International Journal of Railway Research, Vol. 2, No. 2, (2015), 9-17

Iran University of Science and Technology

International Journal of

Railway Research

ISSN: 2423-3838

# Investigation of Parameters Affecting the Travel Time at Tramway Systems: The Case of Athens, Greece

**Christos Pyrgidis [1*], Martha Chatziparaskeva [2], Ioannis Politis [3]**

[1,2,3]Aristotle University of Thessaloniki, Department of Civil Engineering, Thessaloniki, Greece

**ARTICLE INFO**

**Article history**:
Received: 12.01.2015
Accepted: 14.03.2015
Published: 30.06.2015

**Keywords**:
Tramway system
Commercial speed
Reliability
Regression model

**A B S T R A C T**

Within the framework of this paper, various parameters that may affect the efficiency and the reliability of a tramway system are examined. Two linear regression models are built in order to investigate the way these parameters are affecting the commercial speed and the travel time deviation, respectively. The case study is the tramway of Athens which operates since the 2004 Olympic Games. Although numerous interventions have been made in order to improve the provided level of service of the system, a lot of debate among transportation engineers and the users of the system is active. The analysis showed that the most important parameter that affects the commercial speed of the tramway is the corridor type. Other important parameters that can significantly contribute on the increase of the commercial speed are the number of signals, the number of narrow curves and the dwell time at stops. On the other hand, the reliability of the system, defined as the difference between the actual versus the scheduled travel time, was found to be statistically affected by parameters which are related most with the track layout such as the number of narrow curves, the length of inclined segments etc.

## 1. Introduction

One of the key parameters, which 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 therefore the resulting commercial speed depend on different constructional and operational parameters of the system such as: the type of tram corridors, the length per corridor type, the distance between successive stops, the priority given to the tram at road and pedestrian crossings controlled by traffic lights, the track alignment, the driving ability, the time needed for the boarding and alighting of the passengers etc.

Within the framework of this paper, an investigation of the importance of the above mentioned parameters on the travel time is performed. The case study of the analysis is the tramway system of the capital of Greece, Athens.

In July 2010, a study proposing changes in the signaling system of the tramway of Athens was released. These changes aimed to give priority to trams relative to road vehicles during their passage through signaling intersections. These changes were completed in winter 2011. 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.

[*] Professor, Corresponding author
Email address: chpyrgidis@hermes.civil.auth.gr

[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

For the purpose of the research, on site observations carried out along the lines and various parameters potentially affecting the efficiency and the reliability of the tramway system were recorded. Nominal and continuous variables were used as independent variables at two regression models where the dependent variables pertained to be the reliability and the commercial speed. All of data were coded per segment, for the previous stop "i" to the next stop "j", whereas;

a) The reliability was calculated as the time difference (deviation) between the performed and the scheduled travel time at stop "j" and

b) The commercial speed corresponds to the speed per segment in km/h and is calculated by dividing the length of the segment (from stop i to stop j) by the total travel time needed to run this segment (departure time from stop j minus departure time from stop i, including the dwell time at stop j).

Both stepwise and forward regression models were developed in order to find the most appropriate and robust relationship between the examined independent parameters and the depended variables.

The application of the model can give important outcomes regarding the effect that the examined parameters can have on travel time reliability and efficiency of a tramway system.

## 2. Parameters affecting travel time/commercial speed

Travel time and consequently commercial speed of a tramway system depend on many parameters, which affect them at a greater or at a smaller extent. The most important of these parameters are the following:

### Type of tram corridor

Tram has the ability to run on six different types of corridors: A, B, B-, C, D and E. The discrimination between these types has to do with the level of protection of the tram corridor vis a vie the road traffic. The level of protection is directly related with the commercial speed that the tram can reach. Table 1 gives the commercial speed of a tramway for different types of tram corridor, whether tram is given priority at the traffic lights or not [1, 2].

