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Supervisory controller for a LNT-SCR Diesel Exhaust After-Treatment System*

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***Abstract*— Statistical analysis of route history and online traffic information system can provide real-time look-ahead information regarding the route ahead which could be used for powertrain optimisation. A diesel engine NO_x Exhaust After-Treatment System (EATS) for a passenger car application comprised of an engine close-coupled Lean NO_x Trap (LNT) and an underfloor Selective Catalytic Reduction (SCR) is studied. Conventionally, the LNT-SCR operation is coordinated using a rule based controller that primarily utilises the SCR catalyst bed temperature. This paper presents a supervisory control structure that uses look ahead information to improve the performance of the EATS coordinator. Therefore, the supervisory control based EATS coordinator is parameterised with respect to the look ahead data. The parameterised controller calculates setpoints for the NO_x EATS based on Emission Equivalent Fuel Consumption (EEFC). A simulation environment that has been validated with data from the production system was used to carry out the evaluation and compare against the baseline controller. The Supervisory control performance using the EEFC strategy is analysed for the Worldwide harmonized Light vehicles Test Cycle (WLTC). The paper explores a method to utilise a supervisory control structure for the EATS coordinator in an Engine Control Unit. Subsystem synergies that could be harnessed using the supervisory control approach are demonstrated for the EATS. The future work will focus on extending the approach to more subsystems and characterising the look ahead information.**

I. INTRODUCTION

Diesel passenger car engines widely use Lean NO_x Trap (LNT) as the main NO_x Exhaust After-Treatment System (EATS) to fulfil Euro 6b legislation. The introduction of Euro 6d and the Real Driving Emission (RDE) test procedure [1] effectively regulates exhaust emissions in all practical conditions. The RDE requirement and the wider infrastructure for Adblue has promoted urea based Selective Catalytic Reduction (SCR) technology to be adopted in most diesel engine passenger car applications as the main NO_x EATS eg. [2]. The LNT systems now are primarily used for handling emissions during cold start and light load driving. LNT systems consume additional fuel (referred to as DeNOx purges) to reduce NO_x and replenish the capability of the LNT. Regulatory standards for mandatory fleet average CO_2 emission limits of 95 g/km are phasing in from 2020 [3]. This further strengthens the case for the EATS to be used in the most fuel efficient way.

The LNT and SCR have different NO_x conversion efficiency regimes based primarily on the exhaust gas and catalyst temperature conditions. For a hardware configuration as in Fig. 1, a simple EATS control logic is to operate them actively in their most efficient operating conditions. A rule based logic using the exhaust temperature is the baseline reference controller that will be used in this paper as benchmark for comparison of our proposed control strategy.

Although many studies deal with several possible combinations of LNT and SCR, their primary focus has been to utilise the LNT as a reductant producing technology for SCR usage eg.[4], [5], [6]. Less attention has been devoted to control strategies of the active LNT and active SCR combination eg. [2]. Several studies have been carried out for balancing the EGR-SCR for control of tailpipe exhaust NO_x emissions using several ideas including the Equivalent Consumption Minimisation Strategy (ECMS) [7]. Similar approaches have been carried out for Hybrid electric vehicles eg.[8], [9].

Connected cars with powerful and intelligent telematic systems have become the new regime. Hence, vehicles utilising path prediction and route based optimisation has become commonplace [10], [11]. The baseline controller does not take advantage of such additional information due to the inherent control structure.

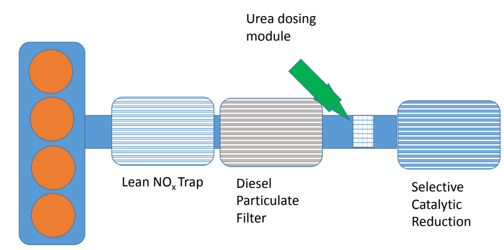

Fig. 1. NO_x Hardware configuration considered for this paper including the combustion engine, the Lean NO_x trap, Diesel Particulate Filter and the Selective Catalytic Reduction units.

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This paper details an EEFC cost based controller strategy for the EATS control that uses the path prediction and utilises the sub system synergies. Minor changes to the local level controller interface were carried out to implement such a supervisory control strategy. The potential savings in total equivalent fuel consumption is simulated using the plant models for the LNT and SCR. The advantages of a supervisory controller to use subsystem synergies is demonstrated in this paper.

II. SYSTEM DESCRIPTION

A. *Hardware Specification*

For the purpose of this paper, a Euro 6d capable turbocharged Diesel combustion engine with exhaust gas circulation (EGR) and an EATS comprised of a LNT of 1.5L, a Catalysed Diesel Particulate Filter (CDPF) and an underfloor SCR catalyst of 3.2L is examined as shown in the Fig. 1. The SCR is equipped with an urea dosing module to spray urea on to a mixing unit in the exhaust pipe for improved ammonia uniformity index.

