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From ITS to C-ITS highway roadside infrastructure: the handicap of a headstart?

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From ITS to C-ITS highway roadside infrastructure: the handicap of a headstart?

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Abstract—To date, traffic remains a major source of societal costs in terms of safety and environment. In Flanders, as in other regions and Member States in the European Union, the government counts on current developments in cooperative, connected and autonomous mobility (CCAM) to achieve European societal objectives. However, the first set of Cooperative Intelligent Transport Systems (C-ITS) services has overlapping objectives with the functionalities of present ITS infrastructure. Therefore, this paper provides a methodology for road authorities to determine, bottom-up, the incremental benefits C-ITS can bring for the highway segments they operate, given the presence of ITS gantries on those segments. This allows to prioritize segments for C-ITS roadside unit (RSU) deployments, taking into account legacy ITS infrastructure. Results show that segments with dense ITS deployments, though having high traffic volumes, should not be prioritized in RSU deployment selection.

Index Terms—techno-economic, socio-economic, cooperative intelligent transport systems

I. INTRODUCTION

Cooperative Intelligent Transport Systems (C-ITS) involves communication between two or more ITS sub-systems, allowing for coordinated actions between multiple actors. As such C-ITS promise to improve road safety, reduce environmental impacts and congestion, and optimise transport efficiency. C-ITS is considered an important intermediate step towards successful automation of driving. The European Commission states that “cooperation, connectivity, and automation are not only complementary technologies; they re-inforce each other and will over time merge completely” [1, p.3].

In Flanders, as in other regions and Member States in the European Union, the government counts on current developments in cooperative, connected and autonomous mobility (CCAM) to achieve European societal objectives [2]. Via the C-Roads initiative, different highways throughout the European Union are currently being equipped with C-ITS communication capabilities to enable a first set of C-ITS use cases, the so-called Day-1 services, as listed in [1]. However, despite the promise of reducing the significant societal costs related to traffic, C-ITS deployments require substantial investments from European Member States in C-ITS roadside units

(RSUs) and in central traffic management systems. Therefore, careful selection of deployment locations is required for two reasons. First, deployments of RSUs can take multiple years, and segments with highest societal costs should hence be targeted first, not to forfeit multiple years of higher benefits C-ITS could bring on these segments. Secondly, adoption of C-ITS, and thus successfulness of use cases is currently still uncertain. Targeting the segments with highest expected benefits increases the probability of obtaining a viable business case, from societal point of view. Indeed, traffic volumes are not uniformly distributed along the Flemish highway network, hence neither are the societal costs traffic induces. Over the last decades, the Flemish government has been using the same rationale for equipping busy highway segments with extensive ITS infrastructure, such as Variable Message Signs (VMS) and Dynamic Lane Signalling (RSS). Since the functionalities of these ITS gantries overlap with the objectives of C-ITS Day-1 Infrastructure-to-Vehicle (I2V) services, the following questions arise: (1) which incremental benefits can C-ITS Day-1 I2V services bring on segments with ITS infrastructure?, and (2) are segments with high volumes still the best choice to start C-ITS RSU deployments, taking into account this overlap?

As most of the current literature either does not discuss overlap with ITS, or does so in a top-down fashion, this work provides a bottom-up methodology for road authorities to determine (1) the overlap between the present ITS infrastructure and C-ITS services for each individual segment, allowing to determine the size of expected incremental C-ITS benefits for each segment (2) the recommended segments to start C-ITS deployments, to ensure highest expected societal benefits. First, Section II discusses work related to societal benefits and investment appraisal of C-ITS. Next, Section III highlights the spatial distribution of societal costs and ITS infrastructure in Flanders, Belgium. Section IV, then, discusses the proposed methodology to determine incremental benefits, and the results for societal environmental benefits are outlined in Section V. Finally, Section VI concludes.