### Priority given to the tram at signalized intersections and pedestrians crossings

Trams, during their passage through signaling intersections, have to stop or to decelerate, until their traffic lights turn green. In the case of a full priority, tram's delays include the time needed by the driver to push the button of priority's activation (3 sec), the time of amber (3 sec) and a safety time (2 sec). This additional time (8 sec) is added to the total travel time, when the tram stop is close to the signalized intersection or when the driver does not have the required time to activate the tram's priority due to the track alignment. In case of lack of priority, the time of the red light and the delays due to deceleration and acceleration before and after the traffic lights, are added to the total travel time. Referring to traffic lights priority for trams, there are two strategies: passive traffic signal priority and activate traffic signal priority (dedicated priority- phasing changes, longer green time and phase and timing adjustment). According to international standards, an increase of commercial speed in the range of 15%-25% can be achieved by giving priority to trams at traffic lights [3, 4].

### Tram dwell time

Dwell time depends on many parameters, such as the number of boarding and alighting passengers, the vehicle occupancy ratio, the fare collection method, the number of doors, the width of doors and the vehicles' floor height. According to international standards, the average dwell time is 20 sec [2].

### Number and distance between tram stops

A great number of tram stops, in combination with short distances between successive stops, can cause delays, since trams have to decelerate and accelerate often. According to international standards, the distance between successive stops should range from 400m to 600m.



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

Table 1. Commercial speed for different types of tram corridor (with and without priority to trams at traffic lights)

| Description of tram corridors | Type | Commercial Speed (km/h) (without priority at traffic lights) | Commercial speed (km/h) resulted from priority to trams at traffic lights (+25%) |
|---|---|---|---|
| Common | E | 12-15 | 12-15 |
| Separated corridor | D | 17.5 | 21.875 |
| Exclusive tram corridor | C | 18-20 | 18-20 |
| Reserved protected corridor with degraded characteristics of separation | B- | 18.5 | 23.125 |
| Reserved protected corridor | B | 20 | 25 |
| Fully exclusive corridor | A | 30 | 30 |

**Alignment**

An additional time (usually 2-10 sec) is added to the total travel time, when there are segments with narrow curves or steep inclines or segments with limited visibility. This additional time concerns each segment with one or more of the above characteristics.

**Waiting time at terminals**

The waiting time at terminals is about 10 min.

**Performances of rolling stock**

The contribution of rolling stock's Kinematic characteristics (acceleration, deceleration, maximum speed) to the commercial speed is considered to be important.

**Number of road and pedestrians intersections**

The greater number of intersections the greater delays is caused. Road Vehicles moving parallel to tram and involving in its route during their turns, also cause delays.

**The period of day**

During peak periods, tram's delays become greater [5, 6, 7].

## 3. The Tram System of Athens

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 [1]. It has a T formation and it connects the center 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. Figure 1 depicts Athens' tramway system with its 3 lines. The tramway system has 46 stops and three of them, Syntagma, SEF and Voula are also terminal stations. The average distance between two successive stops is 516m. Table 2 gives the length of each type of tram corridor for the whole network [3]. In winter 2010, tram's commercial speed increased, since changes in the signaling system were made and priority is given to tram at 82 out of 86 signalized intersections. Table 3 gives the commercial speed for the 3 lines and for 3 sections of the tramway network, and the impact of signaling changes on commercial speed, as well.

Tram's commercial speed on coastal section (SEF- Voula) is higher than that in urban area (Syntagma- Mouson). The lowest speed is recorded on section Syntagma- Vouliagmenis, where tram runs on common corridor.



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

Commercial speed on the Syntagma- Mouson section is 17.74 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). On the contrary, in coastal section SEF-Voula, the commercial speed is approximately 24.18 km/h, and this is regarded as very satisfactory (44% of the total length is tram corridor type B- and 56% of the total length is tram corridor type B). Commercial speed is higher on the SEF-Voula line, than that on the other two lines, since lines 4 and 5 serve the urban area, where the smallest speed is recorded [3,4].