The LNT has the functionality of treating NO_x emissions as well as Hydrocarbons (HC) and Carbon monoxide (CO). This paper primarily focuses on the NO_x treatment functionality. When the diesel engine is operated fuel-lean, the LNT adsorbs NO_x from the diesel engine exhaust and stores them as Nitrates in the catalyst. The adsorbed NO_x can be converted to N_2, CO_2 and H_2O when the exhaust is fuel rich. The LNT utilises the reductants formed during the rich DeNOx purges of the engine. The adsorption efficiency and the maximum adsorption capacity are dependent on the catalyst temperature as depicted in Fig. 2 and Fig. 3 respectively. For details refer to [12]. The conversion efficiency is dependent mainly on the purge length, exhaust space velocity, exhaust gas and catalyst temperature as investigated for eg. in [13].

Urea is stored on board the vehicle in the form of Adblue solution. When injected and sprayed on the mixer, urea is converted to NH_3 by the thermal energy. Conversion of urea to NH_3 in the exhaust pipe is dependent on the exhaust gas temperature, thus restricting NH_3 formation at lower temperatures as shown in Fig. 4. The NH_3 formed converts the NO_x flowing through the SCR catalyst to N_2 and H_2O. Excess NH_3 formed can be adsorbed on to the SCR catalyst. The NO_x conversion efficiency and the maximum NH_3 storage capacity are primarily dependent on the Catalyst temperature as shown in Fig. 2 and Fig. 3. For more details refer to [14],[15].

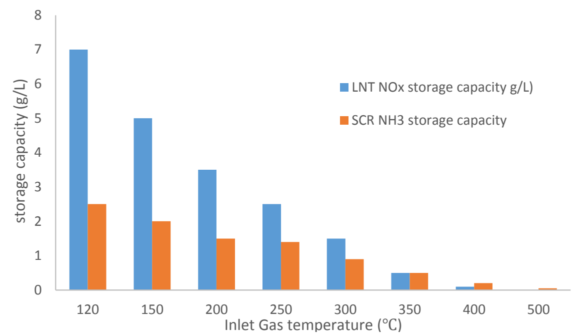

Fig. 3. NO_x storage capacity of a typical LNT catalyst and NH_3 storage capacity of a typical SCR catalyst with different exhaust gas inlet temperatures for a typical passenger car application.

The LNT catalyst has a lower lightoff temperature than the SCR. The LNT and the SCR operate efficiently in different bands of temperatures. The advantage of such a system is to use the LNT during the cold phases of the drive cycle and the SCR during the warm phases. Fig. 2 shows the temperature dependency and their efficiency band on the catalyst temperature. Furthermore, urea dosing requires an adequate mixing distance and mixer design which requires the SCR to be placed downstream of the LNT. However, the energy required to heat the SCR will have to pass through the LNT thus delaying and cooling the exhaust before reaching the downstream SCR. Thermal and physical constraints for urea to NH_3 conversion are demonstrated by Fig. 4. Details of SCR control can be found in [16].

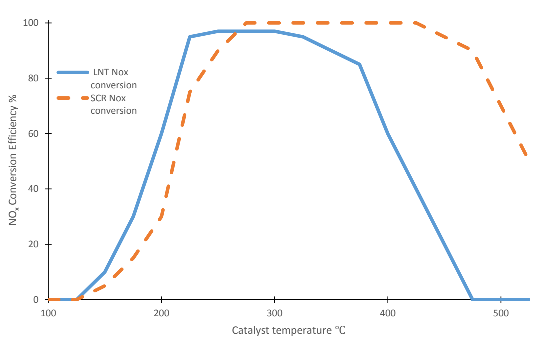

Fig. 2. NO_x Conversion efficiency as a function of catalyst temperature for a Typical LNT and SCR catalyst used in a passenger car application.

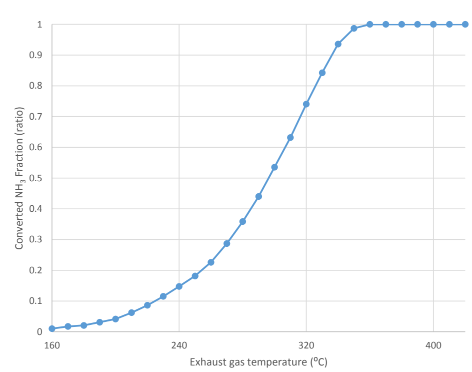

Fig. 4. Adblue to NH_3 conversion Vs exhaust gas temperatures.

