A Misapplication of the Local Ramp Metering Strategy ALINEA
Markos Papageorgiou, Elias Kosmatopoulos, Ioannis Papamichail, and Yibing Wang

Abstract—In a recent series of articles with largely identical contents and results, some claims are raised about the pertinence and performance of the well-known and widely field-applied local ramp metering algorithm ALINEA and of some extended versions thereof. The expressed claims are based on simulation results with a self-made microscopic simulator. This paper shows that the produced simulation results and derived conclusions are based on an insufficient understanding of the feedback character of the ALINEA algorithm, which led to an inappropriate application of the method. More specifically, the mainstream measurement that feeds ALINEA was misplaced so that any occurring congestion could not be monitored; this renders ALINEA blind to the traffic conditions under control and negates the very notion of feedback.

Index Terms—ALINEA, feedback traffic control, ramp metering.

I. INTRODUCTION

In a recent series of articles [1]–[8] with largely identical contents and results, Kerner raises some claims about the pertinence and performance of the well-known and widely field-applied local ramp metering algorithm ALINEA. In a recent series of articles with largely identical contents and results, some claims are raised about the pertinence and performance of the well-known and widely field-applied local ramp

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of the method. Recently, a similar clarification note has also been published [12].

This paper addresses only the part of [1]–[8] that refers to ramp metering, particularly the ALINEA strategy. It is shown that the simulation and derived conclusions in [1]–[8] are based on a misapplication of the method. Recently, a similar clarification note has also been published [12].

II. ALINEA ALGORITHM

Consider the sketched motorway/on-ramp merge area displayed in Fig. 1. Local ramp metering corresponds to controlling (by use of traffic lights) the traffic flow that merges into the mainstream from the on-ramp to maximize the mainstream flow downstream of the on-ramp in response to the prevailing traffic conditions. Different proposed methods may use different kinds or locations of measurements and different algorithms to achieve the stated goal (downstream flow maximization; see [13] for an overview). ALINEA was the first local ramp metering algorithm to be based on a feedback concept (to be more elementarily explained later, see also [9], [10], [13], and [14]).

Local ramp metering strategies are activated at each time interval $T$, whose value is typically selected in the range from 20 to 60 s. More specifically, at the end of each running period $T$, time-averaged measurements of traffic volume (flow) or occupancy (depending on the requirements of the employed control strategy) from the ending period are used to calculate (via the corresponding strategy) the ramp flow to be implemented in the next period. The particular ALINEA algorithm reads

$$r(k) = r(k-1) + K_R [\hat{o} - o_{out}(k-1)]$$  \hspace{2cm} (1)$$

where

- $k = 1, 2, \ldots$ discrete time index;
- $r(k)$ ramp flow (in vehicles per hour) to be implemented during the new period $k$;
- $o_{out}(k-1)$ last measured motorway occupancy (in percent; averaged over all lanes) downstream from the ramp;
- $K_R > 0$ regulator parameter;
- $\hat{o}$ set (desired) value for the downstream occupancy.

The following issues are quite crucial for a proper ALINEA application, as emphasized in [9] and [10].

1) The same value of $K_R$ (equal to 70 veh/h/%) has been used in most simulation or field applications of ALINEA with no for fine tuning. The utilized $K_R$-value is not mentioned in [8].

2) The ramp flow $r(k)$ that results from (1) is truncated if it is inside the range $[r_{min}, r_{max}]$, where $r_{max}$ is the ramp’s flow capacity (e.g., equal to 1800 veh/h for single-lane ramps), and $r_{min} > 0$ is a minimum admissible ramp flow (typically 200–400 veh/h). There is no mention of this in [8].

3) This truncated ramp flow value is used as $r(k-1)$ in (1) in the next time step to avoid the well-known wind-up effect of such I-type (integral) regulators as ALINEA; note that the real ramp flow value $q_r$ at any period may be different than the $r$-value ordered by ALINEA due to a multitude of possible reasons (e.g., traffic light operation inaccuracies, red-signal violations, by-pass ramp lanes for buses or high-occupancy vehicles, lack of ramp demand, etc. [15]). The impact of using $q_r(k-1)$ rather than $r(k-1)$ in (1) is analyzed in [9] and [15]. The handling of this issue is not mentioned in [8].

