REDUCING ENVIRONMENTAL IMPACT BY ADAPTIVE TRAFFIC CONTROL AND MANAGEMENT FOR URBAN ROAD NETWORK

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ABSTRACT

This paper investigates the effectiveness of traffic signal control and variable message sign (VMS) as environmental traffic management tool. The focus is on black carbon and CO_2, which are among the highest contributors to climate change. The modelling tool chain adopted to support this study includes traffic microsimulation, emission model and dispersion model. A number of scenarios have been simulated with different levels of demand and VMS compliance rates. The results demonstrate the potential of these interventions in reducing black carbon and CO_2 emissions and improving air quality.

1. INTRODUCTION

This paper aims to provide useful insights on the effectiveness of adaptive traffic control and management in reducing carbon dioxide (CO_2) and black carbon (BC) emissions in urban context. Traffic control measures such as adaptive signal control and variable message signs are considered in this paper. CO_2 is the primary greenhouse gas contributing to the recent climate change (*1*). BC is formed through incomplete combustion of carboneous materials. It has a significant impact on the Earth's climate system, because it absorbs solar radiation, influences cloud processes, and alters the melting of snow and ice cover (*2,3*). Due to BC being of ultrafine particle size, it also causes serious health concerns: black carbon is associated with asthma and other respiratory problems, heart attacks and lung cancer (*4,5*). Since BC emissions are mainly produced during the breaking and accelerating phases of vehicle movement (*6*), ITS (Intelligent Transport Systems) actions able to reduce stop-and-go phases have the potential to reduce BC emissions.

1.1 Signal control as an ITS strategy

Significant research effort has been dedicated so far to the assessment of the impact of traffic signal control on emissions. Isolated junctions were investigated to study the effects of cycle length on emissions (*7*), to identify the relationship between delay, number of stops and emissions (*8*) and to explore the impact of optimization of phase ordering (*9*). Increasing green time to the main traffic direction by 5% produced a reduction of CO, HC and NOx emissions in the range of respectively 7.21%, 4.54% and 2.63% (*10*).

The impact of traffic signal coordination on emissions has been analysed by (*6*). The authors have integrated microsimulation, emission modelling, and real data to evaluate the impact on CO, HC and NOx emissions of traffic signal coordination. The results show a significant reduction in HC, NOx, CO and CO_2 emissions, in the range 9-14% (extracted from Table 1 of the paper). The authors also studied the emissions under different driving cycles and found out that emission rates for all the pollutants considered in the study are very high during the acceleration stage, but the NOx rate is significant also during deceleration. Other studies confirm the high potential of traffic signal coordination in reducing emissions. The extent of this reduction has been found up to 40% (*6,11,12*).

1.2 Variable message signs as an ITS strategy

The research undertaken on VMS so far has encompassed different work streams: estimate of the compliance rates (*13-16*), impact on traffic performance (*14,17-20*), credibility and understanding of VMS messages (*14,21*), and safety hazard associated to VMS (*15*). Few studies have analysed the impact of VMS on emissions and the majority of these (*15,22,23*) have focused on VMS as a tool to manage incidents and not recurring situations. These studies show the potential of VMS to reduce emissions in the event of not recurrent situations. The actual emission reduction is dependent on the compliance rate as emissions network wide tend to increase when the alternative route becomes congested (*24*).

The literature review reveals that limited effort has been dedicated so far to investigate the potential of VMS as a tool for sustainable traffic management in urban area for recurrent congestion, and no study focuses on black carbon emissions. This study will assess the effectiveness of traffic signal control and VMS rerouting, in isolation and combined, in reducing BC and CO_2 emissions in recurrent congestion in an urban area. The compliance rate is considered as exogenous variable and different levels are set in this study based on the results of the literature review.

This study has been undertaken within the CARBOTRAF project, which aims to support traffic operators in real-time when choosing the most effective ITS action to reduce CO_2 and BC emissions. The project includes on-line and off-line modules: the on-line module is comprised of a decision support system and real time traffic and environmental data monitoring; the off-line module is formed by a database (Look-up-Table, or LUT), where all the simulation results are stored. The decision support system uses the data in the LUT to recommend the best action based on the current traffic conditions. This paper presents the simulation results for different ITS actions under different levels of traffic demand and VMS compliance rates, which serve to inform the LUT in the off-line module.

2. METHODOLOGY

In order to estimate the effectiveness of the ITS actions a modelling tool chain has been set up. The first module of the tool chain involves traffic microsimulation. This produces speed and trajectory for each vehicle at a high time resolution (every 0.5 second). These data are used as input to the second module of the modelling chain: the emission model. This estimates PM_{10} and total carbon emissions on each link of the network. A post-processing tool has been developed to process these data to estimate black carbon and CO_2 emissions per link based on the following assumptions:

- The estimation of amount of CO_2 generated is derived from the Total Carbon by using the atomic weights of Carbon and Oxygen to generate a factor of 44/12 (i.e. one molecule CO_2 weighs 44, one atom carbon weighs 12).
- The estimation of Black Carbon is based upon the predicted PM_{10} emission rates, using the COPERT IV methodology for conversion (*25*)
- The PM_{10} value estimated in AIRE only includes exhaust emission;
- All exhaust $PM_{10} \approx PM2.5$;(*25*)
- EC ≈ BC (*26*).

