ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
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ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

«ΑΡΧΙΜΗΔΗΣ ΙΙΙ – Ενίσχυση Ερευνητικών Ομάδων στο ΤΕΙ Δυτικής Μακεδονίας» - MIS 383583

Υποέργο 08:

Παροχή Προτεραιότητας σε πραγματικό χρόνο σε Μέσα Μαζικής Μεταφοράς

Παραδοτέο 1:

Επισκόπηση βιβλιογραφίας και πρακτικών εφαρμογών

Συγγραφείς: Χριστίνα Διακάκη, Βάγια Δινοπούλου, Ιωάννης Παπαμιχαήλ, Μάρκος Παπαγεωργίου

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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

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Authors:	Christina Diakaki, Vaya Dinopoulou, Ioannis Papamichail, Markos Papageorgiou		

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Table of Contents

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

List of Figures

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

List of Tables

Executive Summary

In the years to come, public transport will be called to play a significant role towards achieving the sustainable transport system objective that has been set for the future, in Europe and beyond. To this end, the quality, accessibility and reliability of its operations should be improved. In this context, the favourable treatment of public transport meanswithin the road network may have, among others, a significant contribution.This favourable treatment can be derived as a result of an appropriate design of the road network facilities and/or the employed signal control at the network junctions.

It is the aim of this project to develop a methodology and related software, which will provide public transport priority through the appropriate adjustment of signal control in case of single as well as multiple priority requests. To this end, within the 1st Work Package, a detailed review of the international literature in relation to the state-of-the-art and practice of public transport priority strategies and methodologies has taken place to identify the trends related to the scope of the project. This deliverable describes the outcomes of this review.

The review focuses on:

- State-of-the art methods and strategies proposed for granting priority to PT vehicles with emphasis to those applied to PT vehicles moving on mixed-traffic lanes;
- Methods, strategies and systems, which are operational at different road networks around the world (state-of-practice).

Issues such as the architecture of the corresponding Urban Traffic Control systems, and the detection and communication devices, although relevant, are not addressed in this review, which focuses on the control logic behind the hardware.

The review has been based on the literature accessed via electronic or compatible libraries and research and technical journals. Information has also been gathered through the internet, and in particular through the web pages of large institutes and organisations, as well as through the web pages of companies involved in the development of public transport priority systems.

The deliverable is structured in 11 sections. The first section provides an introduction to the aims and objectives of the project as well as the scope and the structure of the deliverable.

Section 2 describes the road transport system and its users, and discusses its problems and challenges. It also highlights the significant role public transport will have to play in the years to come, given the ever increasing request for sustainable transport.

Section 3 discusses generally the ways to control the road transport network with an emphasis on signal-control systems, and introduces some basic control-related notions, so as to enable the reader to follow the concepts, which are developed in the following sections.

Section 4 reviews the ways to provide priority to public transport means and provides an introduction and a categorisation of the available public transport favourable measures. As mentioned earlier, such measures may be based on the appropriate design of available facilities and/or the adjustment of signal control.

Facility-design-based measures are employed in case of public transport vehicles moving in mixed-traffic lanes, such as buses and trams. Such measures include different adjustments of the road lanes, so as to include exclusive bus lanes, high occupancy vehicle lanes and reversible bus lanes;or, in cases where road capacity needs to be preserved as much as possible, intermittent bus lanes, dynamic fairways and bus lanes with intermittent priority. Other facility-design-based measures, that may also be employed to provide the desired priority without affecting the signal control of the network junctions, include bus-only roads and busways, bus gates and rising bollards, as well as bus advance areas. Such measures are discussed in Section 5.

As far as signal control is concerned, several adjustments of the traffic lights may be adopted to provide public transport vehicles a favourable treatment at the network junctions. This favourable treatment, which is called priority, may be provided at different levels, depending mainly on the type of the public transport vehicle.

Depending on the specific requirements that the provision of priority aims at addressing, several different signal-control based public transport priority strategies have been developed and applied worldwide. A first classification distinguishes them as fixed-time versusreal-time. Fixed-time strategies are in fact fixed-time signal plans, especially developed to favour the movements of public transport vehicles, while real-time strategies respond to priority requests received in real time. The real-time strategies may be further classified according to several criteria. The first criterion distinguishes real-time strategies in proactive versusreactive, depending on whether the priority request is received well in advance, so as to prepare the signal control to accommodate smoothly the receipt request, or not. The second criterion distinguishes the strategies in rule-based and optimisation-based, depending on whether their control decisions are based on a set of identified conditionsor on the optimisation of an appropriately defined performance index.

The conditionsof the rule-based public transport priority strategies mainly concern schedule or headway adherence, as well as the overall traffic conditions, while priority is usually granted via green extension and stage recall. On the other hand, total delay seems to be the main concern of the optimisation-based strategies.

Section 6 reviews in detail public transport priority measures, which are based, as described above, on the adjustment of signal control at the network junctions, and constitute the prime focus of the deliverable. The levels of priority, the classification of public transport priority strategies, theconditionsand the methods for granting priority, as well as the transition / recovery methods are also discussed in this section; while Section 7 reviews and discusses existing signal-control strategies, which provide priority to public transport means.

According to the findings of the reviews reported in Sections 6 and 7, the relevant scientific literature offers a few examples of fixed-time priority strategies, and numerous examples of real-time priority strategies, mainly of a rule-based nature. The same tendency is observed in the practical applications of public transport priority systems where the real-time, rule-based strategies constitute the vast majority of adopted strategies, as the state-of-practice review reported in Section 8 indicates.

It seems that despite their inability to adequately address issues such as the service of multiple requests and the provision of priority under coordinated signal control, the direct and occasionally aggressive priority, which is provided by the rule-based strategies, still remains the prime subject of research and development within an international community that calls for solutions, which will evidently improve the public transport operations and promote their use. Such findings of the preceding review are discussed in Section 9, in an effort toidentify the current trends and future perspectives in public transport priority systems.

Section 10, finally, summarises the main conclusions and findings of the deliverable.

The deliverable includes also an extensive reference list, as well as an English-Greek dictionary and a Greek glossary of terms for the Greek readers.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

GreekSummary

Στα επόμενα χρόνια, οι δημόσιες συγκοινωνίες θα κληθούν να διαδραματίσουν σημαντικό ρόλο στην επίτευξη του στόχου που έχει τεθεί, τόσο στην Ευρώπη όσο και σε παγκόσμιο επίπεδο, για ένα βιώσιμο σύστημα μεταφορών. Για το σκοπό αυτό, τόσο η ποιότητα και προσβασιμότητά τους, όσο και η αξιοπιστίατους θα πρέπει να βελτιωθούν. Σε αυτό το πλαίσιο, η ευνοϊκή μεταχείριση των μέσων μαζικής μεταφοράς στο οδικό δίκτυο μπορεί να έχει, μεταξύ άλλων, μια σημαντική συμβολή. Μια τέτοια ευνοϊκή μεταχείριση μπορεί να προκύψει ως αποτέλεσμα του κατάλληλου σχεδιασμού των υποδομών του οδικού δικτύου όσο και μέσω παροχής προτεραιότητας σε αυτά, έναντι των άλλων οχημάτων, στους κόμβους του δικτύου.

Στόχος του συγκεκριμένου ερευνητικού έργου είναι να αναπτύξει μια μεθοδολογία και το αντίστοιχο λογισμικό, για τον έλεγχο της φωτεινής σηματοδότησης κόμβων οδικών δικτύων, έτσι ώστε να παρέχεται προτεραιότητα σε μέσα μαζικής μεταφοράς τόσο σε περιπτώσεις όπου τα μέσα μαζικής μεταφοράς προσεγγίζουν τους κόμβους με μικρή συχνότητα, όσο και σε περιπτώσεις όπου στον ίδιο κόμβο διασταυρώνονται πολλές γραμμές (π.χ. λεωφορείων) από διαφορετικές κατευθύνσεις. Για την επίτευξη του στόχου αυτού, στα πλαίσια του 1ου Πακέτου Εργασίας του έργου, πραγματοποιήθηκε μια εκτενής ανασκόπηση της διεθνούς βιβλιογραφίας σε σχέση με στρατηγικές παροχής προτεραιότητας που είτε έχουν αναπτυχθεί σε θεωρητικό επίπεδο, είτε χρησιμοποιούνται στην πράξη. Σκοπός αυτής της βιβλιογραφικής έρευνας ήταν να εντοπίσει τις τάσεις που επικρατούν στο συγκεκριμένο πεδίο. Αυτό το παραδοτέο περιγράφει τα αποτελέσματα της βιβλιογραφικής ανασκόπησης.

Η ανασκόπηση επικεντρώνεται στα εξής θέματα:

- Μέθοδοι και στρατηγικές που έχουν προταθεί για την παροχή προτεραιότητας σε μέσα μαζικής μεταφοράς με έμφαση σε αυτές που αφορούν μεταφορικά μέσα που κινούνται σελωρίδες μεικτής κυκλοφορίας.
- Μέθοδοι, στρατηγικές και συστήματα, τα οποία λειτουργούν σε διάφορα οδικά δίκτυα σε όλο τον κόσμο.

Θέματα όπως η αρχιτεκτονική των αντίστοιχων συστημάτων ελέγχου, καθώς και οι συσκευές ανίχνευσης και επικοινωνίας, αν και σχετικά, δεν εξετάζονται στην παρούσα ανασκόπηση, η οποία επικεντρώνεται σε μεθοδολογικά θέματα.

Η ανασκόπηση πραγματοποιήθηκε μέσω ηλεκτρονικών ή συμβατικών βιβλιοθηκών και ερευνητικών και τεχνικών περιοδικών. Χρησιμοποιήθηκαν επίσης πληροφορίες από το διεθνές διαδίκτυο, και ειδικότερα από ιστοσελίδες μεγάλων ιδρυμάτων και οργανισμών, καθώς και από ιστοσελίδες εταιρειών που συμμετέχουν στην ανάπτυξη συστημάτων προτεραιότητας για μέσα μαζικής μεταφοράς.

Το παραδοτέο διαρθρώνεται σε 11 κεφάλαια. Το πρώτο κεφάλαιο παρέχει μια εισαγωγή στους σκοπούς και στόχους του ερευνητικού έργου, καθώς και στο πεδίο εφαρμογής και τη δομή του συγκεκριμένου παραδοτέου.

Το 2ο Κεφάλαιο περιγράφει το σύστημα των οδικών μεταφορών και των χρηστών του, ενώ σχολιάζει τα προβλήματα και τις προκλήσεις που αντιμετωπίζουν οι οδικές μεταφορές. Υπογραμμίζει, επίσης, το σημαντικό ρόλο που τα μέσα μαζικής μεταφοράς θα κληθούν να διαδραματίσουν τα επόμενα χρόνια, δεδομένου του ολοένα και αυξανόμενουαιτήματος για βιώσιμες μεταφορές.

Το 3ο Κεφάλαιο περιγράφει γενικά τους τρόπους ελέγχου του δικτύου οδικών μεταφορών, με έμφαση στα συστήματα ελέγχου φωτεινής σηματοδότησης. Παραθέτειεπίσης κάποιους βασικούς ορισμούς που σχετίζονται με τον έλεγχο, έτσι ώστε να δώσει στον αναγνώστη τη δυνατότητα να παρακολουθήσει τις έννοιες που αναπτύσσονται στα επόμενα κεφάλαια.

Το 4ο Κεφάλαιο παραθέτει μια επισκόπηση των τρόπων παροχής προτεραιότητας σε μέσα μαζικής μεταφοράς, και παρέχει μια εισαγωγή και μια κατηγοριοποίηση στα μέτρα που μπορούν να ληφθούν με στόχο την ευνοϊκή τους μεταχείριση. Όπως αναφέρθηκε παραπάνω, τα μέτρα αυτά μπορεί να βασίζονται είτε στον κατάλληλο σχεδιασμό των υποδομών του οδικού δικτύου είτε στην παροχή προτεραιότητας έναντι των άλλων οχημάτων στους κόμβους του δικτύου.

Τα μέτρα που βασίζονται στο σχεδιασμό των υποδομών του οδικού δικτύου, αφορούν ουσιαστικά σε μέσα μαζικής μεταφοράς που κινούνται σε λωρίδεςμεικτής κυκλοφορίας, όπως τα λεωφορεία και τα τραμ. Τα μέτρα αυτά περιλαμβάνουν διαφορετικές διαρρυθμίσεις του οδικού δικτύου, ώστε να συμπεριληφθούν λωρίδες αποκλειστικής κυκλοφορίας λεωφορείων, λωρίδες οχημάτων υψηλής πληρότητας καιαναστρέψιμες λωρίδες λεωφορείων, ή στην περίπτωση κατά την οποία είναι επιθυμητό να μην επηρεαστεί έντονα η χωρητικότητα του οδικού δικτύου, διακοπτόμενες λωρίδες λεωφορείων, δυναμικές οδούς, και λωρίδες λεωφορείων με διακοπτόμενη προτεραιότητα. Άλλα μέτρα σχεδιασμού που μπορούν επίσης να χρησιμοποιηθούν για την ευνοϊκή μεταχείριση των μέσων οδικής μεταφοράς περιλαμβάνουν λεωφορειόδρομους, πύλες λεωφορείων και ανερχόμενες κολόνες, καθώς και περιοχές προώθησης λεωφορείων. Τα μέτρα αυτά παρουσιάζονται στο Κεφάλαιο 5.

Όσον αφορά στον έλεγχο φωτεινής σηματοδότησης, αρκετοί είναι οι τρόποι με τους οποίους μπορεί να ρυθμιστεί έτσι ώστε να παρέχει ευνοϊκή μεταχείριση, δηλαδή προτεραιότητα, στα μέσα μαζικής μεταφοράς, σε επίπεδα που μεταβάλλονται ανάλογα με τον τύπο του μέσου μαζικής μεταφοράς στο οποίο απευθύνονται.

Με βάση τις ιδιαίτερες απαιτήσεις που ένα σύστημα ελέγχου με παροχή προτεραιότητας σε μέσα μαζικής μεταφοράς θα πρέπει να ικανοποιεί, διάφορες στρατηγικές ελέγχου έχουν αναπτυχθεί και εφαρμοστεί σε όλο τον κόσμο. Μια πρώτη ταξινόμηση τις διακρίνει σε στρατηγικές σταθερού και πραγματικού χρόνου. Οι πρώτες αφορούν ουσιαστικά σε σταθερά πλάνα σχεδιασμένα να ευνοούν τις κινήσεις των μέσων μαζικής μεταφοράς, ενώ οι δεύτερες ανταποκρίνονται σε ανάγκες παροχής προτεραιότητας που ανιχνεύονται σε πραγματικό χρόνο. Οι στρατηγικές πραγματικού χρόνουδιακρίνονται περαιτέρω με βάσει διάφορα κριτήρια. Το πρώτο κριτήριο διακρίνει τις στρατηγικές σε προβλεπτικές και επενεργούμενες, ανάλογα με το αν λαμβάνουν το αίτημα προτεραιότητας αρκετά προτού το μέσο μαζικής μεταφοράς προσεγγίσει τον κόμβο ώστε να προετοιμάσουν τη φωτεινή σηματοδότηση ή όχι.Το δεύτερο κριτήριο διακρίνει τις στρατηγικές σε στρατηγικές βασιζόμενες σε κανόνες και στρατηγικές βελτιστοποίησης, ανάλογα με το αν οι αποφάσεις για παροχή προτεραιότητας βασίζονται σε ένα σύνολο κριτηρίων ή στη βελτιστοποίηση ενός κατάλληλα ορισμένου δείκτη απόδοσης.

Τα κριτήρια που χρησιμοποιούνται από τις στρατηγικές που βασίζονται σε κανόνες αφορούν κυρίως την τήρηση του χρονοδιαγράμματος του μέσου μαζικής μεταφοράς, την τήρηση της συχνότητας των δρομολογίων, το βαθμό συμφόρησης του δικτύου κ.λπ., ενώ προτεραιότητα χορηγείται συνήθως μέσω παράτασηςτου πρασίνου και ανάκλησης σταδίου. Από την άλλη πλευρά, η συνολική καθυστέρηση όλων των οχημάτων στο οδικό δίκτυο φαίνεται να είναι το κύριο μέλημα των στρατηγικών βελτιστοποίησης.

Το Κεφάλαιο 6 παρουσιάζει εκτενώς τα παραπάνω θέματα, τα οποία αποτελούν και το επίκεντρο του συγκεκριμένου παραδοτέου. Τα επίπεδα προτεραιότητας, η ταξινόμηση των στρατηγικών ελέγχου, τα κριτήρια και οι μέθοδοι παροχής προτεραιότητας, καθώς και οι μέθοδοι που χρησιμοποιούνται έτσι ώστε ο έλεγχος των κόμβων να επιστρέψει στη συνήθη λειτουργία του μετά από την εξυπηρέτηση κάποιου αιτήματος προτεραιότητας παρουσιάζονται επίσης στο κεφάλαιο αυτό, ενώ το Κεφάλαιο 7 σχολιάζει, κατατάσσει ανάλογα με τα ιδιαίτερα χαρακτηριστικά τους και παρουσιάζει τις στρατηγικές ελέγχου με παροχή προτεραιότητας σε μέσα μαζικής μεταφοράς που έχουν προταθεί.

Σύμφωνα με τα αποτελέσματα της ανασκόπησης των Κεφαλαίων6 και 7, η σχετική επιστημονική βιβλιογραφία προσφέρει λίγα παραδείγματα στρατηγικών σταθερού χρόνου και πολλά παραδείγματα στρατηγικών πραγματικού χρόνου κυρίως βασιζόμενων σε κανόνες. Η ίδια τάση παρατηρείται και στις πρακτικές εφαρμογές, στις οποίες, σύμφωνα με τα αποτελέσματα της ανασκόπησης που παρουσιάζεται στο Κεφαλαίο 8, οι στρατηγικές πραγματικού χρόνου που βασίζονται σε κανόνες αποτελούν τη συντριπτική πλειοψηφία.

Φαίνεται ότι παρά την αδυναμία τους να αντιμετωπίσουν επαρκώς ζητήματα, όπως η ταυτόχρονη εξυπηρέτηση πολλαπλών αιτημάτων προτεραιότητας και η παροχή προτεραιότητας σε συνθήκες συντονισμένου ελέγχου στο οδικό δίκτυο, οι στρατηγικές πραγματικού χρόνου που βασίζονται σε κανόνες, με τον άμεσο και σε πολλές περιπτώσεις επιθετικό χαρακτήρα προτεραιότητας που παρέχουν, εξακολουθούν να παραμένουν το κύριο αντικείμενο της έρευνας και ανάπτυξης μιας διεθνούς κοινότητας που αναζητεί λύσεις, οι οποίες με εμφανή τρόπο θα βελτιώσουν τη λειτουργία των μέσων μαζικής μεταφοράς και θα προωθήσουν τη χρήση τους. Τέτοιου είδους ζητήματα σχολιάζονται στο Κεφάλαιο 9, σε μια προσπάθεια εντοπισμού των σύγχρονων τάσεων και των μελλοντικών προοπτικών στα συστήματα παροχής προτεραιότητας.

Το Κεφάλαιο 10, συνοψίζει τα κύρια συμπεράσματα και ευρήματα του παραδοτέου.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Το παραδοτέο περιλαμβάνει επίσης έναν εκτενή βιβλιογραφικό κατάλογο, καθώς και ένα αγγλοελληνικό λεξικό και ένα ελληνικό γλωσσάρι της σχετικής ορολογίας για τους Έλληνες αναγνώστες.

List of Acronyms and Abbreviations

ANN	Artificial Neural Networks
APC	Automatic Passenger Count
APeMS	Arterial Performance Measurement System
ATSP	Adaptive Transit Signal Priority
AVL	Automatic Vehicle Location
BALANCE	BALancing Adaptive Network Control mEthod
BCC	Brisbane City Council
BLIP	Bus Lanes with Intermittent Priority
BLISS	Brisbane Linked Intersection Signal System
CAPRI	Categorized Arrivals-based Phase Reoptimization at Intersections
CCBP	Coordinated and Conditional Bus Priority
CO_2	Carbon Dioxide
CONDUITS	Coordination Of Network Descriptors for Urban Intelligent Transport Systems
COP	Controlled Optimization of Phases
CPM	Critical Path Method
DARVIN	Dynamic Allocation of Right-of-way for transit Vehicles In urban Networks
DBL	Dedicated Bus Lane
DF	Dynamic Fairway
DfT	Department for Transport
EBL	Exclusive Bus Lane
EC	European Commission
EU	European Union
FIFO	First-In-First-Out
FITP	Fourthsquare Integrated Transportation Planning
GA	Genetic Algorithm
GHG	GreenHouse Gas
GPS	Global Positioning Systems

HOV	High Occupancy Lane
IBL	Intermittent Bus Lane
LISCM	Local Intersection Signal Control Module
LP	Linear Program
LRT	Light Rail Transit
MILP	Mixed-Integer Linear Program
MOTION	Method for the OptimizaTION of Traffic signals online
MOVA	Microprocessor Optimised Vehicle Actuation
NBRTI	National Bus Rapid Transit Institute
NCHRP	National Cooperative Highway Research Program
NEMA	National Electrical Manufacturers Association
^oC	Celsius Degree
OPAC	Optimised Policies for Adaptive Control
PAMSCOD	Platoon-based Arterial Multi-modal Signal Control with Online Data
PERT	Program Evaluation and Review Technique
PRIBUSS	PRIoritizing of BUSses in Coordinated Signal systems
PRISCILLA	bus PRIority strategies and Impact SCenarIosdeveLoped on a Large urban Area
PT	Public Transport
PTIPS	Public Transport Information and Priority System
PTM	Public Transport Mean
PTP	Public Transport Priority
r.o.w.	Right of way
RAPID	Realtime Advanced Priority and Information Delivery
RHODES	Regional Hierarchical Optimized Distributed Effective System
RTA	Roads and Traffic Authority
SCATS	Sydney Coordinated Adaptive Traffic System
SCOOT	Split Cycle Offset Optimisation Technique
SPOT	System for Priority and Optimisation of Traffic
SPPORT	Signal Priority Procedure for Optimization in Real-Time

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

SPRINT	Selective PRIority Network Technique
SPRUCE	Selective Priority in the UTCM Environment
SVD	Selective Vehicle Detector
TCRP	Transit Cooperative Research Program
TRAFCOD	TRAFficCOntrol Design
TRANSYT	Traffic Network and Isolated Intersection Study Tool
TUC	Traffic-responsive Urban Control
UITP	International Association of Public Transport
UK	United Kingdom
USA	United States of America
UTC	Urban Traffic Control
UTOPIA	Urban Traffic Optimisation by Integrated Automation
VHB	VanasseHangenBrustlin Inc.
VISGAOST	VISSIM-based Genetic Algorithm Optimization of Signal Timings
VISSIM	Verkehr In Städten - SIMulation
VMS	Variable Message Sign
WCS	Wireless Communication Systems
WP	Work Package

1. Introduction and project overview

1.1. Project aims and objectives

Most urban road networks face serious traffic congestion problems, due to high demand, but also due to the lack of parking spaces and the low attractiveness of public transport (PT). One possibility to improve the situation is offered by increasing the use of PT, provided that its planning will also take into account factors that make its use more attractive. One such factor is the travel time, which, in the case of PT vehicles that move in mixed-traffic lanes, such as buses and trams, is usually considerably increased due to the overall traffic congestion.