4) When ALINEA (or any other local ramp metering strategy) is applied in the field or in microscopic simulation, the ordered ramp flow $r(k)$ must be translated into appropriate green/red traffic signals. There are many different ways of achieving this (see, e.g., [9] and [15]). The handling of this issue is not mentioned in [8].

5) According to the broadly accepted notion of the fundamental diagram (Fig. 2), the mainstream flow $q_{out}$ downstream from the ramp is maximized if the downstream occupancy $o_{out}$ is maintained (via application of (1)) around a critical occupancy value $o_c$, which may be determined from corresponding flow/occupancy measurements (see also [16] and [17] for a real-time estimation algorithm). Kerner [8] dismisses all known traffic flow theories, including the fundamental diagram, in favor of his three-phase traffic theory. Admittedly, the notion of the fundamental diagram as a unique deterministic relationship of flow versus occupancy is a rather rough idealized representation of real traffic phenomena. However, the fundamental diagram is in no way “the theoretical basis of ALINEA,” as wrongly stated in [8]. As a matter of fact, ALINEA is a feedback regulator based on the classical automatic control theory; its aim is to maintain the real value of the variable under control (i.e., of $o_{out}$) near a selected set value $\hat{o}$. An apparently suitable choice for mainstream flow maximization in view of Fig. 2 is $\hat{o} = o_c$. However, ALINEA is also compatible with Kerner’s probabilistic three-phase traffic theory or any high-order traffic flow theory and, most importantly, with the real traffic flow, as will be shown further later in this paper.

We ignore whether issues 1)–6) above have been adequately considered in the simulations of [8]. However, even if all these crucial issues were actually properly addressed, there is a final fundamental issue that was obviously not observed in [1]–[8] and that may, by itself, lead...
to inappropriate application of ALINEA and flawed conclusions; this is the location of measuring $o_{\text{out}}$ on the mainstream, downstream from the on-ramp.

All recent traffic flow theories (including the three-phase one) agree that the occurrence of a congestion due to the merging of the ramp flow with the mainstream flow arriving from upstream leads to a decrease in the mainstream flow downstream from the ramp (this is sometimes called capacity drop), and in fact, local ramp metering attempts to maximize exactly this downstream flow. In particular, ALINEA attempts to avoid congestion by maintaining the mainstream occupancy $o_{\text{out}}$ close to a noncongested target value $\hat{o}$ at which high (or even maximum) flow $q_{\text{out}}$ is observed. To achieve this, the measurement $o_{\text{out}}$ that feeds ALINEA in (1) must, of course, stem from a mainstream location downstream of the ramp, where any occurring merge congestion can be monitored (or is visible).

Where do merge congestions appear first? In real life, merge congestions usually appear first a few hundred meters downstream from the ramp nose, which is, in most cases, downstream from the acceleration lane drop (e.g., location 3 in Fig. 1). This is probably due to the fact that drivers are very attentive while merging from the acceleration lane onto the mainstream, thus tolerating relatively short intervehicle gaps at high speeds (which corresponds to accordingly high flows); after the acceleration lane drop, when drivers relax and attempt to restore their usual gaps, a traffic breakdown first occurs.

For example, mainstream measurements at U.K. motorways collected 450 m downstream from the ramp nose indicate that the merge congestion is visible at this location, which proves that the merge congestion was first created even further downstream [12]. In addition, the excellent ALINEA field results displayed in Fig. 3 were achieved by the use of measurements collected downstream from the acceleration lane drop.

Microscopic simulation models are notorious for their barely realistic lane-change behavior in merge areas. Among other inaccuracies, merge congestion in microscopic simulators occurs typically first at the acceleration lane drop (location 2 in Fig. 1), and the simulator used in [8] is probably no exception.

