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

STATISTICAL ANALYSIS OF TIME LOST BY TRAMS BEFORE DEPARTURE FROM STOPS

M. Bauer[*], **M. Richter**

[*] *Cracow University of Technology, Chair of Transport Systems,*
Ul. Warszawska 24, 31-155 Kraków, Poland
E-mail: mbauer@transys.wil.pk.edu.pl

Keywords: public transport, priorities for trams, modelling, effectiveness, statistical analysis.

Abstract. *The ride of the tram along the line, defined by a time-table, consists of the travel time between the subsequent sections and the time spent by tram on the stops. In the paper, statistical data collected in the city of Krakow is presented and evaluated. In polish conditions, for trams the time spent on stops makes up the remarkable amount of 30 % of the total time of tram line operation. Moreover, this time is characterized by large variability. The time spent by tram on a stop consists of alighting and boarding time and time lost by tram on stop after alighting and boarding time ending, but before departure. Alighting and boarding time itself usually depends on the random number of alighting and boarding passengers and also on the number of passengers which are inside the vehicle. However, the time spent by tram on stop after alighting and boarding time ending is an effect of certain random events, mainly because of impossibility of departure from stop, caused by lack of priorities for public transport vehicles. The main focus of the talk lies on the description and the modelling of these effects.*

1 INTRODUCTION

Realization of tram line operation relies on transporting passengers and enabling them to alight and board on tram stops. It consists of running times of successive sections and times spent by tram on following stops. In polish conditions time spent on stops makes up even 30 % of the total time of tram line operation. It is characterized by a large variability, even during the short periods of the day. The summary time spent by tram on stop consists of alighting and boarding time and time lost by tram on stop after finishing of alighting and boarding time, but before vehicle's departure from stop. In previous polish researches of public transport quality, independently of the way of measurements (manual recording inside vehicle moved along the public transport line, manual recording by persons staying on stops, automatic recording), there were taken into consideration only times of tram's departures from stops. Alternatively, during the more advanced measurements, there were recorded moments of opening and closing doors. The results of those measurements were helpful for designing time-tables, but did not give information about all reasons of the disturbances in tram line operation, especially connected with lack of possibility of departure from stop, soon after finishing the passenger's alight and board. A separate analysis of running time, alighting and boarding time and time lost on stop will allow to identify the different reasons of unpunctuality and irregularity of tram line operation. The results of more scrupulous measurements also allow to implement the different kinds of priorities for trams and (or) let to assure the better location of the stops. In case of tram stop's location near side a signalized intersection, the results of time lost values create the possibility of planning and designing effective solutions, giving priorities for trams in traffic lights.

2 FACTORS, THAT INFLUENCE ONTO VALUE OF TRAM'S TIME LOST ON STOP

There exists a group of reasons which have influence on time lost by trams on stops [4]. The highest part of them are determined by factors, directly connected with lack of priorities in traffic for trams. Remaining factors are connected with street conditions, human factors, public transport organization, environmental and local conditions. To the most important factors belong:

- Way of tram's stop location, in relation to the position of nearest intersection,
- Lack of priorities in traffic lights for public transport vehicles, especially in case of near side stop location,
- Lack of separated tram tracks in the stop's areas,
- Possibility of car's turns left track on intersections, with tram track using,
- Insufficient capacity of closest intersection,
- Insufficient capacity of stop,
- Kind of stop – single or double stopping-space,
- Kind of stop's users – stop only for trams, or trams and buses,
- Accidents and breakdowns in the stop area, or in the neighbourhood of the stop area,

- Location of stop in relation of city zone – close city centre (first ring), city centre (second ring), area outside the centre,
- Way of payment for travel, including possibility of buying tickets in vehicle
- Exact information for passengers
- Dispatching control activities,
- Seasons, weather, atmospheric conditions,
- Kind of day, time of day (workday, holiday, rush-hour),
- Disposition, psychophysical features of drivers and passengers discipline,
- and other factors.