The goal of the proposed project is:

- To develop a methodology and a corresponding software that provides public transport priority (PTP) in real time for PT vehicles approaching a junction with relatively low frequency; and
- To investigate the case of multiple PTP requests, i.e. when several, possibly high-frequency lines from different directions intersect at the same junction.

In both cases, the PTP impact to the rest of the traffic should be taken into account.The corresponding developments and investigations will address the case of PT vehicles moving in mixed-traffic lanes.

In addition to the above, the effectiveness of PTP methodologies forPT and their implications for the rest of the traffic will be investigated in detail through microscopic simulation for a real network using real traffic data.

To achieve the stated goals and objectives, a detailed review of the international literature in relation to the state-of-the-art and practice of PTP strategies and methodologies hastaken place within the 1st Work Package (WP) to identify the trends related to the scope of the project. This deliverable describes, as explained in the next section, the findingsof this review.

1.2.Scope of the deliverable

It is the aim and scope of this deliverable to review existing PTP strategies and methodologies, as well as PTP applications, and thus, to identify trends and challenges related to the scope of the project.To this end, the review focuses on:

- State-of-the art methods and strategies proposed for granting priority to PT vehicles with emphasis to those applied to PT vehicles moving on mixed-traffic lanes;
- Methods, strategies and systems, which are operational at different road networks around the world (state-of-practice).

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Issues such as the architecture of the corresponding Urban Traffic Control (UTC) systems, and the detection and communication devices, although relevant, are not addressed in this review, which focuses on the control logic behind the hardware.

The review has been based on literaturesources accessed via electronic or compatible libraries and research and technical journals. Information has also been gathered through the internet, and in particular through the web pages of large institutes and organisations, as well as through the web pages of companies involved in the development of PTP systems.

1.3.Structure of the deliverable

The deliverable is structured in 9 more sections.

- Section 2 describes the road transport system and its users, and discusses its problems and challenges. It also highlights the significant role PT will have to play in the years to come, given the ever increasing request for sustainable transport.
- Section 3 discusses generally the ways to control the road transport network with an emphasis on signal-control systems, and introduces some basic control-related notions.
- Section 4 reviews the ways to provide priority to Public Transport Means (PTMs), and provides an introduction and a categorisation of the available PTP measures.
- Section 5 reviews shortly PTP measures, which are based on the appropriate design of the road network facilities.
- Section 6 reviews in detail PTP measures, which are based on the adjustment of signal control at the network junctions; these measures constitute the prime focus of the deliverable. The levels of priority, the classification of PTP strategies, the conditionsand methods for granting priority, as well as the transition / recovery methods are also discussed in this section.
- Section 7 reviews and discusses existing signal-control strategies, which provide priority to PTMs.
- Section 8 reviews real-life PTP applications in Europe and internationally.
- Section 9 discusses the findings of the preceding review, and identifies current trends and future perspectives in PTP systems.
- Section 10, finally, summarises the main conclusions and findings of this deliverable.

The deliverable includes also an extensive reference list, as well as an English-Greek dictionary, and a Greek glossary of terms for the Greek readers.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

2. Users, problems and challenges of the road transport system

The road transport system, which is used for the transportation of people and goods, consists of:

- the road network, as well as any existing bicycle and pedestrian paths or spaces;
- the pedestrians;
- the transport means, which include private vehiclesand PT vehicles, such as buses and trams, as well as trucks, bikes, bicycles, etc.; and
- the terminals, which include bus stations, parking spaces, etc.

The continuous increase of the urban population and ofthe mobility of people and goods, as well as of the use of the private vehicle, in combination with the fact that the roadtransport system had not been designed considering such an incredible increase, have resulted in significant traffic and environmental problems.Cities, especially, suffer most from congestion, poor air quality and noise exposure. Urban transport is responsible for about a quarter of CO_2 emissions from transport, while 69% of road accidents occur in cities (EC, 2011a, 2011b).

To confront the significant challenges and set the roadmap towards a sustainable transport system by 2050, the European Union (EU) has released a White Paper on Transportation (EC, 2011c). According to this White Paper, the general objective of achieving a sustainable transport system by 2050 can betranslated into three more specific goals (EC, 2011b):

1. A reduction of Greenhouse Gas (GHG) emissions, consistent with the long-termrequirements for limiting climate change to 2 °C and the overall target to reduce transport-related emissions of CO_2 by around 60% by 2050 compared to 1990.
2. A drastic decrease in the oil dependency ratio of transport-related activities by2050.
3. Limitation ofcongestion growth.

The aforementioned specific policy objectives can be broadly summarised as the prescription to "*use less energy, use cleaner energy and better exploit infrastructure*" (EC, 2011b). The first two objectives overlap to a large extent; they also have significant synergies with the third objective, whichwould typically call for a more extensive use of non-motorised transport means and of PT that reduces both the use of space and the use of energy (EC, 2011b).

> "*The necessary transition from a primarily car based personal mobility in cities to a mobility based on walking and cycling, high quality PT and less-used and cleaner passenger vehicles is the central strategic challenge for cities in the decades to come. These transformations are not only about transport, but are basically a transition to a new way of life in an urban environment*" (EC, 2011a).

Similar goals were set in other parts of the world too. To allow PT to play its significant role towards the sustainable transport goal, the quality, accessibility and reliability of its operations should be improved. Attractive frequencies, comfort, easy access and reliability of

ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

service are the main characteristics,which will ultimately define the extent to which PT will manage to respond to its role. In this context, the favourable treatment of PTMs within the road network may have, among others, a significant contribution. This favourable treatment can be providedas a result of an appropriate design of the road network facilities and/or the employed signal control at the network junctions.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

3. The control of the road network

3.1. Basic notions

A*junction* consists of a number of *approaches* and the *crossing area*. An approach may have one or more *lanes* but has a unique, independent queue. Approaches are used by corresponding *traffic streams*. A *saturation flow* (veh/h) is the average flow crossing the stop line of an approach when the corresponding stream has right of way (r.o.w.), the upstream demand (or the waiting queue) is sufficiently large, and the downstream links are not blocked by queues. Two *compatible* streams can safely cross the junction simultaneously, else they are called *antagonistic*.

A *traffic signal cycle* is one repetition of the basic series of signal combinations at a junction; its duration is called *cycle time* (see Figure 1c). A *stage* (see Figure 1c,d) is a part of the traffic signal cycle during which a particular set of *phases* receives green, where phaseis the set of traffic movements (that may include pedestrians, cycles or general traffic streams), which are controlled by a single *signal aspect* (see Figure 1a,b). Constant *lost* or *intergreentimes* of a few seconds are necessary between stages to avoid interference between antagonistic streams of consecutive stages (see Figure 1d).

There are four possibilities for influencing traffic conditions via traffic lights operation (Papageorgiou et al, 2003).

- *Stage specification*: For complex junctions involving a large number of streams, the specification of the optimal number and constitution of stages is a nontrivial task that can have a major impact on junction capacity and efficiency.
- *Split*: This is the relative green duration of each stage (as a portion of the cycle time) that should be optimised according to the demand of the involved streams.
- *Cycle time*: Longer cycle times typically increase the junction capacity because the proportion of the constant lost times becomes accordingly smaller; on the other hand, longer cycle times may increase vehicle delays in undersaturatedjunctions due to longer waiting times during red.
- *Offset*: This is the stage difference between cycles for successive junctions that may give rise to a “green wave” along an arterial; clearly, the specification of offset should ideally take into account the possible existence of vehicle queues.

The effective and efficient operation of traffic lights is based upon the appropriate choice of the parameters and constraints of the employed control strategies, which aim to influence the traffic conditions in one or more of the aforementioned ways.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

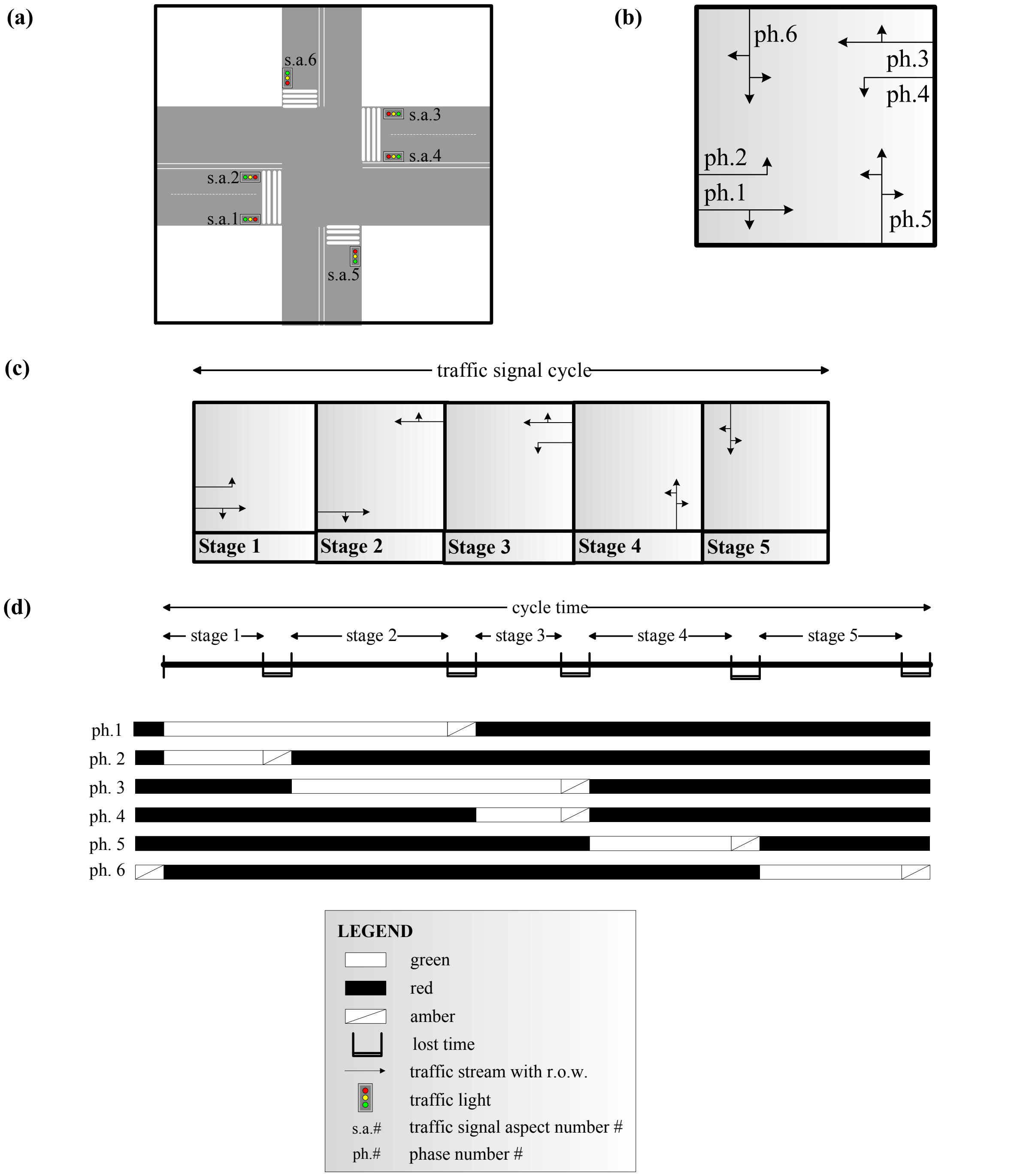

Figure 1. Example of traffic signal cycle: (a) junction and traffic signal aspects; (b) phases; (c) diagram of stage sequence; (d) cycle time allocation to stages; (e) cycle time allocation to phases.

3.2. Control strategies

The crossing of the vehicles and pedestrians at signal controlled junctions is determined by the control strategy, which is selected. Traffic lights were originally installed in order to guarantee the safe crossing of antagonistic streams of vehicles and pedestrians. However, once traffic lights exist, they may lead (under equally safe traffic conditions) to more or less efficient network operations, hence there must exist an optimal control strategy leading to minimisation of the total time spent by all vehicles in the network (Papageorgiou et al, 2003).

Although the corresponding optimal control problem may be readily formulated for any road network, its real-time solution and realisation in a control loop like the one of Figure 2 faces a number of apparently insurmountable difficulties (Papageorgiou et al, 2003):

- The red-green switching of traffic lights call for the introduction of discrete variables, which renders the optimisation problem combinatorial.
- The size of the problem for a whole network is very large.
- Many unpredictable and hardly measurable disturbances (incidents, illegal parking, pedestrian crossings, junction blocking, etc.) may perturb the traffic flow.
- Measurements of traffic conditions are mostly local (via inductive loop detectors) and highly noisy due to various effects.
- There are tight real-time constraints, e.g., decision making within 1 s for advanced control systems.

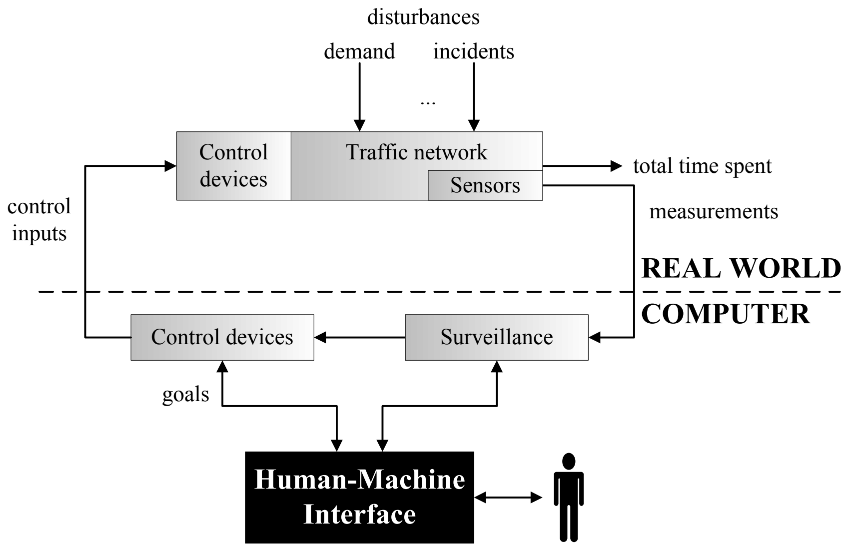

Figure 2. Control loop(adopted by Papageorgiou et al, 2003).

The combination of these difficulties renders the solution of a detailed optimal control problem not practicable for more than one junction. Therefore, proposed strategies for road traffic control introduce a number of simplifications of different kinds or address only a part of the related control problems. Unfortunately, most proposed simplifications render the corresponding control strategies less suitable to address traffic saturation phenomena.

Control strategies employed for road traffic control may be classified (see Figure 3) according to the following characteristics (Papageorgiou et al, 2003):

- *Fixed-time* strategiesfor a given time of day (e.g., morning peak hour) are derived off-line by use of appropriate optimisation codes based on historical constant demands and turning rates for each stream; *traffic-responsive* strategies make use of real-time measurements (typically one or two inductive loops per link) to calculate in real time the suitable signal settings. The main drawback of fixed-time strategies is that their settings are based on historical rather than real-time data. This may be a crude simplification for the following reasons:
  - Demands are not constant, even within a time-of-day.
  - Demands may vary at different days, e.g., due to special events.
  - Demands change in the long term leading to “aging” of the optimised settings.
  - Turning movements are also changing in the same ways as demands; in addition, turning movements may change due to the drivers’ response to the new optimised signal settings, whereby they try to minimise their individual travel times.
  - Incidents and farther disturbances may perturb traffic conditions in a non-predictable way.

  For all these reasons, traffic-responsive strategies, if suitably designed, are potentially more efficient, but also more costly, as they require the installation, operation, and maintenance of a real-time control system (sensors, communications, central control room, local controllers).
- *Isolated* strategies are applicable to single junctions while *coordinated* strategiesconsider an urban zone or even a whole network comprising many junctions. Coordinated control strategies are preferred when the distances of the controlled junctions are relatively small. Somewhere between the aforementioned two categories, we have the *hierarchical* control strategies, whereby the control decisions are taken at different levels. For example, some decisions are taken at a network level, others at the level of a group of junctions and yet others at the level of a single junction.
- Most available strategies are only applicable to*undersaturated traffic conditions*, whereby vehicle queues are only created during the red phases and are dissolved during the green phases; very few strategies are suitable also for *oversaturated conditions* with partially increasing queues that in many cases reach the upstream junctions.
- *Strategies with PTP*, which provide special concessive treatment to the PTMs, and *strategies without PTP*, which do not discriminate the different categories of vehicles.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

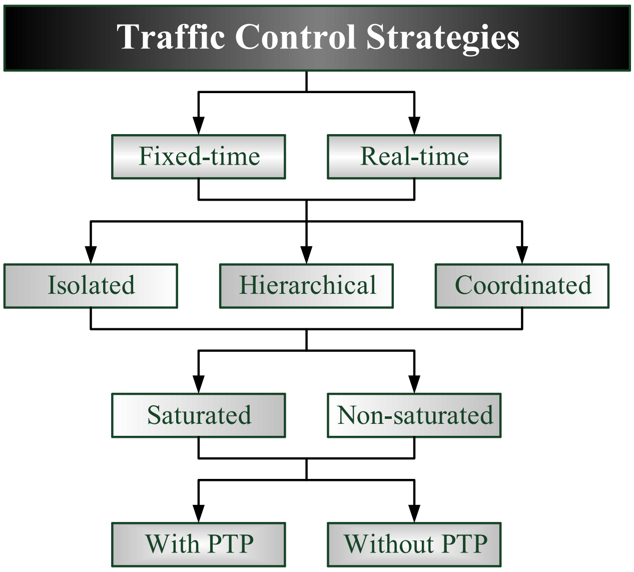

Figure 3.Classification of control strategies.

4. Public transport priority measures

Traffic congestion in road networks is continuously increasing. The resulting negative impacts include significant delays and the associated environmental problems. The usually limited availability of space as well as other economic and ecological reasons prevent the extension of the existing infrastructures, and, along with the continuously increasing mobility requirements, urge for solutions that will mitigatethe serious congestion problems viathe best possible utilisation of the already existing infrastructure. In this context, the shift of the public from the private vehicle towards the available PTMs may have a significant positive contribution. For this reason, it is important that the public is encouraged to utilise as much as possible the PTMs, and one way, among others, to achieve this is to render the service provided by such transportation means more attractive and reliable.

PTMs include buses moving on exclusive or mixed-traffic lanes, Light Rail Transit (LRT), trams and trains, and the relatedPTP measures, which may be used to improve their performance, fall into two general categories:

- *Facility-design-based measures*: These measures are used in the case of PTMs such as buses, which do not necessarily move on fixed paths, and may include exclusive lanes of several configurations (e.g. with-flow, contra-flow, etc.), as well as other infrastructure arrangements that facilitate the movements of the PTMs.
- *Signal-control-based measures*: These measures rely on the signal control and range from changes to fixed-time signal settings to real-time signal priority locally or network-wide,so as to favour the movements of PTMs. Depending on the type of the PTM they aim at, as well as on the capability of the available infrastructure and the potential existence of other facility-design-based measures, the development of such measures may become more or less complex, and their contribution more or less significant.

Following sections describe and discuss the aforementioned categories of PTP measures. The emphasis is onsignal-control-based measures aimed at buses running on mixed- trafficlanes, which constitute the vast majority of the PTMs in Greece.

5. Facility-design-based public transport priority measures

Facility-design-based measures provide priority mainly to buses through appropriate arrangements of the available infrastructure. The most common measure in this category is the *exclusive* or *dedicated bus lane*(EBL or DBL, respectively).

EBLs may be (Higginson, 1999; PRISCILLA, 2001; DfT, 2004):

- *With-flow bus lanes*. Lanes reserved for buses and other priority vehicles travelling in the same direction as non-priority traffic in the adjacent lane(s). The priority lane may be segregated physically or by road markings, and may operate on a full-time or part-time (e.g. peak only) basis. A with-flow bus lane (or sequence of lanes) is often used where congestion on a junction approach would otherwise delay buses. It is the commonest form of bus priority facility.
- *Contra-flow bus lanes*. Lanes reserved for buses and other priority vehicles travelling in the opposite direction to non-priority traffic in the adjacent lane(s). The priority lane is usually physically segregated and operated on a full-time basis. The lane (or sequence of lanes) is often used in one-way roads to reduce travel distances for buses and to provide preferential access to places of passenger attraction (shops, offices etc.).

Both with- and contra-flow EBLs require sufficient road width to enable them to be installed as well as sufficient, with respect to frequency, bus operations to justify their installation. In cases wherethese prerequisites are not satisfied, alternative concepts, such as the *High Occupancy Vehicle* (HOV) and *reversible bus lanes* may be used:

- HOV lanes isa method of utilising spare capacity in existing bus lanes. They can also be used where the introduction of new bus lanes cannot be justified on bus frequency grounds, or as part of a policy to encourage car sharing. HOV lanes are variants of the EBLs. Their basic principle is that only vehicles carrying two or more people, buses and two-wheeled vehicles are permitted to use them during the hours of operation (DfT, 2004; DfT, 2006).
- Reversible bus lanes are mainly used in cases where the space is insufficient for EBLs(Iswalt et al, 2011). Their concept is neither new nor designated specifically for buses. In general, a reversible lane is a lane designated for movement one-way during part of the day and in the opposite direction during another part-of-the day (NCHRP, 2004). The goal of a reversible lane is to provide additional capacity for periodic unbalanced directional traffic demand, while minimising the total number of lanes on a road. Although widely regarded to be one of the most cost-effective methods for increasing the capacity of an existing road, the reversal of traffic flow can require significant investments in traffic control and enforcement, as well as considerable effort to plan and design facilities for this use (NCHRP, 2004). In addition, if not

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

carefully planned, designed and managed, reversible lanes can be hazardous locations for both vehicular and pedestrian traffic (NCHRP, 2004).

