monitoring and control, enhance the system's reliability, support fleet operations and asset management, and improve environmental performance.

Capitalizing upon such capabilities, this paper presents an innovative integrated scheme that aims to rationalize and improve the efficiency of urban freight transport as well as to promote reduced GHG emissions while achieving economic savings and benefits. This scheme utilizes real time "vehicle" level data as a basis for determining traffic flow conditions and calculating aggregate vehicle emissions at a "network" level. Valuable knowledge could be retrieved from massive "vehicle level" data that are used to calibrate the parameters that affect the accuracy of both traffic and emissions "network" models. Taking advantage of the improved models, the proposed scheme supports decision making on traffic management policies that regional authorities implement and companies' route planning.

The remainder of the paper is organized as follows: Section 2 describes the proposed scheme for efficient freight movement and sustainable emissions management and then, Section 3 presents the simulation based analysis conducted to assess the scheme's performance and value in transport planning and operations. The results and the evaluation outcomes are provided in Section 4 and finally, in Section 5 conclusions are drawn and a summary of the potentials about transport emissions measurement and reaction is given.

2. Innovative Scheme for Transport Emissions Management

A win-win scheme, where public authorities offer network traffic information to private transport companies, which in turn provide real time big data at a vehicle level, is presented (Fig. 1). This ensures the use of more improved and more accurate traffic models during the course of evolution achieving a sustainable decision making. Public authorities are able to assess the overall traffic and environmental improvements at a network level but also monitor the impact of measures at individual vehicle or corporate level. The importance of integrating emission-related considerations into the freight-demand management decision making stems from the emerging environmental requirements and standards at the national level, which directly reflect on urban and interurban public authorities.

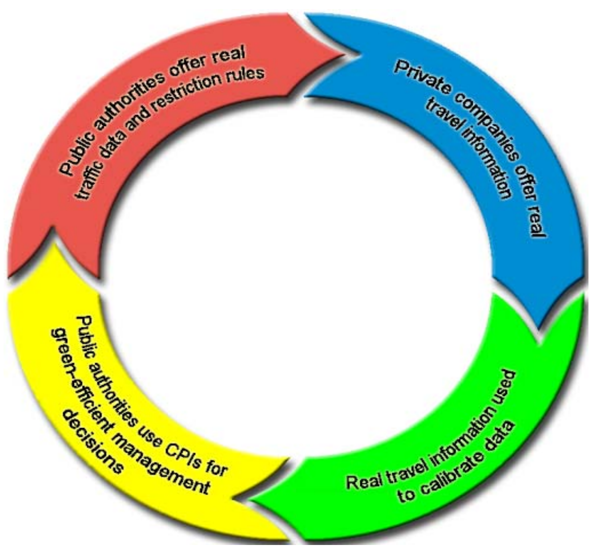

Figure 1. Win – win approach

In particular, FCD (Floating Car Data) utilized as a basis for determining traffic volumes, composition and traffic flow conditions as well as calculating aggregate vehicle emissions at a "network" level using an emissions model such as the well – known COPERT. The traffic data, along with statistical fleet composition, national and local data, are then used for the calculation of vehicle-generated emissions at the network level. Vehicle traffic parameters and data provided by vehicles equipped with monitoring devices are served as an input to the emissions model to calibrate "vehicle" level emissions and generate the environmental footprint at the vehicle level. The assessment of different and various traffic management policies is achieved by the integration of traffic flows and traffic volume data that enable freight movements' evaluation in terms of generated emissions (Fig. 2).

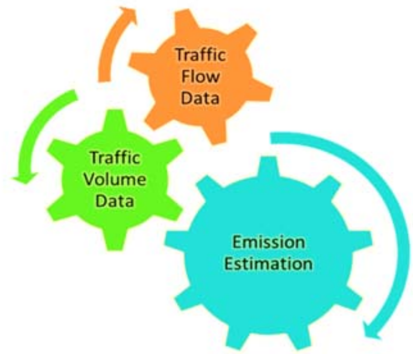

Figure 2. Model overview

Generated traffic maps are used as the real base case (input) for simulated scenarios, which are based on information about movement trends and behaviour using the planning tools of public authorities. Additionally, simulated emissions for various scenarios can be generated for public authorities to study future actions since base case for municipalities are not be generated from questionnaires and/or historical data rather they are based on real world information. Relatively simple technological tools are required and thus, both regional authorities and private companies could use them affordably in order to provide efficient policy making for sustainable urban freight transport reducing the corresponding pollutant emissions generated.