The emission results are used as input for the air quality simulations. The bi-Gaussian dispersion model Immission Frequency Distribution Model (IFDM) is applied. The modelling capability for pollutant dispersion in urban environments has been validated in several studies (*27,28*). Within this project an extra validation of IFDM against historical NO_2 data for Glasgow is also performed.

The various scenarios simulated are compared against a baseline scenario in order to assess the effectiveness of the proposed measures. A number of Key Performance Indicators (KPIs) have been calculated to support the analysis:

- Travel time, speed and delay from a traffic perspective;
- Black carbon, CO_2, NO_x emissions;
- Black carbon and NO_x concentrations for air quality.

These KPIs have been estimated at the network, junction and corridor levels. All results presented in this paper are statistically significant with confidence level (CL) of at least 90%. The corridor and junction locations have been selected in order to capture the areas most likely affected by the proposed measures.

3. TEST SITE DESCRIPTION and ITS ACTIONS

The CARBOTRAF project has implemented this methodology at two test sites: Glasgow and Graz; this paper presents the results from Glasgow.

The test site is located at the West End of Glasgow, which is often affected by severe congestion and air quality problems as it not only connects the radial routes to the city centre for drivers approaching Glasgow from West, but also provides access to the university and other local destinations. Byres Road is located in the core of the test site area and it has been declared air quality management area due to the critical level of pollutant concentration. Suitable ITS actions have been identified with the potential to reduce CO_2 and BC emissions whilst keeping traffic smooth in the test site.

The following measures of adaptive traffic control and management have been simulated:

- Traffic Signal Control (TSC): a new traffic signal plan is proposed at the junction Byres Road /University Avenue which keeps the signal coordination with the adjacent junction at Church Street. The proposed plan reduces the green time from West and North at the benefit of the traffic approaching the junction from the South and the East.
- Variable Message Sign (VMS): the VMS is located on Beith Street, upstream of Byres Road, which is the focus of the project. See Figure 1. The aim is to reroute drivers away from Byres Road. The text displayed on the VMS is: "Congestion on Byres road, take alternative routes". The main alternative route to the city centre is shown in the figure below. Three levels of compliance rate have been simulated: 10,20,30%.
- Combination of TSC and VMS: both the above actions are simulated at the same time with the aim to further smooth traffic flow on Byres Road and reduce emissions.

The location of the ITS actions and the alternative route (Dumbarton/Kelvin Way) is shown in Figure 1 below.