## 4. Regression Models

This section describes the steps that were followed for the data collection, the examination procedure of normality and collinearity of the variables, the specification of the models and the assumptions taken. In addition, it gives the parameters estimates of the regression models and their interpretation.


Figure 1. Athens' tramway system [8]

Table 2. Athens' tramway network- Length of each type of tram corridor [3]

| Network | Corridor of type E | Corridor of type D | Corridor of type B- | Corridor of type B | Total |
|---|---|---|---|---|---|
| Length (m) | 710 | 930 | 11,640 | 10,980 | 24,260 |
| Percentage (%) | 3% | 3.8% | 48% | 45.2% | 100% |

Table 3. Commercial speed at lines and sections of Athens' tramway network [3, 4]

| Line/ section | Commercial Speed ( km/h) (August 2011-with priority) | Variation of commercial speed |
|---|---|---|
| Syntagma- SEF | 20.03 | +18.17% |
| Syntagma-Voula | 20.39 | +14.80% |
| SEF- Voula | 24.47 | +5.52% |
| Syntagma- Vouliagmenis | 15.15 | +14.25% |
| Vouliagmenis – Mouson | 18.49 | +25.86% |
| Syntagma -Mouson | 17.74 | +23.28% |



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

### 4.1. Data Collection and Manipulation

In order to collect the available data needed for the analysis, an on field observation survey was conducted in August 2011. For each of the three tram lines (L1, L2 and L3), two observations per direction were carried out along the lines, the first for a morning and the second for an evening period. For each of the segment that is defined between two successive tram stops, various data were recorded and/or calculated. Taking all these into consideration and applying the Equation (1), a total number of 366 observations resulted.

$$\sum_{i=1}^{46} 1.\prod_{k=1}^{2} 1.\sum_{l=1}^{4} 1 - \sum_{m=1}^{2} 1 = 366\ Observations \quad (1)$$

where:

*i:* denotes the total stops

*k:* denotes the periods of measurement

*l:*denotes the runs/observation at one segment

*m:* denotes the total endpoints of tramway alignment minus one

Table 4, presents the 2 dependent variables (commercial speed and deviation) and the 11 independent variables that are being examined in this paper, together with some information about their measurement scale and their normality values of skewness and kurtosis. Missing values were treated through the pairwise exclusion method.

A brief description/explanation for the aforementioned variables is following:

**Commercial Speed**: corresponds to the speed per segment in km/h and is calculated by dividing the length of the segment (from stop i to stop j) by the total travel time needed to run this segment (departure time from stop j minus departure time from stop i, including the dwell time at stop j).

**Deviation**: is the difference in seconds between the actual time needed for the train to run the segment and the scheduled time. Positive values correspond to delays in trains' arrival at stop j, whereas negative values indicate earlier arrivals.

**Dwell Time at Stops**: The time that a train is waiting at stop j for passengers' boarding and alighting.

**Segment Length**: is the length of the segment from stop i to stop j.

**Length of Curves**: is the total length of the curvature of a segment.

**Length of Curves to Total Length**: is the total length of the curvature of a segment divided by the total length of the segment. This variable can have values from zero (no curves) to one (the segment is constituted only by curves).

**Number of Narrow Curves**: the number of curves of a segment with radius between 25 to 50 meters.

**Length of Steep Inclines (>2.5 %)**: length of inclined segments with gradient more than +2.5%

**Length of Steep Inclines (>2.5 %) to Total Length**: length of inclined segments with gradient more than +2.5% divided by the total length of the segment. This variable can take values from zero to one.

**Total Traffic Signals:** the number of traffic signals (signalized intersections) in a segment (fixed or with adaptive priority).

**Adaptive Priority Signals**: the number of traffic signals in a segment with adaptive traffic signal control priority plan.