As it can be seen, time lost by tram before departure from stop after finishing alighting and boarding passengers depends on a large group of factors. Multitude of those factors makes it impossible to examine them practically. Some of them are immeasurable, others are difficult to estimate. Estimation of local and environmental factors requires very large samples. Of course, there is the possibility to describe time lost on stop, separately for every stop – by determining of time lost distribution. But there is also possibility to prove, that the value of time lost, to a considerable degree, depends on few of the presented factors. In the next chapter, there will be performanced the analysis of time lost in dependence of the type of stop (five cases), the way of stop location in relation to the nearest intersection (six cases) and the way of stop location in relation to the zone of the city (three cases).

3 CLASSIFICATIONS OF TRAM STOPS

There are two basic types of tram stops in Polish cities: permanent stops, where every tram has to stop and request stops, where tram stopping is requested by passenger. Almost all stops have permanent character, the request tram stops are very seldom, and they have not been taken into consideration in current analysis. Most of stops are intended only for trams, but some of them are allowed also for public transport buses, especially in cases, when trams and buses use the same lanes. A large part of tram stops in Kraków is located on separated tracks, and because of that, independent from other vehicle's traffic. The rest of stops is located in the middle part of streets, which causes the possibility of blocking trams by other vehicles at stop's areas. As the result, there are five types of permanent tram stops:

- **Type I** – single tram stops, with one stopping-space located in the middle part of street. Alighting and boarding passengers is held with other vehicles' area using. This kind of stop location causes possibility of blocking tram track by other vehicles' traffic (see Figure 1, Situation a).
- **Type II** – single tram stops, only for trams, with one stopping-space located on separated track. The platform for passengers is located directly to the track. The influence of other vehicles' traffic onto tram traffic is strongly limited (see Figure 1, Situation b).
- **Type III** – with two stopping-spaces located in the middle part of street. Alighting and boarding passengers is held with other vehicles' area using. This kind of stop location causes possibility of blocking tram track by other vehicles' traffic, and reciprocal trams blocking (see Figure 1, Situation c).

- **Type IV** – double tram stops, only for trams, with two stopping-spaces located on separated track. The platform for passengers is located directly to the track. The influence of other vehicles' traffic onto tram traffic is strongly limited, but there is possibility of reciprocal trams blocking (see Figure 1, Situation d).