Another facility-design-based measure, which may be used instead of EBLs, is the *intermittent bus lane* (IBL). The EBL priority measure grants buses an advantage inthe network roads, while the signal-control based measuresgrant buses an advantage at the junctions. The concept of IBL for bus priority has been introduced as a means to combine the advantages of the two aforementioned measures, in an effort to provide permanent advantage to buses while imposing minimumlosses for the remaining traffic (Viegas and Lu, 2001). The concept of IBL has been introduced by Viegas (1996) as an innovative approach to achieve bus priority: "*The IBL consists of a lane in which the status of each section changes according to the presence or not of a bus in its spatial domain: when a bus is approaching such a section, the status of that lane is changed to BUS lane, and after the bus moves out of the section it becomes a normal lane again, open to general traffic. Therefore when bus services are not so frequent, general traffic will not suffer much, and bus priority can still be obtained*" (Viegas et al, 2007).

IBLs are usually located on the rightmost lanes of the road, while some kind of variable light signals are placed on the pavement along the line separating the IBL lane from the next (Viegas and Lu, 2001). When a bus enters an IBL, the longitudinal lights are flashing on, in front of it, indicating that the status of IBL has changed to that of an EBL. Vehicles already travellingon the lane, ahead of the bus, can keep flowing within it, or turn left to the other lanes; while vehicles from other lanes are not permitted topass over flashing lights andenter the IBL. During the movement of the bus in the IBL, the lights behindit are turned off, thus allowing the entrance of vehicles behind the bus. When the bus leaves the IBL, the longitudinal lights are turned off, and the lane becomes a mixed-traffic lane again. Figure 4 depicts an illustrative example of the IBL configuration and operation.

Obviously, the vehicles moving in front of the bus inside the IBL can affect its movement and lead to an undesired speed reduction. IBL signals do not force existing vehicles to move away from the lane. In fact, according to Viegas and Lu (2004), for safety and stability reasons, it should not be possible for the vehicles moving on the IBL lane to leave it when IBL signals are on. Therefore, to enable a bus to run through this lane with less delay, the IBL signals should be switched on at any time necessary to allow an effective longitudinal (downstream) discharge of the vehicles that are driving on the IBL lane, and restrict,at the same time, any additional entry of general traffic from other lanes(Viegas and Lu, 2001). So, under heavy flow conditions, IBL signals may be turned on before the actual bus arrival at the entrance of the IBL, so that space is released to allow the bus to keep moving at its average speed. Similarly, in case oflow flow, IBL signals may be turned on after the bus has entered the IBL, while in very light flow conditions, IBL signals may not needto be switched on at all, thus reducing unnecessary interruptions to the rest of the traffic.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

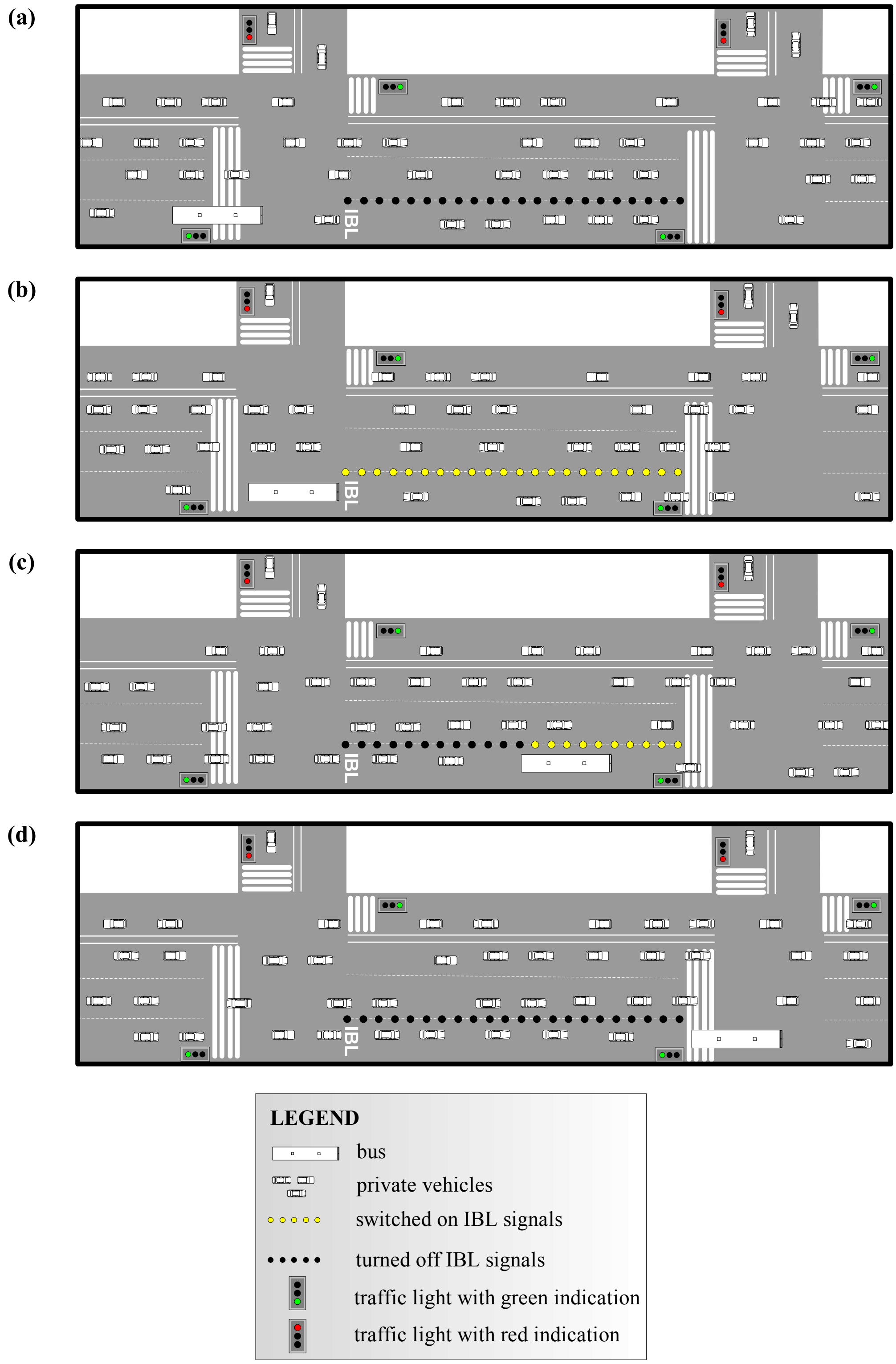

Figure 4.IBL example configuration and operation: (a) bus approaches IBL; (b) bus enters IBL; (c) bus moves on IBL; (d) bus leaves IBL.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

To enable the operation of IBLs,a UTC system needs,at least, an interface to allow the switching on and off of the IBL lights, and another one to detect buses so as to initialise and deactivate, as appropriate, the IBL operation. Variable Message Signs (VMSs) maybealsoused to inform drivers about the operational status of the lane.

The IBL concept has been applied and demonstrated in Lisbon, Portugal (Viegas et al, 2007), while a similar concept called *dynamic fairway* (DF) has been applied and demonstrated in Melbourne, Australia, to assist the tram operations (Currie and Lai, 2008). DF is based on the same principles asIBL; it operates though in the central lane of a road. Both field trials have been successful, although in Lisbon the improvements of the PT operations have been more significant (Viegas et al, 2007; Currie and Lai, 2008). The results of these trials indicate that such concepts do not work well in cases of saturated traffic conditions and/or frequent PT operations. In the first case, the engagement of the lane for PT operations may lead to a severe deterioration of the already heavytraffic conditions; while, in the latter case, the frequent PT operations will inevitably transform the lane into an EBL with what this entails forthe road capacity.

In addition to the aforementioned field trial results, recent simulation investigations based on a two-lanes urban traffic model and comparisons of EBLs, IBLs and mixed-traffic lanes indicate that (Zhu, 2010):

- The PT operations are affected by generic traffic operations when moving on mixed-traffic lanes, especially in congested traffic conditions.
- The EBLs release the PT operations from traffic interference, but strongly disrupt generic traffic, especially in case of congested conditions.
- The IBLs are, under certain conditions (see above), more efficient in improving the bus flow than mixed-traffic lanes, and in maintaining, at the same time, the car flow at a higher level than the EBLs.
- The disruption of generic traffic due to the operation of EBLscan be partly overcome by their opening to the general traffic intermittently, when the bus lanesare not in use by buses.

According to the aforementioned IBL and DF concepts, vehicles moving in front of the bus are not forced to leave the lane upon the bus arrival. Instead, IBLs and DFs rely on signal adjustments to clear the way for the buses. To avoid signal adjustments, Eichler et al (2005, 2006) proposed the concept of *bus lanes with intermittent priority* (BLIP). BLIP is another IBL variant, which forces traffic out of the lane reserved for the bus usingVMSs, so as to avoid changes to the signal settings. However, also BLIP can be combined with signal-control based measures, if desired. Although the conceptual design of BLIP does not require any signal adjustments, which facilitates usability, the enforcement of traffic out the lane when the lane signals turn on, in contrast to the safety and stability principles of IBLs, may disrupt the traffic conditions of the adjacent lanesand become hazardous for vehicular traffic.

Beyond the aforementioned lane-based measures, other priority measures based on the facility design include (Higginson, 1999; PRISCILLA, 2001; DfT, 2004; VHB et al, 2011):

- *Bus-only roads*: Roads where access is prohibited to all but priority vehicles, which may include (for example), emergency vehicles and cyclists in addition to PT vehicles.
- *Busways*: Fully segregated facilities for buses travelling in one or both directions, often positionedin the centre of a road. Buses may operate as normal, or they may be guided by physical or electronic means (e.g. where width is restricted). Examples in Europe are limited (e.g. Essen in Germany, Leeds in UK), but are much more widespread in some overseas countries, particularly in South America.
- *Bus gates* and *rising bollards*: These facilities may be considered when access to a particular street is to be restricted to buses (and any other designated vehicles, e.g. taxis or bicycles). Bus gates can be traffic signals, actuated by the buses, or simply signs restricting access to buses. Rising bollards provide a physical barrier that lowers out of the way when actuated by the bus. They can be particularly useful in enabling direct access by bus to areas where it is desirable to prevent other vehicles from entering, such as shopping streets in town and city centres.
- *Queue jumper lanes orqueue bypass lanes or bus bypasses orbus advance areas*: These facilities, as Figure 5 displays, include short exclusive bus lanes near congested junctions, which allow buses to pass through a signal, in advance of competing traffic. They are provided by widening the roadway as it approaches a junction, and may also include *pre-signals*, i.e. bus-only green lights in advance of the general traffic green light. The objective of these options is to allow buses to pass to the front of the line at junctions while other vehicles arewaiting for the signal to change. Their effect is more significant during congested traffic conditions, where long queues prevent buses to efficiently clear the junctions (Zhou et al, 2006; Zlatkovic et al, 2013). As with EBLs, the employment of these options is subject to the availability of space.

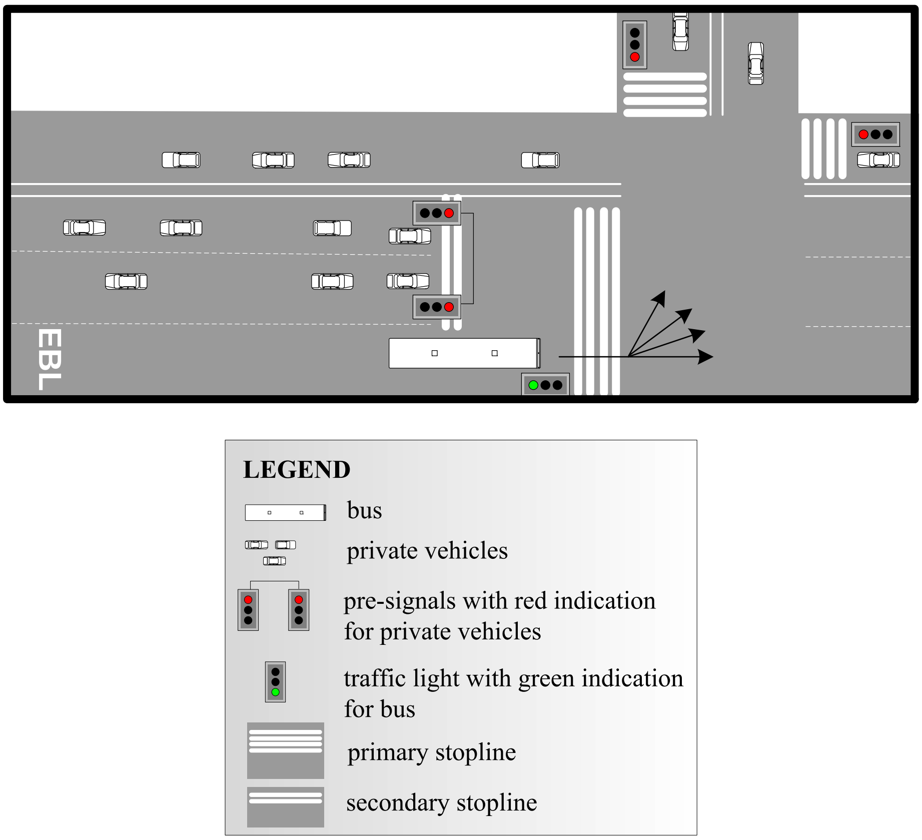

Figure 5.Example configuration and operation of queue jumper lanes.

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ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

6. Signal-control based public transport priority measures

6.1. Introduction

As mentioned in Section 4, one way, among others, to motivatethe public to an increased usage of PTMs, is to render their service more efficient and reliable. From a control point of view, the efficiency and reliability increase may be achieved through the treatment of PT vehicles in a special way or, in other words, through provision of priority against other vehicles at the signal-controlled junctions.

The priority treatment of PT vehicles provides an opportunity to reduce their travel times and hence their passenger waiting times and delays. However, such a preferential treatment is usually at the cost of the service for the other vehicles, and thus, it is often facing considerable opposition from the non-users. It is therefore significant to carefully design and assess the kind and level of priority provision, as well as the background signal control strategy that is applied. Other relevant issues,whichare also covered in the rest of this section, include the methods and conditionsthat may be used for granting priority to PT vehicles, as well as the transition and recovery methods, which may be employed after the service of priority requests, in order to allow signal control to return tonormal operation in a smooth way.

6.2. Levels of priority

The level of provided priority varies among the different types of served PTMs.Highway-rail crossings are typically assigned the highest priority that provides the most aggressive manipulation of the signal controller (Nelson and Bullock, 2000).

Emergency vehicles, such as fire trucks, are typically assigned a slightly lower priority to allow a signal from a highway-rail grade crossing to override the emergency vehicle request.Buses, trams and LRTs are generally assigned an even lower priority. Such requests typically do not cause major disruptions of the stage order, but modify the normal green splits to serve the received priority requests.

6.3. Classification of strategies

Several strategies for signal priority have been developed, which may be classified according to different criteria that, in fact, address the different requirements the strategies aim to respond to (see Figure 6).

A first classification of priority strategies distinguishes them as fixed-timeversusreal-time:

- The *fixed-time* or *passive* or *off-line* strategies may include adjustment of cycle length, stage splitting, area-wide timing plans, and metering priority. They are, in fact, fixed-time plans developed so as to accommodate the operations of PT vehicles by considering factors such as travel times, and/or reducing the cycle length to reduce

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

delay, and/or providing stage sequences designed to more frequently serve a phasethat has a high demand of PT vehicles. The problem with these strategies is their lack of real-time abilities.

- The *real-time*or *active*or *traffic-responsive*strategies attempt to overcome the disadvantages of fixed settings via real-time operation. To this end, they require the ability to detect or identify in real-time PT vehicles approaching signalised junctions via, at least, Selective Vehicle Detectors (SVDs), such e.g. bus loops and transponders on buses. The sophistication and resulting performance though of these strategies may be improved in case of availability of more advanced systems such as Automatic Vehicle Location (AVL) and Global Positioning Systems (GPS), which provide in real-time more detailed PT-vehicle related data.

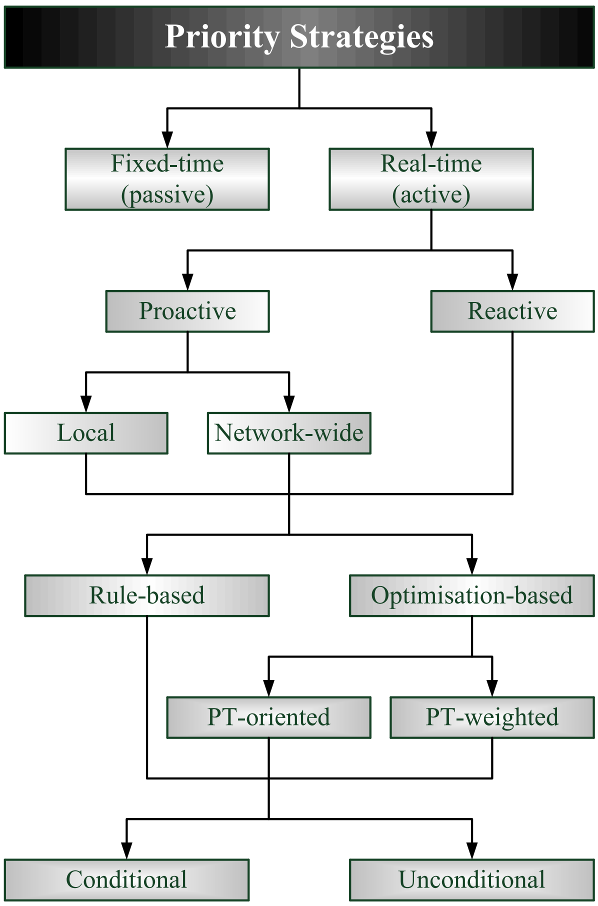

Figure 6.Classification of priority strategies.

The real-time strategies may be further classified according to several criteria. The first criterion addresses their reactive versuspredictive nature, and distinguishes them as *reactive*versus*proactive*:

- The reactive strategies represent essentially the current state-of-practice. They are applied at each junction separately of the others, and provide isolated treatment to the received priority requests, independently of whether the priority request has been received atan isolated or co-ordinated controlled junction. The reactive strategies receive a request for service as the vehicle approaches the junction.

- The proactive strategies represent a rather limited recent research direction towards the development of strategies that attempt to proactively respond to priority requests. They receive a request of service well in advance, perhaps when the PT vehicle is one or more signals upstream. This advance requestallows the strategy to plan for the arriving vehicle(s), to accommodate multiple requests for service, and to co-ordinate the vehicles' transfer point of operation. The priority control decision could intelligently begin to transition the signal timing to effectively serve the priority request(s) with minimal disruption to the rest of the traffic. It should be noted that, for a proactive strategy to be effective, it must account for the stochastic dwell times of the PT vehicles. Proactive strategies may be further distinguished as:
  - *local*, when implemented at isolated junctions;versus
  - *network-wide*, when they attempt to improve the progression of PT vehicles within a network, through the adjustment of the coordination timing parameters.

The second criterion refers to the employed methodology, according to which the real-time strategies may be classified as *rule-based*versus*optimisation-based*:

- The rule-based priority strategies make their priority decisions, which may include stage extension, stage recall, special stage introduction, etc., based on a set of identified rules. As they operate in real-time, they require the ability to detect or identify in real-time PT vehicles approaching signalised junctions, so as to serve them the sooner possible. Depending on the capability of the corresponding sensors, the rule-based priority strategies may be distinguished in *unconditional*versus*conditional* or *differential*:
  - Unconditional strategies provide priority regardless of the status of the PT vehicle, i.e. regardless of whether the vehicle really needs to be treated in a special way at its approach to a signal-controlled junction (e.g. the vehicle may be well in advance of its schedule, thus it does not need any priority treatment).
  - In conditional or differential strategies, the decisions are usually made based on the schedule or headway adherence of the arriving vehicle. This assumes that the signal control system knows the operating status of the arriving vehicle, which in turn impliesthat the application of conditional strategies requires additional real-time information regarding the operating status of a detected PT vehicle.
- The optimisation-based strategies attempt to provide PTP based on the optimisation of some performance criterion; primarily delay (passenger delay, vehicle delay, weighted vehicle delay or combination). They use actual observed (both private and public) vehicle arrivals as inputs to a traffic model that either evaluates several

alternative timing plans to select a most favourable option, or optimises the actual timing in terms of stage durations and stage sequences. Depending on whether the performed optimisation is limited or not on the PT-operations, the optimisation-based priority strategies may be further distinguished in *PT-weighted*versus*PT-oriented*:

– PT-weighted strategies are incorporated (as integral parts)in signal control strategies, whereby PT vehicles receive higher weights than ordinary vehicles while optimising an appropriate performance index in real time.
– PT-oriented strategies represent a rather recent research direction. These strategies are based on the optimisation of an appropriately defined PT-oriented performance index in real time, so as to respond to the received priority requests and provide priority to the detected PT vehicles the soonest possible. In contrast, however, to the rule-based strategies, they may more easily consider multiple priority requests. In a similar way to the rule-based strategies, these strategies may be distinguished in *unconditional* and *conditional* or *differential*.

Section 7 reviews some representative priority strategies, while following sub-sections present and discuss conditions and methods for granting priority, as well as transition and recovery methods.

6.4. Conditionsfor granting priority

As mentioned earlier, the real-time rule-based priority strategies as well as the real-time PT-oriented optimisation-based strategies may be either conditional or unconditional. Usually, the conditional decisions are made based on the schedule or headway adherence of the arriving PT vehicle. This means that only late vehicles are considered for priority at the signal-controlled junctions.Recently, a new headway-related concept has been introduced, whereby priority should be granted based on the comparison of the headway of the PT vehicle from the scheduled headway of the following PT vehicle (Hounsell and Shrestha, 2012). Theoretical analysis and simulation results indicate better resulting operational efficiency in terms of passenger waiting times when priority is granted based on this condition rather than on mere headway adherence.

Other conditions that may also be used for granting priority include:

- *Route progression*. According to this condition, the decision to grant priority at a junction considers the arrival time of the vehicle at the downstream junction(s). In case the vehicle will arrive at the downstream junction during red, because, e.g. the downstream junction is a non-priority one, priority may not be provided, since after all, the vehicle will be delayed anyhow.
- *Downstream congestion*. This conditionconsiders traffic conditions downstream of the location of the PT vehicle and ensures that no priority will be granted to a vehicle that cannot benefit from it, e.g. due to a downstream blocking of traffic caused by congestion.

An additional condition, which has beenreceivingrecently increasing attention due to the continuously increasing congestion levels in urban areas, relates to the prevailing traffic conditions. According to this condition, priority is provided only if it is not expected to lead to a significant deterioration of the overall traffic conditions. To apply this condition, several indices have been proposed including:

- the degree of saturation at the priority junction;
- the average traffic load of the junction approaches;
- the presence of queues; and
- the availability of spare green time, given the degree of saturation at the priority junction's approaches.