The core pillar of the entire scheme is the development of the system modules and tools aiming to cover the user requirements. The vehicle-level services support fleet managers to organize processes and apply strategies for an improved performance of the corporate transport activity in terms of environmental impact. Similarly, the network-level activities offer aggregate emissions estimations that depict the environmental behaviour of the traffic movements in the wider area. Within the context of this pillar, traffic data are utilized to ensure the successful emissions modelling and the generation of a historic database about pollutant emission regions in the area of interest. More accurate estimations and more robust emissions models could be assured with the use of calibrated traffic data and precise parameters settings.

2.1. Emissions Estimation

Emissions modelling requires the integration of the traffic flow (i.e. average speed of a vehicle traversing a road segment) and traffic volume data (i.e. total number of vehicles traversing each road segment, type of vehicles traversing each road segment) utilizing real-time traffic conditions from FCD (for example data from GPS probes). These big data are used to generate static distributions and on-line information about volume of traffic on road segments allowing either the emissions estimation in a given set of road segments or the emissions estimation of a specific fleet of vehicles utilizing a common emissions model (such as ARTEMIS, COPERT4 etc.). The generated maps of estimated emissions offer visualizations that depict the environmental behaviour of the traffic movements in the wider area.

These estimated values are compared with the real-world emissions obtained by vehicles for the model's evaluation and evolution. Real-time information at a vehicle level i.e. tones – km, emissions, vehicle type and location are used to evaluate the performance of the abstract results generated comparing real traffic and emissions data with the results derived by the model. These real-time data also constitute the basis in order to determine more accurate values for the several parameters of the model in an effort to evolve its performance. Hence, realistic values are set to the parameters of the model that affect emissions calculation supporting accuracy and precision.

The innovative scheme for efficient freight movement and sustainable emissions management could assist fleet operators to make assessments on the relation between their business activity and the emissions produced. The reaction time for the assessment is near real time allowing for direct evaluation of the applied distribution strategy i.e. selecting appropriate vehicle technology, evaluating driver profiles, providing focused training to drivers, improving scheduling and truck loading and / or selecting most appropriate itineraries.

From public authorities perspective, overall traffic and environmental improvements at a network level (reduce traffic externalities and consequently mitigate high concentrations of pollutants) could be assessed in a short term basis. Furthermore, public authorities can monitor the impact of measures at individual vehicle or corporate level. This win-win collaboration enhances the performance of evolution and it could result to both higher energy savings and emission reductions gaining competitive advantage for the logistic companies that implement the aforementioned scheme.

3. Simulation Based Analysis

In an effort to evaluate the performance of the proposed scheme regarding traffic management decisions and policies of a city, an experimental simulation model is undertaken as part of a case study for the Thessaloniki urban area in Greece and presented in Figure 3(a) and Figure 3(b). The studied area is physically and logically represented by incorporating network geometry (number of lanes, lanes width, etc.), vehicle characteristics and dynamics (different vehicle types, vehicle proportions, top speed), traffic control settings (link speeds, signposting, traffic signs, various restrictions imposed such as information on speed limits, one-way and pedestrian segments) as well as drivers' behavioural characteristics such as mean target headway, mean reaction time etc.

(a) (b)

Figure 3. (a) Test site: Thessaloniki urban area, Greece; (b) Modelled network

The network considered to build the base case scenario consists of 228 nodes connected by links representing 462 km of roadway, and a total of 38 zones which represent entrance/exit areas of vehicles to the city and inner city origins and destinations points. The Base Case scenario simulates the morning peak hours of a typical weekday in Thessaloniki area, reflecting the regular conditions in the test site where public and private stakeholders do not interact and traffic flow and volume information are not diffused among them.

Studying the simulation results gained, three main roads (Fig. 4) in the city centre are highly congested which indicates that increased GHG emissions are diffused to the air due to the transport activity in the area. These central roads are a critical part of the road network and connect the east with the west part of the city.