II. RELATED WORK

As mentioned in Section I, the European Commission has agreed on a technologically mature and highly beneficial set of C-ITS services to be deployed first, based on the work

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of the C-ITS platform [3]. These Day-1 services involve two broad categories of services, being (1) hazardous location notification, e.g. road works warning, and (2) signage applications, e.g. in-vehicle speed limits. Note that Day 1.5 services have been defined as well, to be deployed in a next phase. C-ITS services can also be categorized in terms of the types of ITS subsystems communicating. In Vehicle-to-Vehicle (V2V) communication, passenger cars communicate directly with each other, without the need of supporting infrastructure. In Infrastructure-to-Vehicle (I2V), the messages are disseminated via the roadside infrastructure, be it messages generated centrally based on traffic conditions, or rebroadcasting of vehicle messages to upcoming traffic. Since services based on I2V communication require C-ITS communication capabilities at the roadside, different European Member States, as part of the C-Roads Platform, have implemented and are still implementing C-ITS roadside units (RSUs) within C-ITS pilot deployment projects. This enables a fully connected transportation system, aimed at improving road safety, reducing environmental impacts and congestion, and optimising transport efficiency [4]. Table I provides an overview of the I2V C-ITS Day-1 services that will be considered in this research, as well as the impact each of these services is estimated to bring in terms of safety and environment. The numbers are from the Final Report of the Study on the Deployment of C-ITS in Europe [3], summarizing different large European studies on C-ITS.

Several studies have performed impact analysis of C-ITS services [5]–[8]. Furthermore, several reports discuss quantitative results for Europe, such as [3], [4], [9]. Although the aforementioned European analyses provide many important insights, they are not always able to provide tangible investment guidance to individual road authorities. First, the cost-benefit analyses is generally approached in a top-down fashion, mostly for Europe as a whole. As such, they fail to discuss the potential of C-ITS with regard to the specific conditions of an individual Member State. Indeed, there is large heterogeneity in congestion, safety and infrastructure levels, which determine the “baseline” of the analysis (do-nothing or do-minimum scenario, as defined in [10]). This baseline is important, since the European Guide on Cost-Benefit Analysis [10] stresses the importance of incremental benefits compared to that baseline. In contrast, European studies on C-ITS appear not to take into account the overlap with existing ITS infrastructure for C-ITS I2V services. An exception is the work performed in the COBRA project [11]–[14], but the correction for existing infrastructure is also done in a top-down fashion. In this European COBRA study [13], a legacy function matrix was used to determine the overlap qualitatively. Next, based on expert views, network coverage of the Variable Message Signs (VMS), display options, the frequency, importance, timeliness, accuracy, reliability and visibility of the message, the overlap was expressed as impact reduction factors, estimated in steps of 25% [14]. As an example, the overlap of different types of VMS with the C-ITS Traffic Jam Ahead Warning-service is provided. It remains unclear, however, how this relates to other

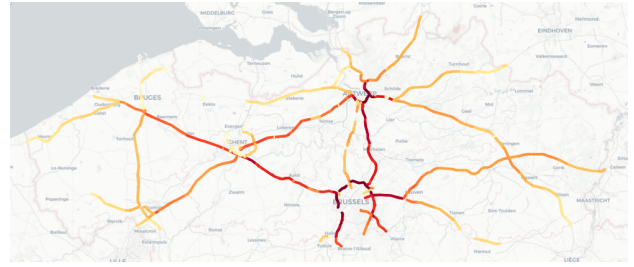


Fig. 1. Average passenger car volumes per day per segment (2019)

C-ITS services. Furthermore, it is unclear what is understood with network coverage of VMS. Is a segment covered as soon as a VMS sign is present, is the part of the segment after the VMS covered, or only the part of the segment for which the boards are visible?

In terms of dynamic highway signs, VMS as well as Dynamic Lane Signalling (Rijstrooksignalisatie, RSS), are heavily used by European road authorities for managing traffic flows. Important to note is that RSS in Flanders is used for -legally enforceable- command/prohibition signs, and thus a limited set of signs are broadcasted via this means. Also note that, since RSS message should be legally enforceable, it is legally established how they should be organised, as discussed in e.g. [15]. For this reason, RSS is overlapping with C-ITS services that aim at controlling traffic speed. This is in contrast with VMS, which purpose is more informative, and any custom message can be distributed, provided readability of the messages, as specified in e.g. [16]. Because VMS is not used for legally enforceable messages, VMS can be deployed more sparsely over the Flemish highway network, as will be discussed in Section III.