User-defined constraints on the above indices prohibit the provision of priority to avoid severe adverse impacts to the rest of the traffic.Other approaches that may also be used for the same purposesinclude (Skabardonis, 2000):

- *Inhibition*: Limitation of the frequency of priority provision to PT vehicles. This approach may not be required if conditional priority is provided that limits anyway the frequency of priority provision.
- *Compensation*: Provision of more green time to non-priority movements after the service of a priority request. This approach may not work well if the priority stage serves also significant traffic movements. In this case, the additional time allocated to the non-priority stages may lead to the creation of excessive queues in the streets that are served during the priority stage.

These latter approaches may not be always beneficial, and, if priority is provided when only some pre-specified conditions are satisfied, i.e. only provided to vehicles that really need it or can benefit from it, they should better be avoided(Skabardonis, 2000).

Finally, other conditions, which may be used to assist the decision ofproviding or not priority that are not directly related to the prevailing traffic conditions but rather try to address socioeconomic goals,include:

- Passenger delay;
- Passenger waiting time (at bus stop); and
- Total person delay (in both private and PT vehicles);

According to these conditions, priority should be provided, if it is expected to lead to theirreduction.Consideration of such goals requires availability of advanced detection and communication infrastructure.

6.5. Priority methods

A review of the related literature indicates that there are several specific ways to provide priority to PT vehicles, i.e. several ways of modifying the background traffic signals so as to accelerate the passage of public transport vehicles. These modification methods may either be considered explicitly (e.g. in rule-based PT priority strategies) or they may result as a solution of related optimisation problems. The main methods adopted include (see also Figures 7-12):

- *Green extension*: This method refers to the extension of green time to serve a PT vehicle approaching towards the end of the green time (see Figures 7 and 8). It is commonly used where the detection is relatively close to the priority junction and is subject to constraints like maximum extension time, minimum green-time for non-priority stages, etc.
- *Stage recall or early green or red truncation*: This method refers to the recall of a stage, if its signal is on red at the estimated arrival time of a PT vehicle (see Figures 7 and 9). It may involve the (green) truncation of more than one stages, subject to minimum green-time constraints, which sometimes is called *double early green* (Wahlstedt, 2011). As green extension,stage recall is also commonly used where the detection is relatively close to the priority junction.
- *Stage skipping*: The previously mentioned methods do not affect the normal stage sequence. An alternative and stronger form of priority is to omit one or more stages from the normal stage sequence so as to allow for the service of a priority request as soon as possible (see Figures 7 and 10).

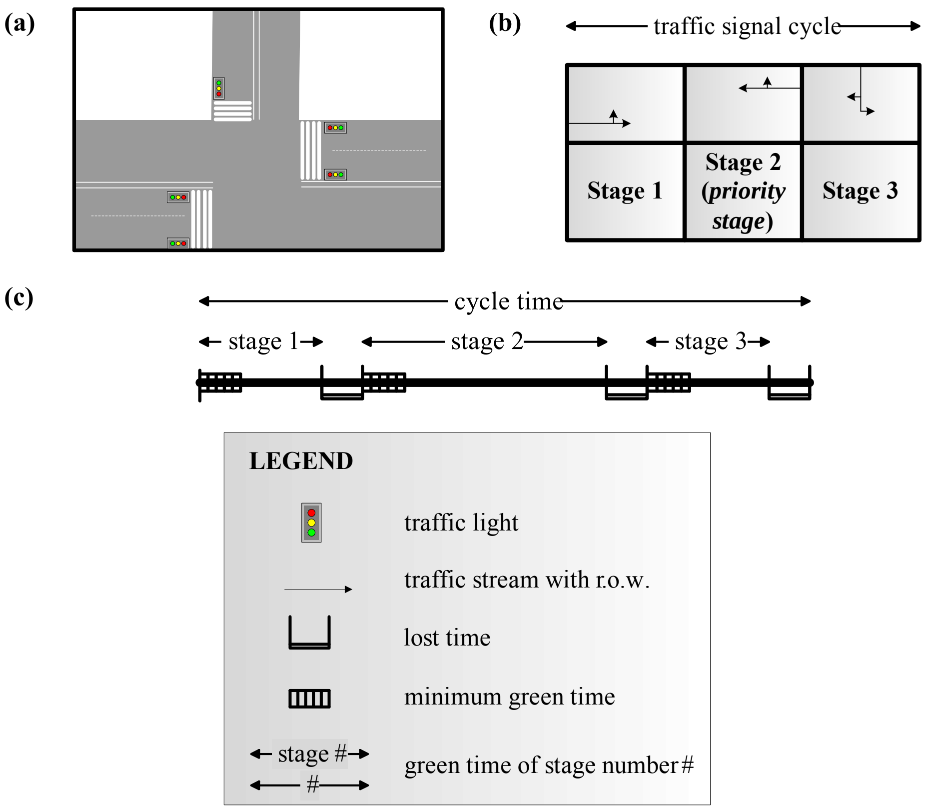

Figure 7.Example of traffic signal cycle: (a) junction and traffic movements; (b) diagram of normal stage sequence; (c) normal cycle time allocation to stages.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
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επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

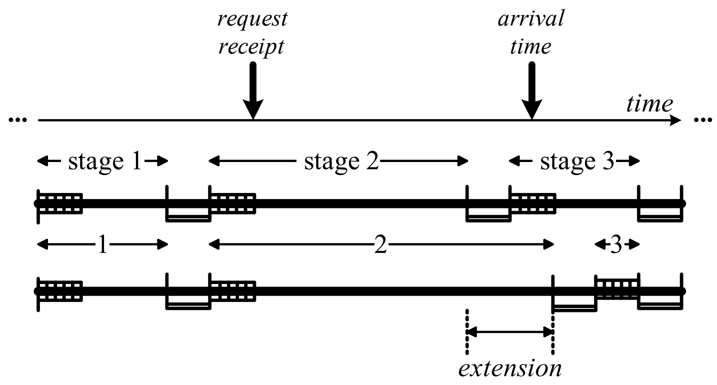

Figure 8.Example application of green extension at junction of Figure 7.

- *Stage re-ordering or stage rotation*: An also stronger form of priority is to modify the normal sequence, i.e. to activate a stage,which is later in the order, before others to serve a received priority request (see Figures 7 and 11).
- *Special stage*: According to this method, a special stage is allocated to the movements of PT vehicles and is introduced into the normal sequence at the first available opportunity in order to serve a received priority request(see Figures 7 and 12). This might mean that other stages may have to be truncated to their minimum green times (as in stage recall) or even totally skipped (as in stage skipping). The introduction of special stage simultaneously with the truncation of other stages is sometimes called *double special stage*(Wahlstedt, 2011).

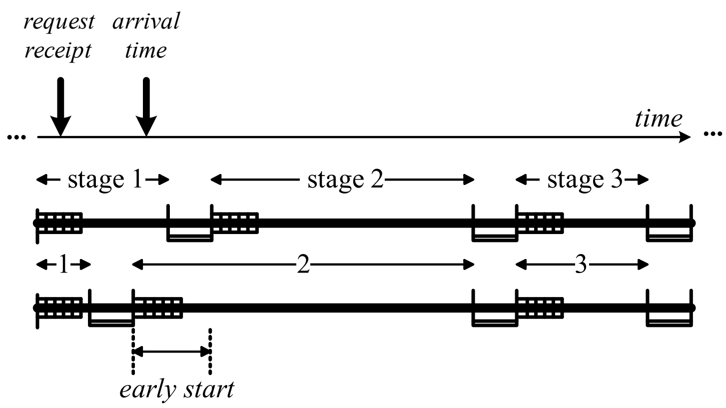

Figure 9.Example application of stage recall at junction of Figure 7.

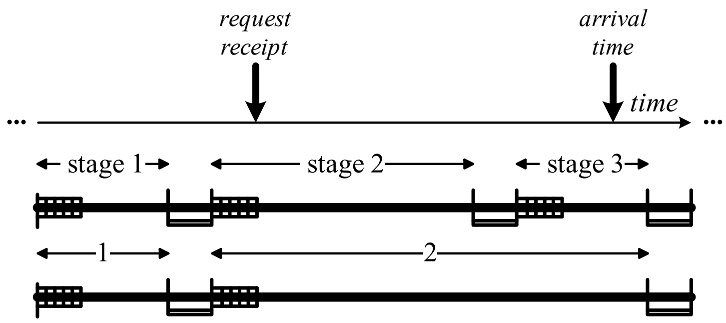

Figure 10.Example application of stage skipping at junction of Figure 7.

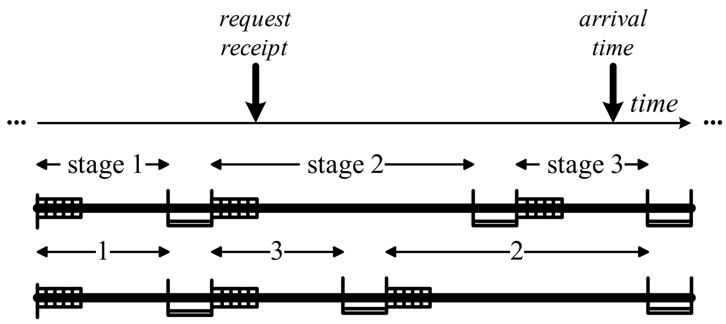

Figure 11.Example application of stage re-ordering at junction of Figure 7.

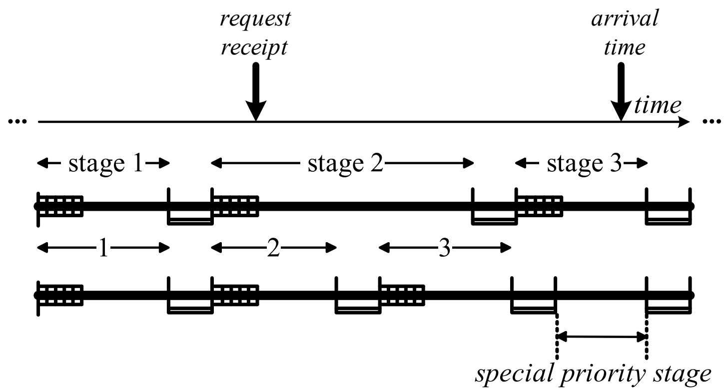

Figure 12.Example application of special stage at junction of Figure 7.

Other methods include the following:

- *Offset modification*. This method adjusts the start time of fixed plans considering the difference between the detection time of a PT vehicle and the ideal time in the cycle for the vehicle to arrive at the detection point (Gardner et al, 2009). The fixed-time plans are delayed or anticipated depending on whether the vehicle is late or early.
- *Cycle extend*: This method extends the cycle time to 1.5 times the normal cycle length to ensure that the PT vehicle arrives at a green stage and to retain signal coordination (Ekeila et al, 2009). The solution is executed over two cycles, replacing three cycles

ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

of normal cycle length; eventually, the cycle is reduced to its normal length. The cycle extension strategy has been presented theoretically in many papers, its application in real-life projects, though, is rare due to its impact on cross street traffic.

- *Retaken start*: This method returns the stage to green, if conflicting groups have not yet become green (i.e.duringintergreenperiods)(Wahlstedt, 2011).
- *Special plan or green wave*: This refers to a priority system where a special (fixed-time) plan is initiated in the UTC system to provide a sequence of green signals along a series of junctions for the selected PT vehicles. This is usually implemented for emergency vehicles, and can hardly be justified for PT vehicles.
- *Queue Dissipation*: This method provides green time to the PT vehicle's approach either by green extension or by stage recall, until the time the vehicle is expected to arrive at a nearside stop. Then, it truncates the priority stage in order to provide a green stage to the cross streets,as long as the PT vehicle is serving passengers at the stop. The method may be used when the detected PT vehicle is not expected to be able to complete passenger service by the end of the regular or extended priority stage, but its performance depends heavily on prediction accuracy(Lee et al 2005).
- *Priority stage truncation:* This method truncates the green time of the PT vehicle's approach to allow the faster return to it in the subsequent cycle. It is used when the PT vehicle is not expected to clear the junction even if green extension or stage recall is provided. This method also depends heavily on prediction accuracy of travel estimation, since an early truncation of the priority stage may increase the queue length on the PT vehicle's approach and PT vehicle's delay as a result (Lee et al 2005).

The aforementioned methods may be used as isolated or in combinations to provide priority to PT vehicles as described in the strategies reviewed in the following section.

6.6. Transition and recovery methods

In a reactive rule-based strategy, the disruption of normal signal timing can be significant in cases of high level priority for PT. The ability of the background signal control strategy to respond to this disruption will affect the overall system performance.

Traditionalreactive priority strategies usually distortsignal coordination when the priority request is served. In some systems, after the priority request has been served, the *recovery* process begins and defines how much time must be added and/or subtracted from stages to allow the actual signal timing to realign itself with the system coordination point (TCRP, 1998). This addition/subtraction of time can be distributed over several signal control cycles.

Another approach, called *transition*, allows the signal timing to intelligently adapt the service of a priority request with the traffic signal coordination strategy with minimal disruption to the flow of private vehicles (TCRP, 1998).

A transition differs from a recovery in that transition is generally proactive and may involve adjusting timing on multiple signals to accommodate for system-wide coordination (e.g.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
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ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

adjust the coordination points at several junctions along an arterial to maintain a progression band as much as possible).Both transition and recovery differ from compensation, mentioned earlier in Section 6.4 in that they serve different purposes. Compensation aims at counterbalancing the negative impacts, to the non-priority stages,of priority provision, while transition and recovery aim at restoring signal coordination.

7. Review of traffic control strategies with public transport priority

7.1. Fixed-time strategies

The first and mostacknowledgeable fixed-time priority strategy mentioned in the relevant literature is the one offered by TRANSYT (Traffic Network and Isolated Intersection Study Tool). TRANSYT (Robertson, 1969), is the most popular co-ordinated fixed-time signal control tool. TRANSYT[1]is used to produce network-wide fixed-time plans, which take into account bus or tram lines and their respective frequencies. Clearly, since TRANSYT optimises fixed-time settings, there is no need to detect individual special vehicles during field application of the obtained signalling results.

More recently, a few additional approaches have been proposed, which, however, may combine fixed-time settings with real-time vehicle-actuation and PT priority actions at individualjunctions. To start with, Ma and Yang (2007) proposed a strategy that calculates off-linesignal offsets and stage lengths so as to minimise delays at junctions. Their calculations are based on a mathematical formulation of the relationship of bus frequency, signal cycle, signal status, bus headway deviation and bus delay. In their approach, they also assume that the signal control system, implementing the signal plans derived as discussed above, may provide additional active priority treatment to PT vehicles via green extension. Based on the concepts developed in this approach, Ma and Yang (2007, 2008 and 2010) extended later on their initial approach to a real-time optimisation-based priority strategy (see Section 7.2.2.2).

Stevanovic et al (2008) proposed VISGAOST (VISSIM-based Genetic Algorithm Optimization of Signal Timings), an optimisation program coupling a Genetic Algorithm (GA) with the VISSIM[2] (VerkehrInStädten - SIMulation) micro-simulation software. Depending on the intended signal control strategy (fixed-time or real-time), VISGAOST optimises off-line appropriate signal timing parameters. The GA is used to search the space of the potential solutions, which are evaluated through VISSIM simulation runs. As far as the control of general traffic is concerned, if fixed-control, either isolated or coordinated, is to be applied, VISGAOPT optimises the cycle time, split and stage sequence, as well as offsets when necessary for coordination purposes; while in case that vehicle-actuated control is to be applied atisolated junctions, VISGAOPT optimises maximum green times and stage sequence. In any of the above cases, VISGAOST allows, either simultaneously with or after the optimisation of the aforementioned signal settings, also the optimisation of signal priority parametersfor the real-time application of either green extension or stage recall upon receipt of priority requests.

[1]https://www.trlsoftware.co.uk/products/junction_signal_design/transyt [accessed 11.12.2012]
[2]http://www.ptv-vision.com/en-uk/products/vision-traffic-suite/ptv-vissim/overview/ [accessed 31/1/2013]

Finally, Estrada et al (2009) proposed a simulation-based optimisation strategy aiming at minimising the travel time of bus users by modifying traffic signal coordination in a network. Starting from a given passive signal priority system and considering as a constraint a maximum admissible delay of private vehicle users, the proposed simulation model estimates the travel times of all vehicles, taking into account some unpredicted (stochastic) events such as illegal loading or unloading vehicle operations, vehicle parking manoeuvres etc., in order to reproduce their variability. The estimated travel times are then used by an iterative Genetic Algorithm (GA), which identifies appropriate offsets aiming at minimising the total travel time of all network users.

7.2. Real-time strategies

7.2.1. Rule-based strategies

Most known priority strategies fall in the category of reactive, rule-based strategies. Such priority logic is even embedded into the logic of new-generation controllers. The controllers receive a priority request from some type of special PT detection device. The implemented priority logic can have varying levels of effect, depending on the parameters defined in the controller and the point in time within a cyclewhen the request is received. The average effectiveness and impact of this approach depend highly on the selection of these parameters.

Some noticeable early efforts towards the development of reactive rule-based PTP strategies include SCOOT (Split Cycle Offset Optimisation Technique), SCATS (Sydney Coordinated Adaptive Traffic System), PRIBUSS (PRIoritizing of BUSses in Coordinated Signal systems), BCC-RAPID (Brisbane City Council - Realtime Advanced Priority and Information Delivery), SPRINT (Selective PRIority Network Technique), BALANCE (BALancing Adaptive Network Control mEthod), MOVA (Microprocessor Optimised Vehicle Actuation) and TRAFCOD (TRAFficCOntrol Design).

SCOOT[3]has been developed by Hunt et al (1982), and was extended later in several respects including priority request treatment. SCOOT utilises traffic measurements, obtained by SVDs or AVL devices, upstream of the network junctions to feed a network model, which runs repeatedly in real time to investigate the effect of incremental changes of splits, offsets, and cycle time. The changes, which turn out to be beneficial in terms of a selected performance index, are submitted to the signal controllers for application.

SCOOT has a number of facilities that can be used to provide priority to PT vehicles(Nash et al, 2001; Oliveira-Neto et al, 2009). A sort of ‘passive’ priority, which does not differentiate between vehicles, can be given to links or routes using appropriate split and offset weights within the considered performance index. As all vehicles on aweighted link receive a similar benefit, the level of priority that can be given in this way is limited. ‘Active’ priority can be given to individual buses via green extensions, to prevent a bus from being stopped at the start

[3]https://www.trlsoftware.co.uk/products/traffic_control/scoot[accessed 11.12.2012]
http://www.scoot-utc.com/ [accessed 11.12.2012]

of red; and stage recalls,to start the bus green earlier than normal. In addition, SCOOT MC3 version allows stage skipping. Differential priority allows for different levels of priority to be given to certain buses, e.g. limited priority to late buses and high priority to very late buses, but no priority to those ahead of schedule. All these techniques are controlled by user-set parameters to prevent the priority from causing undesired extra delay to other vehicles.

SCATS[4] (Lowrie, 1982) ordinary signal control uses information from vehicle detectors, which are located immediately in advance of the stopline, to adjust signal timing in response to variations in traffic demand and system capacity. Control in SCATS is effectuated in two levels, the strategic and the tactical. Strategic control determines suitable network-wide signal timings based on the average prevailing conditions. Tactical control operates at the individual junction level providing the signal timings to be implemented locally, taking into account the constraints imposed by the strategic level. SCATS PT priority logic (TCRP, 1998; PRISCILLA, 2001) includes green extension, stage recall, introduction of special stages, stage skipping, and stage reordering to serve late-running buses and trams according to one of three available priority levels (Gardner et al, 2009):

- high priority, where the necessary stage is called immediately, even skipping other stages, if necessary;
- medium priority, where stage skipping is not allowed; and
- low priority, where no special treatment is performed.

The high priority scheme is used for trams, while buses are treated at the medium priority level.

Recently, SCATS has been connected with the PTIPS[5] (Public Transport Information and Priority System), which usesGPS and radio communication data about buses and their locations to predict their arrival at traffic lights, thus allowing SCATS to provide some sort of proactive priority, particularly for late-running buses.

PRIBUSS was developed in Stockholm in the early 1990s (Wahlstedt, 2011), has been included as standard in most signal controllers on the Swedish market, and is the common method for PT priority in Sweden. PRIBUSS can be considered as a toolbox of PT priority procedures for the traffic engineer to choose from, when designing the traffic signalling. It is developed for conditional PT priority on top of the normal primary fixed-time control. The engineer decides on the procedures, conditions and limitations to be applied by parameter programming.The tool may be used for both isolated and coordinated signal control. The priority and compensation actions are effectuatedlocally, based on the corresponding code which is implemented in each signal controller.Priority is provided in a First-In-First-Out (FIFO) basis via green extension, retaken start, stage recall, special stage, double early green or double special stage.

[4] http://www.scats.com.au/ [accessed 11.12.2012]
[5] http://www.scats.com.au/product_family_future.html [accessed 30.01.2013]
http://www.rta.nsw.gov.au/usingroads/scats/scats_publictransport.html [accessed 30.01.2013]

The BCC-RAPID bus priority and passenger information system was initially conceived as part of the BLISS (Brisbane Linked Intersection Signal System) Urban Traffic Control (UTC) system, which has been developed by the Brisbane City Council and shares a similar philosophy with SCATS (Fox et al, 1998). Upon detection of a bus, BCC-RAPID checks whether it qualifies for priority, and if it does, priority is provided either through green extension or stage recall. A bus is qualified for priority, if it is behind schedule.

SPRINT (Fox et al, 1998) grantspriority to buses at junctions controlled by fixed-time signal control strategies. Upon bus detection, an algorithm is used to determine signal timings that will let the bus clear the junction at the earliest possible time with either a green extension or a stage recall. The algorithm uses a traffic model for the bus and the rest of thetraffic in an attempt to optimise the signal timings subject to a number of user-defined constraints including:

- the maximum number of cycles that are allowed to be modified by SPRINT;
- the difference of a SPRINT-calculated stage, compared to the base plan;
- the maximum saturation levels for providing priority;
- the recovery periods, etc.

BALANCE[6] (Tommey et al, 1998; Fox et al, 1998) is a two-level signal control strategy. At the upper, tactical level, centralised control is performed for all junctions, while at the lower, operational level, decentralised local adjustments take place for each junction. PTP in BALANCE is provided at the lower level via green extension, stage recall or introduction of special stages. The level of the provided priority ranges from no priority to absolute priority, and is defined based upon the general traffic situation and the delay of the competing PT lines.