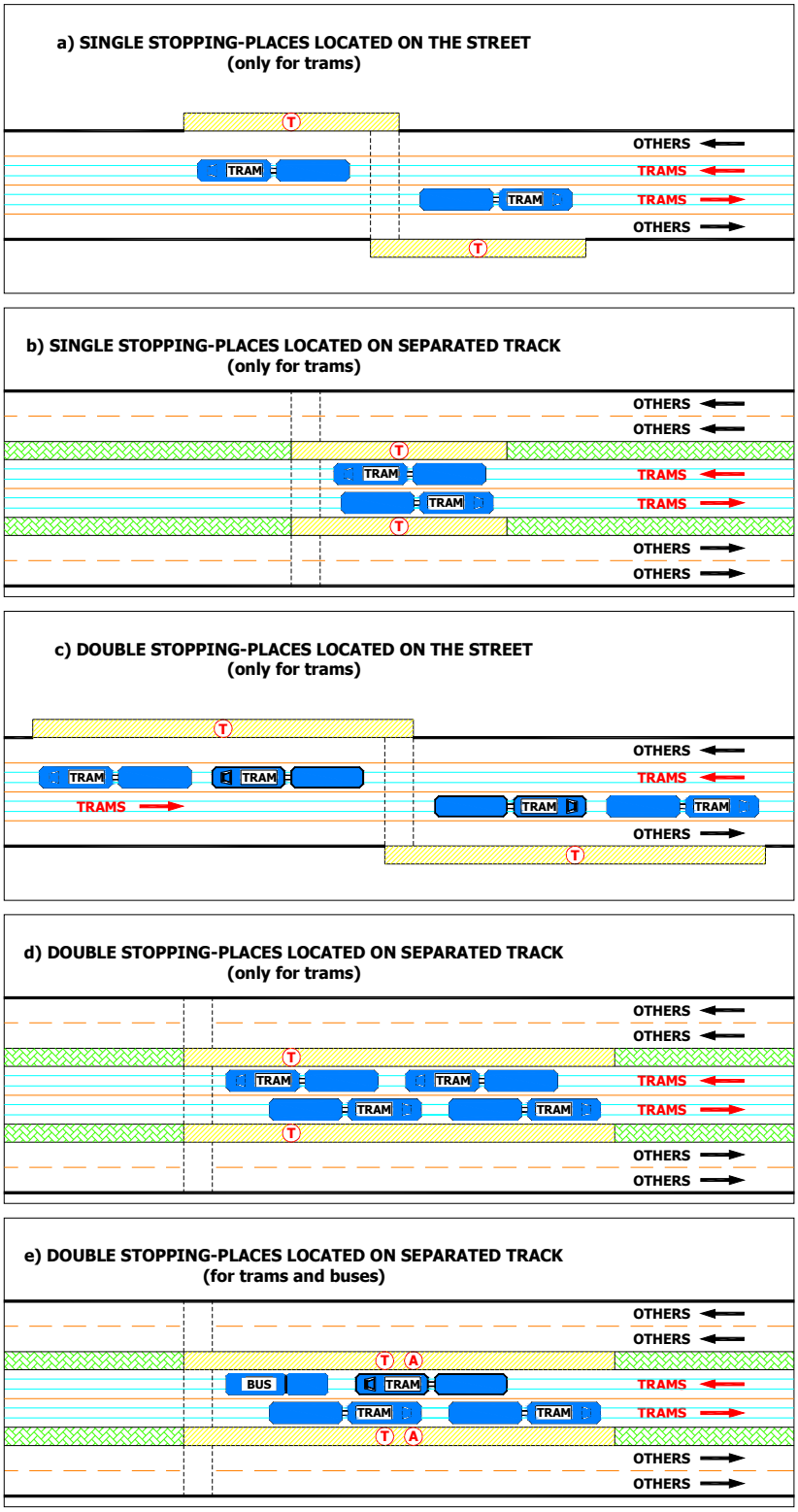


Figure 1: Schemes of types of tram stops

- **Type V** – double, common tram and bus stops, with two stopping-spaces located on separated lane for trams and buses. The platform for passengers is located directly to the tram-bus lane. The influence of other vehicles' traffic onto tram and bus traffic is strongly limited, but there is possibility of reciprocal trams and buses blocking. This solution is applied only in cases of common separated lanes for trams and buses (see Figure 1, Situation e).

Schemes of all spoken types of tram stops are shown in Figure 1.

The presented types of tram stops could be located in very different ways. They can be located in the close neighbourhood of the nearest intersection (when stop is situated within range of intersection) or mid block (when the distance from stop to nearest intersection is significant). There is also possibility of tram stop location near side or far side nearest intersection. Kind of neighbouring intersection is very important as well – whether it is a signalized or a non-signalized intersection. In case of stops, which are located near side signalized intersections, it is also worth to take into consideration, whether priorities for trams in traffic lights are assured. Summing up, there are six principal possibilities of tram stops location in relation to the nearest intersection. Schemes of the defined tram stop's locations are presented in Figure 2.

- **Location I** – tram stop is located far side signalized intersection.
- **Location II** – tram stop is located near side signalized intersection and trams do not have priorities in traffic lights.
- **Location III** – tram stop is located near side signalized intersection and trams have priorities in traffic lights (green signal is given to vehicle, which has finished alighting and boarding passengers).
- **Location IV** – tram stop is located far side non-signalized intersection.
- **Location V** – tram stop is located near side non-signalized intersection.
- **Location VI** – tram stop is located mid block, far from neighborhood intersections.

One more relevant classification of tram stops is based on their location in relation to various parts of the city. The traffic conditions are different in close old city area, where partial restrictions for private cars are assured, wide city centre and remaining areas of the city. But this classification has general character, and could be treated with caution. There are proposed three possibilities of stop locations in relation to the zone of the city (see Figure 3).

- **Zone I** – close city centre, all stops are located inside first ring (including stops on perimeter of first ring). This zone is characterized by a large density of intersections and relatively short stopping spaces. There are also possible restrictions for chosen groups of vehicles.
- **Zone II** – wide city centre, tram stops are located between first and second ring (including stops on perimeter of second ring). This zone is characterized by larger stopping spaces and a lower density of intersections.
- **Zone III** – tram stops located outside city centre (outside second ring). This zone is characterized by large stopping spaces and a small density of intersections.