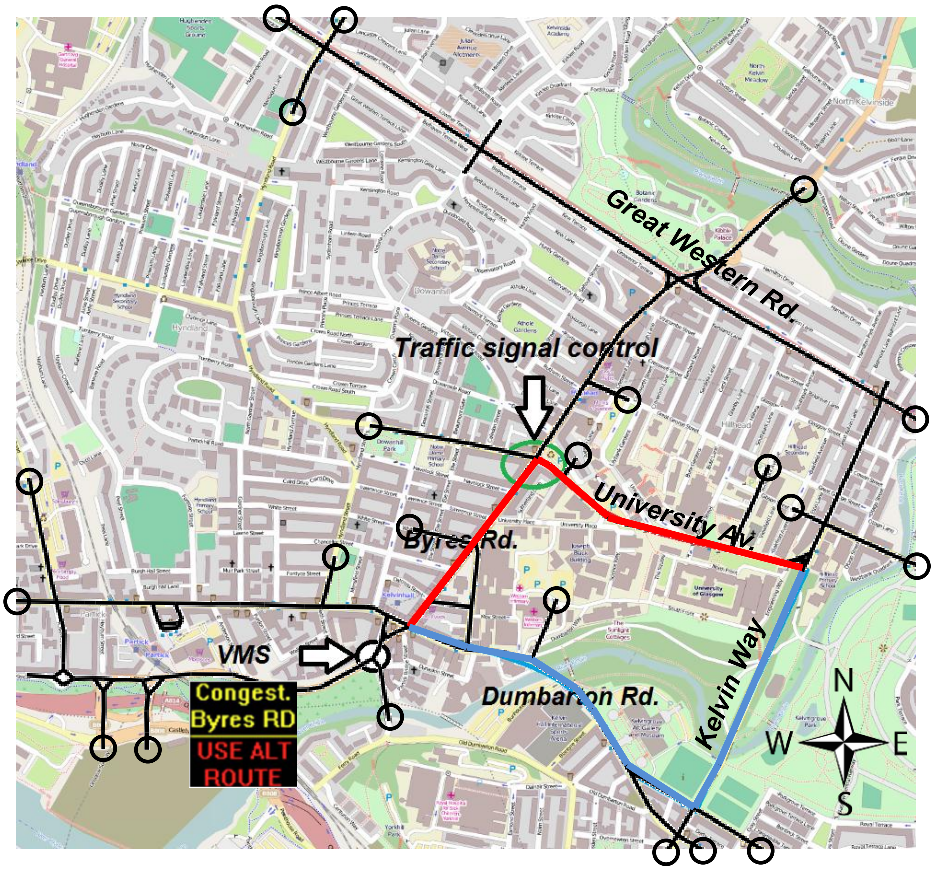


Figure 1. Layout of the test network (in black dark line). The circles represent the 21 traffic zones. The locations of two ITS actions are shown with arrows. The two main corridors are highlighted with red and blue; the latter is recommended by the VMS

4. SIMULATION SETUP

The microsimulation traffic model for the West End of Glasgow city has been developed by using S-Paramics for this study. This traffic model represents the existing scenario for the base year of the study (2012) for AM peak (08:00-09:00). The base model has been calibrated and validated against existing traffic flows from detectors and counts from surveys. The term validation is used to demonstrate that traffic flows in the model are within an acceptable tolerance of the observed traffic flows. The guidance on this is provided by the Design Manual for Roads and Bridges (DMRB). The model is calibrated to have 85% of modelled traffic flows within 5

GEH (GEH is a statistical formula used to derive the difference between observed and modelled flows).

The Glasgow base model has been calibrated and validated by using two different data sources: manual counts and traffic flows from the screenline detectors. The manual counts are classified counts and vehicles are distinguished in: car, van, LGV and HGV. They had been previously undertaken by Glasgow City Council and the CARBOTRAF team at different dates. The data have been scaled in order to reference to a typical working day Monday-Thursday of May 2010. The screenline detectors were available only at two locations of the test site. These detectors are four per location, two per direction and one per lane. The data have been provided for 60 dates. However not all are usable for this purpose as some fall in public holiday or school holiday. We have therefore filtered out this data, which left 42 useful dates. Out of these, 19 have been used for the calibration, leaving the remaining data for the model validation. The traffic volumes have been averaged across the various dates. This data together with the manual counts have allowed generating a “survey” file required for the matrix estimation.

Seven vehicle types are defined in the model, their equivalent Passenger Car Unit (PCU) are computed. The conversion of the PCU is based on the Transport for London’s traffic modelling guidelines (*29*).

Vehicle/driver behaviour characteristics are represented by aggression and awareness factors in S-Paramics. These factors influence a driver’s gap acceptance, car following and lane changing characteristics. By default a normal distribution of behaviour is assumed. This assumption has also adopted in the current model. The microsimulation adopts a vehicle fleet composition based on the AADF data for Glasgow city from the Department for Transport from 2000 to 2010.

Building on the base model for a period of 8-9am, five different scenarios have been generated to take into account demand variability across different days of the week within Monday - Thursday. Based on processed historical data from the loop detectors five boundary conditions have been generated to represent demand increase from different directions into the network.

5. SIMULATION RESULTS

This section reports the simulation results for the Glasgow network to assess the impact of the ITS actions on traffic, emissions and air quality. The results are discussed for the different ITS actions simulated:

- Traffic Signal Control (TSC)
- Variable Message Sign (VMS)
- Combined TSC and VMS.

The location of the ITS actions is shown in Figure 1 The simulation results are presented in terms of Key Performance Indicators (KPIs) as described in the methodology section. Several corridors have been considered in the analysis to ensure any other localised effect of the ITS actions was captured. The two corridors more often referred here are also used in the graphical user interface (GUI) for the traffic operators within the CARBOTRAF project. These corridors are:

- GUI_Byres_University (indicated in red in Figure 1)

- GUI_Dumbarton_Kelvin (indicated in blue in Figure 1)

The following sections present and discuss the results of the simulation for the above ITS actions. All the scenarios have been simulated for the 5 boundary conditions. The simulations have been run using 25 random seeds for each boundary condition and the results have been averaged.

5.1 Traffic Signal Control

This subsection presents simulation results for the TSC scenario where a new traffic signal plan is proposed at the junction Byres/University av. The signal plan also coordinates with the adjacent junction. The proposed plan keeps existing cycle time while reducing the green time from North (by 4s) and West (by 7s) while extending the green time for the traffic approaching the junction from the South (by 2s) and the East (by 7s).