MOVA[7] (Fox et al, 1998; Gardner et al, 2009) is a traffic signal control method for isolated junctions that analyses lane-by-lane detector data and controls the signal timings so as to optimise delays and stops or, in case of oversaturation, capacity. Bus priority is implemented within MOVA using SVDs to distinguish buses from other vehicles. Priority is provided via green extension, stage recall or stage skipping, subject to user-specified constraints.

In TRAFCOD (Furth and Muller, 1999), control is formulated in terms of traffic streams without any reference to stages. Control is expected to follow a given cyclic sequence structure specified by the traffic engineer; streams with no demand, however, may be skipped. Normally, each stream appears once per cycle (cycle is not fixed). An exception is free realisation in which a tram, bus, or other priority stream with infrequent requests and a small need for green time can be introduced anywhere in the cycle (though not until conflicting streams have become red). Free realisation streams do not appear in the sequence structure.

[6] http://www.gevas.eu/1/products/individual-traffic/traffic-control/ [accessed 31.01.2013]
[7] http://www.trl.co.uk/software/software_products/traffic_and_network/mova.htm [accessed 31.01.2013]

Activation of both normal streams and free realisation streams is based on a purely traffic-actuated logic.

In contrast to the previously described reactive strategies, Balke et al (2000) describe a proactive rule-based priority strategy. The approachconsists of four modules, the prediction, the priority assessment, the strategy selection and the strategy implementation module. Using the detected bus co-ordinates, the locations of a possible bus stop and of the stop line, the normal operational characteristics of the bus and the dwell times, the prediction module specifies the arrival times of the buses at the bus stops and the stop lines. Given the arrival times, the priority assessment module assesses the need for priority based on schedule adherence;only late buses are granted priority. Then, the strategy selection module selects the most appropriate priority method to apply. Available methods include green extension, stage recall and introduction of a special priority stage. The selected priority method is forwarded for implementation via the strategy implementation module. The application of this approach requires availability of an AVL/GBS system.

A proactive PTP strategy has also been proposed by Wadjas and Furth (2003). According to this approach, PTP vehicles are detected two to three cycles in advance of their arrival at the junction stopline, and stage lengths are either extended or compressed so that the priority serving stage is green for a 40 s arrival time window. To estimate the necessary arrival time window, prediction is performed based on traffic control and traffic events as well as dwell times at intervening stops. The approach may be applied unconditionally to all PT vehicles or only to those that are behind of schedule, while in case of conflicting requests, only the most delayed vehicle is served. To apply the approach, occupancy and PT vehicle detectors are necessary.It should be noted that the approach can be combined with actuated control using traffic density and queue length estimation, PT vehicle stopline actuation, and peer-to-peer communication for coordination in the peak travel direction.

Finally, several other rule-based PTP strategies of a reactive nature have been proposed in the relevant literature with their major differences falling mainly in the following areas:

- Bus arrival time estimation
- Reaction in case of multiple priority requests.
- Criteria for granting priority.

These strategies are outlinedbelow.

To start with, Diakaki et al (2003) proposed a PTP extension of theTUC (Traffic-responsive Urban Control) strategy. TUC is a signal control strategy of a modular structure, which aims at controlling, in a coordinated way, urban road networks. TUC is particularly useful under saturated traffic conditions and consists of three main modules:

- Split Control aiming at minimising the risk of oversaturation and queue spillback.
- Cycle Control aiming at adapting the cycle time to the currently observed maximum saturation level in the network.

- Offset Control aiming at creating "green waves", taking into account the possible existence of vehicle queues.

For the priority treatment of PT vehicles, TUC may be implemented with an additional module, which modifies locally (i.e. at each junction) TUC's network-wide decisions to serve priority requests based on a FIFO basis. According to the PTP logic of TUC, if a PT vehicle is detected within a link, the state of the traffic signal is directly modified to allow the vehicle to cross the junction the earliest possible. In TUC, priority for buses is provided viagreen extension or stage recall; while making this decision,the average traffic load of the competing stages may be taken into account.The modification of the signal plans is based upon the time required for the PT vehicle to travel from the detection location to the stopline. In case of exclusive bus lanes, this travel time is readily calculated based on the PT vehicle's nominal speed, while in case of mixed traffic, the estimation is based on the discharge rate of the vehicles that are estimated to be present between the detection location and the stopline. Bus detectors and traditional loop detectors (for the rest of traffic) suffice to apply the priority logic of TUC.

In case of networks with many, partially crossing PT transport lines and frequent movements of PT vehicles, PTP may be implemented by TUC through the appropriate weighting of the measurements utilised in its split control module to reflect the presence of PT vehicles. This implementation is easy, since it actually forces the split decision algorithm of TUC to favour the movements of PT vehicles. It does not provide priority in the classical sense of the direct (or at least the sooner possible) switching of the traffic lights to allow a detected PT vehicle to pass; it has, however, the advantage, as compared to the previously described PTP approach of TUC, that it avoids the creation of major disturbances to the signal plans.

Kim (2004) developed a PTP strategy for single priority requests. In this approach, priority is granted by green extension, stage recall or special stage for buses that exceed a given passenger load. To select the appropriatePTP method, the travel time of the PT vehicle from the detection point to the junction stopline is calculated based on a probabilistic estimation of the dwell time intervals. To apply this approach, PT vehicle detectors are necessary, as well as an Automatic Passenger Count (APC) system. PT vehicles are also assumed to be equipped with a GPS so that their position in the network may be traced at all times.

Kim et al (2005) proposed a PTP strategy, which provides priority via green extension or stage recall for late buses, based on their estimated arrival time. In case of multiple priority calls for conflicting signal stages, the priority necessity of each call is determined based on its corresponding headway delay. The call with the higher necessity is served, while all other conflicting calls are withdrawn. The implementation of the approach assumes availability of SVDs.

Lee et al (2005) proposed a PTP strategy, which consists of two fundamental components:

- A micro-simulation-based PT vehicle travel prediction model and
- A priority operation model.

The prediction model predicts bus travel times within a detection zone, and can co-operate with any dwell time estimation model for junctions with nearside bus stops so as to provide arrival time estimates, considering not only travel time but dwelling time too. Based on the results of the prediction model, the priority model then selects the best priority actionsfor the approaching PT vehicle among pre-specified plans designed to provide green extension, stage recall, priority stage truncation or queue dissipation. To minimise interruptions of the normal signal operation, priority is not provided when the expected effects are not significant. For the implementation of the approach, availability of a SVD deviceis required.

Li et al (2005) developed a PTP strategy, which uses information on the predicted bus arrival, estimated queue conditions, signal status and pedestrian presence information to determine the appropriate priority method. To this end, availability of AVL/GPS systems on buses and loop detectors for the rest of the traffic are necessary. Upon receipt of a request, to predict the bus arrival time, the bus travel time and queue discharge time need to be estimated. The travel time estimate is based on a combination of historical and real-time speed estimates, while the queue discharge time estimate is based on actual counts of arrivals from loop detectors and estimated departure rates. The appropriatedwelling times are not taken into account in this algorithm, since in case of bus stops, priority requests are sent only after departure from the bus stop locations.

The proposed algorithm attempts to minimise bus delays, while also limiting the negative impact on the rest of the traffic and ensuring pedestrian safety.In order to keep balance among these objectives, priority is provided exactly as needed by buses up to a certain limit. Priority is provided either via green extension or stage recall for fixed cycle times, and with changes that take effect at the start of the cycle when the bus is supposed to enter the junction.

Leeds City Councilhas developed the SPRUCE[8] (Selective Priority in the UTCM Environment) system. SPRUCE aims at co-ordinating signals for buses and trams. Priority in SPRUCE is provided by adjusting the start time of fixed plans, considering the difference between the detection time of a bus/tram and the ideal time in the cycle for the vehicle to arrive at the detection point (Gardner et al, 2009). The fixed-time plans are delayed or forwarded depending on whether a bus/tram is late or early.

Skabardonis and Geroliminis (2008) developed a PTP strategy as part of a research project aiming at developing an online performance measurement system for signalised arterials and networks (Arterial Performance Measurement System (APeMS)). The proposed strategy builds upon and extends a PTP strategy developedearlier by Skabardonis (2000). The new approach to PTP involves system-wide adjustments to the signal timing plans and priority at specific signals on the basis of real-time information on the traffic conditions and the bus arrivals. The strategy tries to minimise the adverse impacts to the rest of the traffic and favours bus movements considering queue presence, schedule adherence, spare green time and bus route progression.

[8]http://www.docstoc.com/docs/34544558/Leeds-City-Council---DOC [accessed 30.01.2013]

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

The first step in the aforementioned strategy is to determine if signal priorityshould be given to a bus. This is based on comparing the scheduledand actual bus arrival times. The actualarrival time is estimated from a travel time model using AVLdata, signal status data, and flow and occupancy detector data.If the bus is behind schedule, priority service is initiated. Oncepriority service begins, the next step is to identify the non-saturated junctions for which the priority can be applied. To this end, the analytical model for arterial travel time estimation developed within the same APeMS project is used. Then, the proposed algorithm selects the most appropriate methodfor providing priorityto the bus among the introduction of special stage, green extension, or stage recall. To implement the particular approach, bus-related data from an AVL system, as well as general flow and occupancy measurements from traditional loop detectors are needed.

Liao et al (2008) and Liao and Davis (2011) proposed a PTP strategy, which provides priority on the basis of schedule adherence and number of passengers using AVL/GPS and Wireless Communication Systems (WCS). Priority is provided for single requests on a FIFO basis,via either green extension or stage recall. Different treatments are considered for buses that have to stop for dwelling after being detected and before reaching the priority junction.

Ekeila et al (2009) proposeaPTP strategy, which detects a PT vehicle via an AVLsystem anduses a linear model to predict its arrival time at the priority junction. Based on the specific point within the cycle that the arrival has been predicted to occur, the strategy responds to the priority request either through green extension,or stage recall, or cycle extend. The approach applies unconditionally to all buses, on the basis of a FIFO service rule.

Shen and Kong (2009) proposed a distributed road network traffic coordination control approach with bus priority based on the principles of fuzzy theory and Artificial Neural Networks (ANN). According to this approach, the whole road network is regarded as a large-scale system, while every junction of the network is considered as a sub-system. Based on local data, the proposed approach tries to optimally control the local traffic signals, whereby, to account for network performance and coordination, local decisions consider also traffic conditions in adjacent junctions. To perform local control, a competitive scheme is adopted,whereby the next stage competes with the current stage to receivethe green signal. If extending the current stage can make the traveling vehicle team and the traveling buses nearby the local junction pass without stoppage, and maximise, at the same time, the ratio between the sum of efficient green signal time and signal cycle time length, then the current stage maintains the green signal.

In the heart of the aforementioned strategy lays the Local Intersection Signal Control Module (LISCM), which has three sub-modules, the bus priority, the green observation, and the stage switch module. Each module has its own fuzzy rule base, which is implemented via a respective ANN. The first module decides which buses should be given priority, the second module calculates the stop degree of the current stage, and the third module decides whether to switch to the next stage, based on the outputs of the two former modules. As far as bus priority is concerned, the bus priority module considers all buses calling for the current stage, as well as all buses calling for the next stage, and decides, based on 17 fuzzy rules, for a green extension or stage recall in order to serve the buses calling for the current or the next stage, respectively.The application of the approach requires availability of vehicle detectors, as well as bus detection and location devices.

Kuang and Xu (2012) proposed a real-time traffic signal control strategy with PTP. The objective of this method is to reduce the delays of passengers and special vehicles by allowing change of stage sequence and green extensions. According to this strategy, the cycle stage with the highesturgency is first selected to become the next stage in the sequence. The urgency of a stage is estimated based on its respective number of vehicles, their stopping time, and their weight. Buses and private vehicles receive different weights. Knowing the current and the next stage in sequence, a fuzzy controller including 33 rules is then used, which decides whether to provide a green extension to the current stage or move to the next based on the number of vehicles of each of these stages. A multi-layer ANN has been used to implement the fuzzy controller. The application of the approach requires availability of SVDs, as well as estimates of vehicle loads and delays.

Hounsell and Shrestha (2012) proposed a PTP strategy where priority is provided via green extension or stage recall to a bus when its headway is higher than the scheduled headway of the bus behind it (following bus). To implement this approach, therefore, only a SVD deviceis necessary.

Finally, Lin et al (2013) developed a PTP strategyaiming at reducing the bus headway variance so as to minimise the total passenger waiting time at the next bus stops. They also aim at a strategy capable to handle multiple priority requests of buses from different routes. The strategy has been designed to make priority decisions based on the AVL/GPS data regarding the buses' locations.

According to this strategy, buses are granted priority via green extension or stage recall, if the following conditionsare satisfied:

- The total bus passenger waiting time will be reduced.
- The total person delay will not be increased.

To limit traffic disruptions on the cross streets, only one priority treatment (either the green extension or the stage recall) can take place within the same cycle.

The satisfaction or otherwise of the above criteria is identified based on:

- the estimation ofthe maximum permissible duration for green extension or stage recall for the prevailing traffic conditions; and
- the estimation of the potential benefits from granting priority to a different number of detected buses via headway calculations, estimations of average passenger waiting times at bus stops, delay reductions for bus and private vehicle passengers.

7.2.2. Optimisation-based strategies

This category includes priority strategies, which employ optimisation techniques in order to respond to priority requests. Such strategies are reviewed below.

PRODYN (PROgrammationDYNamique) is an optimisation-based real-time signal control strategy, which does not consider explicitly splits, offsets and cycles (Farges et al, 1983). Instead, given a pre-specified staging, PRODYN addresses the optimal specification of the next few switching times over a future time horizon, starting from the current time and the currently applied stage, based on the dynamic programming method and the rolling horizon procedure. The optimisation kernel of PRODYN is applied to each junction individually. The original implementation of PRODYN included consideration for PTP by treating PT vehicles as being equivalent to several private vehicles. Then, PRODYN was revised to explicitly model PT vehicles operations (TCRP, 1998). The PTP control objective of PRODYN is to minimise total delay at a junction, with coordination provided by sharing of vehicle arrival forecasts with adjacent junctions.

SPPORT (Signal Priority Procedure for Optimization in Real-Time) is a fully distributed heuristic signal control method that explicitly considers priority to PT vehicles (Han and Yagar, 1992; Dion and Hellinga, 2001). Similarly to PRODYN, the SPPORT model is also acyclic, in the sense that it does not use the traditional concepts of cycle and green split. At each decision point, instead, the control decisions are whether or not to end the current stage and which stage to go to next if the current stage is to be terminated. This approach has been adopted to provide the necessary flexibility to respond to large unexpected changes in traffic demands or to efficiently accommodate PT priority requests.

According to SPPORT, signal control is performed at each junction, but considering its neighbouring junctions in the aim of network-wide coordination. The signal control process is based upon the response to 9 key events that may occur on a given junction approach, two of which correspond to PT vehicle operations. The events are prioritised according to user-defined weights, while a simulation model, embedded in SPPORT, projects traffic movements on each junction approach and exit links. After completing traffic projection, traffic conditions at each decision point within the decision horizon are evaluated against signal control rules, and requests calling for a green or red indication are generated with their priority level for each key traffic event identified. After the generation of signal requests, the SPPORT model generates signal switching decisions using a multi-objective decision-making process so as to accommodate as best as possible the list of generated green and red signal indication requests.

To account for the fact that it is not always easy to determine the relative importance of different events, so as to provide corresponding weights, SPPORT allows the user to provide more than one lists with prioritised events. When more than one listsare provided, the signal optimisation algorithm generates a candidate timing plan for each list and then selects for implementation the one yielding the best performance on the basis of a generalised performance function that can linearly combine stops, delay, and travel time incurred by all vehicles traveling across the controlled junction within the evaluation period.

UTOPIA/SPOT[9](Urban Traffic Optimisation by Integrated Automation / System for Priority and Optimisation of Traffic) is a hierarchical real-time control system that provide priority to transit vehicles by continuously optimising the signal settings over shorttime intervals (TCRP, 1998; Wahlstedt, 2011). At the upper, network level of UTOPIA/SPOT, optimisation is performed based on a cost function, which takes into account the traffic state of all networkjunctions. At the lower, local level, then, signal settings are determined by optimising a cost function adapted to the current local traffic situation. Within UTOPIA/SPOT, PT vehicles are represented as weighted platoons of private vehicles, and their movements, including stops, are predicted to allow junctions to get prepared in advance of their arrival.

DARVIN (Dynamic Allocation of Right-of-Way for Transit Vehicles In Urban Networks) is a bus priority control system aiming at improving bus progression in mixed traffic while optimising overall performance of the network (Duerr, 2000). To achieve its aims, DARVIN:

- Computes vehicle movements and interactions of buses and private vehicles in the network and evaluates the quality of control using specified performance measures.
- Performs a simultaneous adjustment of all relevant signal control parameters in a specified time horizon applying a GA with problem-specific operators aiming at minimising a weightedcombination of delays and stops.
- Computes a mapping function for the optimal adjustment of the control parameters because of changes in the traffic state using anANN.

RHODES/BUSBAND (TCRP, 1998; Mirchandani et al, 2001) is an extension of the RHODES (Regional Hierarchical Optimized Distributed Effective System) signal control system for provision of priority to buses. The RHODES system includes a traffic simulation model and consists of five modules: the network flow optimisation, the junction optimisation, the platoon flow prediction, the link flow prediction, and the parameter and state estimation module. The network flow optimisation and the platoon flow prediction modules form together the network control logic of RHODES, while the junction optimisation and the link flow prediction modules form the junction optimisation logic. Given the output of the parameter and state estimation module, the network control logic of RHODES establishes coordination constraints for each network junction. Then, given these constraints, the junction control logic adjusts locally the signal control settings, via dynamic programming optimisation, so as to best utilise the junctions' capacities.

Priority within the extended RHODES/BUSBAND system may be provided in either of the following two approaches:

[9] http://swarco.com/mizar-en/Products/Urban-Systems/UTOPIA [accessed 02/02/2013]

- *Phase constrained*. According to this approach, the network control logic imposes a constraint to the junction control logic, which forces the latter to provide for the appropriate stage for agiven bus movement.
- *Weighted bus*. In the standard RHODES algorithms, each vehicle (including buses) is treated alike. By giving to each bus a variable weight, that depends on the number of on-board passengers and on its delay, if behind schedule, RHODES tends to give priority for late buses with many passengers.

Lateron, Mirchandani and Lucas (2004) introduced the CAPRI (Categorized Arrivals-based Phase Reoptimization at Intersections) strategy, which may be viewed as an extension of the BUSBAND logic. CAPRI integrates:

- the predicted arrivals of PT vehicles (buses, trams or light rail) at the signals and appropriately provides signal priority;
- the predicted arrivals of trains at an at-grade rail crossing and appropriately adjusts stage durations to mitigate the disruption from the signal switch in response to the arriving train; and
- the predicted (and/or advised) route for an emergency response unit to provide a least-disruptive pathway from unit's home (depot) to incident location with appropriately set staging for the traffic signals on the path.

As far as PT vehicles are concerned, CAPRI works similarly with BUSBAND, and thus, it may be easily integratedwithinRHODES, as well aswithinother systems that operate with a similar logic,such as OPAC (Optimised Policies for Adaptive Control)(Gartner et al, 1991), PRODYN and UTOPIA/SPOT.

MOTION[10] (Method for the OptimizaTION of Traffic signals online) is another hierarchical signal control system, which integrates two components: the MOTION central component, and the MOTION local component (Busch and Kruse, 2001; Gardner et al, 2009). The MOTION central component creates plans, which may then be adjusted by the local componentaccording to the local prevailing traffic conditions.

MOTION can provide priority in two ways:

- The MOTION central component performs stage sequence, split and offset optimisation limited to those options, that provide for the existence of a green time window for the PT vehicles at their expected arrival times.
- The MOTION local component provides local PT-oriented adjustments according to an assessment of the current local traffic conditions.

Liu et al (2003) proposed a method to optimise in real-time the green time allocation considering bus priority requests. According to this method, an optimisation model is used,

[10]http://www.siemens.com.co/SiemensDotNetClient_Andina/Medias/PDFS/473_20080305152745.pdf [accessed 30.01.2013]

which aims at minimising the average delay of all vehicles subject to prevailing capacity and operational constraints. This model searches for the critical approaches of each stage, optimises through a linear program (LP) the departure flow rates and converts the departure flow rates into appropriate signal parameters. The optimised signal parameters are then compared with the currently applied signal timings to determine whether a replacement is necessary. To take into account priority requests, the arrival of a bus with priority request is represented by weighting the arrival demand of the associated approach with a factor, which is defined based on traffic demands, the queuing conditions at every approach of the junction, and information on the lateness of the bus.

Based on earlier efforts (Vasudevan and Chang, 2001), Vasudevan (2005) designed a real-time arterial signal control system that gives priority to buses while simultaneously maximising progression bandwidths and optimising signal timing plans at each junction along the arterial. The architecture of the proposed system is divided into three levels:

- At the higher level(network or progression control) bandwidths are maximised using a modified version of the MULTIBAND bandwidth maximisation model and traffic flow predictions from anANN model developed from real data.
- At the intermediate level(local or junction control) signal timing plans are optimised subject to bandwidth constraints. The objective of the employed optimisation technique is to minimise a weightedcombination of vehicle queue lengths, delays and stop times, with constraints on the bandwidth and minimum green time.
- At the lower level(bus priority control), whenever a bus is detected and is a candidate for priority, it is granted priority based on the optimisation of a performance index, which is a function of bus schedule delay, automobile and bus passenger delays, and vehicle delays, subject to bandwidth and minimum green constraints. For the optimisation, dynamic programming is used under a rolling horizon concept with one control variable, the decision to switch or not the current stage to the next.

To qualify a bus for priority treatment under the aforementioned approach, it should not need to stop at a downstream bus stop and/or to head towards bus depot after the completion of this route. The approach allows also for the consideration of multiple priority requests.

Building also on earlier efforts (Li et al, 2005), which leaded to the rule-based strategy mentioned in Section 7.2.2.1, Li et al (2008) developed an Adaptive Transit Signal Priority (ATSP) concept with the following main features:

- An AVL/GPS system is used on buses to continuously monitor their locations.
- The AVL/GPS data are used in an arrival time flow prediction model, which is based on an adaptive recursive least-squares method, and is used to predict the bus arrival times atjunctions.

The approach makes real-time decisions adaptive to the movements of PT vehicles, traffic conditions and signal status, and provides priority to PT vehicles, via the stage recall or green extension methods, if warranted, while trying to make a trade-off between bus delay savings and the impacts on the rest of the traffic. To this end, an optimisation model is developed and used aiming at minimising the weighted sum of traffic delay and bus delay at an isolated junction. The weights in this model reflect the trade-off among the two considered types of delay and are determined through negotiations among the stakeholders on how much preference the PT operation should be given. The optimisation model is activated only when PT vehicles are expected to arrive during red periods.