B. Simulation Description

A plant model of the LNT and the SCR is used in the simulation environment to evaluate the control strategies. The thermal flow and the chemical reactions of both the catalysts have been well established for the accuracy required for the control strategy simulation. The LNT model gives an estimate of the NO_x stored in the catalyst, the NO_x slipped and the converted NO_x during purge. The SCR model provides an estimate of the NH_3 stored on the catalyst, the NO_x and NH_3 slipped over the catalyst. Both catalyst models provide an estimate of their respective catalyst temperatures and their interaction with the exhaust gas. The EATS plant models are fed with a recording of the measured engine out pollutant species with the corresponding exhaust temperatures. A model of the purge condition that modifies the emission species and their concentration is used when a DeNOx purge is requested by the LNT controls. This is the only modification to the engine out recording that is otherwise unchanged. An engine model such as in [17] can also be used. The models developed using different softwares are simulated using Qtronic's Silver with the Python API. For more details on the simulation tool, refer [18]. The simulation platform schematic is shown in the Fig. 5.

III. BASELINE CONTROL

A. Local level Controls

The diesel engine normally operates fuel lean. A purge request is sent by the LNT controller when a certain stored NO_x threshold is reached. This purge request is accepted dependent on the engine operating conditions (especially dynamic constraints) and activated when the conditions are satisfied. The SCR catalyst monitors the stored NH_3 buffer for which there exists a certain target coverage. The NO_x flow consumes the NH_3 buffer as it reacts in the SCR. The NH_3 buffer is regulated using an NH_3 governor.

B. Baseline control strategy

The baseline control operates the EATS such that under the low temperature regime, the LNT is activated until the SCR has sufficient NO_x conversion. Thus colder exhaust regimes are dominated by the LNT while warmer regimes are covered by the SCR. The bridging gap is covered by both the catalysts. Thus the SCR catalyst bed temperature sets the criterion for the EATS controls. This way the EATS fulfils NO_x tailpipe targets set by the calibration of the individual subsystems.

IV. SUPERVISORY CONTROL

A. Need for Supervisory control

Although the baseline control is able to operate the EATS effectively, there is room for improvement in consumption of Adblue and Fuel. The baseline controller does not distribute the NO_x conversion efficiency targets for the LNT and the SCR. Instead the NO_x converted by the LNT is independent of the NO_x that is converted by the SCR. There are potential fuel and Adblue consumption saving with an optimal splitting of the total EATS NO_x conversion efficiency targets to the LNT and SCR. Such an efficiency division could guarantee the total EATS effectiveness while reducing total consumption. Possible split combinations of target EATS NO_x conversion efficiency are shown in Fig. 6. An interface to implement such a supervisory controller that provides an optimal split between the LNT and SCR is proposed.

The supervisory layer calculates the target EATS NO_x conversion efficiency (η_{EATS}) for a certain portion of the drive cycle (hereafter referred to as a segment) based on the engine out NO_x emissions. This desired η_{EATS} could be split between the LNT NO_x conversion efficiency η_{LNT} and the SCR NO_x conversion efficiency η_{SCR} as in Fig. 6. The objective with the supervisory controller is to aim for an realistic split between the two with the minimum possible Emission Equivalent Fuel Consumption.

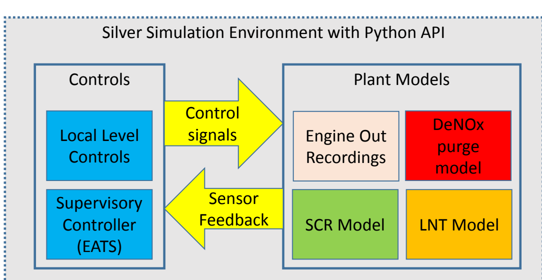

Fig. 5. Simulation environment used in this paper for control strategy development

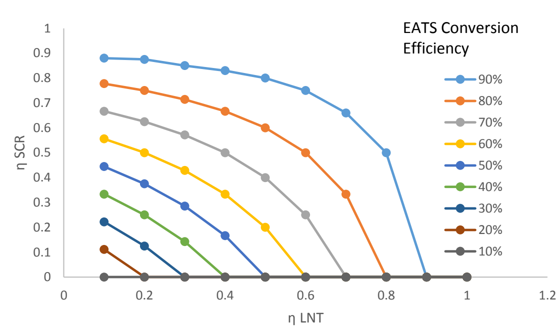

Fig. 6. LNT-SCR NO_x conversion efficiency balance for target EATS NO_x conversion efficiency.

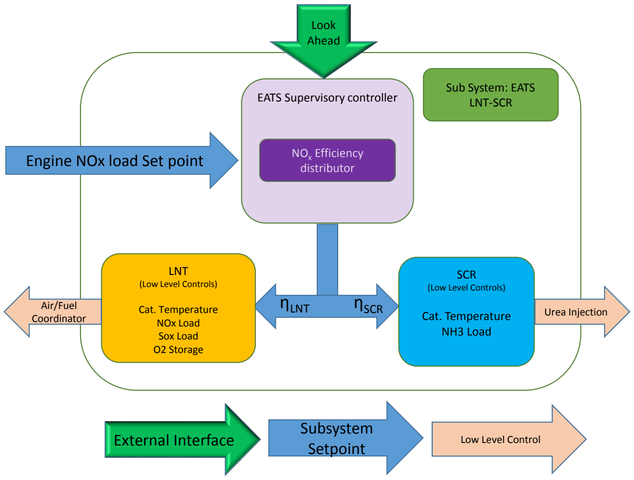

Fig. 7. Supervisory Control Structure indicating signal flows and interface between the Supervisory Controller, Local controller and actuators.