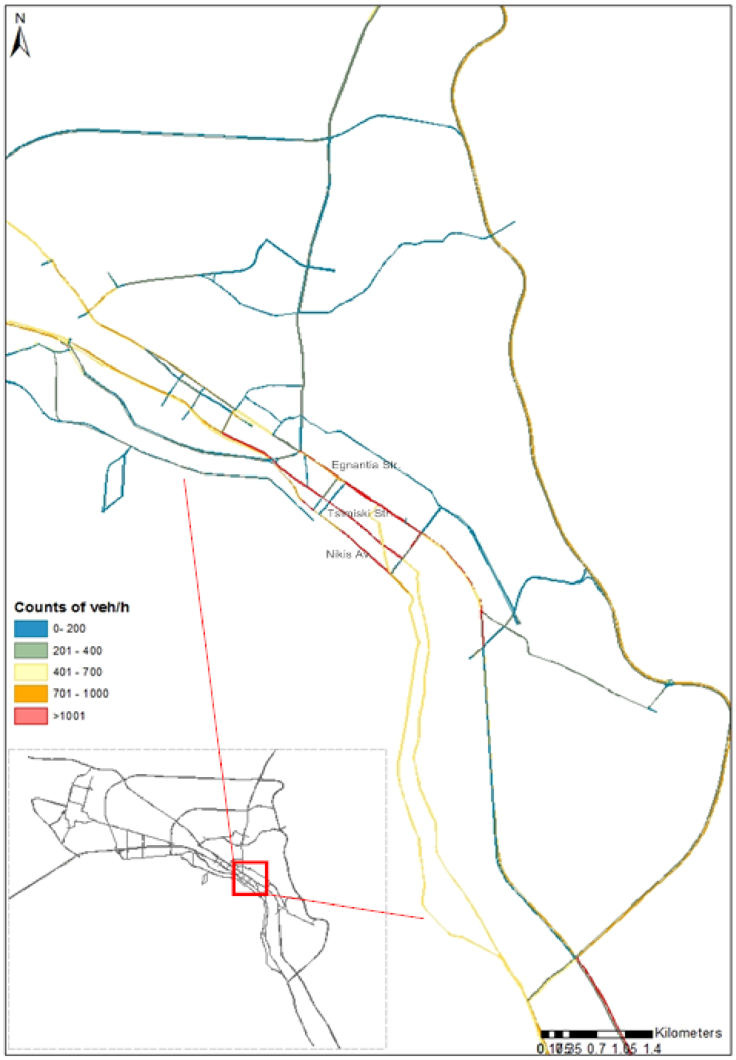

Figure 4. Traffic Map: Highly congested roads in Thessaloniki area

3.1. Stakeholders' Perspectives

From fleet operators perspective, a recent trend in urban freight transport services is eco-driving (Sivak and Schoettle, 2012) which indicates an environmental friendly driving manner achieving significant effects on fuel economy and relevant reductions in GHG emissions. According to McKinsey Report (2009), eco-driving could lead even to 3% abatement in global emissions if applied broadly and an improved driving behaviour is suggested as a lever for improving air quality reducing CO2 emissions. Based on the above, fleet operators in modern companies implement this strategy seeking for more fuel and environmental efficient routing. Following the eco-driving strategy, the goal of the fleet operators is to improve driving performance and maximize truck's actual fuel efficiency by maintaining constant speed when possible and avoiding strong acceleration or braking. A slight increase in the driver's anticipation distance and a decrease in reaction time could also promote eco-friendly driving. According to Thijssen *et al*. (2014), a slight improvement of the anticipation distance yields to notably lower energy consumption and thus, lower pollutant emissions in the air. In addition, Larsson and Ericsson (2009) claim that fuel economy is correlated significantly with the reaction times and the compliance with the proposed speed profiles.

On the other hand, public authorities' role is to implement traffic management policies and measures to ensure urban distribution does not affect the service for the city residents. Limited traffic zones (LTZ) is a widely implemented measure (CIVITAS, 2013) which imposes access restrictions and parking policies in order to reduce traffic in highly congested areas of a city. Dedicated zones via access management are mainly implemented to reallocate priority of transport modes reshaping the urban environment (Boschetti *et al*., 2014). Moreover, priority zones could be also developed in an attempt to reduce the circulation level in the city centre achieving alternative distribution flows. Such policy, though can lead to emissions reductions, it is also possible to increase the GHG emissions since traffic is reassigned to the near target area of the road network (Rebound Effect) resulting in increased congestion and trucking miles travelled (NCFRP, 2015).

3.2. Experimental test case

Considering private and public perspectives as described above, an implementation case is investigated where private stakeholders impose eco-driving strategy for their fleets and public authorities apply limited traffic access in the city centre for truck distributions. To this end, a simulation model is developed to evaluate the performance of the proposed strategy and indicate how the proposed innovative scheme is utilized to achieve sustainable emissions management. Building upon the base case scenario, two additional scenarios were investigated: (i) the implementation scenario where eco-driving is imposed by fleet operators at a vehicle level and trucks are banned from the three highly congested road segments in the city centre (Fig. 4) from 7am to 9am at a network level (without any data exchange between private and public stakeholders), and (ii) the evolutionary scenario which simulates the case where both private and public stakeholders have exchanged their data at a vehicle and network level following the proposed innovative scheme. This enhances decision making and allows the implementation of successful future actions and plans for more efficient freight movements and sustainable emissions management applying adjusted strategies and proper measures.