The main benefit of TSC can be noted on Byres corridor for all boundary conditions as the green time Northbound has been extended. The impact at local level depends on the boundary condition. Under boundary conditions 1, 3 and 5 with increased demand from West or North the benefits of TSC are clear at all levels: junction, corridor and network. Traffic conditions improve on Byres Road in the South part and the reduction of

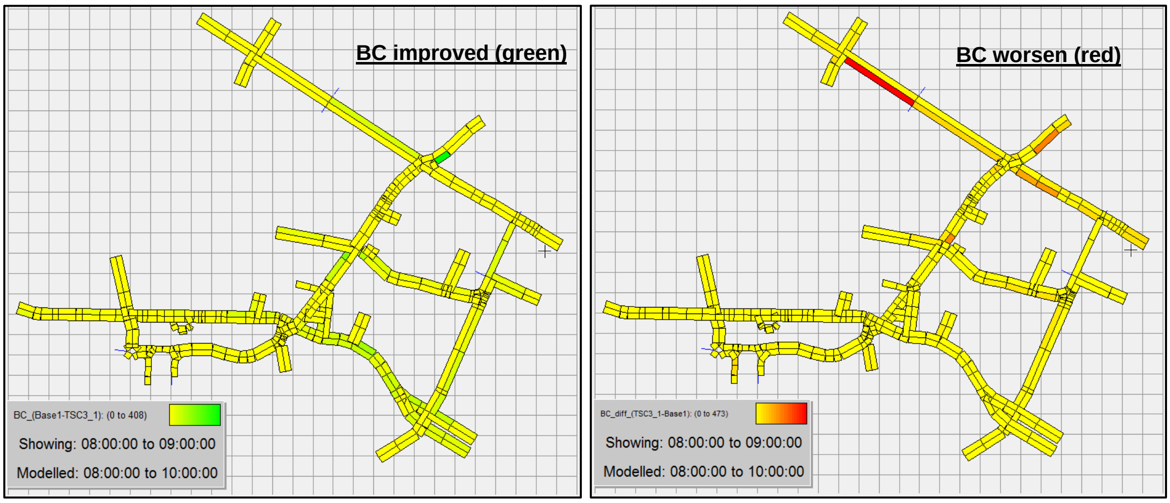
green time on the North and West arms of the junction causes only minor additional delays on these approaching links.
The results suggest also a rerouting effect for some traffic (up to 17 veh/h in boundary condition 5) from the blue route (see Figure 1) to the red route; this is due to the increased green time for vehicles approaching the junction from the South, which makes the Byres Rd route more attractive. Nevertheless the overall impact on Byres Road is positive as the traffic indicators present a reduction in delay up to 5-6%.

The reduction of green time at the junction from the West still satisfies the inflow demand without reaching the saturation flow under boundary condition 1, 3 and 5. Under boundary condition 2 with moderate increased demand from the West the saturation flow is reached with the proposed TSC signal plan causing overall minor worsening at junction level. When the demand from the West is substantially increased (boundary condition 4) the worsening on the link approaching from the West is critical and causes a local increase in delay by 161s and overall at junction level:

- A reduction in speed by 23%
- An increase in delay by 33%.

The increased green time on University Avenue Westbound causes a substantial reduction in delay on this corridor, which in turn leads to a flow shift towards the more attractive route for all boundary conditions.

The overview of the BC emissions under boundary condition 1 is shown below in **Error! Reference source not found.**