III. SPATIAL DISTRIBUTION OF SOCIETAL COSTS AND INFRASTRUCTURE

In this section, the geographical spread of societal costs and the present ITS infrastructure will be discussed, and the overlap between those.

A. Spatial distribution of societal costs for inter-urban road traffic

For obvious reasons, the main driver of societal costs related to road traffic is the total amount of vehicle kilometers driven. Indeed, traffic volumes drive societal costs both directly (emissions) and indirectly (traffic jams, traffic accidents). Therefore, Fig. 1 depicts an overview of the volumes of passenger cars on the Flemish highway segments found in Flanders for 2019. It is clear that traffic volumes are not uniformly distributed along Flemish highways: higher volumes are found on the segments that connect the “Flemish Diamond”, i.e. the four metropolitan areas of Ghent, Antwerp, Brussels and Leuven, and the ring roads encircling some of these cities.

1) *Environment*: Emissions from traffic volumes can be derived rather straightforward by multiplying with segment lengths and average emission values for the Flemish fleet.

TABLE I
IMPACT PERCENTAGE FOR DAY-1 V2I C-ITS SERVICES [3]

C-ITS Day-1 I2V Service	Fatalities reduction [%]	Injuries reduction [%]	CO ₂ reduction [%]	Overlap coefficient (IC_i)
In-vehicle signage (VSGN)	1.04	0.46	0.00	1.00
In-vehicle speed limits (VSPD)	6.90	3.90	2.3	1.00
Probe Vehicle Data (PVD)	3.30	4.90	0.006	0.00
Roadworks warning (RWW)	1.90	1.50	0.00	0.50
Weather conditions (WTC)	3.43	3.35	0.005	0.50
Shockwave damping (SWD)	7.80	5.00	0.005	0.75
Total reduction	16.50	10.50	2.31	

Since the societal costs from emissions are directly proportional to the traffic volumes, representation of the spatial distribution of these societal costs is similar to Fig. 1.

2) *Safety*: Fig. 2 presents the average amount of accidents per kilometer for the period 2016-2018. It is clear that again the R1 (ring Antwerp) and R0 (ring Brussels) are locations with a high occurrence of accidents. Traffic accident victims, being fatalities and light or heavy injuries come at a certain societal cost, thus representing the spatial distribution of societal costs for safety.

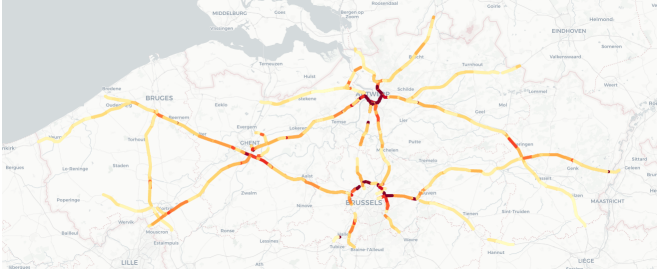


Fig. 2. Average amount of accidents (2016-2018), per kilometer

B. Spatial distribution of existing ITS infrastructure

The Flemish Roads and Traffic Agency at present has a substantial amount of ITS hardware deployed along the Flemish highways¹. Apart from induction loops all over the highway network, 160 variable message signs (VMS) and 447 gantries for dynamic lane signalling (Rijstrooksignalisatie, RSS) are currently in operation, as discussed by [17]. Fig. 3 shows the exact locations of gantries. It is clear that, apart from some exceptions, most of infrastructure is deployed there where traffic volumes are highest, notably around the ring of Antwerp and its connected highway segments, and to a lesser extent around Gent and between Brussels and Leuven. Since these locations coincide with the segments representing the highest societal costs, it implies that the Flemish government to date indeed has used societal costs as the primary decision criterion for ITS deployment.