B. Conversion Efficiency Distribution - Interface

The supervisory controller calculates and sets the conversion efficiency targets for the LNT and SCR local controllers. The control parameter for the LNT, u_{LNT} would track η_{LNT} and u_{SCR} would track η_{SCR}, subject to the physical limitations.

$$\eta_{EATS} = \eta_{LNT} + \eta_{SCR} - \eta_{LNT} * \eta_{SCR} \tag{1}$$

In a predicted Load-Speed scenario, the complete drive cycle is broken down into segments that have a certain characteristic. For each identified segment (S), it is possible to estimate the Engine out NO_x emissions (EO_{NO_x}), Flow and Temperature with the help of an Engine model. This is then used to calculate the required η^{trg}_{EATS} to ensure satisfaction of the tailpipe limit ($TPlim_{NO_x}$).

$$\eta^{trg}_{EATS} = f(EO_{NO_x}, TPlim_{NO_x}) \tag{2}$$

The challenge is then to optimally distribute η_{EATS} between the LNT and the SCR. The lowest cost combination of η_{LNT} and η_{SCR} for the necessary η_{EATS} is calculated using a cost function that is detailed later. The target η_{LNT} is tracked by altering the target NO_x threshold curve for the LNT purge. This is shown in Fig. 8. The greater the threshold, the lesser the LNT efficiency and lesser the fuel consumption. But the LNT becomes unavailabe for NO_x storage until purged. The decision on the SCR is imposed similarly by altering the NH_3 buffer target as shown in Fig. 9. However, targets greater than the NH_3 slip risk are avoided to ensure that the low level controller is capable to eliminate such an instance. Thus the set points of LNT and SCR NO_x conversion are suitably translated to the appropriate control actions for the subsystems. Degradation of SCR and LNT catalyst efficiencies due to ageing and temporary poisoning are overcome due to the compensation by the local controllers. The SCR local control usually has an

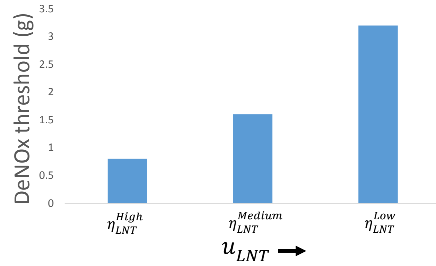

Fig. 8. LNT DeNOx purge threshold modification by introducing the LNT supervisory control parameter u_{LNT}.

additional compensation added to the urea doser. The LNT local control usually has a factor for modifying the LNT threshold.

C. Optimisation problem

The cost incurred in the EATS system are from the joint usage of LNT and SCR. The EATS is to be optimised with the available controls of urea dosing (SCR) and the fuel rich purge (LNT). The combination of RDE legal demand and engineering target ($C_f < 1.0$) on the NO_x tailpipe is set as a constraint along with a peak NH_3 slip constraint. This leads to the setting of the cost function as:

$$\begin{aligned} \min_{u_{EATS}} \quad & \int_{t_0}^{t_f} C_{EATS} dt \\ \text{s.t.} \quad & \frac{\int_{t_0}^{t_1} m_{NO_x}}{\int_{t_0}^{t_1} V_{speed}} dt <= C_f * 80 (mg/km), \\ & \max NH_3 <= 10 PPM. \end{aligned} \tag{3}$$

The controls available to the EATS are

$$u_{EATS} = [u_{LNT}, u_{SCR}]^T$$

$$u_{LNT} \in \{\eta^{Low}_{LNT}, \eta^{Medium}_{LNT}, \eta^{High}_{LNT}\}$$

$$u_{SCR} \in \{\eta^{Low}_{SCR}, \eta^{Medium}_{SCR}, \eta^{High}_{SCR}\}$$

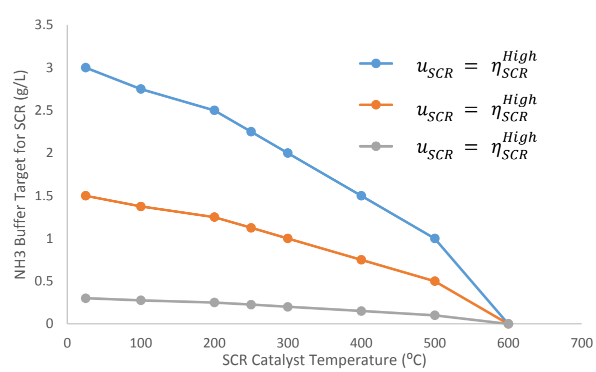

Fig. 9. Target Ammonia buffer in the SCR modified by introducing the SCR supervisory control parameter u_{SCR}.