**Fixed Plan Signals:** the number of traffic signals in a segment with fixed traffic signal control plan. **Corridor Type:** corresponds to the tramway corridor type of the segment. Ordinal values were coded as follows: Exclusive Protected Corridor (B) was coded as 1, Exclusive Protected Corridor with poor characteristics (B-) was coded as 2, Exclusive



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

Table 4. Descriptive and Normality information of the variables

| # | Variable Name | N | Min | Max | Mean | S.D. | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Value | Value | Value | Value | Value | Value | Std. Error | Value | Std. Error |
| 1 | Commercial Speed (km/h) | 366 | 5.4 | 50.9 | 22.3 | 7.7 | 1.0 | .13 | 1.3 | .25 |
| 2 | Deviation (sec) | 366 | -91.0 | 194.0 | -4.37 | 22.4 | 1.6 | .13 | 8.9 | .25 |
| 3 | Dwell Time at Stops (sec) | 322 | 8.0 | 37.0 | 16.7 | 4.0 | 1.5 | .14 | 3.5 | .27 |
| 4 | Segment Length (m) | 366 | 320.0 | 900.0 | 535.3 | 140.0 | .8 | .13 | .2 | .25 |
| 5 | Length of Curves (m) | 366 | .0 | 564.4 | 232.6 | 126.2 | .3 | .13 | -.4 | .25 |
| 6 | Length of Curves to Total Length | 366 | .0 | .9 | .4 | .2 | -.1 | .13 | -1.0 | .25 |
| 7 | Number of narrow curves | 366 | .0 | 4.0 | .5 | 1.0 | 2.0 | .13 | 3.5 | .25 |
| 8 | Length of Steep Inclines (>2.5%) (m) | 354 | .0 | 487.0 | 60.0 | 96.4 | 2.0 | .13 | 4.0 | .26 |
| 9 | Length of Steep Inclines (>2.5%) to Total Length | 354 | .0 | .7 | .1 | .2 | 1.5 | .13 | 1.2 | .26 |
| 10 | Total Traffic Signals | 366 | .0 | 4.0 | 1.9 | 1.3 | .3 | .13 | -.9 | .25 |
| 11 | Adaptive Priority Signals | 366 | .0 | 4.0 | 1.7 | 1.3 | .5 | .13 | -.7 | .25 |
| 12 | Fixed Plan Signals | 366 | .0 | 4.0 | .2 | .7 | 4.4 | .13 | 18.3 | .25 |
| 13 | Corridor Type | 366 | 1.0 | 4.0 | 1.7 | .7 | 1.2 | .13 | 2.3 | .25 |
| | Valid N (listwise) | 310 | | | | | | | | |

Separated Corridor (D) was coded as 3 and finally, Common Corridor with the road traffic (E) was coded as 4. In the seldom case were two different corridor types existed in the same segment, the type with the longest length within the segment was coded.

### Specification of the models

As mentioned before, within the framework of this paper two models were developed in order to test the potential parameters that may affect the efficiency and the reliability of the tramway system of Athens. With this respect, the two models are examining the influence of the 11 independent variables of Table 4 on the dependent variables, *Commercial Speed* (Model 1 – The Speed model) and *Deviation* (Model 2 – The Deviation Model). Thus, the two model specifications for the linear regressions can be written as:

**Speed or Deviation** = $b_o + b_1 \times$ (Dwell Time at Stops) + $b_2 \times$ (Segment length) + $b_3 \times$ (Length of curves) + $b_4 \times$ (Length of curves to total length) + $b_5 \times$ (Number of steep tums) + $b_6 \times$ (Length of steep inclines) + $b_7 \times$ ((Length of steep inclines to Total length) + $b_8 \times$ (total traffic signals) + $b_9 \times$ (Adaptive priority signals ) + $b_{10} \times$ (fixed plan signals) + $b_{11} \times$ (corridor type)

For the parameters' estimation, the Ordinary Least Squares (OLS) discrepancy function was applied.