¹Data of ITS infrastructure is available at Open Data Flanders: <https://opendata.vlaanderen.be/>

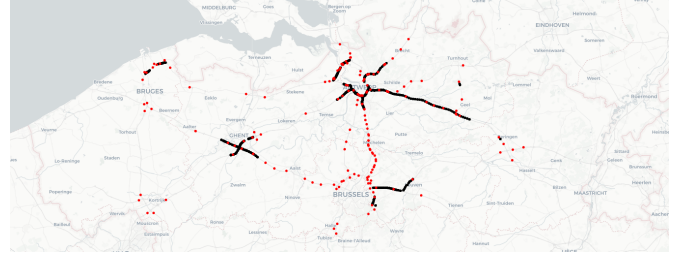


Fig. 3. Locations of ITS gantries with message screens in Flanders, with red dots depicting locations for Variable Message Signs (VMS) and black dots representing Lane Signalling Screens (RSS)

IV. OVERLAP BETWEEN ITS SERVICES AND C-ITS DAY-1 V2I SERVICES

Since the locations that appear to be a priority from a societal cost point of view, quite often are the ones equipped with ITS services, the question arises which incremental benefits Cooperative ITS can bring. Indeed, the Day-1 I2V C-ITS services explained in Section II, have overlapping functions with ITS services deployed via ITS infrastructure. For that reason, it is unclear to what extent the societal cost reductions attributed to the C-ITS services, as discussed in Section II, still hold on ITS equipped segments. Therefore, this section will propose a methodology to estimate incremental benefits, by defining how to determine overlap between ITS and C-ITS services.

First, since VMS and RSS have different capabilities, one should determine which functions of C-ITS services overlap with the functions for each of the different ITS infrastructure elements. Table II depicts, in binary fashion, if the function or capabilities of ITS infrastructure components (VMS or RSS) is overlapping with the function of C-ITS services. Because VMS can present any kind of informative message to upcoming traffic, the table shows that VMS has much of the required capabilities to fulfill the Day-1 I2V C-ITS functions.

It is unclear, however, when a segment has ITS infrastructure, how much overlap to take into account. The authors of [18] state that for the I2V service In-Vehicle Signage, “the driver can thus be informed about current traffic regulations and advices at all times and not only during brief moments when passing by fixed traffic sign or gantries”, and that “with the help of the In-Vehicle-Signage service, it is expected to

TABLE II
OVERVIEW OF OVERLAP BETWEEN DAY-1 V2I HIGHWAY SERVICES AND ITS INFRASTRUCTURE COMPONENTS.

Day-1 V2I highway services (i)	Function	VMS ($\alpha_{i,vms}$)	RSS ($\alpha_{i,rss}$)
In-vehicle signage (VSGN)	Traffic signalling, traffic info (and rerouting)	1	0
In-vehicle speed limits (VSPD)	Indicate dynamic speed	1	1
Probe Vehicle Data (PVD)	Detect vehicle	0	0
Roadworks warning (RWW)	Act in operational driving task, dose traffic	1	1
Weather conditions (WTC)	Warn for external conditions	1	0
Shockwave damping (SWD)	Act in operational driving task, dose traffic	1	1

improve the driver's awareness and reduce the number and severity of traffic accidents". Indeed, it can be argued that it could be beneficial to have a more continuous interface to the driver when steering traffic flows. Therefore, this work determines the overlap of ITS services with C-ITS by taking into account the density of those ITS installations, so that incremental benefits of C-ITS are larger when ITS installation density is lower, and vice versa. To do so, the amount of VMS and RSS gantries, per segment, is required, denoted as C_{vms} and C_{rss} in Eq.1 and 2.

The amount of ITS infrastructure overlapping with a specific service i , on a segment j , is then defined as the number of relevant ITS gantries on segment j , and presented as $C(i, j)$, as shown in Eq. 6. $\alpha_{i,vms}$ and $\alpha_{i,rss}$ can be found for each service in Table II. Based on $C(i, j)$, the ITS deployment presence ($dp_{i,j}$) and ITS deployment density ($dd_{i,j}$) of a segment can be defined, as outlined in Eq. 7 and Eq. 8. Finally, Eq. 4 depicts the determination of the ITS overlap correction per segment and per service ($OC_{i,j}$). The total ITS overlap per segment (OC_j) results from the sumproduct of intra C-ITS overlap scores (IC_i , see Table I) and $OC_{i,j}$, as shown in Eq. 5.