Including the cost of Adblue (m_{adblue}) consumption, Fuel consumption during DeNox purges (m_f), difference between initial and final states of the catalyst (Ammonia coverage fraction ($\tilde{\theta_{NH_3}}$) for the SCR and NO_x coverage fraction ($\tilde{\theta_{NO_x}}$) for the LNT),the cost function is expressed as

$$C_{EATS} = C * \theta_{EATS}{}^{T} \tag{4}$$

$$C = \begin{bmatrix} C_1 & C_{11} & C_2 & C_{22} \end{bmatrix}$$

$$\theta_{EATS} = \begin{bmatrix} m_{adblue} & \tilde{\theta_{NH_3}} & m_f & \tilde{\theta_{NO_x}} \end{bmatrix}$$

$$\tilde{\theta_{NO_x}} = \theta^{final}_{NO_x} - \theta^{initial}_{NO_x}$$

$$\tilde{\theta_{NH_3}} = \theta^{initial}_{NH_3} - \theta^{final}_{NH_3}$$

The low level controller has an inherent Ammonia slip prevention mechanism that forbids the attainment of such a state. The tailpipe NH_3 constraint is absorbed in the objective function implicitly by placing a cost on the Adblue consumption. This eliminates the inefficient dosing of Adblue and reduces risk for over consumption. The cost coefficients are discussed in the optimisation subsection. Additional LNT and SCR costs could include oil dilution, driver comfort, thermal ageing, frequency of filling Adblue. These however are not in the scope of this paper.

D. Control Parameter determination

The target η_{EATS} must be attained using the u_{EATS} control. A full factor simulation with different initial conditions of the catalyst and u_{EATS} yields the associated cost that is stored as a function of the corresponding segment. The lowest cost pair u_{EATS} for the given segment S and initial condition θ^{EATS}_{init} defines the Supervisory control setpoint. The segment is defined by trace pairs of Vehicle Speed ($\tilde{V_{Spd}}$) and Engine Load ($\tilde{T_{Engine}}$). The initial conditions considered are the coverage fraction of NO_x stored in the LNT ($\theta^{initial}_{NO_x}$) and the NH_3 stored in the SCR ($\theta^{initial}_{NH_3}$). Alternately, an online model could also estimate the EATS cost for the provided look ahead horizon. This paper however focuses on an offline optimisation that is used to obtain the optimal parameters for the supervisory controller. The optimisation methology is graphically summarised in Fig. 10 and the following Equations.

$$C_{EATS} = g(u_{EATS}, S, \theta_{init}) \tag{5}$$

$$\theta_{init} = \begin{bmatrix} \theta^{initial}_{NH_3} & \theta^{initial}_{NO_x} \end{bmatrix}$$

$$S = h(\tilde{V_{Spd}}, \tilde{T_{Engine}})$$

E. Cost factor determination

The calculation of the setpoints depend on the characteristics of the driving segment, the target EATS conversion, the initial catalyst states and the desired final catalyst states. The development of the metric (defined in 4) to calculate the optimal setpoint are discussed below.

- The cost of SCR (C_1 and C_{11}): Equivalent cost of Adblue dosed and difference between the Initial and final NH_3 buffer levels. To determine the Adblue and the NH_3 buffer coefficient, the adblue required for corresponding stored amount is calculated and an additional factor of availability is added to the NH_3 buffer.
- The cost of the LNT (C_2 and C_{22}): Equivalent cost of DeNOx purges and difference between the initial and final NO_x stored levels. To determine the LNT DeNOx purge and NO_x stored, the cost of each purge compared to removal and a certain non-availability cost factor for the NO_x stored is added.
- The weight of the LNT and the SCR costs combined (Weighting between C_1, C_{11} and C_2, C_{22})): For the equivalent consumption, the LNT cost is weighted more than the SCR to counter for the fuel cost and non-availability of favourable driving conditions always.
- The hard constraint to fulfil the legal demands of NO_x tailpipe: An infinite cost is assigned when tailpipe NO_x emissions exceed the engineering target.