Ma and Yang have also made several efforts towards the development of PTP strategies focused on two issues:

- Provision of priority under signal coordination.
- Provision of priority to multiple requests.

Their first effort leaded to the passive priority strategy described in Section 7.2.1 (Ma and Yang, 2007). Extending the concepts developed therein, Ma and Yang (2008) proposed a real-time control framework consisting of the following three hierarchical levels:

- The upper, priority classification level focuses on classifying and filtering different priority requests.
- The middle, passive priority strategy level gives a priority timing plan based on statistical data.
- The lower, active priority strategy level makes online priority decisions, including prediction of schedule deviation, selection of control object for signal priority, identification of critical junctions, decision for permitted priority frequency, and establishment of a recovery strategy.

Lateron, they further extended their approach proposing a Coordinated and Conditional Bus Priority (CCBP) strategy (Ma et al, 2010) with two characteristic control features:

1. the control object, which is a coordinated signalised group of several junctions along an arterial, which also includes several stops; and
2. the control objective, which is the minimisation of the gap between the estimated bus delay and the permitted bus delay as defined by the bus operation system.

In addition, under CCBP:

- The cycle length and offsets are kept unchanged.
- The normal stage order and duration of the non-coordinated stages is not significantly altered.
- The priority method is selected on the basis of predicted bus arrival times.
- Priority is provided only to the buses that are truly in need of it.
- Priority is provided at a junction only when it is useful to minimise the total bus delay deviation at the coordinated signalised junction groups.

The CCBP approach includes four main modules:

- A bus delay prediction module, which predicts bus delay under the control of a primary signal plan.
- A priority request generation module, which decides whether a bus needs to be given priority based on an estimation of delay.
- A bus signal priority strategy and relative bus delay calculation module, through which bus delay under different priority treatments is calculated. This module includes mainly two types of priority strategies. One type, which is used to decrease bus delay at junction, when the bus is behind schedule; and another type, which is used to increase bus delay at junction when the bus is ahead of schedule. To decrease bus delay at a junction, green extension, stage insertion, or stage recallmay beused; while to increase delay, green truncation or red extension may beused.
- A priority strategy combination and optimisation module, that generates the optimal priority strategy for each junction group. To this end, a mathematical programming model is adopted, which, considering all available priority methods per strategy type, tries to minimise the gap between the estimated bus delay and the permitted bus delay.

In case of multiple priority requests, the proposed approach allows the simultaneous application in one cycle of at most two of all priority methods, while only one stage insertion is permitted per cycle.

Beyond the above efforts, Ma and Bai (2007) were also working on the issue of multiple priority requests, andthey developed a decision tree-based method to optimise the serving sequence for multiple bus priority requests. According to this method, the multiple priority requests are classified intomultiple requests for single phase, andmultiple requests for multi stages, and a decision tree is used to optimise the service sequence of these two kinds under the decision objective of minimising the average person delay of all priority requests.

The above decision-tree based approach was found to belimited, especially when considering the real-world operational characteristics of multiple bus requests in detail, i.e. schedule deviation, bus occupancy, delay at cross streets, etc. For this reason, Ma et al (2012) developed a new control framework aiming at providing efficient priority control for multiple bus requests as well as minimising the overall negative impacts on the control system.The new framework consists of two modules: minimisation of system disturbance and optimisation of the serving sequence. The first module assigns the required minimum green time to a traffic movement based on its volume and a threshold value of saturation degree. Given the constraints from the system disturbance minimisation module as input, a dynamic programming model is then used, within the second module, to generate the optimal signal timings and serving sequence for a set of bus priority requests in a cycle.

In order to improve the PT system’s reliability rather than just reducing bus delays at junctions, the proposed model minimises the weighted bus delays at the junction considering both bus occupancy and schedule deviation. The proposed framework assumes availability of an optimal signal plan for the general traffic demand in each cycle, as well as threshold values of the saturation degree. Such parameters can be fixed or dynamically determined by the urban traffic control system.

The proposed control model is based on the bus arrivals in a foregone cycle. However, such information is usually unknown at the beginning of a cycle and bus priority requests are also unpredictable. In order to take into account the latest bus arrival and vehicular demand information, and facilitate real-time operation, the proposed framework is applied under a rolling horizon, equal to the cycle time, scheme:

The issue of serving multiple priority requests was addressed by many other researchers too. To start with, Head et al (2006) developed a decision model capable of treating multiple priority requests. The model is based on a precedence graph structure, which is analogous to the classical project management techniques of a Gantt chart, Critical Path Method (CPM), and Program Evaluation and Review Technique (PERT), but is formulated to address the structural and operational issues of traffic signal control directly. The goals of this novelanalytical model are to provide:

- A structure for analysing signal state transitions;
- An extensible framework to allow consideration of new features and functions; and
- A more efficient signal timing that considers multiple objectives, such as PT vehicles priority requests, vehicle demands, and pedestrian needs.

As far as priority is concerned, requests are assumed to come from buses, heavy rail, commercial vehicles, and adjacent junctions (for coordination purposes). It is also assumed that the prioritisation of many requests is done externally to the controller, and that only requests that have been selected for service are considered. The precedence-based controller logic model is applied then to the problem of selecting phase durations that best serve multiple requests for priority. The goal is to achieve the minimum delay for a set of several requesting vehicles (not all vehicles) based on a formulation that includes:

- An objective function to minimise the priority request delay;
- Precedence relationship constraints, which represent the controller stage and interval behaviours;
- Selection variables and constraints to determine the cycle containing a service stage for each priority request.

The resulting problem is a mixed-integer mathematical programming problem, which can be solved by using readily available tools, but, according to its developers, difficult to be implemented, especially in an embedded environment, such as an embedded Linux system.

To overcome the aforementioned problem, Head et al (2007) modified their approach to become mixed-integer linear, which improved the solvability, but it was still depending on using commercial optimisation solvers. For this reason, He et al (2011a) proposed a solver-free heuristic algorithm for traffic signal control with simultaneous multiple priority requests at isolated junctions in the context of vehicle-to-infrastructure communications, i.e. assuming that advanced communication systems are available between vehicles and controllers. According to this new approach, the priority control problem initially treated by Head et al (2006, 2007) was simplified to a polynomial solvable cut problem by adding the following assumptions:

- The stage sequence is fixed.
- A temporally based FIFO rule holds for all requests for the same stage.
- All requests can be served in two cycles.

Each cut combination corresponds to a unique serving sequence of priority requests, and a greedy search algorithm searches for the best solution, within a defined tolerance range, by assessing the total priority delay of each cut combination. Several candidate cycle and stage assignments are evaluated to ensure that the best solution is found, and the search stops when a candidate assignment and optimised stage timings are found that cannot be improved by reassigning priority requests or changing stage timings.

Within the same concept of vehicle-to-infrastructure communications,He et al (2011b) proposed also a platoon-based mathematical formulation called PAMSCOD (Platoon-based Arterial Multi-modal Signal Control with Online Data) to perform arterial (network) traffic signal control while considering multiple travel modes. PAMSCOD considers two modes of traffic composition: buses and passenger vehicles; which are able to send a “green light” request to the traffic controller, when approaching a junction. The “green light” request includes travel mode, position, speed, and requested traffic signal stage. Single requests are categorised and clustered into platoons by priority level and stage. Then, a mixed-integer linear program (MILP) is solved online for future optimal signal plans based on the real-time arterial platoon request data and traffic controller status. The objective of the optimisation is to minimise the overall weighted delay both at the current junction and at downstream junctions. The employed weights can be set to different values for each mode, as well as each different platoon; depend on the priority level of the mode; and can be adjusted for individual vehicles according to other real-time information, such as vehicle occupancy. PAMSCOD modelling is also based on the precedence graph initially proposed by Head et al (2006).

Finally, optimisation-based strategies have also been proposed by Christofa and Skabardonis (2011) and Christofa et al (2012), as well as by Zhao et al (2013).

Christofa and Skabardonis (2011) developed a real-time, traffic-responsive signal control system that minimises the total person delay at the traffic signals. The goal of this approach is to optimise the signal timings, such that conditional priorityis granted for the PT vehicles on the basis of their passengeroccupancy. Conditional priority is used as a way to assign prioritywhen two or more PT vehicles are expected to arrive at the junction at approximately the same time and compete for priority. Inaddition, the effect of PTP on the rest of the traffic at the junction istaken into account by includingin the objective function the total person delay for all vehicles present at the junction. The proposed approach applies to isolated junctions.

The formulation of Christofa and Skabardonis (2011) is based on the assumption of fixed cycle lengthswith a fixed stage sequence. The vehicle arrivals and service timesfor all vehicles at the signalised intersection are assumed to be deterministic, and the arrivals of the PT vehicles at the junction areassumed to be known in real time. It is also assumed that PT vehicles travel on mixed traffic lanes.The developed mathematical program minimises the total person delay at the junction by changing the green times for each stage of a cycle constrained by a fixed cycle length and the minimumgreen times for junction approach. The mathematical program is run once forevery cycle.

Using the same model as above, transformed though via appropriate integer variables in order to avoid the “if-then” decisions of the original model, Christofa et al (2012) developed, lateron, a traffic-responsive signal control system for signal priority on conflicting routes of PT vehicles. The new formulation results in a MILP problem, for which the Branch-and-Bound method is used,leading global optimality. Apart from tests with deterministic demand and PT arrivals, the system has been tested with predictions for demands and measured PT arrivals.

Finally, Zhao et al (2013) developed a coordinated priority control optimisation model. According to this approach:

- The coordinated junction group between two successive bus stops is defined as a control unit.
- Buses are detected after leaving the upstream stop, before their arrival at the first junction of a control unit.
- The dynamic interactions of priority strategies between adjacent junctions within a control unit are modelled using a bus delay model and an ineffective priority time model.
- ALP model is developed to generate optimal priority strategies in order to reduce the bus travel time, in case priority is actually necessary, and to ensure that the applied priority treatments are effective. Control variables for the optimisation model are the type of priority (no priority, green extension, stage recall) and the time needed for extension or truncation, if priority is provided.

The control model of Zhao et al (2013) provides priority to single requests on a FIFO basis for delayed buses using exclusive lanes. The proposed framework is suitable for mixed-traffic lanes, given that its bus delay model is suitably extended to address the impacts of other vehicles.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

8. PTP system applications

8.1. Introduction

Although a few efforts towards PTP have been reported as early as in the 1970s, the most serious efforts did not start until the late 1980s;since then, with ever increasing interest. Nowadays, many cities around the world include within their UTC systems special priority features; at the same time they increasingly also adopt facility-design-based measures, such as EBLs, bus gates, rising bollards, etc., in an effort to improve their PT operations, thus encouraging modal shift and promoting the use of PT means.

Early, as well as more recent reviews and reports of operational PT priority systems may be found in:

- The Bus Priority Resource Pack of the UK Department for Transport (DfT) (DfT, 2004), focusing on UK case studies;
- TCRP[11] (1998), Baker et al (2004) and Smith et al (2005), focusing mainly on USA and Canada; and
- Fox et al (1998), PRISCILLA (2001) and Gardner et al (2009), which provide a more global perspective.

According to these reviews, the reported PTP applications in European cities, as well as in cities in the rest of the world, concern strategies of different architectures (centralised or decentralised), which also employ different detection and communication devices and systems. Despite their differences though, the vast majority of these strategies are based on a reactive, rule-based, conditional logic, which favours the movements of PT vehicles,as observed in the improvements reported within the aforementioned reports, at a higher or lower degree, depending upon the adopted priority levels as well as the availability of other facility-design-based measures, which are often additionally employed.

Despite the state-of-the art advances since the decade of 90s, itbecomes obvious from the state-of-practice review of the following sub-sections thatonly a few of the proposed state-of-the-art PTP strategies (reviewed in Section 7), have actually been employed in practice, and even fewer have undergone even a limited field trial. Beyond BALANCE, BRIBUSS, MOVA, PRODYN, RAPID, SCATS, SCOOT, SPRINT, SPRUCE, TUC and UTOPIA/SPOT, which are either fully adopted or have undergone extended field trials, limited field trials have also been reported for the strategies proposed by:

- Li et al (2008) and Skabardonis and Geroliminis (2008) in San Mateo County, USA;
- Liao et al (2008) and Liao and Davis (2011) in the city of Minneapolis, USA; and

[11] http://www.signalsystems.org.vt.edu/documents/Attach/I13_Head.pdf [accessed 18.02.2013]
http://www.signalsystems.org.vt.edu/documents/SignalControlWorkshop2002/TCRP_A-16A_Overview_Head.pdf[accessed 18.02.2013]

- Ma et al (2010) in the Ji'nan City, Shandong province, China.

8.2. The European experience

The European philosophy to PT priority has been rather aggressive, with provision of higher priority levels and less concern forthe potential negative impacts to the rest of the traffic (TCRP, 1998). According to a recent study of Kaparias et al (2010), the bus seems to be the most common PT means in European cities, with the length of the bus networks ranging from a few to thousands ofkilometres (e.g. the bus networks of The Hague and Zurich extend to 150 and 175 km, respectively; while the London's bus network covers 9300 km). According to the same study, cities of similar size have considerably different bus network lengths, depending on the presence of other PT means in the city. Light rail/tram systems are also very common in European cities.

To improve the performance and efficiency of PT and hence encourage the modal shift, many European cities employ PT priority measures, mainly of a facility-design-based nature,EBLs in specific (Kaparias et al, 2010).

Among the European countries, UK has a long history of PTP-related initiatives. In 2004, the UK DfT released a Bus Priority Resource Pack (DfT, 2004), which, among others, describes some representative case studies that have been designed to demonstrate the range of possible measures and to provide some indication onthe conditions, under which these measures may be suitable for practical deployment. The study concludes that the most appropriate measure in any one location depends upon the local conditions (e.g. traffic levels, number and frequency of bus services, available space) prevailing in that area.

According to theUK DfT study (DfT, 2004), a significant number of junctions in the UK use MOVA with SVDs for the provision of PTP. SCOOT applications with PTP have also been reported in London, Southampton, Glasgow, York, Cardiff, Leeds, Winchester, Leicester, Norwich, Brighton and Hove. In addition,SPRUCE has been developed and applied in Leeds, where also a UTOPIA/SPOT trial took place, whileSPRINT and TUC trials have taken place in London (Fox, 1998; PRISCILLA, 2001; DfT, 2004; Gardner, 2009), and Southampton (Kosmatopoulos et al, 2006), respectively.

UTOPIA/SPOT is the main UTC system of Turin[12], Italy, also responsible for PTP provision. It has also been applied inBologna, Italy (Fox, 1998; PRISCILLA, 2001;Gardner, 2009), as well as in Bucharest[13], Romania, and Gothenburg (Gardner, 2009) and Stockholm, Sweden (Wahlstedt, 2011). In Stockholm, the PRIBUSS strategy has also been developed and is currently included as standard in most signal controllers on the Swedish market (Wahlstedt, 2011). Beyond the aforementioned ones, other strategies have also been developed

[12] http://www.swarco.com/mizar-en/Projects/ITS-References/URBAN-TRAFFIC-MANAGEMENT-PUBLIC-TRANSPORT,-Italy,-Turin-5T-S.R.L [accessed 19.02.2013]
[13] http://www.swarco.com/mizar-en/Projects/ITS-References/URBAN-TRAFFIC-MANAGEMENT,-Romania,-Bucharest-City-of-Bucharest [accessed 19.02.2013]

locally,both in Swedish and Italian cities, such as Malmo and Genoa, respectively, based on a reactive, rule-based, conditional logic (Gardner et al, 2009).

PRODYN applications with PTP have been reported in Pau and Toulouse, France (Fox, 1998; PRISCILLA, 2001),while, more recently, other strategies have been developed and applied locally in French cities, such as Nantes and Toulouse, based on a reactive, rule-based, conditional logic (Gardner et al, 2009). PRODYN applications have also been reported in Brussels, Belgium (Fox, 1998; PRISCILLA, 2001), while BALANCE (Fox, 1998) applications have been reported in Krakow[14], Poland, and Munich, Germany. Other locally developed and applied reactive, rule-based, conditional strategies have also been reported in German cities, such as Stuttgart (Gardner et al, 2009).

Beyond the aforementioned ones, the relevant literature reports on several other, locally developed and applied,reactive, rule-based, conditional strategies in Aalborg (Denmark), Helsinki (Finland), Vienna (Austria), Suceava (Romania), Tallinn (Estonia), Prague (Czech Republic), and Geneva and Zurich, Switzerland (Gardner et al, 2009).

The case of Zurich, Switzerland is perhaps the most noticeable from all reported PTP cases, where a full PT-oriented philosophy and approach has been developed and adopted since 1970, which has resulted in a full bus-tram priority via all available means (both facility-design and signal-control based). This philosophy and approach have produced mobility and traffic conditions that have enabled a significant modal shift towards PT; it has been reported that approximately 42% of trips in Zurich are made by PT means (Gardner et al, 2009).

8.3. The international experience

Similarly to Europe, several PTP initiatives have been reported in other cities in the rest of the world. In Australia, two systems mainly appear: SCATS and RAPID, which have in the country. SCATS, which was developed by the Roads and Traffic Authority (RTA) of New South Wales, is applied in Melbourne and Sydney, while RAPID has been developed and applied in Brisbane, Australia, and in Auckland, New Zealand, as well (Fox et al, 1998; Gardner et al, 2009).

SCATS and SCOOT applications are quite numerous around the globe, for examplein Toronto, Canada (Currie and Shalaby, 2008), for the formar; andinFortaleza(Oliveira-Neto et al, 2009) and Sao Paulo[15], Brazil, and Santiago[16], Chile, for the latter.

According to Baker et al (2004) and Smith et al (2005), in USA and Canada, several PTP systems have been developed by local or state traffic/highway departments, with the level of deployment varyingconsiderably from location to location, and ranging from equipping afew junctions and a limited number of buses, to equippingentire corridors and to system-wide deployment. Examples include the PTP systems ofArlington Heights, Atlanta, Napa,

[14] http://www.gevas.eu/1/references/traffic-control-krakow/ [accessed 19.02.2013]
[15] http://www.scoot-utc.com/SaoPaulo.php?menu=Results [accessed 19.02.2013]
[16] http://www.scoot-utc.com/Santiago.php?menu=Results [accessed 19.02.2013]

Bremerton, Burlington, Charlotte, Chicago, Glendale, Houston, Los Angeles, Minneapolis, Oakland, Orlando, Philadelphia, Pittsburgh, Port Townsend, Portland, Richland, Sacramento, Salt Lake City, San Francisco, San Mateo, Seattle, St. Cloud, Tacoma, Union City and Washington in USA, as well as the PTP systems of Calgary, Ottawa, Toronto and Vancouver in Canada (Baker et al, 2004; Smith et al, 2005).

In the aforementioned USA and Canada applications, the most commonly used PTP strategy for buses operating in mixed-traffic laneshas been green extension andstage recall, which is typicallyavailable on the NEMA-based proprietary softwarepackages that are used by over 40% of the corresponding responsible agencies (Smith et al, 2005). Although many older systems use absolute priority, more recent systems tend to use conditional priority and allow also for stage skipping (Smith et al, 2005; Altun and Furth, 2009).

PTP applications have also been reported for Japan[17], where priority is provided mainly via green extension and stage recall (Gardner et al, 2009).

[17]http://www.utms.or.jp/english/cont/seigyo/index4.html [accessed 20.02.2013]

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

9.Current trends and future perspectives

The significant advances in information, computer and communication technologies have created the basis and offered efficient and reliable ingredients towards the development of real-time traffic signal control systems, which respond to the prevailing traffic conditions. The literature on recent fixed-time signal control systems is limited, and the same trend is also observed as far as fixed-time PTP strategies are concerned. The review though of these few approaches sets off the offsets to be the most significant parameter to optimise for priority provision, followed by the green splits of the fixed priority-oriented signal plans. Table 1 summarises the characteristic of the fixed-time PTP approaches reviewed in Section 7.2.1.

Table 1. Outline of proposed fixed-time PTP strategies.

Reference	Features
TRANSYT (Robertson, 1969)	Optimisation-based calculation of fixed-time signal plans (split, cycle and offset) for buses/trams
Ma and Yang (2007)	Optimisation-based calculation of stage lengths and offsets for given cycles
VISGAOST (Stevanovic et al, 2008)	Optimisation-based calculation of fixed-time signal timing plans (split, cycle, offset and stage sequence), plus priority settings for a real-time application of green extension or stage recall
Estrada et al (2009)	Optimisation-based calculation of offsets for given cycles and splits from an available passive signal priority system

As far as real-time, rule-based PTP strategiesare concerned, the state-of-the-art review of Section 7.2.2.1, which is summarised in Table 2, reveals the following:

- Priority decisions are based mainly on schedule adherence, although the rule-based character of these strategies allows for simultaneous consideration of many different criteria. This of course requires the establishment of trade-offs among the different criteria, whichmay often be competitive.
- Priority is mainly provided via green extension and stage recall. These methods have been identified to be sufficiently effective; while creating the least disruption to the rest of the traffic operations.
- Most of the proposed strategies are of a reactive nature, although many of them employ travel time predictions, and occasionally also dwell time estimations, to identify the bus arrival time at the junction’s stopline. Although proactive strategies may have better performance and lead to less disruptions to the rest of the traffic, they require advanced infrastructureto achieve their goals, which may not be always available, and accurate prediction models and techniques, which by itself is an issue for further research and development.

- Most of the proposed strategies respond to single requests on a FIFO basis. In case of multiple priority requests, two approaches have been identified. According to the first approach, requests are prioritised on the basis of the delays of the competing PT vehicles, and the most delayed vehicle is served. According to the second approach, the consequences of all available priority methods to all PT vehicles as well as to the other vehicles are estimated, and the method with the most positive overall impactis selected.

To provide priority either in a reactive or in a proactive manner, a rule-based strategy needs to know the arrival time of the PT vehicle at the junction’s stopline. Most strategies estimate this arrival time based on the corresponding travel time of the PT vehicle, and perform this estimation either based directly on traffic measurements or based on predictions obtained from traffic measurements. A few strategies consider also the case where bus stops exist among the bus detection location and the junction’s stopline. No matter how it is performed, the arrival time estimation is critical for the performance of the strategy, and constitutes one more area susceptible of further research. The availability of advanced monitoring, measuring and communication systems, such as AVL/GPS, and APCsystems,allows for more detailed and accurate measurements and PT-related data, which, if appropriately exploited, may improve significantly the performance of the strategies.

A final area susceptible of further research relates to the weakest point of all available real-time rule-based strategies, which is their inability to efficiently accommodate multiple, competitive or not, priority requests. As mentioned earlier, some researchers try to overcome this problem by prioritising the received requests, while others try to identify the priority method with the best overall effects. Despite these efforts, however, this issue is rather difficult to handle within the frame of a rule-based strategy, and still offers a great challenge for further investigation and development of new approaches.