Let:

$$C_{vms}(j) := \text{Amount of VMS gantries on segment } j \quad (1)$$

$$C_{rss}(j) := \text{Amount of RSS gantries on segment } j \quad (2)$$

$$i := \text{Day-1 I2V service index} \quad (3)$$

Then:

$$OC_{i,j} = a \cdot dp_{i,j} + (1 - a) \cdot \frac{dd_{i,j}}{dd_{ITS,full}} \quad (4)$$

$$OC_j = \sum_i OC_{i,j} \cdot IC_i \quad (5)$$

With:

$$C(i, j) := \alpha_{i,vms} \cdot C_{vms}(j) + \alpha_{i,rss} \cdot C_{rss}(j) \quad (6)$$

$$dp_{i,j} := \begin{cases} 0 & \text{if } C(i, j) = 0 \\ 1 & \text{otherwise} \end{cases} \quad (7)$$

$$dd_{i,j} := \frac{C(i, j)}{|j|} \quad (8)$$

As can be seen from Eq. 4, a weighted sum of a binary term for deployment presence ($dp_{i,j}$) and a relative ITS deployment

density term ($\frac{dd_{i,j}}{dd_{ITS,full}}$) is used. This approach requires two assumptions, being (1) the weights of the terms and (2) the benchmark against which the segment ITS density is compared ($dd_{ITS,full}$). The former are determined by the value a , and the respective term weights are a and $(1 - a)$. The a parameter thus determines the extent to which a segment is considered covered as soon as ITS infrastructure is present (binary overlap score), versus determining overlap as a fraction based on ITS infrastructure density. A smaller a parameter provides more weight to the density term, and results, ceteris paribus, in a lower overlap score. A value of 0.75 is assumed for this parameter.

The second assumption relates to the ITS deployment density term ($\frac{dd_{i,j}}{dd_{ITS,full}}$). The underlying assumption is that there is an incremental benefit of having constant access to information (C-ITS messages displayed on in-vehicle screen) compared to exposure to the same kind of information in an intermittent fashion, via ITS signs, as discussed above. Therefore, the inter-ITS gantry distance is compared with 250 meter, in line with the reading distance assumed for the VMS text size (750 ft), as reported by [19]. The inter-ITS gantry distances of 250 meter would then correspond to readable information at all times, and thus with 100% overlap of C-ITS services, implying no additional C-ITS benefits. The inter-ITS gantry distance of 250 meter is expressed as a deployment density parameter (amount of installations per kilometer, $dd_{ITS,full}$), and equal to $\frac{1}{0.250}$. In Section V, the impact of altering both assumptions will be investigated.

V. RESULTS

In total, 246 segments out of 2297 Flemish highway segments are found to have one or more ITS gantries. For those segments, the average overlap (OC_j) amounts to 80% percent. This means that, for the reported impact of C-ITS services, as reported in Tab. I, only 20% of that potential impact should be taken into account, because existing ITS services already address the same societal problem. Note that, since C-ITS services have different reported impact on fatalities, injuries and CO₂ reduction, the correction per societal cost is different. Highest correction is found for CO₂ reduction (86%), while corrections for safety are less pronounced: injuries (76%) and fatalities (78%). Fig. 4 shows the resulting map of ITS overlap with environmental benefits by C-ITS services.

In what follows, the impact of changing the two model assumptions are investigated. Next, the environmental case

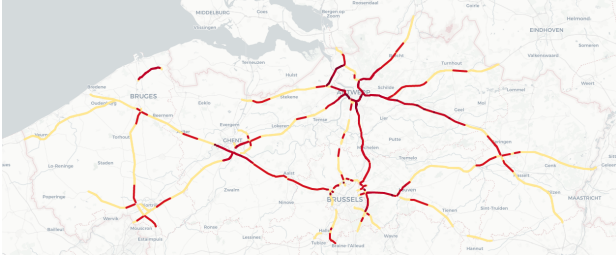


Fig. 4. ITS average overlap correction per segment, for CO₂ reduction

will be used to analyse the spatial distribution of expected societal C-ITS benefits, as it is directly proportional to traffic volumes and therefore very suitable to illustrate the results, whereas the accident data only spans three years and is hence more fragmented.