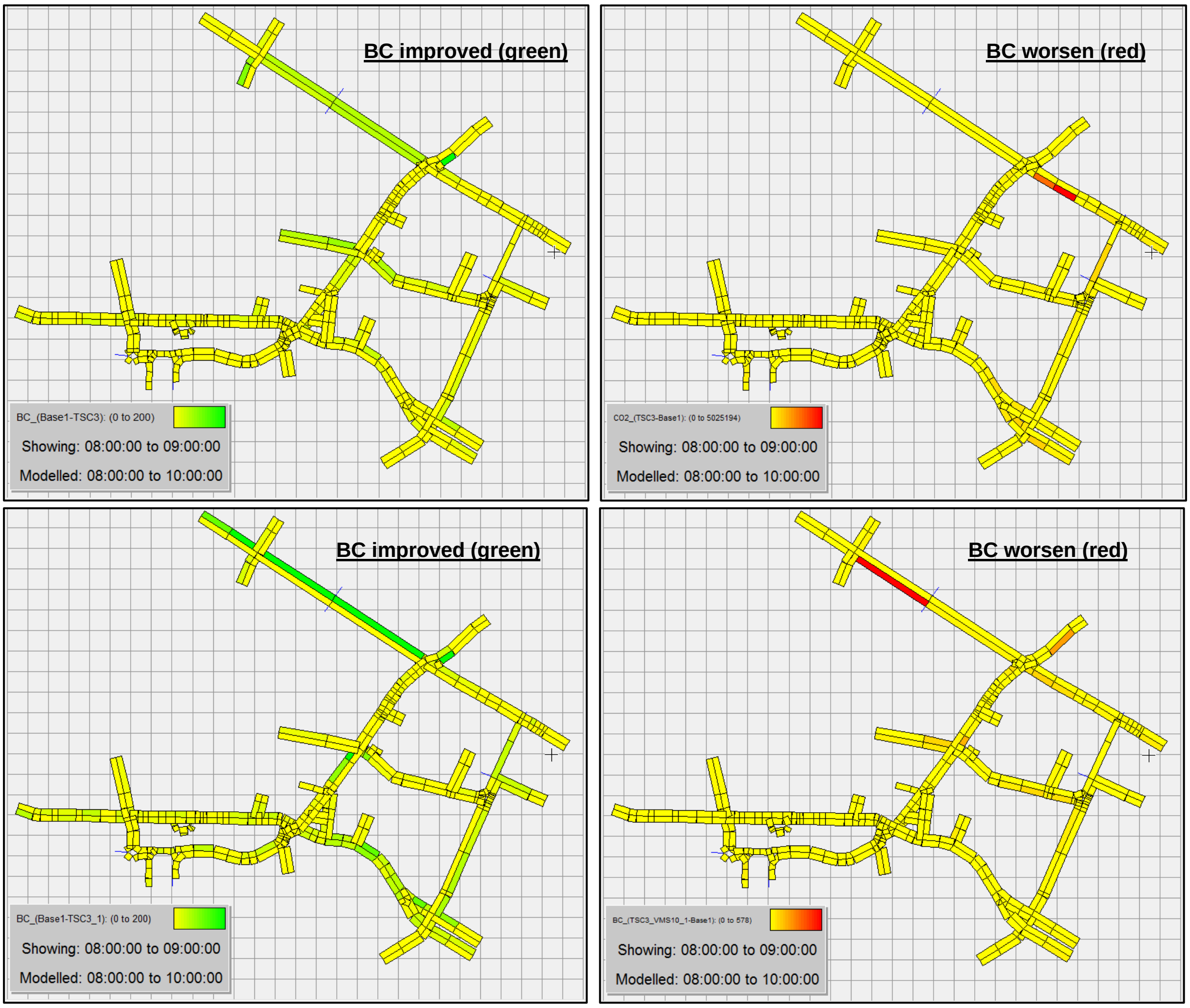


Figure 2. Comparison of BC emissions under boundary condition 1: First row: Base vs. TSC; Second row: Base vs. VMS30; Third row: Base vs. TSC-VMS30

The diagrams on the left display the improvements made by implementing the TSC in term of emissions on the network. The right hand side diagrams show the emission increases after implementing TSC. The BC emissions are reduced on the South and East arm of the junction. This was expected due to the effect of extending the green time on those two arms in TSC. There is an improvement on both Byres Road and Dumbarton Road corridors. However, the BC emissions get worse on the westbound traffic at Great Western Road (on the top left of the diagram above); this is most likely caused by the extension of green time on Northbound and Westbound traffic on Byres Road and University Avenue junction, so traffic initially queuing at that junction is shifted towards the Great Western Road junction, causing an increase in emissions at the top of Byres Road.

In conclusion TSC brings significant benefits for boundary conditions 1, 3 and 5 at all levels. Under boundary conditions 2 and 4 the effect is mixed and overall the benefits at some locations (e.g. at the southern end of Byres Rd) outweigh the disbenefits at others (e.g. junction level and northern end of Byres Rd). A critical analysis has to note though that some of these effects (e.g. rerouteing) are influenced by the simulation software in particular by the settings of the routeing algorithm. In S-Paramics, the rerouting behavior is conditioned by defining the percentage of ‘familiar’ drivers who have perfect knowledge of the network (i.e. current generalized costs). These drivers will then re-route if the alternative provides an improvement, while unfamiliar drivers will retain their original routing. This behaviour may be unrealistic in cases where delay reductions are too small to be perceived by regular drivers over time and would not normally be apparent to a driver at the point of making his routing decision. However some other effects are actually very realistic: such as the easing of congestion on the arms where the green time has been extended and the increased delay on the other arms where the green time has been reduced.

The change in emissions due to the traffic signal control impacts the pollutant levels. The impact on BC concentrations along the network varies with both the emissions and the meteorological conditions (wind direction, wind speed, stability class). Simulations have been performed for 252 meteo conditions. The change in simulated BC concentration for Traffic Signal Control *vs.* the base scenario is illustrated in the figure below, averaged over all meteo conditions for boundary condition 1. The impact of an ITS measure proves highly location dependent. For the central junction of Byres Road and University Avenue, the change in BC concentration ranges from a decrease in BC by 0.18 µg/m³ to an increase by 0.13 µg/m³.

