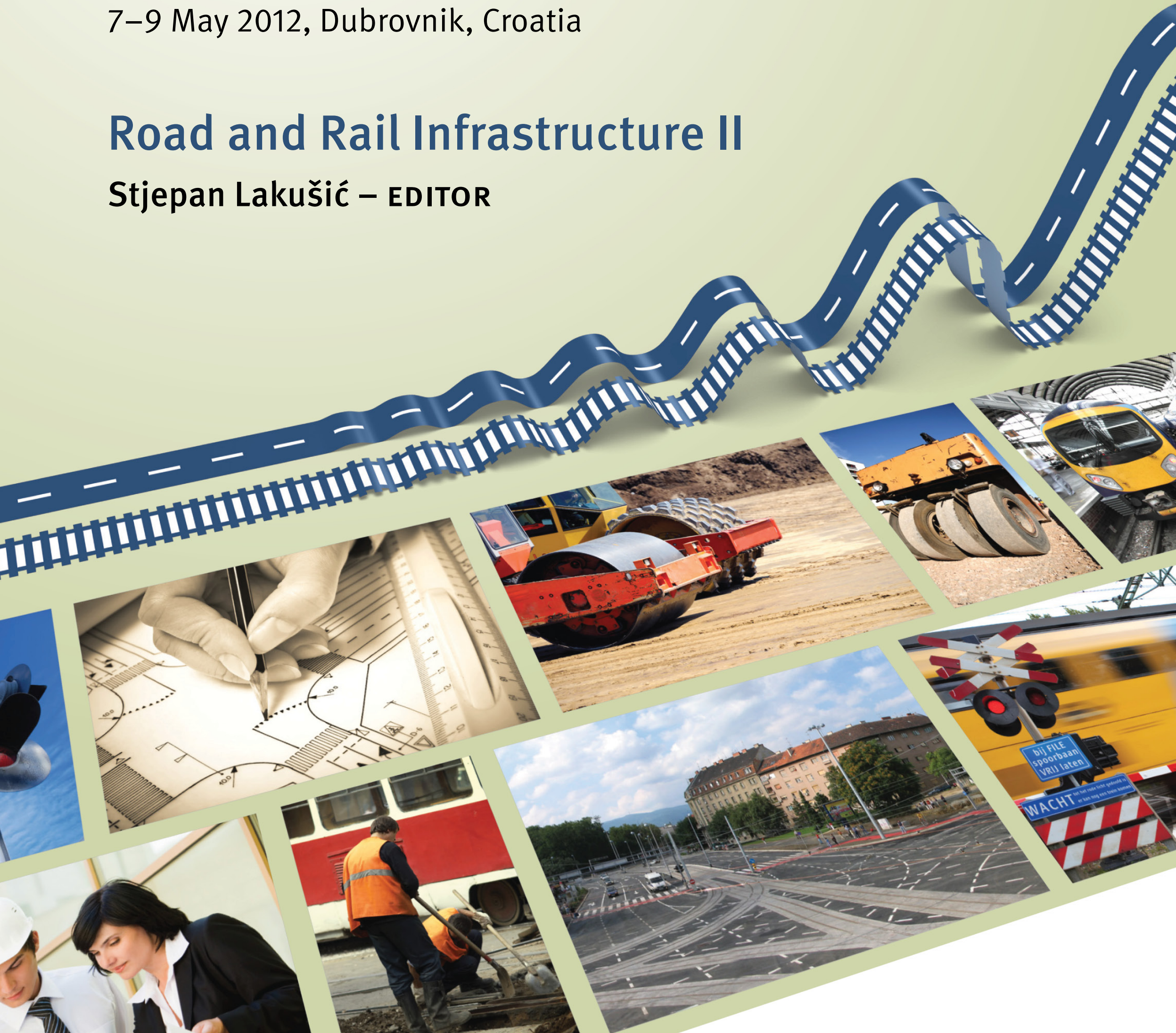
CETRA 2012

2nd International Conference on Road and Rail Infrastructure

7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA 2012
2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

TITLE
Road and Rail Infrastructure II, Proceedings of the Conference CETRA 2012

EDITED BY
Stjepan Lakušić

ISBN
978-953-6272-50-1

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Katarina Zlatec · Matej Korlaet