## 5. Results

Table 5 presents the regression parameters estimates for the two models. Further, Figure 2 presents the normal P-P plots as well as the histograms for the regression standardized residuals. Regarding Model 1 (the Speed Model which measures the efficiency of the system) the beta coefficient of the constant shows the commercial speed, being the entire independent variable equal to zero (or in the case of the ordinal variable corridor type equal to B – Exclusive Protected). The most significant parameter that affects the commercial speed is the corridor type ($b_{11}=-1.07$) and as expected it is negatively correlated with the dependent variable (e.g. the more a tramway corridor is unprotected from the road traffic, the lower its commercial speed per segment could be). As Table 5 shows for Model 1, all the statistically significant parameters are negatively affecting the commercial speed, with the exception of the



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

variable *Segment Length*. The coefficient of determination ($R^2$) is calculated to 0.39 whereas the McFaddens' Adjusted $R^2$ is equal to 0.39, meaning that the proportional variance of the data is in an almost satisfactory magnitude. Finally, the Durbin Watson index value reveals an autocorrelation in the residuals. Model 2, measures the effect of the examined independent variables at the reliability of the tramway system, e.g. the effect on the deviation of the actual versus the scheduled travel time per segment. From the results that are presented in Table 5 regarding the Model 2, it can be concluded that alignment characteristics such as the number of narrow curves as well as the length of inclined segments are significantly affecting the travel time deviation. On the other hand the independent variables which are related with the operability of the system are having limited contribution in deviations' explanation and estimation (only the number of intersections with fixed signal plans variable is statistically significant). The Durbin Watson index shows a non-correlation of the residuals compared to Model 1.

## 6. Discussion

For each one of the independent variables that are presented, important qualitative and quantitative outcomes can be derived related with their effect at the two examined dependent variables of Commercial Speed and Time Deviation. Figure 3, presents the effect of the number of narrow curves both on commercial speed and time deviation. As it is expected, the greater the number of narrow curves is on a segment, the lower the commercial speed is as

Table 5. Parameter Estimates and Regression Model results

| | **Model 1 – The Speed Model** | | | | | **Model 2 – The Deviation Model** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model | Un. Coe. | | St. Coe. | | | Un. Coe. | | St. Coe. | | |
| | B | Std. Error | Beta | t | Sig. | B | Std. Error | Beta | t | Sig. |
| (Constant) | 23.938 | 2.211 | | 10.828 | 0.000 | -6.672 | 1.943 | | -3.433 | 0.001 |
| Dwell Time at Stops | -0.445 | 0.091 | -0.231 | -4.882 | 0.000 | n.s. | | | | |
| Segment Length | 0.022 | 0.003 | 0.404 | 8.709 | 0.000 | n.s. | | | | |
| Total Traffic Signals | -1.444 | 0.331 | -0.236 | -4.368 | 0.000 | n.s. | | | | |
| Corridor Type | -1.738 | 0.602 | -0.154 | -2.886 | 0.004 | n.s. | | | | |
| Number of Narrow Curves | -1.070 | 0.416 | -0.133 | -2.572 | 0.011 | 3.785 | 1.859 | 0.123 | 2.036 | 0.043 |
| Length of Steep Inclines (>2.5%) | n.s. | | | | | 0.365 | 0.053 | 1.202 | 6.852 | 0.000 |
| Length of Steep Inclines (>2.5%) to Total Length | n.s. | | | | | -175.431 | 29.666 | -1.037 | -5.914 | 0.000 |
| Fixed Plan Signals | n.s. | | | | | 9.586 | 2.424 | 0.24 | 3.955 | 0.000 |
| **Model Summary** | | | | | | | | | | |
| R Square | 0.394 | | | | | 0.161 | | | | |
| Adjusted R Square | 0.384 | | | | | 0.150 | | | | |
| RSME | 6.03 | | | | | 27 | | | | |
| Durbin Watson | 1.11 | | | | | 1.41 | | | | |
| **ANOVA** | | | | | | | | | | |
| Regression | 7,189 | | | | | 42,657 | | | | |
| Residuals | 11,054 | | | | | 222,541 | | | | |
| Total | 18,243 | | | | | 265,199 | | | | |
| df | 5 | | | | | 4 | | | | |
| F | 39.54 | | | | | 14.62 | | | | |
| Sig | 0.000 | | | | | 0.000 | | | | |



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

well as the greater the observed delays of the trains could be (increase of deviation).