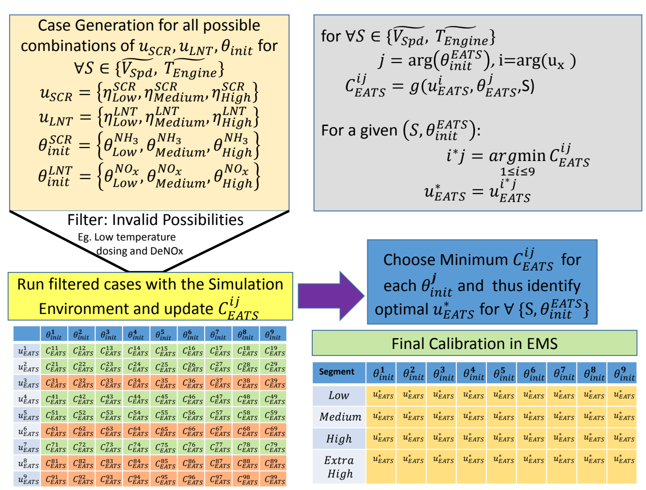

Fig. 10. Visualisation of optimisation methodology to determine optimal u^*_{EATS} for a specific drive cycle segment with a known initial catalyst coverage fraction $\{S, \theta^{init}_{EATS}\}$.

V. WLTC Case Study

A. Simulation

For the purpose of examination of the proposed supervisory control strategy described above, a proposed comparison of performance against the baseline control is detailed. For the purpose of segmentation of the drive cycle, the WLTC cycle is divided into 4 parts based on the speed profile as (1) Low, (2) Medium, (3) High and (4) Extra high. This is shown in the Fig. 11. The described segmentation is only an initial proposal for the current study to investigate the control structure potential. If applied in practice, this would be carried out by discretizing the Look ahead information during driving. A more detailed study on the approach to segmentation and characterisation will be carried out in the future.

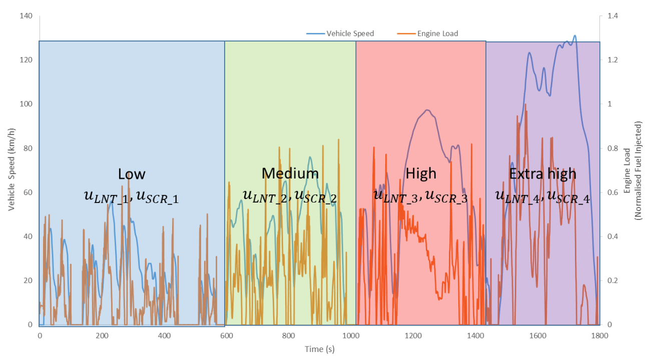

Fig. 11. WLTC cycle indicating the schematic of segmentation used for estimation of the LNT and SCR supervisory control parameters.

For the decision variables to ensure good setpoint tracking of the subsystem efficiencies, the nature of the problem is converted to a markovian decision type. Thus the states necessary for the optimisation of the future depend entirely on the information available at the current time of decision making as detailed in Equation 5. The decision accounts for the segment type and the initial catalyst conditions. Empty, half - filled and completely full catalyst state combinations with all the segments are simulated and the feasible conversion efficiencies are obtained. The corresponding cost metric (from Equation 4) is applied based on the Catalyst consumption and the Catalyst states.

B. Segment sequences

The calculated optimal setpoints are applied for each of the segments (as shown in Fig. 11) and the results of total consumption and final catalyst states are obtained. To add more complexity, the segments can be rearranged in several fashions. Considering the 4 segments, there are 4! possible combinations of the segments if no repetition is considered. The reordered segments are shown in the Fig. 12 for further clarity. The first sequence (seq1234) is the normal WLTC. The baseline and supervisory control strategies are simulated for all the 4! arranged segments

Sequences	Sequential Order [1] [2] [3] [4]			
seq1234	Low	Medium	High	Extra High
seq1243	Low	Medium	Extra High	High
seq1324	Low	High	Medium	Extra High
seq1342	Low	High	Extra High	Medium
seq1423	Low	Extra High	Medium	High
seq1432	Low	Extra High	High	Medium
seq2134	Medium	Low	High	Extra High
seq2143	Medium	Low	Extra High	High
seq2314	Medium	High	Low	Extra High
seq2341	Medium	High	Extra High	Low
seq2413	Medium	Extra High	Low	High
seq2431	Medium	Extra High	High	Low
seq3124	High	Low	High	Extra High
seq3142	High	Low	Extra High	High
seq3214	High	Medium	Low	Extra High
seq3241	High	Medium	Extra High	Low
seq3412	High	Extra High	Low	Medium
seq3421	High	Extra High	Medium	Low
seq4123	Extra High	Low	Medium	High
seq4132	Extra High	Low	High	Medium
seq4213	Extra High	Medium	Low	High
seq4231	Extra High	Medium	High	Low
seq4312	Extra High	High	Low	Medium
seq4321	Extra High	High	Medium	Low

Fig. 12. WLTC segment sequence orders tested. The different segments indicated by the numbers (1)Low, (2)medium, (3)high and (4)extra-high are arranged in all possible combinations. The sequence names such as seq1234 are used later in the results section.

of the WLTC. The initial conditions for these sequences can also be changed. A comparison study of the controller performance when the catalyst states are Empty, Half filled and Full w.r.t. their capacities is carried out.