COPIES
600

A CIP catalogue record for this e–book is available from the National and University Library in Zagreb under 805372

Proceedings of the
2nd International Conference on Road and Rail Infrastructures – CETRA 2012
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Road and Rail Infrastructure II

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2nd International Conference on Road and Rail Infrastructure

THE IMPACT OF THE IMPLEMENTATION OF GREEN WAVE IN THE TRAFFIC LIGHT SYSTEM OF A TRAMWAY LINE –THE CASE OF ATHENS TRAMWAY

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Abstract

One of the key parameters, which determine the quality of service provided to the users of a tramway system, is travel time. The duration of travel and therefore the resulting commercial speed depend on the type of tram corridors, the length per corridor type, the distance between successive stops and the priority given to the tram at road and pedestrian crossings controlled by traffic lights. This paper focuses on the investigation of the impact of the green wave implementation in the signalling system of a tramway line. In this framework a) the different signalling systems adopted in tramway networks all over the world are described as well their impact on travel duration is analysed and compared b) the impact of giving priority to tram at traffic lights, on its commercial speed and for different scenarios of corridor typology, is examined, using empirical mathematical formula c) moreover, the recent implementation of the green wave policy in Athens' tramway system is examined and its impact on travel duration is evaluated, based both on in situ collected data and on international standards. According to the results of this work, a) if priority is given to the tram at traffic lights then the duration of travel can be reduced by 5%–35 %, b) Athens tram system has achieved reduction of travel time up to 19% regarding the different track sections of the network c) further reduction in travel times in Athens tram system can be achieved by additional interventions, regarding the signalling system, the type and the protection of corridors and the distance between stops.

Keywords: tram signalling system, Athens tramway, green wave; commercial speed

1 Introduction

One of the key parameters that determine the quality of service provided to the users of a tramway system is travel time. Short duration of travel makes tram much more attractive to the passengers and contributes to the increase of its potential patronage. The duration of travel and consequently the commercial speed of the trains depend on many parameters and mainly on the type of tram corridors, the length per type, the distance between successive stops and the traffic signalling system, along the tram corridor and at road and pedestrian crossings. (Commercial speed is defined as the quotient of covering distance towards total travel time, including delays and waiting time at stops).

This paper focuses on one of the above parameters. More, specifically, it investigates the impact of giving priority to trams at traffic lights, on travel time and on commercial speed achieved along a line. In this framework, this paper:

- Attempts to quantify the increase of commercial speed which can potentially result from giving priority to trams at traffic lights. This effort is based on data from different tramway networks and on empirical mathematical formulas.

- Investigates the interventions recently implemented in the signalling system of Athens' tramway network and evaluates them by comparing recent with previous travel times.
- Quests and proposes additional measures that can contribute to a further increase of commercial speed recorded in Athens' tramway network.

At this point, it should be mentioned that Athens' tramway network started its commercial operation in the summer of 2004 and it renders transport services in the city of Athens and in a broader area, in combination with metro, trolley and urban buses. However, a part of potential users of Athens' tramway network are not satisfied with offered service level. They declare that the major cause is the low commercial speed and therefore long travel time.
In July 2010 a study proposing changes in the signalling system of the tramway of Athens was released. These changes aim to give priority to trams relative to road vehicles during their passage through signalling intersections. These changes were completed in winter 2011.

2 Tramway signalling system basic principles

The basic principles of tram signalling systems are that a) priority at traffic signal locations should be given to trams and b) at level crossings; there should be collaboration between the different signalling systems intended for trams, road vehicles and pedestrians.
Referring to traffic lights priority for trams, there are two strategies:

- Passive Traffic Signal Priority: In these systems, traffic lights are set to turn green based on an average tram speed. In other words, the detection of a tram at crossings with traffic lights is not necessary. Priority is given by a standard procedure: favourable cycle time – favourable green time at each phase of the cycle time – coordination.
- Activate Traffic Signal Priority: In this strategy, the approaching tram sends a signal to the traffic signal controller to change in predefined limits the signal in its favour. The traffic signal priority is more effective than the passive traffic signal priority, as it is based on a dynamic response to a transit request.

There are four types of activate traffic signal priority systems: [1], [2], [3].