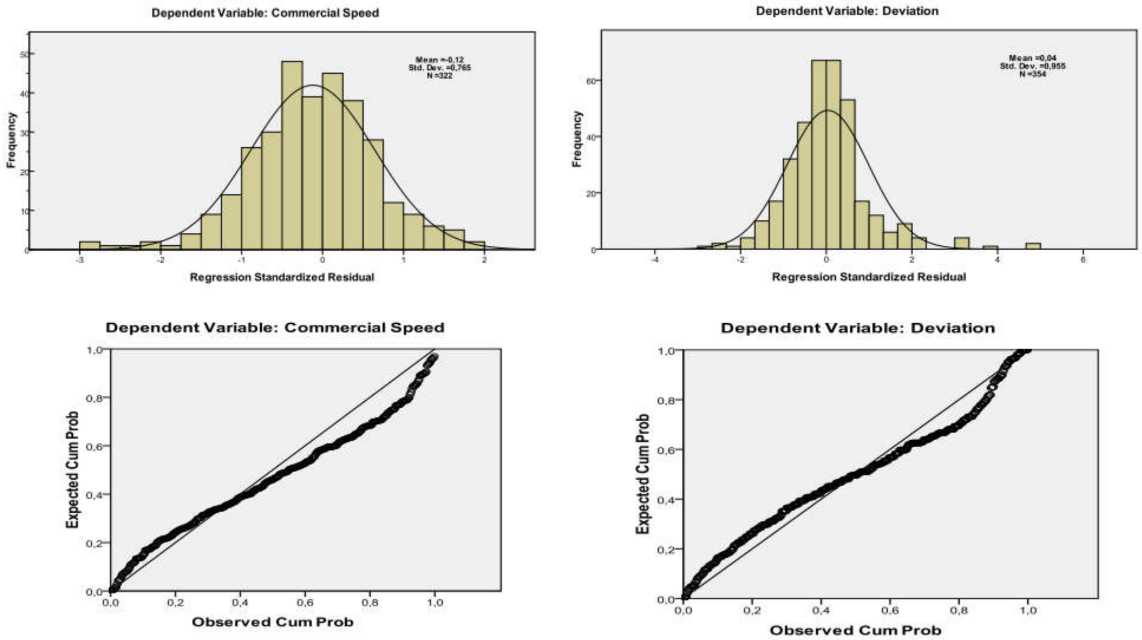


Figure 2. Normal P-P plots and histograms for the regression standardized residuals