As a matter of fact, the exact location of first appearance of the merge congestion is not crucial for ALINEA. Wherever the congestion first appears, it will propagate rapidly in the upstream direction; thus, any detector location for the $o_{\text{out}}$ measurement between the ramp nose and the location of the first congestion appearance is good enough to enable ALINEA to monitor the possible increase of $o_{\text{out}}$ beyond the set value $\hat{o}$. Note the following, however.

1) The closer the measurement location to the congestion first-appearance location is, the faster the ALINEA reaction will be.

2) If the measurement is located upstream from the acceleration lane drop, then the corresponding detector cross section may have to cover the acceleration lane as well.

It is now quite trivial to see that, due to the feedback character of (1), it is impossible for a properly applied ALINEA not to dissolve the mainstream merge congestion (provided, of course, that there is sufficient storage space on the ramp and that the arriving mainstream flow $q_{\text{in}}$ from upstream is not very high; more specifically, we should have $q_{\text{in}} + r_{\text{min}} < q_{\text{cap}}$) in either simulation or real traffic environments. More specifically, any negative regulation error $\hat{o} - o_{\text{out}}(k - 1)$ in (1) is integrated (accumulated) over time, reducing the last ramp flow value $r(k - 1)$ more and more from time-step to time-step, until $o_{\text{out}}$ becomes smaller than or equal to its target value $\hat{o}$ (and vice versa). More generally, the ALINEA regulator (1) acts smoothly (no rough switchings) to maintain the variable under control ($o_{\text{out}}$) close to its target ($\hat{o}$), despite any occurring disturbances. This is the very notion of feedback control that may be read in elementary control engineering textbooks.

It should be noted that the control-theoretic analysis of ALINEA in [9] was based on model linearization that is strictly valid only for $o_{\text{out}} < o_{\text{cr}}$. However, it was mentioned that ALINEA also acts in a suitable way (as outlined above) when $o_{\text{out}}$ happens to increase beyond...
$\alpha_q$. The closed-loop stability of ALINEA for any $\alpha_{\text{out}} \in [0, 100]$ was eventually shown mathematically in [18] under quite general assumptions.

Fig. 3 provides a sample of ALINEA field-application results at the Craighall junction of the M8-East motorway in Glasgow, U.K., during the afternoon peak hour. It may be seen that ALINEA maintains quite smoothly the measured occupancy (continuous line) around the set value of 26% (dashed line). It has been shown mathematically [9], [14] and can be verified from Fig. 3 that the average value of $\alpha_{\text{out}}$ over time is exactly equal to $\hat{\alpha}$, provided no constraints (e.g., $r_{\text{min}}$, $r_{\text{max}}$, queue override, lack of ramp demand, etc.) are activated, which would perturb the application of (1). These conditions were, indeed, met in the results of Fig. 3 up to 18:00 h; the slight drift of $\alpha_{\text{out}}$ after 18:00 h in Fig. 3 is due to lack of ramp demand. Fig. 3 demonstrates beyond any modeling assumption (real data) that ALINEA has no difficulty in driving the downstream occupancy back to the set point in case of temporary overcritical departures; this is in direct contrast to the simulation results and related claims in [1]–[8]. The observed variations of the controlled occupancy around the set point of 26% are due to corresponding variations of the arriving mainstream flow that acts on the feedback control loop as a disturbance [9].

After this elementary exposition, one may ask what went wrong with the simulations in [8]. The answer should be quite clear. The emulated measurement used to feed ALINEA in [8] was placed downstream (probably at location 3 in Fig. 1) from the congestion first-appearance location (probably location 2 in Fig. 1), thus rendering ALINEA blind to the occurring congestion and negating its feedback character. It seems that the requirement for detector placement downstream from the ramp (to enable feedback control) was misunderstood in [1]–[8] as a requirement for detector placement downstream from the merge bottleneck (which negates the notion of feedback control or, more precisely, limits feedback control without reason to undercritical traffic states only).