- Dedicated Priority – Phasing Changes
- Longer Green Time
- Phase and Timing Adjustment
- Intelligent Transport Systems Approaches

Collaboration among traffic signalling systems is extremely necessary, as a lack of coordination can result in delays for other vehicles. The frequency of interruption of signalling in favour of trams affects the recovery time of a signalized intersection.

3 Quantification of signalling impacts on travel time and on commercial speed of trams

3.1 Estimation of the impact of giving priority to trams at traffic lights based on data from different tramway networks

Table 1 gives, indicatively, different signalling systems adopted in tramway networks all over the world and their impact on travel time of both trams and the rest involved traffic.

Table 1 Tram signalling systems and their impact on traffic [4]

Signaling system– Place of implementation	Strategies of giving priority to trams	Impact
BALANCE – Munich	Phasing changes– Longer green time	Reduction of travel time by up to 14% for both trams and the rest traffic
UTOPIA –Torino	Improvement based on existing traffic conditions	Reduction of trams' travel time in the range of 15%–25%
SPOT–Gutenberg, Europe, USA	Giving priority to trams using algorithms that don't take into account traffic congestion.	Reduction of trams' travel time in the range of 5%–15% – No impact on other public transport vehicles
TUC–Southampton, Tel Aviv, Jerusalem	Maintenance of phases and timing– Maintenance of phases – Phase and timing adjustment	Reduction of trams' travel time by up to 33.3%
SCATS–Melbourne	Combination of activate and passive traffic signal priority	Reduction of trams' travel time in the range of 6%–10%. Reduction of 1%–7% for the rest traffic
Stuttgart	Longer green time–Full priority	Reduction of trams' travel time by up to 50% and short delays on the rest traffic
Zurich	Priority by detection of the approaching tram B	Minimization of trams' delays at signalized intersections

3.2 Estimation of commercial speed using empirical mathematical formula

Table 2 (columns 1, 2, 3) gives the commercial speeds of a tramway for different types of tram corridors, as they resulted empirically from both measurements and the following assumptions: [5], [6]

- The average distance between two successive tram stops is 500m.
- The average time of stopping at each stop for passenger embarkment and disembarkment is 20 sec.
- No priority is given to trams at traffic lights.

The commercial speed is calculated on the basis of equations (1) and (2):

$$I_E / V_E + l_D / V_D + I_C / V_C + l_{B-} / V_{B-} + l_B / V_B + I_A / V_A = t \quad (1)$$

$$V_{com} = S / t \quad (2)$$

Where S is total routing length; t is total routing travel time, V_{com} is commercial speed; l_E, l_D, l_C, l_{B-}, l_B, l_A represent length of track section with type of corridor corresponding to E, D, C, B-,B, A; V_E, V_D, V_C, V_{B-},V_B, V_A represent commercial speed corresponding to corridors of category E, D, C, B-,B and A.

Table 2 Commercial speed for different types of tram corridors (with and without priority to trams at traffic lights) [5], [6]

Name of tram corridors	Type	Commercial speed (without priority at traffic lights) (km/h)	Commercial speed (km/h) resulted from priority to trams at the traffic lights (+15%)	Commercial speed (km/h) resulted from priority to trams at the traffic lights (+25%)
(1)	(2)	(3)	(4)	(5)
Common	E	12–15	12–15	12–15
Separated corridor	D	17.5	20.125	21.875
Exclusive tram corridor	C	18–20	18–20	18–20
Reserved protected corridor with degraded characteristics of separation	B-	18.5	21.275	23.125
Reserved protected corridor	B	20	23	25
Fully exclusive corridor	A	30	30	30

3.3 Estimation of the impact of giving priority to trams at traffic lights based on a combination of 3.1 and 3.2

Based on the data in table 2, it can be easily concluded that a travel time reduction in the range of 5%–35% can be achieved by giving priority to trams at traffic lights. This reduction corresponds to an increase of the trams' commercial speed in the range of 5.26%–53.8%. According to other researches, the commercial speed of a tramway can increase by up to 35% by giving priority to trams at signalized intersections.
Taking into account these data, a 15%–25% increase in commercial speed seems to be a reasonable expectation. Table 2 (columns 4 and 5) gives the commercial speed, determined empirically, after having considered that the tram is given priority at traffic lights on types B-, B and D of tram corridors. (At trams running on types E and C cannot be given priority, whereas priority is given on type A, as the trams run on a completely exclusive corridor.) [5], [6]