C. Simulation Results : Fuel and Adblue Consumption

A comparison of the performance between the baseline controller and the supervisory controller is carried out for the differently arranged WLTC segment sequences. Each sequence had identical initial catalyst conditions, engine out exhaust emission species and temperature profile. Fig. 13 shows the Adblue consumption and DeNox fuel consumption for the controllers. The DeNOx Fuel consumption is lower for the supervisory controller than the baseline controller. The Adblue consumption is higher for the supervisory controller than the baseline controller. In the cost function, the LNT usage was made to be more expensive than the SCR. This is apparent in the performance comparison.

D. Simulation Results : End of Cycle Catalyst States

The End of cycle catalyst states of the LNT and SCR are compared in Fig. 14. Quite similar to the reflections on the LNT and SCR balancing, the LNT is used quite passively as is indicated. The SCR NH_3 buffer is quite similar between the controllers even as the consumption might be higher with the supervisory controller. The supervisory controller is also able to predict the end state conditions since these have been pre-calculated. Thus the next segment's control parameters can already be estimated as soon as the next segment in the drive cycle is known.

E. Simulation Results : NO_x emissions and Total cost

The Tailpipe exhaust NO_x emissions and the total cost are compared in Fig. 15. The supervisory controller is able to track the target η_{EATS} much better which isn't

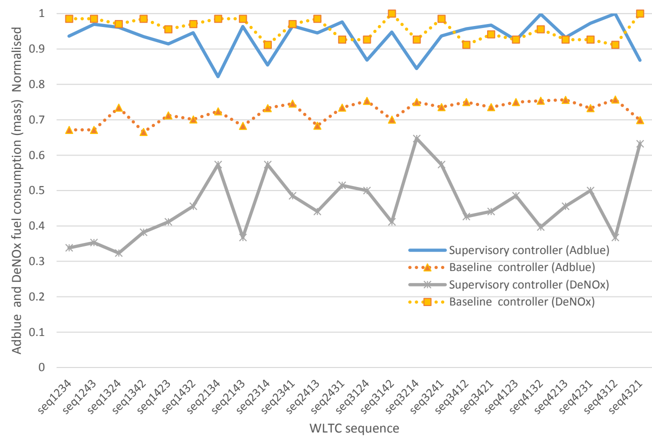

Fig. 13. Normalised Total Adblue and DeNOx Fuel consumption (mass) for the WLTC segment sequences - Comparing the Baseline controller and the Supervisory Controller. Sequence order denoted by the form seqxxxx on the horizontal axis refers to the specific WLTC segment order described in Fig. 12.

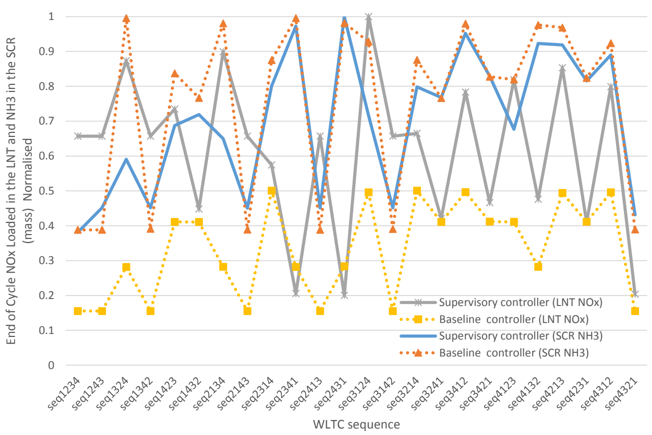

Fig. 14. Normalised End of Cycle NO_x and NH_3 (mass) for the WLTC segment sequences - Comparing the Baseline controller and the Supervisory Controller. Sequence order denoted by the form seqxxxx on the horizontal axis refers to the specific WLTC segment order described in Fig. 12.

possible with the baseline controller. This would enable a fuel efficient engine operation since the risk margin is reduced due to better NO_x EATS efficiency tracking. Both controllers are well within the legal NO_x tailpipe limits. The effect of using the EEFC based strategy is noticeable in the comparison on the total cost for the respective controllers where the Supervisory control has a lower cost in all cases.