III. Probabilistic Features of Traffic Flow

The failure of ALINEA to maintain the mainstream occupancy downstream of the on-ramp close to its set value in [1]–[8] was attributed by Kerner to the probabilistic character of traffic flow. Although this conclusion is apparently utterly flawed, it is worthwhile to discuss the impact of some probabilistic features of traffic flow on ALINEA’s operation and efficiency.

Analysis of real traffic data from motorway merge areas by various authors [19]–[22] indicates that the recurrent (daily) traffic breakdown during peak hours (in the absence of ramp metering) in a specific merge site may occur at different flow values (i.e., at different $q_{\text{kap}}$ in Fig. 2) on different days, even under the same weather and lighting conditions. Although the reasons for these differences might well be deterministic, but not yet understood, we may call this phenomenon a probabilistic (or uncertain) motorway capacity. What are the consequences for motorway traffic control? There are many ramp metering strategies (see [13]), including the popular demand–capacity local ramp metering strategy, that target a prespecified $q_{\text{kap}}$-value; to this end, ramp flow is allowed to enter the mainstream only to an extent such that the sum of the mainstream flow arriving from upstream plus the ramp flow is close to $q_{\text{kap}}$, but since the real capacity $q_{\text{kap}}$ is random (within certain limits), such a ramp metering policy may either under-load the motorway (on days where $q_{\text{kap}} > q_{\text{cap}}$) or lead to traffic breakdown (on days where $q_{\text{kap}} < q_{\text{cap}}$). More generally, any traffic control strategy (for any control measure) based on specific flow thresholds or targeting a specific flow capacity value is likely to underperform or even fail due to the probabilistic traffic flow behavior.

On the other hand, analysis of real traffic data from motorway merge areas or other bottlenecks by various authors [21], [22] indicates that the critical occupancy $\alpha_{\text{cr}}$, at which the maximum mainstream flow $q_{\text{cap}}$ is observed during the daily peak hours, is quite stable from day to day. In fact, even under adverse (e.g., rainy) traffic conditions, $\alpha_{\text{cr}}$ was found to be quite stable [22], [23], in contrast to $q_{\text{cap}}$. What are the implications of these findings for ALINEA operation?

1) Since $\alpha_{\text{cr}}$ is not varying strongly from day to day, it is relatively easy to select a proper and reliable set value $\hat{\alpha}$ for ALINEA. If, due to stochastic events, the real occupancy temporarily exceeds $\hat{\alpha}$, it is no problem for ALINEA to move it back close to $\hat{\alpha}$, as explained earlier on the basis of (1) and as demonstrated in the field results of Fig. 3. Even if, to be on the safe side, $\hat{\alpha}$ is selected slightly lower than $\alpha_{\text{cr}}$ (as recommended in [9]), the corresponding flow value $q_{\text{out}}$ is still very close to $q_{\text{cap}}$ (Fig. 2).

In extreme cases where the real $\alpha_{\text{cr}}$ value varies more strongly (e.g., due to truck percentage variations), one may adopt an available real-time estimation algorithm [16], [17] to track the $\alpha_{\text{cr}}$ changes and enable a corresponding further increase of the downstream flow.

2) The mentioned probabilistic variations of motorway capacity $q_{\text{cap}}$ from day to day pose absolutely no problem to ALINEA, in contrast to other flow-based ramp metering strategies (such as the demand–capacity strategy). By maintaining the occupancy $\alpha_{\text{out}}$ close to the selected set value $\hat{\alpha}$, ALINEA leads to (exactly or nearly) capacity flow, whatever the real capacity value actually happens to be on any specific application day.