4 The impact of giving priority to Athens' tramway system

4.1 Network's condition before signalling changes

The tramway network of Athens has a T formation [7], [8]. It connects the centre of Athens (Syntagma) with Paleo Faliro, via Nea Smyrni and it branches off along the Seaside Avenue towards Alimo, Elliniko ,Glyfada and Voula on one side and towards Faliriko Delta and Neo Faliro (SEF) on the other. Athens' tramway network has a total length of 24.260 km and includes the following 3 lines:

- Line 3 (Thoukydidis): SEF–Voula – length 15.964 km with 31 tram stops
- Line 4 (Aristotelis): SEF–Syntagma – length 14.155 km with 28 tram stops
- Line 5 (Platonas): Syntagma–Voula – length 18.474 km with 37 tram stops

Lines 4 and 5 include a common section: 'Syntagma– Mousson'. This section crosses densely populated areas, while the 'SEF– Voula' section runs near (or along) the Saronic Gulf Coast [7], [8].

Table 3 gives the length of each type of tram corridor for the whole network and table 4 gives length, types of tram corridors, travel time and commercial speed for the 3 lines and for 3 sections of the tramway network. The data in table 4 resulted from measurements taken in March 2010 (tram was given priority at 15 out of 81 signalized intersections). In addition to the data in tables 3 and 4 data, it is notable that:

- It was planned that tram would run on the type B tram corridor (reserved and protected) along the L. Vouliagmenis–Mousson section. However, this does not happen because pedestrians encroach upon the tram corridor. This problem is also noted on the SEF– Voula route, but to a smaller extent.
- The average distance between two successive stops is 516 m, but there are successive stops placed at a shorter distance (383 m), mainly in sections in urban area (the L. Vouliagmenis–Mouson section)
- There are 264 points where the tram intersects with pedestrian or vehicular flows. The tram should pass through these intersections carefully and at a low speed. Even if these intersections coincide to a large extent with pedestrian crossings, and even if these points are reduced to 120, the tram encounters difficult points along its route, or difficult points of intersection with other vehicles or with pedestrians, every 200 m on average.
- Commercial speed in the Syntagma–Mouson section is 14.39 km/h (8.5% of the total length is tram corridor type E, 11.2% of the total length is tram corridor type D, 55.7% is type B-, and 24.6% is type B). According to equations 1 and 2 and table 2, commercial speed could potentially increase to 20.52 km/h, supposing that priority is given to the tram at all signalized intersections (this represents a 15% increases in commercial speed). On the contrary, in coastal section SEF–Voula, the commercial speed is at about 23.2 km/h, and this is regarded as satisfactory (44% of the total length is tram corridor type B- and 56% of the total length is tram corridor type B). Assuming that priority to the tram increases commercial speed by 25% the speed could potentially increase to 24.18 km/h.

Table 3 Athens' tramway network – Length of each type of tram corridor [9]

Corridor type	E	D	B-	B	Total
Length (m)	710	930	11,640	10,980	24,260
Percentage %	2.9 %	3.8 %	48.0%	45.3	100%

Table 4 Travel time and commercial speed in sections of Athens' tramway network (March 2010) [9]

Line/ section	**Length (km)**	**Type of tram corridor**	**Travel time (min)**	**Commercial speed (km/h)**
Line 4: Syntagma– SEF	14.155	B,B- ,D ,E	50.1	16.95
Line 5 : Syntagma–Voula	18.474	B,B- ,D ,E	62.4	17.76
Line 3 : SEF–Voula	15.964	B , B-	41.3	23.19
Section Syntagma–L. Vouliagmenis	1.548	D , E	7.0	13.26
Section L. Vouliagmenis–Mouson	6.513	B, B- , D	26.6	14.69
Section Syntagma–Mouson	8.061	B,B- ,D ,E	33.6	14.39