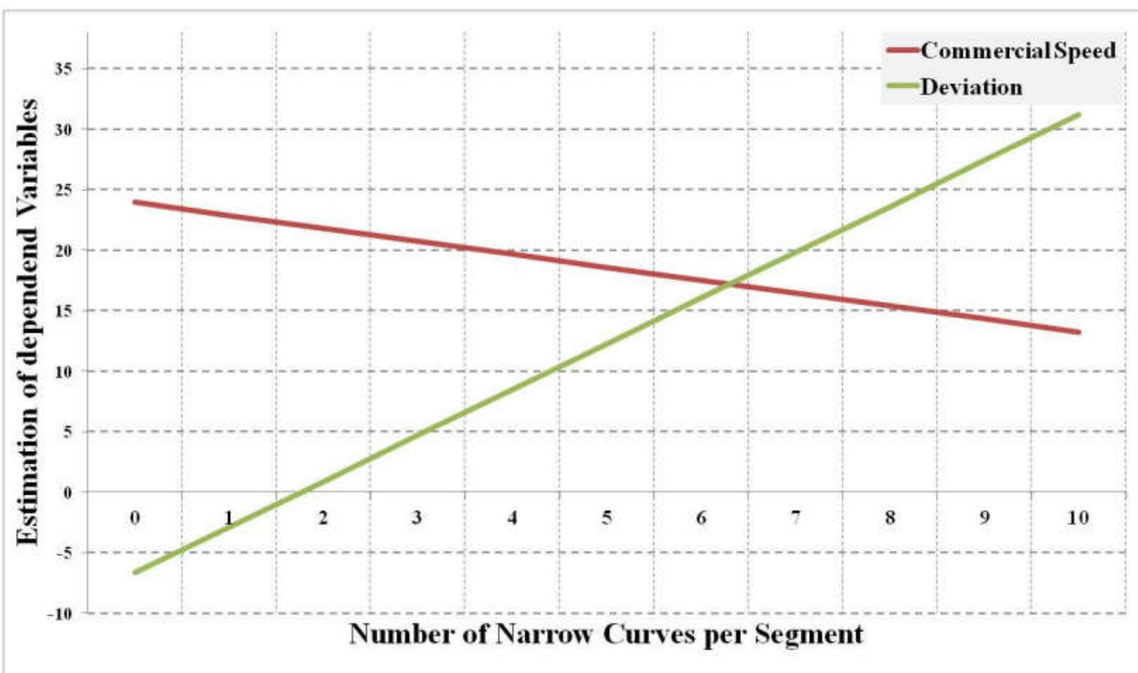


Figure 3. The effect of Narrow Curves at Commercial Speed and Time Deviation



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]

The proposed methodology can be useful for transport authorities and local stakeholders who have to decide between alternative tramway alignments. It gives the opportunity for the ex-ante estimation of the reliability and efficiency of the planned new system. For the case of an existing system like that of Athens, the proposed tool can be used for rescheduling of the routes (e.g. upgrade of tramway protection level will increase the commercial speed thus the link travel time) as well as interventions on the infrastructure of the system (decrease of fixed plan signals so as to improve reliability). As the last note it should be highlighted that the method should be enriched with more data from other tramway systems worldwide so as to increase the robustness of the estimations.

## References

[1] C. Pyrgidis, A. Stathopoulos , The new light rail transit system of Athens, Greece, Rail Engineering International, No 4, (2004), pp.6-10.

[2] A. Bieber, Les choix techniques pour les transports collectifs, École Nationale des Ponts et Chaussées, Paris, France, 1986.

[3] C. Pyrgidis, M. Chatziparaskeva, The impact of the implementation of green wave in the traffic light system of a tramway line –The case of Athens tramway, CETRA, 2nd International Conference on Road and Rail Infrastructure, Dubrovnik, Croatia, May 2012.

[4] M. Chatziparaskeva, The impact of the implementation of green wave in the traffic light system of a tramway line – The case of Athens' tramway, Master thesis, Civil Engineering Department, Aristotle University, Thessaloniki, October 2011.

[5] S-H. Cao, Yuan, Z.-Z. ZhaO, Characteristics analysis and model establishment for passenger boarding time in urban rail transit, Tiedao Xuebao/ Journal of the China Railway Society, Vol. 31, Issue 3, (2009), pp.89-93.

[6] R. Fernadez, P. Zegers, G. Weber, N. Tyler, Influence of platform height, door width and fare collection on bus dwell time, Transportation Research Record, (2010), pp.59-66.

[7] M. Bauer ,M. Richter, Statistical analysis of time lost by trams before departure from stops, 17th International Conference on the Applications of Computer Science and Mathematics in Architecture and Civil Engineering, K Gürlebeck and C. Könke (eds.), Weimar, Germany, 12–14 July 2006.

[8] Urban Rail Transport "STASY" website, www.stasy.gr retrieved from www.tramsa.gr on July 2010



[ Downloaded from ijrare.iust.ac.ir on 2025-07-19 ]