F. Simulation Results : Different Initial conditions

A comparison of performance is also carried out for diverse initial catalyst (LNT (L) and SCR(S)) conditions. Empty (E), Half-loaded(H) and Full loaded (F) catalyst states are considered. Totally 9 combinations of possible initial conditions are then simulated for the 4! sequences of the WLTC cycle. The results of the findings are shown in Fig. 16 for the supervisory controller and in Fig. 17 for the baseline controller. Under all initial conditions,

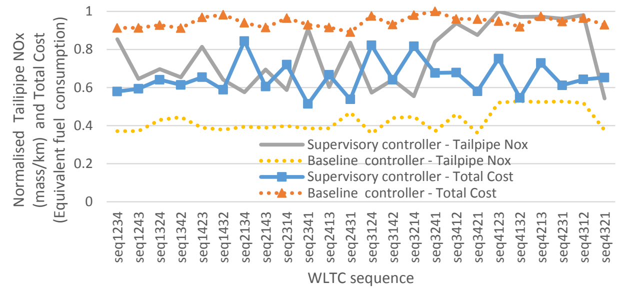

Fig. 15. Normalised Tailipe NO_x (mass/km) and the Total cost (Equivalent Fuel Consumption calculated by the cost function) for the WLTC segment sequences - Comparing the Baseline controller and the Supervisory Controller. Sequence order denoted by the form seqxxxx on the horizontal axis refers to the specific WLTC segment order described in Fig. 12.

the supervisory controller has the minimum cost. This is evident as the scale is the same for both Fig. 16 and Fig. 17. Some of the lines in the supervisory controller seem to cross each other. This could be due to the level of discretisation in the supervisory control parameter determination. Also noticeable is the difficulty level in optimisation for certain sequences. For eg. seq3124 and seq2134 tend to have a relatively higher cost compared to other sequences. The almost circular structure for the baseline controller indicates that the baseline controller does not utilise the sub system synergies of the LNT and the SCR.

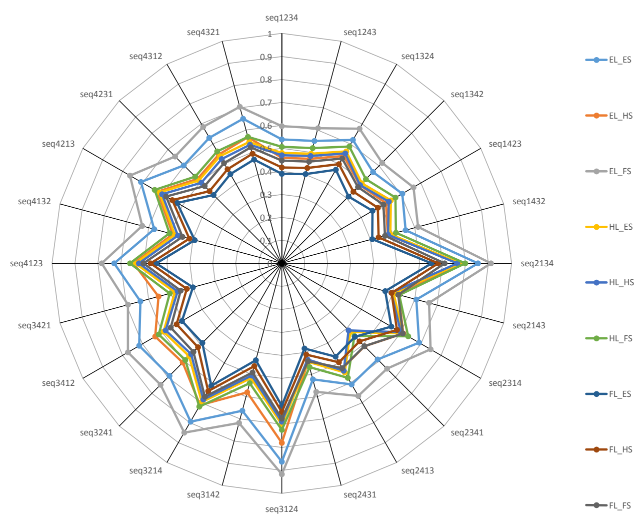

Fig. 16. Supervisory Control: Normalised cost comparison with different initial conditions of the LNT and SCR catalyst. E,H,F indicate Empty, Half-loaded and Full loaded catalyst states. L,S indicate the catalysts LNT and SCR. Sequence order denoted by the form seqxxxx on the horizontal axis refers to the specific WLTC segment order described in Fig. 12.

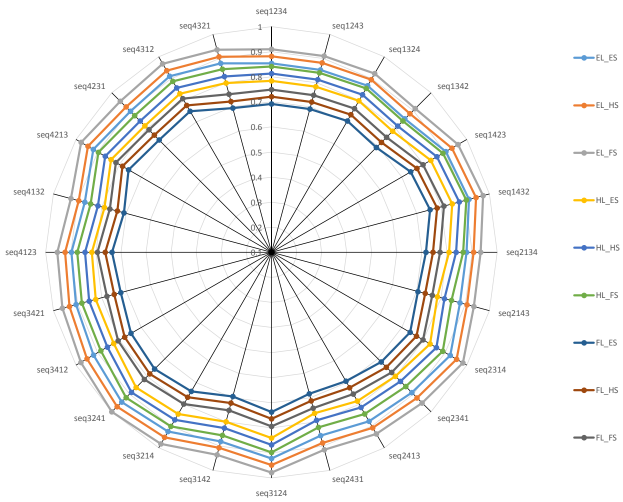

Fig. 17. Baseline Control: Normalised cost comparison with different initial conditions of the LNT and SCR catalyst. E,H,F indicate Empty, Half-loaded and Full loaded catalyst states. L,S indicate the catalysts LNT and SCR. Sequence order denoted by the form seqxxxx on the horizontal axis refers to the specific WLTC segment order described in Fig. 12.

VI. Conclusion and future work

The supervisory control strategy that provides a set-point for the EATS NO_x conversion is able to accomplish the goal of reducing total consumption as defined by the performance metric. The minimal interface change needed and the non-interference of the supervisory layer in the local control are key factors that make it simpler to implement. Connected cars with predictions of Speed-Load profile will be able to realise the potential by implementation of the supervisory control structure. The pollutant prediction model that was developed during the initial phase of research will be an enabler for such a strategy [17]. Future work on characterisation of the segments, covering more engine subsystems is planned in the next stages as continuation of this study.

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