4.2 Network's condition after changes to the signalling system

Following changes in signalling, trams are given priority at 73 out of 81 signalized intersections. The intersections where changes in signalling were implemented are primarily in urban area (Syntagma–Mouson section). Moreover, changes regarding the distance of the tram's detection and the distance of the priority requests have been made, and many technical problems of intersections have been addressed. The signaling system of Athens' tramway network is a combination of Balance system (Munich) and of the system applied in Stuttgart. In August 2011, measurements of the travel time of 12 routes (these 12 routes pertain to 3 lines of tramway network) were taken. The purpose of these measurements was to pin point the impact of signalling changes on travel time and on commercial speed. New travel time has been compared with the travel time measurements of March 2010. Table 5 gives the results of this comparison, which refer to both travel time and commercial speed.
There is a reduction in travel time at all sections. The largest reduction (18.87%) is recorded in the urban area (Syntagma–Mouson section), and the smallest reduction (5.25%) is recorded on the SEF–Voula line. Likewise, there is an increase in commercial speed – increases of 15%–18% were noted on lines 4 and 5, where the tram runs through the urban area, whereas commercial speed has increased by 5.52% on line 3: SEF–Voula (coastal section). An increase of 23.28% has been recorded for the urban Syntagma–Mouson section.

Table 5 Comparison of travel time and commercial speed on lines and sections of Athens' tramway network– March 2010/ August 2011

Line/ section	Travel time (min) (March 2010–without priority)	Travel time (min) (August 2011–with priority)	Variation according to March 2010	Com. Speed (km/h) (March 2010–without priority)	Com. Speed (km/h) (August 2011–with priority)	Variation according to March 2010
Syntagma–SEF	50.1	42.4	-15.36%	16.95	20.03	+18.17%
Syntagma–Voula	62.4	54.3	-12.91	17.76	20.39	+14.80%
SEF–Voula	41.3	39.1	-5.25%	23.19	24.47	+5.52%
Syntagma–Vouliagmenis	7.0	6.1	-12.43%	13.26	15.15	+14.25%
Vouliagmenis–Mouson	26.6	21.1	-20.56%	14.69	18.49	+25.86%
Syntagma–Mouson	33.6	27.3	-18.87%	14.39	17.74	+23.28%

4.3 Additional interventions for the increase of commercial speed

The latest data of commercial speed on the SEF–Voula route, as recorded in table 5, seem to be satisfactory. On the contrary, commercial speed should increase on the Syntagma–Mouson route. The suggested interventions for additional improvements to the service level provided to the users of the Athens' tramway system are as follows:

1 Completion of the implementation of giving priority to tram at all signalized junctions. This measure will reduce travel time on the Syntagma–Mouson section by up to 1 minute.
2 Reduction of the number of stops on the L. Vouliagmenis – Mouson route is advisable.
3 Ensuring of the operation of corridors where trams run, according to the typology for which they are planned to operate (convention of type B- tram corridor to tram corridor of type B).
4 Construction of a separated and protected tram corridor along the Syntagma–Mouson section (convention of type D tram corridor to tram corridor of type B). – Interventions 3

and 4 would likely reduce travel time by up to 5 minutes.
5 Better marking of the tram's presence.
If these interventions are implemented, commercial speed on the Syntagma–Mouson section would increase from 17.74 km/h to 21.70 km/h

5 Conclusions

The conclusions resulting from this study regarding the signalling system of a tramway network generally, and the signalling system of Athens' tramway network specifically, are the following:

- There are many different signalling systems that are adopted in tramway networks all over the world that give priority to trams vis–à–vis other vehicles during their passing through signalized intersections. According to the data of examined systems, giving priority to trams at traffic lights can increase commercial speed by 5% to 50%. An increase of 15%–25% seems to be realistic.
- The strategy of giving priority at signalized intersections to the trains of Athens' tramway network resulted in a reduction of travel time in all sections. The largest reduction (18.87%) is recorded in the urban area (Syntagma–Mouson section), and the smallest reduction (5.25%) is recorded on the SEF–Voula line. Correspondingly, the increase of commercial speed is up to 23.28% (from 14.39 km/h to 17.74 km/h) on the Syntagma–Mouson section and up to 5.52% (from 23.19 km/h to 24.47km/h) on the SEF–Voula line.
- Additional interventions can further increase commercial speed in urban area.

The results of this paper determine the actual operational capabilities of Athens' tramway network and define the framework for their achievement. Users of urban transport in Athens should be aware of these capabilities in order to encourage tram use over other transport means.

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