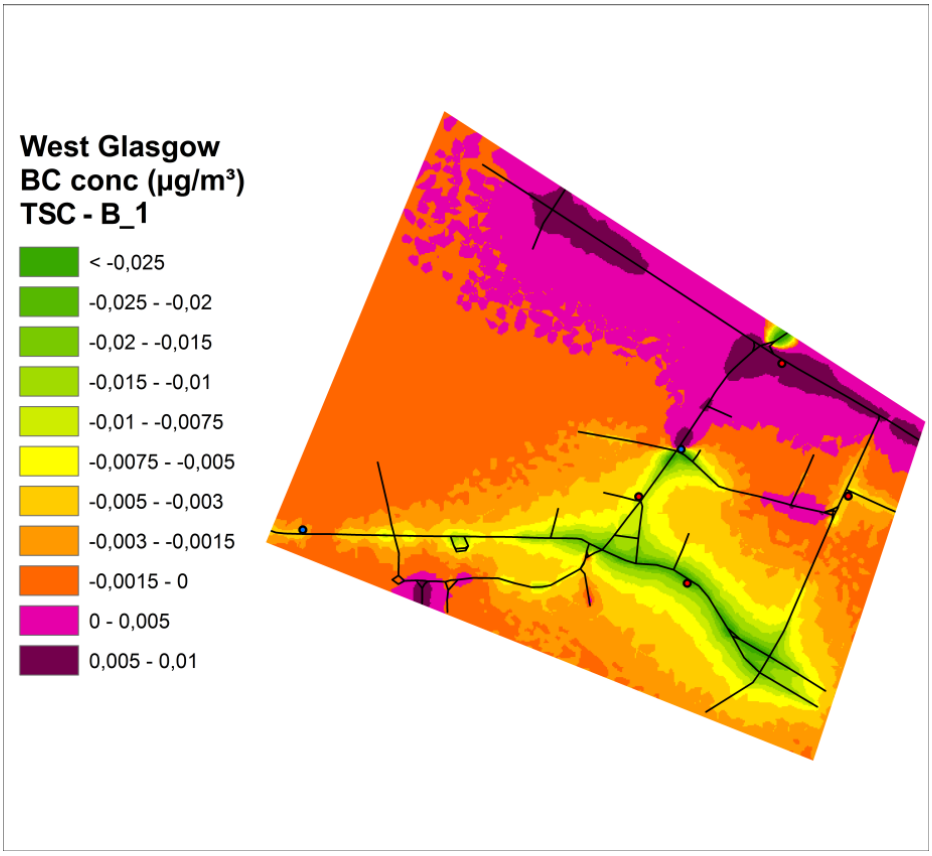


Figure 3. BC concentration difference map, TSC vs. base, boundary condition 1, results averaged for all meteo conditions

5.2 Variable Message Sign

This section provides an overview of the results of the simulation for the scenarios VMS10, VMS20, VMS30, which simulate the effect of a VMS located on Beith Street (South of Byres Road) for the three levels of compliance rate. The three different percentages have been chosen in line with the literature review (references are included section 1). The location of the VMS and the alternative route are shown in the Figure 1. The text displayed on the VMS is: “Congestion on Byres road, take alternative routes”.

Considering the location of the VMS the main alternative route to Byres Road to reach the city centre from South West is Dumbarton Road and Kelvin Way (also indicated in Figure 1). In order to capture the potential flow shift towards this alternative route, we have first identified the target OD pairs, which are potentially affected by the VMS; the scenarios then simulate that a specific number of vehicles, respectively 10%, 20% and 30% of the target OD pair flows, are forced to use the alternative route Dumbarton/Kelvin Way. This effect is implemented by using the path routeing function.

These scenarios have been simulated for the 5 boundary conditions. The simulations have been run using 25 random seeds and the results have been averaged.

From a traffic perspective VMS10 and VMS20 bring minor but statistically significant reduction in delay network wide for boundary conditions 1, 3 and 5 in the range 0-3%. For boundary conditions 2 and 4 the implementation of VMS10 and VMS20 causes an increase in delay by 1-3% network wide. For VMS30 the results on a network wide level are similar to VMS10 and VMS20 for boundary conditions 3, 4 and 5, while for boundary condition 1 the delay increases by 1% and for boundary condition 2 the delay decreases by 1%.

At corridor level the major effects, as expected, take place on Byres Road where the simulation results for all compliance rates and boundary conditions except 4 show a reduction in delay by 3-9%. These improvements are only partially offset by worsening of traffic conditions along the alternative route (Dumbarton_Kelvin Way) where delay increases up to 2% for all boundary conditions except 4. The results under boundary condition 4 differ from the other boundary conditions as they show a substantial worsening of traffic conditions at corridor and network level. This is explained because the demand from South, increased under this condition, causes substantial delay on Kelvin Way (480sec) already in the base scenario without the VMS. The additional vehicles shifted to this corridor due to the VMS of course increase the already critical congestion. As a result of VMS30 we have an increase in delay by 20% on the VMS alternative route (Dumbarton_Kelvin Way). To conclude, the VMS action brings significant reduction in delay under boundary conditions 1, 3 and 5 up to 9% at corridor level, and up to 3% at network level. The effect of VMS at corridor level is highly dependent on both boundary condition and compliance rate.

Similarly to traffic results, the VMS actions bring a relatively small improvement on black carbon emissions for boundary condition 1, 3 and 5 in the range of 0-2% (network level). VMS30 performs slightly better than VMS10 and VMS20 under boundary condition 1. Figure 3 illustrates the spatial distribution of black carbon emissions for VMS30.