A. Sensitivity analysis of model parameters

In Section IV, two model assumptions were made, being (1) the weights of the dp and dd terms (a and $1 - a$), and (2) the benchmark against which the segment ITS density is compared ($dd_{ITS,full}$). The a parameter was assumed to be 0.75, meaning that a segment is 75% considered covered as soon as ITS infrastructure is present, and the remaining 25% depends on the ITS infrastructure density. It is evident that smaller values for a , ceteris paribus, result in higher potential incremental benefits of C-ITS services. Next, the $dd_{ITS,full}$ was based on 250 meter, requiring ITS gantries to be 250 meter apart to obtain 100% overlap with C-ITS services. Higher values for that inter-ITS distance, ceteris paribus, result in fewer potential incremental benefits for C-ITS services. Therefore, overlap scores are investigated for different combinations for each of the assumptions. For a , values between 0 and 1 are considered, in steps of 0.25. The inter-ITS distance values range from 250 meter to 1000 meter, the distance used in [3] for C-ITS RSU deployments. Tab.III shows the resulting overlap scores for environmental benefits, for the 246 segments with ITS gantries. It is evident that when a is 1 and thus only deployment presence is considered, the overlap amounts to 100%. The lowest overlap score is found for a 0 and inter-ITS distance 250 meter. The default parameter combination in this analysis, being a equal to 0.75 and inter-ITS distance equal to 250 meter, results in previously mentioned 86%, which is close to the average value of 85% for all scenarios.

B. Environmental C-ITS benefits

As the segments with highest societal costs are, in most cases, equipped with ITS gantries, the question now arises whether the effect of reduced potential for incremental benefits by C-ITS outweighs the effect of substantially high societal costs on those segments. Therefore, this section will discuss the spatial distribution of environmental benefits in Flanders in the light of ITS overlap. As mentioned in the discussion on spatial distribution of environmental benefits, the societal costs from emissions are directly proportional to the traffic volumes.

TABLE III
SENSITIVITY ANALYSIS OF THE AVERAGE OC_j FOR ENVIRONMENTAL BENEFITS, FOR DIFFERENT VALUES FOR MODEL PARAMETERS a (Y-AXIS) AND INTER-ITS DISTANCE DEFINING $dd_{ITS,full}$ (X-AXIS)

	250	500	750	1000
0.0	0.44	0.69	0.8	0.85
0.25	0.58	0.77	0.85	0.89
0.5	0.72	0.84	0.9	0.92
0.75	0.86	0.92	0.95	0.96
1.0	1.0	1.0	1.0	1.0

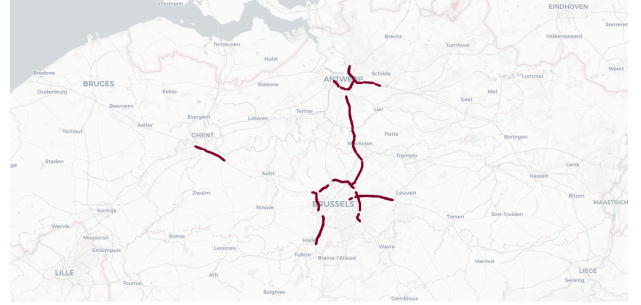


Fig. 5. Segments with highest CO₂ reduction per kilometer, without ITS correction

Emissions from traffic volumes per segment can be derived by multiplication with segment length and average emission values for the Flemish fleet. Combining with the information of C-ITS reduction, one can determine the total amount of CO₂ that can be reduced by C-ITS Day-1 I2V services.