Since the flow $q$ is roughly proportional to the product $\alpha \cdot v$ (occupancy times mean speed), i.e., $q \sim \alpha \cdot v$, a further conclusion may be drawn from the uncertainty of motorway capacity $q_{\text{cap}}$ and relative stability of the critical density $\alpha_{\text{cr}}$. Because $q_{\text{cap}} \sim \alpha_{\text{cr}} \cdot v_{\text{cr}}$, the uncertainty of $q_{\text{cap}}$ implies a corresponding uncertainty of $v_{\text{cr}}$ (i.e., the critical speed) at which the capacity flow occurs. Thus, ramp metering (or other motorway traffic control) strategies that base their decisions on specific mean speed thresholds or target a specific mean speed value may partly suffer from similar disadvantages mentioned earlier for flow-based strategies due to the $v_{\text{cr}}$ uncertainty.

IV. Upstream-Measurement-Based ALINEA

Several motorways are equipped with mainstream detectors placed just upstream from the on-ramp nose (location 1 in Fig. 1). To avoid the cost of installing additional detectors downstream from the on-ramp for ALINEA application, an estimation formula was derived in [14] that allows the real-time calculation of downstream occupancy estimates $\hat{\alpha}_{\text{out}}$ based on available measurements of upstream occupancy $\alpha_{\text{in}}$, upstream flow $q_{\text{in}}$, and ramp flow $q_{\text{r}}$. That formula was extended in [12] to also cover situations where a merge congestion has actually occurred, although the extension does not significantly affect the produced ramp metering rates. Both formulas were tested in [12] on the basis of real data and were found to be reasonably accurate, even without any calibration of some included parameters.

The results reported in [12] indicate, on the basis of real data evidence, that ALINEA may be successfully applied by the use of upstream measurements, provided that these measurements are appropriately used to produce reliable estimates of the downstream occupancy (UP-ALINEA). This had been successfully demonstrated in [14] via macroscopic simulation. The same was also attempted in [8], with mixed results. On one hand, it was found in [8] that UP-ALINEA,
Indeed, suppresses the merge congestion, which is not surprise, because the upstream occupancy measurement \( \delta_{\text{up}} \) and, hence, the estimate \( \bar{\delta}_{\text{out}} \) monitor the congestion and allow for the algorithm (1) to address it, as explained earlier. On the other hand, it was found in [8] that UP-ALINEA was not able to maintain the target occupancy \( \bar{o} \) and, therefore, produced a lower downstream flow \( q_{\text{out}} \) (and, hence, higher ramp delays) than the ordinary ALINEA with the same target value \( \bar{o} \). What are the possible reasons for this?

1) Any of the crucial issues 1)–6) mentioned earlier were not properly taken into account in the simulations of [8].
2) The estimates \( q_{\text{out}} \) that were shown in [12] to reliably follow \( \bar{\delta}_{\text{out}} \) in real traffic data are less reliable for the microscopic simulator used in [8]; this would, of course, indicate a problem with the simulator—not with UP-ALINEA. Whatever the reason might be, there is no indication of a malfunction by UP-ALINEA, and it is for Kerner [8] to carefully check what went wrong with the employed application and simulation environment in [8].

V. ANCONA RAMP METERING STRATEGY

Kerner proposed, in [1]–[8], ANCONA, which is a new local ramp metering strategy. ANCONA employs real-time measurements of mean speed (or occupancy) that are collected upstream of the on-ramp (location 1 in Fig. 1) and applies a switching rule (based on prespecified mean-speed thresholds). More specifically, ramp metering is not applied until a congestion sets in, after which, a restrictive ramp flow value is applied to dissolve the congestion; then, ramp metering is released again until congestion reappears, and so forth. The following comments may be made with regard to the ANCONA logic.