The air quality levels for the VMS scenarios follow the trends observed for the total emissions network wide. VMS10, VMS20 and VMS30 yield similar results. VMS30 performs slightly better for boundary condition 1, VMS20 for boundary condition 2. The change in BC concentrations at the central junction of Byres Road and University Avenue ranges from decreased BC concentrations by 0.05 µg/m³ 0.10 µg/m³ and 0.11 µg/m³ to BC concentration increases by 0.02 µg/m³, 0.01 µg/m³ and 0.01 µg/m³ for respectively VMS10, VMS20 and VMS30. The actual change in BC concentration depends on the combination of meteo condition and traffic state. The effects of the VMS system on the air quality levels proves smaller than the traffic light optimization.

5.3 Combined TSC-VMS

This section provides an overview of the results of the simulation for the scenario combined TSC-VMS where both the traffic signal plan at the Byres/University junction proposed within the TSC scenario, and the VMS at various compliance rates (10/20/30 %) described above, are simulated at the same time.

Also this scenario has been simulated for the 5 boundary conditions and the simulation has been run using 25 random seeds and the results have been averaged.

On a network wide level the combination of TSC and VMS brings traffic improvement for all boundary conditions and compliance rates with a reduction in delay in the range 3-6%. Also the combined strategy always brings substantial traffic improvement for the corridor Byres Road/University Avenue for all boundary conditions and compliance rates; in particular, we have:

- An increase in speed by 19-24%
- A reduction in delay by 21-29%.

However these benefits are partially offset by increased delay:

- Up to 8% along Dumbarton Road and / or Kelvin Way (the alternative route highlighted in blue in Figure 1) under boundary conditions 1, 2 and 4;
- Up to 36% at the junction Byres Road / University Avenue (highlighted in red in Figure 1) under boundary conditions 2 and 4, mainly due to the reduced green time in TSC on the West arm of the junction.

In this combined strategy, a significant re-distribution of flow is observed. The increased green-time allocated to the East arm of the junction, combined with the VMS re-routing action leads to a shift of flow from Byres Road to Dumbarton Road/Kelvin Way. This leads to improvement in traffic KPIs on Byres Road.

The emissions are also reduced on Byres Road in the combined strategy. This leads to the improvement on the emission KPIs on the Byres road and University Avenue corridor. However, more vehicles are shifted to the Dumbarton/Kelvin way, consequently increased emissions are observed on that corridor

The combined use of VMS and TSC leads to larger effects on the air quality levels compared to the separate traffic measures. Drops in BC concentration of up to 0.29 µg/m³ are simulated for the core junction on Byres Road. For most boundary conditions the improvements in air quality are significantly larger than the increases in BC at locations to which the traffic is re-routed. Overall, the average impact for all traffic scenarios and meteo conditions remains however fairly limited (3% overall improvement).

5.4 Overview of results and discussion

The combined ITS strategy TSC_VMS is recommended when the traffic state is close to boundary conditions 3 or 5, as simulations in these two scenarios show traffic improvement at all spatial levels and for all compliance rates. The strategy can still bring benefits under boundary condition 1 as long as the compliance rate is lower than 30%.

Table 1 provides an overview of the results for the delay and the black carbon emissions on a network wide level, junction level, and on the two corridors used on the user interface to inform the traffic control operators: GUI_Byres_University and GUI_Dumbarton_KelvinWay. The results presented in this overview are expressed as range of differences in percentage between the ITS action scenario and the baseline scenario across all boundary conditions. Only the statistically significant values (confidence level>90%) have been included in the table.

Table 1. Overview impact of ITS actions on delay and black carbon emissions; the ranges refer to the % difference ITS action vs base for all the boundary conditions

Key Performance Indicator	**ITS action**	**Network**	**Junction**	**Corridor: GUI_Byres_Uni**	**Corridor: GUI_Dumbarton_Kelvin**
Delay	TSC	[-5%,-3%]	[-9%,33%]	[-24%,-21%]	[-8%,4%]
	VMS10	[-2%,3%]	[-4%,-1%]	[-7%,0%]	[-2%,11%]
	VMS20	[-3%,2%]	[-5%,-2%]	[-9%,3%]	[-4%,9%]
	VMS30	[-1%,4%]	[-5%,-3%]	[-9%,5%]	[-2%,20%]
	TSC-VMS10	[-4%,-3%]	[-8%,36%]	[-27%,-21%]	[-8%,-3%]
	TSC-VMS20	[-6%,-3%]	[-9%,33%]	[-29%,-23%]	[-6%,4%]
	TSC-VMS30	[-4%,-2%]	[-11%,31%]	[-29%,-25%]	[-5%,7%]
BC emissions	TSC	[-1%, 1%]	[-3%, 26%]	[-8%, -6%]	[-5%, 3%]
	VMS10	[0%, 2%]	[-4%, 1%]	[-4%, 5%]	[-1%, 1%]
	VMS20	[-1%, 1%]	[-4%, 0%]	[-5%, 4%]	[-3%, 3%]
	VMS30	[-1%, 2%]	[-5%, 2%]	[-5%, 5%]	[-3%, 4%]
	TSC-VMS10	[-3%, 1%]	[-3%, 30%]	[-8%, -5%]	[-5%, 3%]
	TSC-VMS20	[-3%, 0%]	[-7%, 27%]	[-10%, -5%]	[-2%, 2%]
	TSC-VMS30	[-3%, 1%]	[-8%, 26%]	[-11%, -2%]	[-5%, -1%]