1) *Without correction for ITS infrastructure:* Assuming full adoption of C-ITS, C-ITS services would reduce emissions of CO₂ by passenger cars in Flanders by 59 kton per year, without correction for overlap with ITS. Note that the 246 segments containing ITS gantries account for 19.2 kton, or 34% of theoretical environmental benefits, while representing only 22.5% of total highway segments length. Fig. 5 shows 150 segments that have the highest amounts of CO₂ reduction per kilometer. In line with the highest traffic volumes, these segments are to be found at the ring roads of Antwerp and Brussels, and the E19 highway road connecting those. Some segments close to the city of Ghent are shown as well. Since a high overlap with locations of existing VMS and RSS gantries, as was depicted in Fig. 3, can be noticed, the next subsection will look at the results with corrections for that infrastructure presence.

2) *With correction for ITS infrastructure:* Taking into account ITS infrastructure overlap reduces the total reduction CO₂ to 43 kton, a 26% reduction. ITS-equipped highway segments now only represent 3.6 kton, a reduction by approximately 80%, as discussed above. Analogous to previous subsection, Fig. 6 shows the 150 best segments in terms of CO₂ reduction, taking into account corrections. As the ring road of Brussels (R0) only has VMS gantries, the effect of overlap with existing ITS did not prevent those segments to maintain the segments where C-ITS could bring most benefits

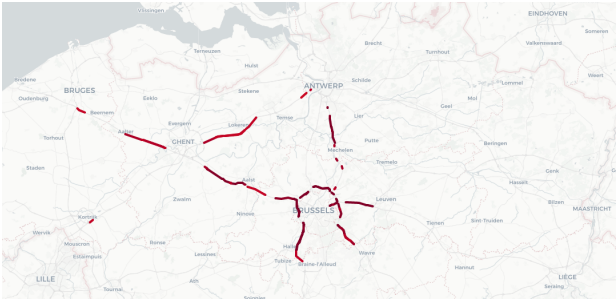


Fig. 6. Segments with highest CO₂ reduction per kilometer, with ITS correction

in terms of emissions and thus environment. However, as the ring road of Antwerp is more densely equipped with both VMS and RSS, the highway segments it consists of do not longer belong to the segments where incremental benefits of C-ITS are highest. The same effect is to be found at Ghent and most of the E19, except for some segments that are not that densely equipped with VMS gantries. Furthermore, segments of the E40 highway between Brussels and Ghent, and the E17 between Antwerp and Ghent are now found to have highest potential C-ITS benefits. This is mainly due to limited ITS infrastructure on those segments, despite processing relatively high volumes of cars, as can be seen in Fig. 3 and Fig. 1.

VI. CONCLUSIONS

To date, traffic remains a major source of societal costs in terms of safety and environment. As a result, the European Commission has expressed major ambitions in reducing those, and counts on technologies such as Cooperative Intelligent Transport Systems (C-ITS) to reach those ambitions. Successful deployment of many of the C-ITS services requires C-ITS roadside units (RSUs) for Infrastructure-to-Vehicle (I2V) communication. Since RSUs require substantial investments, it is important for road authorities to evaluate which highway segments should be prioritized in deployments. As public investments should be evaluated based on incremental benefits, this research provides a bottom-up methodology for road authorities to determine (1) the overlap between the present ITS infrastructure and C-ITS services for each individual segment, allowing to determine the size of expected incremental C-ITS benefits for each segment (2) the recommended segments to start C-ITS deployments, to ensure highest expected societal benefits. It was found that taking into account overlap of C-ITS services with ITS functionalities has significant impact on the incremental benefits. Segments at the R1 ring road around Antwerp, Belgium, with dense ITS deployments, should not be prioritized in RSU deployments, though having high traffic volumes. Segments at the R0 ring road around Brussels, on the other hands, should still be prioritized, as ITS infrastructure is less densely present on those segments.

Although the discussed methodology is applied to Flanders, it is valuable for any other country aspiring to roll out C-ITS road infrastructure, provided societal costs per segment are

available. Future work could include more empirical insights or expert views on ITS overlap. Furthermore, more I2V, as well as V2V services supported by RSUs, could be included to determine incremental benefits. Finally, the prioritization exercise for the safety societal benefits also deserves further attention.

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