In line with the previous remarks, the adjusted parameters which aim to replicate real eco-driving conditions for the Thessaloniki case study consist of the maximum acceleration/deceleration, top speed limit, perception reaction time and headway factor. Suitable value adjustments are provided for each parameter based on the data obtained about itineraries, emissions and driving profiles from the on board telematics devices. The latter have been installed in the participated corporate trucks of this case study providing real life information at a vehicle level. More specifically, the corresponding parameters of gradual acceleration/ deceleration are decreased by 40% and 60% for familiar and unfamiliar drivers, respectively. The top speed parameter experiences a 7% decrease since it was found to provide a good compromise for drivers' behaviour. Finally, the headway factor increases to 25% and the perception reaction time is reduced by 50%.

Within the context of the proposed management scheme, aggregate emissions estimations offered at network level that depict the environmental behaviour of the traffic movements in the wider area of Thessaloniki city. Traffic data were categorized based on vehicle type which ensures the successful modelling and the generation of historic database for traffic flows in the studied area utilizing previous information about travelled routes as well as geographic information data (i.e. road classes and number of lanes). Private stakeholders could access this information to organize their processes and apply strategies for an improved performance of their corporate transport activity while they offer their vehicle level data on return. They provide information about their vehicle itineraries and other relevant data (i.e. speed, fuel consumption, acceleration/deceleration, etc.). Utilizing both network and vehicle level data, static distributions are generated and data about traffic volume on road segments are estimated.

Thoroughly, the total number of vehicles and the corresponding ratio of each type (i.e. car, trucks, etc.) are provided at a network level while the number of trucks per road segment is determined at a vehicle level. Hence, the normalized counts of vehicles per road segment could be defined and Fig. 5 depicts that one road is more highly congested in practice comparing to the others. To this end, the evolutionary scenario simulates the case where trucks are banned only from this road within 7am to 9am.

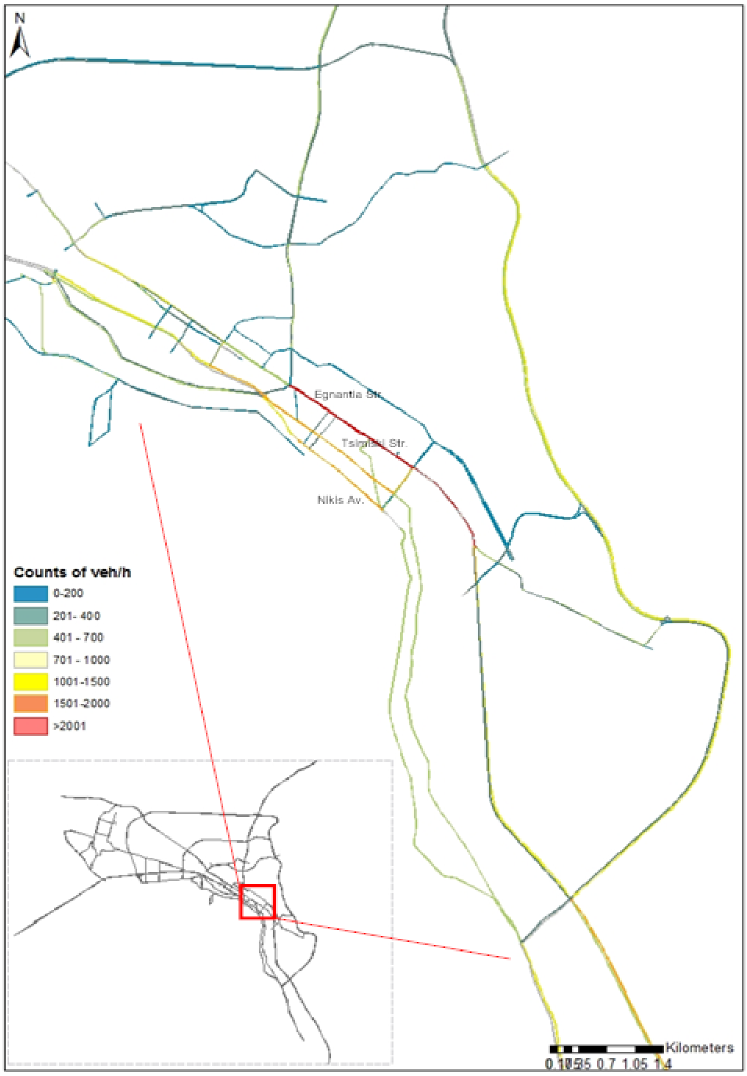

Figure 5. Traffic Map: Highly congested roads in Thessaloniki area (normalized data)