Table 1 shows that the impact of the ITS actions varies depending on the spatial reference of the indicators: at network and corridor levels the combined ITS action TSC-VMS10 seems to bring the highest benefits in terms of traffic across all spatial KPIs. However, at junction level all the VMS scenarios always bring improvement to traffic, while the combined action can also increase the delay due to the increased red time to certain arms of the junction.

The results of the simulations also show that the impact of these actions is highly dependent on the boundary condition (as demonstrated by the wide ranges of values) and, to a lesser extent, on the potential compliance rate of the VMS. Most traffic and emission improvements occur under boundary conditions 1, 3 and 5 with increased demand from the North. When the demand from the South and the West is higher (boundary conditions 2 and 4), all the proposed ITS strategies do not seem to improve traffic conditions, but can actually cause substantial worsening at local levels. Black carbon emissions also tend to get worse when congestion builds up under these boundary conditions. It is therefore recommended to monitor the inflows to understand the current traffic levels before activating the ITS strategies. This will be dealt with in CARBOTRAF. Moreover, the decision whether or not to activate an ITS strategy will be taken by the traffic control operators with the support of the DSS, which receives real-time data from the traffic sensors.

With regards to the VMS impact, the compliance rate also plays a key role. Under boundary conditions 1 with increased demand from the West, only VMS10 and VMS20, alone or in combination with TSC, improve traffic conditions. However, these benefits are not achieved when the VMS compliance rate reaches 30%. It is therefore recommended to undertake a preliminary analysis to estimate the potential compliance rate on site as it differs significantly across different contexts, as shown in the literature review, and it can influence the effectiveness of the action. Within the CARBOTRAF project, this analysis will be undertaken in the initial phase of the trial using loop data; the scenarios with VMS compliance rates different from the values monitored on site will be ignored by the DSS.

From an air quality perspective the presented traffic measures can improve the air quality levels by 3% averaged over the study area. For several locations much larger improvements are observed, which are however offset by increased emissions at other parts of the network. The maximal impact on BC concentrations obtained in the simulations is 0.3 µg/m³.

6. LIMITATION and FUTURE RESEARCH

The paper shows the potentiality of traffic signal control and VMS rerouting to reduce emissions and improve traffic conditions and air quality. However the impact of the proposed ITS actions is affected by a number of factors, such as level of demand, assumptions underlying the assignment in the microsimulation, VMS compliance rate. With regards to the first factor, the proposed study considers a relatively coarse variation of the initial demand through the five boundary conditions. The results show indeed that the impact can be either positive or negative depending on the boundary condition. It would be beneficial to investigate this further through a more fine variation of the demand to provide more generalised results about the benefits achievable through these interventions.

The traffic and environmental impacts of the proposed ITS actions are also dependent on specific assignment assumptions such as the proportion of drivers familiar with the network, who are more likely to reroute and also the type of assignment algorithm. The latter can be either a stochastic or deterministic user equilibrium, which allows taking into account of the variability of the perceived generalised costs across different drivers. The assignment can also include a dynamic feedback which entails updating the generalised costs at a given iteration, so the drivers can revise their initial route choice based on the current congestion. This functionality allows taking into account of network congestion, which alters travel times compared to a free-flow condition. It is therefore expected this assumption to provide more realistic forecasts of route choice. However a too frequent update of the costs may lead to an extreme situation where drivers are changing their route too often for a very minor cost difference. This can became of course unrealistic as drivers may not be able to perceive small differences in the actual costs neither may be able to forecast the level of congestion on downstream links. Therefore a possible future research will involve an in depth analysis of the assignment assumptions and related sensitivity analysis.

As previously noted in the paper the results are also sensitive to the VMS compliance rate. This has been considered here as an exogenous variable, however a more accurate estimate of the ITS actions’ impact would benefit from a better estimate of the compliance rate. A further research will entail modelling the compliance rate as an endogenous variable to study its interaction with the traffic flows across the network.

From an air quality perspective a limitation of this study is that possible effects of augmented concentration in narrow street canyons could not be taken into account due to the absence of detailed information on the building height and locations, however the modelling tools allow for this inclusion in the future when the data may become available.

7. ACKNOWLEDGEMENT

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