Table 2. Outline of proposed real-time rule-based PTP strategies.

Reference	Priority conditions	Priority methods	Reactive / proactive response	Response to single/multiple requests	Minimum implementation requirements
SCOOT (Hunt et al, 1982; Nash et al, 2001; Oliveira-Neto et al, 2009)	Schedule adherence	✓ Green extension ✓ Stage recall ✓ Stage skipping	Reactive	Single request service on FIFO basis	SVDs
SCATS (Lowrie, 1982; TCR, 1998; PRISCILLA, 2001; Gardner et al, 2009)	Schedule adherence	✓ Green extension ✓ Stage recall ✓ Stage skipping ✓ Special stage ✓ Stage reordering	Reactive	Single request service on FIFO basis	SVDs
PRIBUSS (Wahlstedt, 2011)	User-defined constraints	✓ Green extension ✓ Stage recall ✓ Special stage ✓ Retaken start ✓ Double early green	Reactive	Single request service on FIFO basis	SVDs

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Reference	Priority conditions	Priority methods	Reactive / proactive response	Response to single/multiple requests	Minimum implementation requirements
BCC-RAPID (Fox et al, 1998)	Schedule adherence	✓ Double special stage ✓ Green extension ✓ Stage recall	Reactive	Single request service on FIFO basis	SVDs
SPRINT (Fox et al, 1998)	User-defined constraints	✓ Green extension ✓ Stage recall	Reactive	Single request service on FIFO basis	SVDs
BALANCE (Tommey et al, 1998; Fox et al, 1998)	✓ Schedule adherence ✓ Traffic conditions	✓ Green extension ✓ Stage recall ✓ Special stage	Reactive	Single request service on FIFO basis	SVDs
MOVA (Fox et al, 1998; Gardner et al, 2009)	User-defined constraints	✓ Green extension ✓ Stage recall ✓ Stage skipping	Reactive	Single request service on FIFO basis	SVDs
TRAFCOD (Furth and Muller, 1999)	Unconditional priority	Special stage	Reactive	Single request service on FIFO basis	SVDs
Balke et al (2000)	Schedule adherence	✓ Green extension ✓ Stage recall	Proactive	Single request service on FIFO basis	AVL/GPS

Reference	Priority conditions	Priority methods	Reactive / proactive response	Response to single/multiple requests	Minimum implementation requirements
Wadjas and Furth (2003)	Unconditional priority or Schedule adherence	✓ Special stage ✓ Green extension ✓ Stage recall	Proactive	Single request services on basis of delay	SVDs
TUC (Diakaki et al, 2003)	Average traffic load of competing stages	✓ Green extension ✓ Stage recall	Reactive	Single request service on FIFO basis	SVDs
Kim (2004)	Passenger load of buses	✓ Green extension ✓ Stage recall ✓ Special stage	Reactive	Single request service on FIFO basis	✓ SVDs ✓ APC system ✓ GPS
Kim et al (2005)	Schedule adherence	✓ Green extension ✓ Stage recall	Reactive	Single request services on basis of delay	SVDs
Lee et al (2005)	Expected effects on buses	✓ Green extension ✓ Stage recall ✓ Priority stage truncation ✓ Queue dissipation	Reactive	Single request service on FIFO basis	SVDs

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Reference	Priority conditions	Priority methods	Reactive / proactive response	Response to single/multiple requests	Minimum implementation requirements
Li et al (2005)	✓ Schedule adherence ✓ Impacts to the rest of traffic	✓ Green extension ✓ Stage recall	Reactive	Single request service on FIFO basis	✓ Loop detectors ✓ AVL/GPS
SPRUCE (Gardner et al, 2009)	Schedule adherence	Offset modification	Reactive	Single request service on FIFO basis	SVDs
Skabardonis (2000) and Skabardonis and Geroliminis (2008)	✓ Queue presence ✓ Schedule adherence ✓ Spare green time ✓ Bus route progression	✓ Green extension ✓ Stage recall ✓ Special stage	Reactive	Single request service on FIFO basis	✓ Loop detectors ✓ AVL
Liao et al (2008) and Liao and Davis (2011)	✓ Schedule adherence ✓ Passenger number	✓ Green extension ✓ Stage recall	Reactive	Single request service on FIFO basis	✓ AVL/GPS ✓ WCS
Ekeila et al (2009)	Unconditional priority	✓ Green extension ✓ Stage recall ✓ Cycle extend	Reactive	Single request service on FIFO basis	AVL
Shen and Kong (2009)	✓ Bus stopping at traffic lights ✓ Efficient green time / cycle	✓ Green extension ✓ Stage recall	Reactive	All competing PT vehicles are considered under the specified	✓ SVDs ✓ AVL

Reference	Priority conditions	Priority methods	Reactive / proactive response	Response to single/multiple requests	Minimum implementation requirements
	time ratio			conditions	
Kuang and Xu (2012)	✓ Passengers delay ✓ PT vehicles delay	✓ Green extension ✓ Stage reordering	Reactive	All competing PT vehicles are considered under the specified conditions	SVDs
Hounsell and Shrestha (2012)	Headway of bus compared to scheduled headway of following bus	✓ Green extension ✓ Stage recall	Active	Single request service on FIFO basis	SVDs
Lin et al (2013)	✓ Total passenger waiting time ✓ Total person delay	✓ Green extension ✓ Stage recall	Active	All competing PT vehicles are considered under the specified conditions	AVL/GPS

ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Concerning real-time, optimisation-based strategies, Table 3, which summarises the review findings of Section 7.2.2.2, indicates thatthe first efforts referred to PT-weighted approaches, i.e. approaches that are integrated within the frame of a more general signal control strategy,usually of a hierarchical structure. Priority is not provided in the sense of the direct switching of the traffic lights to allow a detected PT vehicle to cross the junction without the need to stop. Instead, the detected PT vehicles are used to appropriatelychargethe corresponding performance indices, so that the optimisation results will favour their movements.

This approach allows for the consideration of multiple priority requests, it does not consider though criteria such as schedule adherence, passenger delays and waiting times, etc., which seem to be critical for the effective and reliable operation of PT services. For this reason, the recent trend, in optimisation-based strategies, is PT-oriented strategies, which focus on the operation of PT vehicles, may or may not consider the rest of the traffic within their optimisation procedures, and are often activated only when PT vehicles are detected to approach signal-controlled junctions.

PT-oriented optimisation-based strategies develop performance indices, which may combine several priority criteria, as rule-based strategies do. Instead, however, of the use of rules to identify an appropriate priority method, such as green extension, stage recall, etc. these strategies optimise in real time the developed performance index to identify the appropriate signal parameters. An appropriatesolution method in this respect is dynamic programming, using as control variable the decision to switch or not from the currently running stage to the next. This approach was initially introduced in the COP (Controlled Optimization of Phases) (Sen and Head, 1997) signal control algorithm, which lays at the lower level of the RHODES signal control system. LP and MILP, as well as heuristic algorithms, GAs and ANNs have also been used.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Table 3. Outline of proposed real-time optimisation-based PTP strategies.

Reference	Weighted / oriented PT treatment	Cost function (to be minimised)	Response to single/multiple requests	Minimum implementation requirements
PRODYN (Farges et al, 1983; TCRP, 1998)	PT-weighted	Total delay	Response to multiple requests	SVDs
SPPORT (Han and Yagar, 1992; Dion and Hellinga, 2001)	PT-weighted	Linear combination of stops, delay, and travel time of all vehicles	Response to multiple requests	SVDs
UTOPIA/SPOT (TCRP, 1998; Wahlstedt, 2011)	PT-weighted	Function of traffic state	Response to multiple requests	SVDs
DARVIN (Duerr, 2000)	PT-weighted	Combination of delays and stops of all vehicles	Response to multiple requests	SVDs
RHODES/BUSBAND (TCRP, 1998; Mirchandani et al, 2001)	PT-weighted	Total delay (or stops or queue lengths)	Response to multiple requests	SVDs
RHODES/CAPRI (Mirchandani and Lucas, 2004)	PT-weighted	Total delay (or stops or queue lengths)	Response to multiple requests	SVDs
MOTION (Busch and Kruse, 2001; Gardner et al, 2009)	PT-weighted	Function of traffic state	Response to multiple requests	SVDs
Liu et al (2003)	PT-weighted	Average delay of all vehicles	Response to multiple requests	SVDs
(Vasudevan and Chang, 2001) and Vasudevan (2005)	PT-oriented	Function of bus schedule delay, automobile and bus passenger delays,	Response to single requests; consideration of	✓ AVL/GPS

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Reference	Weighted / oriented PT treatment	Cost function (to be minimised)	Response to single/multiple requests	Minimum implementation requirements
		and vehicle delays	multiple requests possible	✓ APC system
Li et al (2008)	PT-oriented	Weighted sum of traffic delay and bus delay	Response to single requests	AVL/GPS
CCBP (Ma and Yang, 2008; Ma et al, 2010)	PT-oriented	Gap between estimated and permitted bus delay	Response to single requests	AVL/GPS
Ma and Bai (2007)	PT-oriented	Average person delay of all priority requests	Response to multiple requests	✓ AVL/GPS ✓ APC system
Ma et al (2012)	PT-oriented	Weighted bus delays considering both bus occupancy and schedule deviation	Response to multiple requests	✓ AVL/GPS ✓ APC system
Head et al (2006, 2007)	PT-oriented	Delay of all vehicles requesting priority	Response to multiple requests	AVL/GPS
He et al (2011a)	PT-oriented	Delay of all vehicles requesting priority	Response to multiple requests; FIFO response to requests for the same stage	Vehicle-to-infrastructure communication system
PAMSCOD (He et al, 2011b)	PT-weighted	Total delay	Response to multiple requests	Vehicle-to-infrastructure communication system
Christofa and Skabardonis (2011) and Christofa et al (2012)	PT-oriented	Total person delay	Delay-based response to single requests	✓ AVL/GPS ✓ APC system

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο

ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ

ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Reference	Weighted / oriented PT treatment	Cost function (to be minimised)	Response to single/multiple requests	Minimum implementation requirements
Zhao et al (2013)	PT-oriented	Bus travel time	FIFO response to single requests	AVL/GPS

This new-generation of optimisation-based strategies offers the ability to consider multiple priority criteria, the complexity of the resulting problems though seem to create problems for real-time applications, and the development of optimisation algorithms capable in this respect is an issue for further research and development. Farther main issues for further research and development include:

- Provision of priority under signal coordination; and
- Consideration of multiple requests.

Despite the significant advances in the state-of-the-art of reactive optimisation-based strategies, the state-of-practice, as the review of Section 8 indicates,still demonstrates insistency to the reactive, rule-based strategies, with an increasing tendency towards the conditional ones. It seems that, despite their inability to adequately address the issue of multiple requests, the direct and occasionally aggressive priority, which may be provided by the rule-based strategies, still remains the subject of research within an internationally community that calls for solutions, which will evidently improve the PT operations and promote their use.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

10. Conclusions

In the years to come, PT will be called to play an increasingly significant role towards achieving the sustainable transport system objective that has been set for the future, in Europe and beyond. To this end, the quality, accessibility and reliability of its operations should be improved. In this context, the favourable treatment of PTMs within the road network may have, among others, a significant contribution. This favourable treatment can be derived as a result of an appropriate design of the road network facilities and/or the employed signal control at the network junctions.

Facility-design-based measures are employed in case of PT vehicles moving in mixed-traffic lanes, such as buses and trams. Such measures include different adjustments of the road lanes, so as to include EBLs, HOVs and reversible lanes, or in case where road capacity needs to be preserved as much as possible, IBLs, DFs and BLIP. Other facility-design-based measures, that may also be employed to provide the desired priority without affecting the signal control of the network junctions, include bus-only roads and busways, bus gates and rising bollards, as well as bus advance areas.

As far as signal control is concerned, several adjustments of the traffic lights may be adopted to provide PT vehicles a favourable treatment at the network junctions. This favourable treatment, which is called priority, may be provided at different levels depending mainly on the type of the PT vehicle.

Depending on the specific requirements that the provision of priority aims at addressing, several different signal-control based PTP strategies have been developed and applied worldwide. A first classification distinguishes them as fixed-time versusreal-time, depending on whether the priority decisions are made in real-time in response to arrivingpriority requests. The real-time strategies may be further classified according to several criteria. The first criterion addresses the reactive versus predictive nature of the priority strategies, and distinguishes them as reactive versusproactive, depending on whether they respond to requests of PT vehicles at the time they approach a junction or earlier in time. The second criterion distinguishes the strategies to rule-based versusoptimisation-based, depending on whether their control decisions are based on a set of identified criteria or on the optimisation of an appropriately defined performance index.

The conditions, which may be considered by real-time, rule-based PTP strategies, mainly concern schedule or headway adherence, as well as the overall traffic conditions, while priority is usually granted via green extension and stage recall. On the other hand, total delay seems to be the main concern of the optimisation-based PTP strategies.

The relevant scientific literature offers a few examples of fixed-time PTP strategies, and numerous examples of real-time PTP strategies, mainly of a rule-based nature. A similar tendency is observed in the practical applications of PTP systems, where the real-time, rule-based strategies constitute the vast majority of the adopted strategies. It seems that, despite their inability to adequately address issues such as the service of multiple requests and the provision of priority under coordinated signal control, the direct and occasionally aggressive priority, which is provided by the rule-based strategies still remains the prime subject of research and development within an internationally community that calls for solutions, which will evidently improve the PT operations and promote their use.

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επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
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English-Greek dictionary

Active PTP strategy	Στρατηγική παροχής προτεραιότητας σε πραγματικό χρόνο
Antagonistic traffic streams	Ανταγωνιστικά ρεύματα κυκλοφορίας
Approach	Πρόσβαση
Automatic vehicle location system	Σύστημα αυτόματου εντοπισμού οχημάτων
Busbypass	Λωρίδαπαράκαμψηςλεωφορείου
Bus advance area	Περιοχήπροώθησηςλεωφορείου
Bus gate	Πύληλεωφορείου
Bus lane with intermittent priority	Λωρίδαλεωφορείουμε διακοπτόμενη προτεραιότητα
Bus-only road	Δρόμος μόνο για λεωφορεία
Busway	Λεωφορειόδρομος
Compatible traffic streams	Συμβατά ρεύματα κυκλοφορίας
Compensation	Αποζημίωση για παροχή προτεραιότητας
Conditional PTP strategy	Στρατηγική παροχής προτεραιότητας υπό όρους
Contra-flow bus lane	Λωρίδα λεωφορείου αντίθετη στο ρεύμα κυκλοφορίας
Coordinated signal control strategies	Στρατηγική συντονισμένου ελέγχου σηματοδότησης
Crossing area	Περιοχή διασταύρωσης
Cycle time	Περίοδος σηματοδότησης
Dedicated bus lane	Λωρίδα αποκλειστική κυκλοφορίας λεωφορείων
Differential PTP strategy	Στρατηγική παροχής προτεραιότητας υπό όρους
Dynamic Fairway	Δυναμική οδός
Early green	Ανάκληση σταδίου
Exclusive bus lane	Λωρίδα αποκλειστική κυκλοφορίας λεωφορείων
Facility-design-based PTP measures	Μέτρα παροχής προτεραιότητας βάση σχεδιασμού υποδομής
Fixed-time PTP strategy	Στρατηγική παροχής προτεραιότητας σταθερού χρόνου
Fixed-time signal control strategy	Στρατηγική ελέγχου φωτεινής σηματοδότησης σταθερού χρόνου
Global positioning system	Παγκόσμιο σύστημα εντοπισμού θέσης

Green extension	Παράταση χρόνου πράσινης ένδειξης
Green split	Σχετική διάρκεια χρόνων πρασίνου
Green time	Χρόνος πράσινης ένδειξης
Green wave	Πράσινο κύμα
Hierarchical signal control strategy	Ιεραρχική στρατηγική ελέγχου φωτεινής σηματοδότησης
High occupancy vehicle lane	Λωρίδα οχημάτων υψηλής πληρότητας
Inhibition	Αναστολή παροχής προτεραιότητας
Intergreen	Ενδιάμεσος χρόνος μεταξύ πράσινων ενδείξεων ή ενδιάμεσος χρόνος
Intermittent bus lane	Διακοπτόμενη λωρίδα κυκλοφορίας λεωφορείων
Isolated signal control strategy	Στρατηγική μεμονωμένου ελέγχου φωτεινής σηματοδότησης
Junction	Κόμβος
Local PTP strategy	Τοπική στρατηγική παροχής προτεραιότητας
Lost time	Απολυμένος ή χαμένος χρόνος
Mixed-traffic lane	Λωρίδας μεικτής κυκλοφορίας
Network-wide PTP strategy	Στρατηγική παροχής προτεραιότητας δικτύου
Off-line PTP strategy	Στρατηγική παροχής προτεραιότητας σταθερού χρόνου
Offset	Χρονική μετατόπιση
Optimisation-based PTP strategies	Στρατηγική παροχής προτεραιότητας με βελτιστοποίηση
Passive PTP strategy	Στρατηγική παροχής προτεραιότητας σταθερού χρόνου
Phase	Φάση
Pre signal	Προειδοποιητικός φωτεινός σηματοδότης
Proactive PTP strategies	Προβλεπτική στρατηγική παροχής προτεραιότητας σε μέσα μαζικής μεταφοράς
Queue Dissipation	Διάλυση ουράς οχημάτων
Queue jump	Προσπέραση ουρών
Queue jumper lane	Λωρίδα προσπέρασης ουρών
Reactive PTP strategy	Επενεργούμενη στρατηγική παροχής προτεραιότητας σε μέσα μαζικής μεταφοράς
Real-time PTP strategy	Στρατηγική παροχής προτεραιότητας σε πραγματικό χρόνο

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΕΚΠΑΙΔΕΥΣΗ ΚΑΙ ΔΙΑ ΒΙΟΥ ΜΑΘΗΣΗ
επένδυση στην κοινωνία της γνώσης
ΥΠΟΥΡΓΕΙΟ ΠΑΙΔΕΙΑΣ & ΘΡΗΣΚΕΥΜΑΤΩΝ, ΠΟΛΙΤΙΣΜΟΥ & ΑΘΛΗΤΙΣΜΟΥ
ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ

Recovery	Ανάκτηση συντονισμού
Red time	Χρόνος κόκκινης ένδειξης
Red truncation	Ανάκληση σταδίου σηματοδότησης
Retaken start	Επανέναρξη σταδίου
Reversiblebuslane	Αναστρέψιμη λωρίδα κυκλοφορίας λεωφορείων
Risingbollards	Ανερχόμενες κολόνες
Rule-based PTP strategy	Στρατηγική παροχής προτεραιότητας βασιζόμενη σε κανόνες
Saturationflow	Ροή κορεσμού
Selective vehicle detector	Επιλεκτικός ανιχνευτής οχημάτων
Signal cycle	Κύκλος σηματοδότησης
Signal staging	Διαχωρισμός σηματοδότησης σε στάδια
Signal-control-based PTP measures	Μέτρα παροχής προτεραιότητας βάση ελέγχου φωτεινής σηματοδότησης
Stage	Στάδιο
Stage recall	Ανάκληση σταδίου σηματοδότησης
Stage re-ordering	Αναδιάταξη σταδίων
Stage rotation	Περιστροφή σταδίων
Stage sequence	Διαδοχή σταδίων
Stage skipping	Παράλειψη σταδίου
Stop line	Γραμμή διακοπής πορείας
Traffic lane	Λωρίδα κυκλοφορίας
Traffic signal	Φωτεινός σηματοδότης
Traffic signal aspect	Όψη σηματοδότη
Traffic stream	Ρεύμα κυκλοφορίας
Traffic-responsive PTP strategy	Στρατηγική παροχής προτεραιότητας σε πραγματικό χρόνο
Traffic-responsive signal control strategy	Στρατηγική ελέγχου φωτεινής σηματοδότησης σε πραγματικό χρόνο
Transition	Μετάβαση σε συντονισμό
Unconditional PTP strategy	Στρατηγικήπαροχήςπροτεραιότηταςάνευόρων
Variable message sign	Πίνακας μεταβλητών μηνυμάτων
With-flow bus lane	Λωρίδα λεωφορείου παράλληλη στο ρεύμα κυκλοφορίας

Greek glossary of terms

Αναδιάταξη σταδίων (Stagere-ordering)	Μέθοδος παροχής προτεραιότητας κατά την οποία τροποποιείται η διαδοχή των σταδίων σηματοδότησης, δηλαδή ενεργοποιείται ένα στάδιο που έπεται, πριν από την κανονική του σειρά έτσι ώστε να εξυπηρετηθεί ένα αίτημα προτεραιότητας.
Ανάκλησησταδίου (Earlygreenήredtruncationήstagerecall)	Μέθοδος παροχής προτεραιότητας κατά την οποία πραγματοποιείται ανάκληση ενός σταδίου σηματοδότησης το συντομότερο δυνατό, σε περίπτωση που το μέσο μαζικής μεταφοράς φτάσει στον κόμβο στη διάρκεια του κόκκινου σήματος.
Ανάκτηση συντονισμού (Recovery)	Διαδικασία που χρησιμοποιείται μετά την παροχή προτεραιότητας για να ανακτήσει ο κόμβος, του οποίου η σηματοδότηση τροποποιήθηκε, το συντονισμό του με το υπόλοιπο δίκτυο.
Αναστολή παροχής προτεραιότητας (Inhibition)	Περιορισμός της συχνότητας με την οποία παρέχεται προτεραιότητα σε μέσα μαζικής μεταφοράς σε ένα κόμβο.
Αναστρέψιμη λωρίδα κυκλοφορίας λεωφορείων (Reversiblebuslane)	Λωρίδα κυκλοφορίας λεωφορείων η οποία χρησιμοποιείται προς τη μια κατεύθυνση για κάποιο τμήμα της ημέρας και προς την άλλη κατεύθυνση για κάποιο άλλο τμήμα.
Ανερχόμενες κολόνες (Risingbollards)	Ειδικές κολόνες οι οποίες παρεμποδίζουν τη γενική είσοδο οχημάτων σε κάποια περιοχή και κατεβαίνουν για να επιτρέψουν την είσοδο σε λεωφορεία ή άλλα οχήματα που χρήζουν προτεραιότητας.
Ανταγωνιστικά ρεύματα κυκλοφορίας (Antagonistictrafficstreams)	Ρεύματα κυκλοφορίας που δεν μπορούν να διασχίσουν ταυτόχρονα, με ασφάλεια, έναν κόμβο.
Αποζημίωση για παροχή προτεραιότητας (Compensation)	Παροχή περισσότερου χρόνου πρασίνου στα ανταγωνιστικά κυκλοφοριακά ρεύματα μετά την εξυπηρέτηση ενός αιτήματος παροχής προτεραιότητας.
Απολυμένος ή χαμένος χρόνος (Losttime)	Ο χρόνος ενός σταδίου που καταναλώνεται στις εκκινήσεις των οχημάτων, την εκκένωση του κόμβου από τα οχήματα και σε τυχόν περιόδους καθολικής κόκκινης ένδειξης.
Γραμμή διακοπής πορείας (Stopline)	Η διαγράμμιση στο σημείο μιας πρόσβασης πίσω από την οποία στοιχίζονται τα οχήματα όταν το κυκλοφοριακό ρεύμα της πρόσβασης βρίσκεται σε αναμονή.
Διαδοχή σταδίων (Stage sequence)	Η προκαθορισμένη κυκλική σειρά κατά την οποία διαδέχεται το ένα στάδιο το άλλο στη διάρκεια της περιόδου του κύκλου σηματοδότησης.
Διακοπτόμενη λωρίδα κυκλοφορίας λεωφορείων (Intermittentbuslane)	Λωρίδα κυκλοφορίας η οποία βρίσκεται στο δεξί τμήμα του δρόμου και μετατρέπεται σε λωρίδα αποκλειστικής χρήσης από λεωφορεία, μόνο όταν λεωφορείο κινείται σε αυτήν. Είναι εξοπλισμένη με ειδική φωτεινή σήμανση και

πίνακες μεταβλητών μηνυμάτων που ενημερώνουν τους οδηγούς για την τρέχουσα κατάσταση χρήσης της. Όταν ένα λεωφορείο εισέλθει στη λωρίδα αυτή, τα οχήματα που ήδη βρίσκονται εντός της δεν είναι υποχρεωμένα να αποχωρήσουν, αλλά δεν επιτρέπεται να εισέλθουν άλλα οχήματα μπροστά στο λεωφορείο. Όταν το λεωφορείο εξέλθει από τη συγκεκριμένη λωρίδα, αυτή παραδίδεται και πάλι στο σύνολο της κυκλοφορίας.