4. Evaluation and Impacts

The developed microscopic simulation models are stochastic in nature and for this reason multiple repetitions of each model (scenario) are required with different random number seeds in each run. The latter implemented to estimate the mean with a certain level of confidence and the minimum number of required runs is computed using the following equation:

$$N = (2 \times t_{(1-a/2),N-1} \times \frac{s}{CI_{1-a\%}})^2 , \quad (1)$$

where: s is the standard deviation of the estimated emissions based on the already conducted runs; $t_{(1-a/2),N-1}$ is the critical value of the Student's t-statistic at the significance level a; N is the number of repetitions; $CI_{1-a\%}$ is the confidence interval for the true mean and a represents the probability of the true mean not lying within the confidence interval. The total number of runs for this simulation study is 11.

Computational results are typically ranked according to the main objective and the relevant performance indicators. The main objectives is to minimize the GHG emissions generated due to transport activities in the urban area and therefore, the key performance indicators of effectiveness are the following:

carbon monoxide (CO), carbon dioxide (CO2), total hydrocarbons (TH), oxides of nitrogen (NOx) and fuel consumption (FC). Pollution levels are estimated for every link in the network by summing the emissions of each individual vehicle within a link considering the vehicle type, the speed, the acceleration/deceleration profile and the link gradient. Average emissions values are provided for 1-hour increments for the period between 7am to 10am.

Table 1 summarizes the results obtained and each column lists the performance indicators reflecting the average emissions generated on each link of the network. The bottom section of each scenario depicts the mean values (MV) for the total time period studied (morning peak hours). Compared to the base case, CO reductions up to 9.55%, CO2 reductions up to 9.30%, TH reductions up to 9.42%, NOx reductions up to 10.05% and FC reductions up to 9.31% are achieved with the implementation scenario. However, the maximum reductions achieved with the evolutionary scenario and results obtained illustrate the performance of the proposed scheme. In particular, improved GHG emissions are obtained with reductions up to 9.82% in CO emissions, 9.44% in CO2, 9.62% in TH, 10.38% in NOx and 9.45% in FC.

Table 1. Average Emissions Levels and Fuel Consumption per link for all vehicles in Thessaloniki network

	Time period	CO (mg)	CO2 (mg)	TH (mg)	NOx (mg)	FC (mL)
Base Case	7am-8am	7209.87	1327539	549.8133	1136.083	563.1371
	8am-9am	5818.72	1078352	445.303	910.156	457.4063
	9am-10am	6573.266	1207286	500.8201	1035.348	512.1379
MV		**6533.952**	**1204392**	**498.645**	**1027.196**	**510.894**
Implementation Scenario	7am-8am	7203.328	1327196	549.6246	1128.455	562.9884
	8am-9am	5803.092	1075639	444.1582	906.3737	456.2546
	9am-10am	4722.722	874246.3	361.2882	736.9959	370.8342
MV		**5909.714**	**1092361**	**451.6903**	**923.9414**	**463.359**
Evolutionary Scenario	7am-8am	7162.656	1324035	547.3917	1121.081	561.6308
	8am-9am	5793.241	1075114	443.5764	903.5829	456.0271
	9am-10am	4721.734	872900.1	361.021	737.0251	370.2676
MV		**5892.544**	**1090683**	**450.663**	**920.5631**	**462.6418**

5. Conclusions

The proposed scheme is able to achieve collaboration among stakeholders and develop synergies even between companies from different sectors in order to allow data and experience sharing, which are critical for the system's success and sustainability. Both public and private stakeholders can interact to monitor and evaluate the impact of traffic policies and measures over time as well as the level of success of routing strategies and their relevant decisions such that scheduling and truck loading, selecting itineraries and vehicle technology. The simulation analysis proves the competitiveness of the proposed integrated scheme and demonstrates how this innovative scheme could be applied in practice to evaluate the overall performance of both corporate actions (such that training to drivers for a more defensive driving behaviour) and applied freight transport policies (imposed by regional stakeholders) in an area.

The core competency of the proposed scheme lies on its evolutionary process which allows assessing the collective environmental impact of the decision making and the operational measures since it is not typically the sum of the impacts of each individual measure taken separately. Furthermore, it reinforces the acquisition of knowledge and experiences that result on sustainable decisions and significant benefits. A worth pursuing implementation is towards the assessment of future environmental decision making for the maintenance and improvement of road network where simulated scenarios based on real base case could be used to study future actions and plans.

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