1) It is quite likely that ANCONA switching ramp metering could, indeed, maintain the downstream flow \( q_{\text{out}} \) at a reasonably high level by preventing the occurrence of serious congestion. This, however, has to be tested in the field.
2) The switching (bang-bang) character of ANCONA looks somewhat simplistic from a control engineering point of view. Bang-bang control (e.g., employed in electric irons) is the most basic feedback control strategy. In the case of motorway traffic, it may have negative implications for traffic safety due to the deliberate continuous creation of mean speed disruptions on the motorway mainstream.
3) The targeted effect of ANCONA could also be achieved by the use of downstream measurements, as in ALINEA, rather than the currently proposed upstream measurements. Since merger congestion is monitored earlier by downstream measurements, this may have a beneficial effect on ANCONA’s reaction time and efficiency. In fact, ANCONA is applied in [8], with measurements collected up to 300 m downstream from the ramp nose.
4) Mean-speed measurements are slightly costlier than occupancy measurements and may not be available in some installations.
5) The required effort for calibration of the speed thresholds and of further ANCONA control parameters for each specific application site is not known. Probabilistic effects with regard to mean speeds may have a negative impact on the strategy’s reliability.
6) Local ramp metering has clear limitations of achievable efficiency [13]; it is not clear how ANCONA could possibly be embedded in a potentially more efficient coordinated ramp metering scheme.

As final advice, microscopic simulators are useful tools, but their notoriously inaccurate lane-changing behavior in merge areas limits their reliability for elaborate investigations and detailed quantitative comparisons. This is particularly true when testing ramp metering control measures, which affect mainly the merge areas of on-ramps.

VI. CONCLUSION

It has been shown, based on elementary analytic treatment as well as real-data evidence, that all claims raised in [1]–[8] with regard to ALINEA and its variations on the basis of simulation investigations are dubious or utterly flawed. On the positive side, [1]–[8] provided an opportunity to clarify some issues that might be helpful to future users of ALINEA, which are specifically listed as follows.

1) ALINEA must be fed with occupancy measurements collected downstream from the ramp at a distance where potential merge congestion is visible.
2) The probabilistic character of traffic flow capacity in merge areas, in contrast to the rather stable critical occupancy, were shown to favor efficient ALINEA application, as compared to other known local ramp metering strategies.

It should be stressed that any new proposal for improved ramp metering is welcome, but an insightful and careful design, comparison, and test is required for sensible conclusions. Blind simulation runs may sometimes hide essential issues to be encountered in field-application conditions or create phantom phenomena that are never actually encountered in real traffic conditions.

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Ensemble of Multiple Pedestrian Representations

Loris Nanni and Alessandra Lumini

Abstract—In this paper, a new approach for pedestrian detection is presented. We design an ensemble of classifiers that employ different feature representation schemes of the pedestrian images: Laplacian EigenMaps, Gabor filters, and invariant local binary patterns. Each ensemble is obtained by varying the patterns used to train the classifiers and extracting from each image two feature vectors for each feature extraction method: one for the upper part of the image and one for the lower part of the image. A different radial basis function support vector machine (SVM) classifier is trained using each feature vector; finally, these classifiers are combined by the “sum rule” [2]. Moreover, the results obtained by a pedestrian detector based on warm symmetrical object detection (e.g., [19]) and a pedestrian detector based on artificial vision techniques (e.g., [18] and this paper) may be combined to obtain further reduction of the errors.

Several works have shown that a classification method based on a single image representation does not perform as well as a method where several image representations are combined [28]. For example, a personal authenticator based on palm images has been proposed [27], where, from each palm image, three feature vectors are extracted. Three different matchers are trained using a different feature vector and then combined at the score level.

In this paper, we present a component-based pedestrian detector. The images are divided into two parts: the upper and the lower. Then, for each subimage, several feature vectors are extracted, and a different radial basis function SVM is trained for each feature vector. Finally, these classifiers are combined by the “sum rule” [2]. Moreover, to reduce the computational time, each classifier is trained using a different subset of the training images.

II. PROPOSED SYSTEM

The block diagram of the proposed pedestrian detector system is shown in Fig. 1. First, the images are normalized to reduce the lighting effects using the method proposed in [4]. Then, each image is divided into two subimages: the lower and upper parts. From each part, we

1 Implemented as in the Matlab Toolbox OSU SVM Toolbox, the parameters used in all the tests are C = 1000 and Gamma = 1.