Διάλυση ουράς οχημάτων (QueueDissipation): Μέθοδος παροχής προτεραιότητας κατά την οποία δίνεται πράσινο στο στάδιο του κύκλου σηματοδότησης που εξυπηρετεί την κίνηση του μέσου μαζικής μεταφοράς, μέχρι αυτό να φτάσει στη στάση που μεσολαβεί μεταξύ της τρέχουσας θέσης του και του κόμβου. Στη συνέχεια δίνεται κόκκινο στο στάδιο αυτό, έτσι ώστε όσο το μέσο μαζικής μεταφοράς βρίσκεται στη στάση να εξυπηρετηθούν τα ανταγωνιστικά κυκλοφοριακά ρεύματα.

Διαχωρισμός σηματοδότησης σε στάδια (Signalstaging): Ο αριθμός, η σύνθεση και η διαδοχή των σταδίων σηματοδότησης ενός κόμβου.

Δρόμος μόνο για λεωφορεία (Bus-onlyroad): Δρόμος στον οποίο απαγορεύεται η είσοδος όλων των οχημάτων πλην λεωφορείων και ενδεχομένως άλλων οχημάτων που χρήζουν προτεραιότητας.

Δυναμική οδός (Dynamic Fairway): Παραλλαγή της διακοπτόμενης λωρίδας λεωφορείων. Βρίσκεται στη μέση του δρόμου και εξυπηρετεί τραμ.

Ενδιάμεσος χρόνος μεταξύ πράσινων ενδείξεων ή ενδιάμεσος χρόνος (Intergreen): Το σταθερό χρονικό διάστημα που παρεμβάλλεται ανάμεσα στο τέλος της πράσινης ένδειξης του σταδίου σηματοδότησης που τερματίζεται και της αρχής της πράσινης ένδειξης του επόμενου σταδίου, με στόχο να αποφευχθεί ενδεχόμενη εμπλοκή των ανταγωνιστικών ρευμάτων κυκλοφορίας των διαδοχικών σταδίων.

Επανέναρξη σταδίου (Retaken start): Μέθοδος παροχής προτεραιότητας κατά την οποία πραγματοποιείται επανέναρξη του σταδίου που εξυπηρετεί το μέσο μαζικής μεταφοράς που προσεγγίζει τον κόμβο, αν δεν έχει δοθεί ακόμα πράσινη ένδειξη για τα ανταγωνιστικά κυκλοφοριακά ρεύματα (δηλαδή κατά τη διάρκεια του ενδιάμεσου χρόνου).

Επενεργούμενη στρατηγική παροχής προτεραιότητας σε μέσα μαζικής μεταφοράς (ReactivePTPstrategy): Στρατηγική που χειρίζεται αιτήματα παροχής προτεραιότητας που λαμβάνει από μέσα μαζικής μεταφοράς την ώρα που αυτά προσεγγίζουν τον κόμβο στον οποίο αιτούνται προτεραιότητα.

Επιλεκτικός ανιχνευτής οχημάτων (Selectivevehicledetector): Σύστημα ανίχνευσης οχημάτων το οποίο έχει τη δυνατότητα να διακρίνει τον τύπο τους.

Ιεραρχική στρατηγική ελέγχου φωτεινής σηματοδότησης (Hierarchicalsignalcontrolstrategy): Στρατηγική ελέγχου που βασίζεται σε μια ιεραρχική δομή δυο τουλάχιστον επιπέδων. Στο ανώτερο επίπεδο λαμβάνονται αποφάσεις για το σύνολο του ελεγχόμενου οδικού δικτύου, ενώ στα κατώτερα επίπεδα λαμβάνονται αποφάσεις που αφορούν είτε σε μικρότερα τμήματα είτε και σε μεμονωμένους κόμβους βάσει των τοπικών

	κυκλοφοριακών συνθηκών.
Κόμβος (Junction)	Η συνάντηση δυο ή περισσότερων οδών.
Κύκλος σηματοδότησης (Signal cycle)	Μια πλήρης διαδοχή όλων των ενδείξεων των σηματοδοτών ενός κόμβου.
Λεωφορειόδρομος (Busway)	Πλήρως διαχωρισμένο τμήμα δρόμου στο οποίο κινούνται μόνο λεωφορεία και ενδεχομένως και άλλα οχήματα που χρήζουν προτεραιότητας.
Λωρίδα αποκλειστική κυκλοφορίας λεωφορείων (Dedicatedήexclusivebuslane)	Λωρίδα κυκλοφορίας στην οποία επιτρέπεται η κυκλοφορία λεωφορείων, καθώς και άλλων οχημάτων που χρήζουν προτεραιότητας.
Λωρίδα κυκλοφορίας (Traffic lane)	Τμήμα πρόσβασης που χρησιμοποιείται από οχήματα διατεταγμένα το ένα πίσω από το άλλο.
Λωρίδα λεωφορείου αντίθετη στο ρεύμα κυκλοφορίας (Contra-flowbuslane)	Λωρίδα κυκλοφορίας η οποία χρησιμοποιείται από λεωφορεία, τα οποία κινούνται σε κατεύθυνση αντίθετη από αυτή των υπολοίπων παράλληλα κινούμενων οχημάτων.
Λωρίδα λεωφορείου με διακοπτόμενη προτεραιότητα (Buslanewithintermittentpriority)	Λωρίδα κυκλοφορίας η οποία μετατρέπεται σε λωρίδα αποκλειστικής χρήσης από λεωφορεία, μόνο όταν λεωφορείο κινείται σε αυτήν. Είναι εξοπλισμένη με ειδική φωτεινή σήμανση και πίνακες μεταβλητών μηνυμάτων που ενημερώνουν τους οδηγούς να εξέλθουν από τη λωρίδα κατά την είσοδο του λεωφορείου σε αυτήν. Όταν το λεωφορείο εξέλθει από τη συγκεκριμένη λωρίδα, αυτή παραδίδεται και πάλι στο σύνολο της κυκλοφορίας. Αποτελεί παραλλαγή της διακοπτόμενης λωρίδας λεωφορείων.
Λωρίδα λεωφορείου παράλληλη στο ρεύμα κυκλοφορίας (With-flowbuslane)	Λωρίδα κυκλοφορίας η οποία χρησιμοποιείται από λεωφορεία, τα οποία κινούνται στην ίδια κατεύθυνση με αυτή των υπολοίπων παράλληλα κινούμενων οχημάτων.
Λωρίδα μεικτής κυκλοφορίας (Mixed-trafficlane)	Λωρίδα κυκλοφορίας η οποία μπορεί να χρησιμοποιηθεί από όλα τα οχήματα.
Λωρίδα οχημάτων υψηλής πληρότητας (Highoccupancyvehiclelane)	Λωρίδα κυκλοφορίας την οποία μπορούν να χρησιμοποιήσουν οχήματα στα οποία επιβαίνουν τουλάχιστον 2 επιβάτες.
Λωρίδα παράκαμψης λεωφορείου (Busbypass)	Τμήμα δρόμου το οποίο επιτρέπει σε λεωφορεία να παρακάμψουν τυχόν κυκλοφοριακή συμφόρηση που συναντούν στην πορεία τους.
Λωρίδα προσπέρασης ουρών (Queuejumperlane)	Μικρού μήκους λωρίδα κυκλοφορίας που χρησιμοποιείται για να δώσει την ευκαιρία στα μέσα μαζικής μεταφοράς να προσπεράσουν τα οχήματα που κινούνται παράλληλα με αυτά και να προπορευτούν κατά την κίνησή τους προς τον κόμβο. Σε πολλές περιπτώσεις η χρήση της συνδυάζεται με προειδοποιητικούς φωτεινούς σηματοδότες.

Μετάβαση σε συντονισμό (Transition) — Διαδικασία που χρησιμοποιείται μετά την παροχή προτεραιότητας για να ανακτήσει ο κόμβος, του οποίου η σηματοδότηση τροποποιήθηκε, το συντονισμό του με το υπόλοιπο δίκτυο. Μοιάζει με την διαδικασία ανάκτησης συντονισμού με τη διαφορά ότι η μετάβαση επιστρέφει τον κόμβο σε συνθήκες συντονισμού με πιο ομαλό τρόπο από ότι στην ανάκτηση.

Μέτρα παροχής προτεραιότητας βάση σχεδιασμού υποδομής (Facility-design-basedPTPmeasures) — Μέτρα τα οποία προσπαθούν να ευνοήσουν την κίνηση των μέσων μαζικής μεταφοράς,βασιζόμενα στον κατάλληλο σχεδιασμό των υποδομών του οδικού δικτύου.

Μέτρα παροχής προτεραιότητας βάση ελέγχου φωτεινής σηματοδότησης (Signal-control-basedPTPmeasures) — Μέτρα τα οποία προσπαθούν να ευνοήσουν την κίνηση των μέσων μαζικής μεταφοράς, βασιζόμενα σε κατάλληλες ρυθμίσεις της φωτεινής σηματοδότησης.

Όψησηματοδότη (Traffic signal aspect) — Τμήμα του σηματοδότη που ελέγχει μια ή περισσότερες κινήσεις προς μια κατεύθυνση.

Παγκόσμιο σύστημα εντοπισμού θέσης (Globalpositioningsystem) — Σύστημα το οποίο έχει τη δυνατότητα να παρέχει ακριβείς πληροφορίες για τη θέση ενός σημείου, το υψόμετρό του, την ταχύτητα και την κατεύθυνση της κίνησής του.

Παράλειψη σταδίου (Stage skipping) — Μέθοδος παροχής προτεραιότητας κατά την οποία επιτρέπεται η παράλειψη κάποιου/ων σταδίου/ίων από την κανονική διαδοχή με στόχο ένα αίτημα για προτεραιότητα να ικανοποιηθεί το συντομότερο δυνατό.

Παράταση χρόνου πράσινης ένδειξης (Greenextension) — Μέθοδος παροχής προτεραιότητας κατά την οποία επεκτείνεται ο χρόνος πράσινης ένδειξης σε περίπτωση που το μέσο μαζικής μεταφοράς αναμένεται να φτάσει στον κόμβο στο τέλος της διάρκειας του πρασίνου.

Περίοδος σηματοδότησης (Cycle time) — Η χρονική διάρκεια του κύκλου σηματοδότησης.

Περιοχή διασταύρωσης (Crossing area) — Περιοχή του κόμβου στην οποία διασταυρώνονται οι προσβάσεις του.

Περιοχή προώθησης λεωφορείου (Busadvancearea) — Τμήμα δρόμου το οποίο επιτρέπει σε λεωφορεία να παρακάμψουν οχήματα που συναντούν στην πορεία τους.

Περιστροφή σταδίων (Stage rotation) — Μέθοδος παροχής προτεραιότητας κατά την οποία περιστρέφεται η διαδοχή των σταδίων σηματοδότησης έτσι ώστε ένα αίτημα προτεραιότητας να εξυπηρετηθεί το συντομότερο δυνατό.

Πίνακας μεταβλητών μηνυμάτων (Variablemessagesign) — Πρόκειται για ηλεκτρονικό πίνακα που χρησιμοποιείται στα οδικά δίκτυα για να παρέχει στους ταξιδιώτες πληροφορίες, προειδοποιήσεις κ.λπ.

Πράσινο κύμα (Green wave) — Η δημιουργία μιας συνεχούς ροής οχημάτων χωρίς διακοπή λόγω κόκκινης ένδειξης κατά μήκος μιας οδού που περιλαμβάνει μια σειρά από κόμβους οι οποίοι ελέγχονται με φωτεινούς σηματοδότες.

Προβλεπτική στρατηγική παροχής προτεραιότητας σε μέσα μαζικής μεταφοράς (ProactivePTPstrategies)	Στρατηγική που χειρίζεται αιτήματα παροχής προτεραιότητας που λαμβάνει από μέσα μαζικής μεταφοράς αρκετή ώρα πριν αυτά να προσεγγίσουν τον κόμβο στον οποίο αιτούνται προτεραιότητα.
Προειδοποιητικός φωτεινός σηματοδότης (Presignal)	Φωτεινός σηματοδότης που χρησιμοποιείται για να κρατήσει τα ιδιωτικά οχήματα σε απόσταση από ένα κόμβο ώστε να δώσει την ευκαιρία στα μέσα μαζικής να προπορευτούν κατά την πορεία τους προς αυτόν.
Πρόσβαση(Approach)	Οδός που προσεγγίζει κόμβο. Μπορεί να περιλαμβάνει μια ή περισσότερες λωρίδες κυκλοφορίας, έχει όμως μια μοναδική και ανεξάρτητη ουρά οχημάτων.
Προσπέραση ουρών (Queue jump)	Μέθοδος παροχής προτεραιότητας κατά την οποία δίνεται πράσινο στο μέσο μαζικής μεταφοράς πριν από τα άλλα οχήματα που κινούνται παράλληλα με αυτό έτσι ώστε να τα προσπεράσει και να προπορευτεί κατά την κίνησή του προς τον κόμβο.
Πύλη λεωφορείου (Busgate)	Υποδομή η οποία χρησιμοποιείται για να επιτρέψει την είσοδο εντός συγκεκριμένης περιοχής, μόνο σε λεωφορεία, μέσω φωτεινών σηματοδοτών ή άλλου είδους σήμανσης.
Ρεύμα κυκλοφορίας (Traffic stream)	Ροή οχημάτων που χρησιμοποιεί μια πρόσβαση.
Ροή κορεσμού (Saturationflow)	Η μέγιστη κυκλοφοριακή ροή που διέρχεται από τη γραμμή διακοπής πορείας μιας πρόσβασης, όταν το αντίστοιχο κυκλοφοριακό ρεύμα έχει προτεραιότητα, η ανάντη ζήτηση ή άλλως η ουρά των οχημάτων που βρίσκονται σε αναμονή για να διασχίσουν τον κόμβο είναι αρκούντως μεγάλη και οι κατάντη οδοί δεν είναι φραγμένες από ουρές οχημάτων.
Στάδιο (Stage)	Το τμήμα της περιόδου κατά το οποίο ένα σύνολο φάσεων λαμβάνει ταυτοχρόνως πράσινο, δηλαδή δίνεται προτεραιότητα σε ένα ή περισσότερα συμβατά ρεύματα κυκλοφορίας σε έναν κόμβο.
Στρατηγική ελέγχου φωτεινής σηματοδότησης σε πραγματικό χρόνο (Traffic-responsivesignalcontrolstrategy)	Στρατηγική η οποία χρησιμοποιεί μετρήσεις από τις τρέχουσες κυκλοφοριακές συνθήκες, για να υπολογίσει σε πραγματικό χρόνο κατάλληλες ρυθμίσεις για τους φωτεινούς σηματοδότες.
Στρατηγική ελέγχου φωτεινής σηματοδότησης σταθερού χρόνου (Fixed-timesignalcontrolstrategy)	Πρόκειται για σταθερά πλάνα σηματοδότησης που αναπτύσσονται βάσει ιστορικών μετρήσεων σταθερής ζήτησης και ποσοστών στροφής για τα διαφορετικά κυκλοφοριακά ρεύματα και εφαρμόζονται σε συγκεκριμένες χρονικές περιόδους της ημέρας.
Στρατηγική μεμονωμένου ελέγχου φωτεινής σηματοδότησης (Isolatedsignalcontrolstrategy)	Στρατηγική που λαμβάνει αποφάσεις ελέγχου μεμονωμένα για κάθε κόμβο λαμβάνοντας υπόψη μόνον τις τοπικές κυκλοφοριακές συνθήκες.
Στρατηγική παροχής προτεραιότητας	Στρατηγική η οποία παρέχει προτεραιότητα σε όλα τα μέσα

άνευ όρων (UnconditionalPTPstrategy)	μαζικής μεταφοράς ανεξάρτητα από την κατάστασή τους, ανεξάρτητα δηλαδή από το αν χρειάζονται ή όχι ειδική μεταχείριση.
Στρατηγική παροχής προτεραιότητας βασιζόμενη σε κανόνες (Rule-basedPTPstrategy)	Στρατηγική της οποίας οι αποφάσεις για παροχή προτεραιότητας σε μέσα μαζικής μεταφοράς βασίζονται σε ένα σύνολο κριτηρίων.
Στρατηγική παροχής προτεραιότητας δικτύου (Network-widePTPstrategy)	Στρατηγική που παρέχει προτεραιότητα σε μέσα μαζικής μεταφοράς τροποποιώντας συντονισμένα τη φωτεινή σηματοδότηση ενός συνόλου κόμβων.
Στρατηγική παροχής προτεραιότητας με βελτιστοποίηση (Optimisation-basedPTPstrategies)	Στρατηγική της οποίας οι αποφάσεις για παροχή προτεραιότητας σε μέσα μαζικής μεταφοράς βασίζονται στη βελτιστοποίηση ενός κατάλληλα ορισμένου δείκτη απόδοσης.
Στρατηγική παροχής προτεραιότητας σε πραγματικό χρόνο (Active ή real-time ή traffic-responsivePTPstrategy)	Στρατηγική που παρέχει προτεραιότητα σε μέσα μαζικής μεταφοράς ανταποκρινόμενη σε ανάγκες που ανιχνεύονται σε πραγματικό χρόνο.
Στρατηγική παροχής προτεραιότητας σταθερού χρόνου (Fixed-timeήoff-lineή passivePTPstrategy)	Πρόκειται ουσιαστικά για σταθερά πλάνα σηματοδότησης σχεδιασμένα έτσι ώστε να ευνοούν τις κινήσεις των μέσων μαζικής μεταφοράς.
Στρατηγική παροχής προτεραιότητας υπό όρους (Conditionalή differentialPTPstrategy)	Στρατηγική η οποία παρέχει προτεραιότητα σε μέσα μαζικής μεταφοράς μόνον εφόσον πληρούνται κάποιοι όροι (π.χ. το όχημα που αιτείται την προτεραιότητα είναι καθυστερημένο).
Στρατηγική συντονισμένου ελέγχου σηματοδότησης (Coordinatedsignalcontrolstrategies)	Στρατηγική που λαμβάνει αποφάσεις ελέγχου συνολικά για ένα τμήμα δικτύου ή και όλο το δίκτυο βάσει των συνολικών κυκλοφοριακών συνθηκών που επικρατούν σε αυτό.
Συμβατά ρεύματα κυκλοφορίας (Compatible traffic streams)	Κυκλοφοριακά ρεύματα που μπορούν να διασχίσουν ταυτόχρονα και με ασφάλεια έναν κόμβο.
Σύστημα αυτόματου εντοπισμού οχημάτων (Automaticvehiclelocationsystem	Σύστημα το οποίο έχει τη δυνατότητα να εντοπίζει αυτόματα τη γεωγραφική θέση ενός οχήματος.
Σχετική διάρκεια χρόνων πρασίνου (Greensplit)	Η σχετική διάρκεια του πράσινου κάθε σταδίου σηματοδότησης, ως ποσοστό της περιόδου σηματοδότησης.
Τοπική στρατηγική παροχής προτεραιότητας (LocalPTPstrategy)	Στρατηγική που παρέχει προτεραιότητα σε μέσα μαζικής μεταφοράς τροποποιώντας τη φωτεινή σηματοδότηση ενός μεμονωμένου κόμβου.
Φάση (Phase)	Το σύνολο των ρευμάτων κυκλοφορίας οχημάτων που ελέγχονται από μια μοναδική όψη σηματοδότη.
Φωτεινός σηματοδότης(Traffic signal)	Ο εξοπλισμός που χρησιμοποιείται για τον έλεγχο της κυκλοφορίας οχημάτων και πεζών σε κόμβους.

Ευρωπαϊκή Ένωση
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ΕΙΔΙΚΗ ΥΠΗΡΕΣΙΑ ΔΙΑΧΕΙΡΙΣΗΣ
ΕΣΠΑ 2007-2013
πρόγραμμα για την ανάπτυξη
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

Χρονική μετατόπιση (Offset)	Το χρονικό διάστημα μεταξύ ενός χρονικού σημείου αναφοράς και της πρώτης εμφάνισης της πράσινης ένδειξης σε μια από τις όψεις ενός σηματοδότη. Χρησιμοποιείται σε περίπτωση συντονισμένου ελέγχου μιας σειράς κόμβων για τη δημιουργία πράσινου κύματος.
Χρόνος κόκκινης ένδειξης (Redtime)	Το χρονικό διάστημα κατά το οποίο η όψη ενός σηματοδότη εμφανίζει την κόκκινη ένδειξη.
Χρόνος πράσινης ένδειξης (Greentime)	Το χρονικό διάστημα κατά το οποίο η όψη ενός σηματοδότη εμφανίζει την πράσινη ένδειξη.