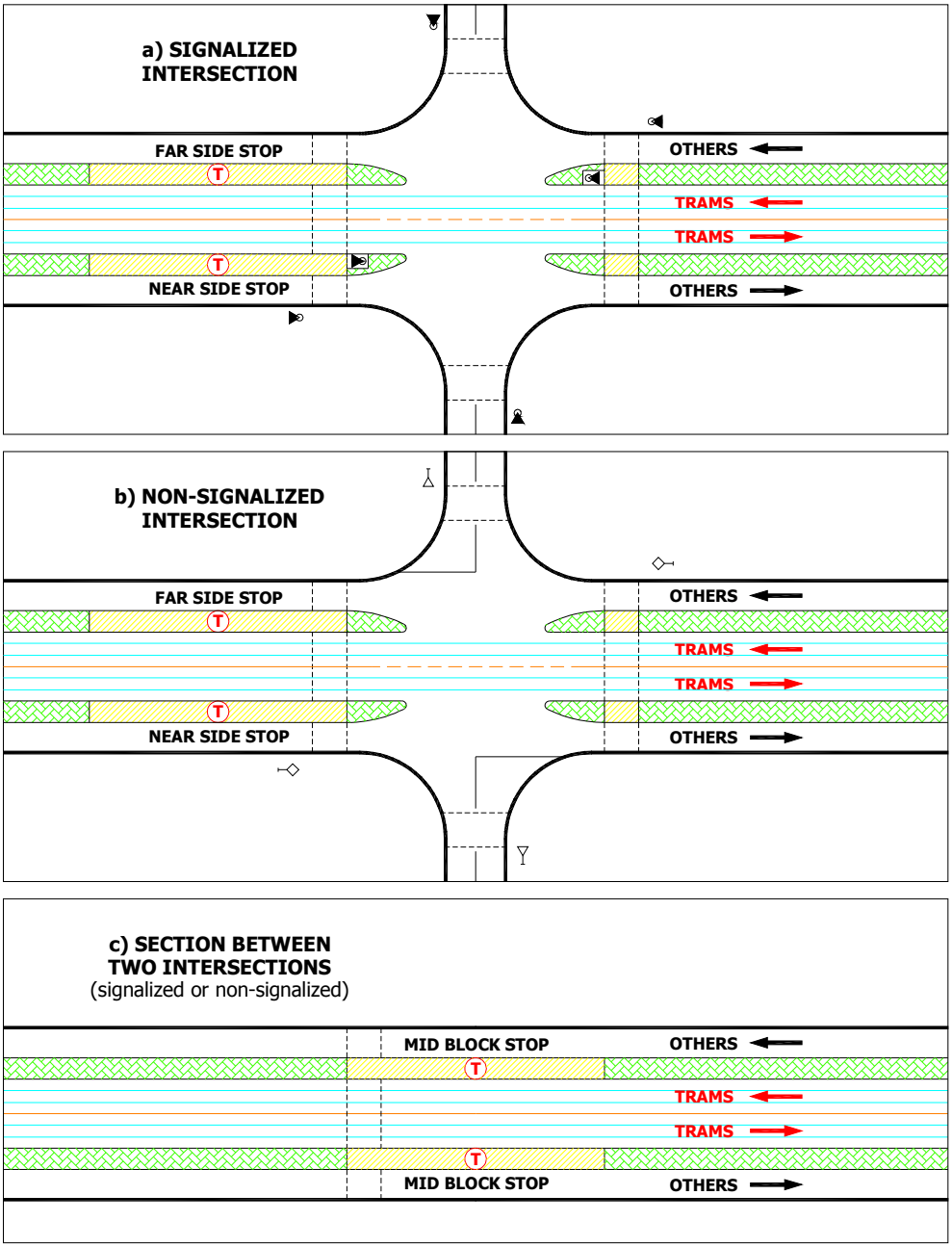


Figure 2: Schemes of possible tram stop's locations.

A general description of time lost is difficult. However, the presented classifications of tram stops could be helpful in time lost consideration. The type of stop, the location in relation to the nearest intersection and the city zone could give information about the value of expected time lost by tram on stop.

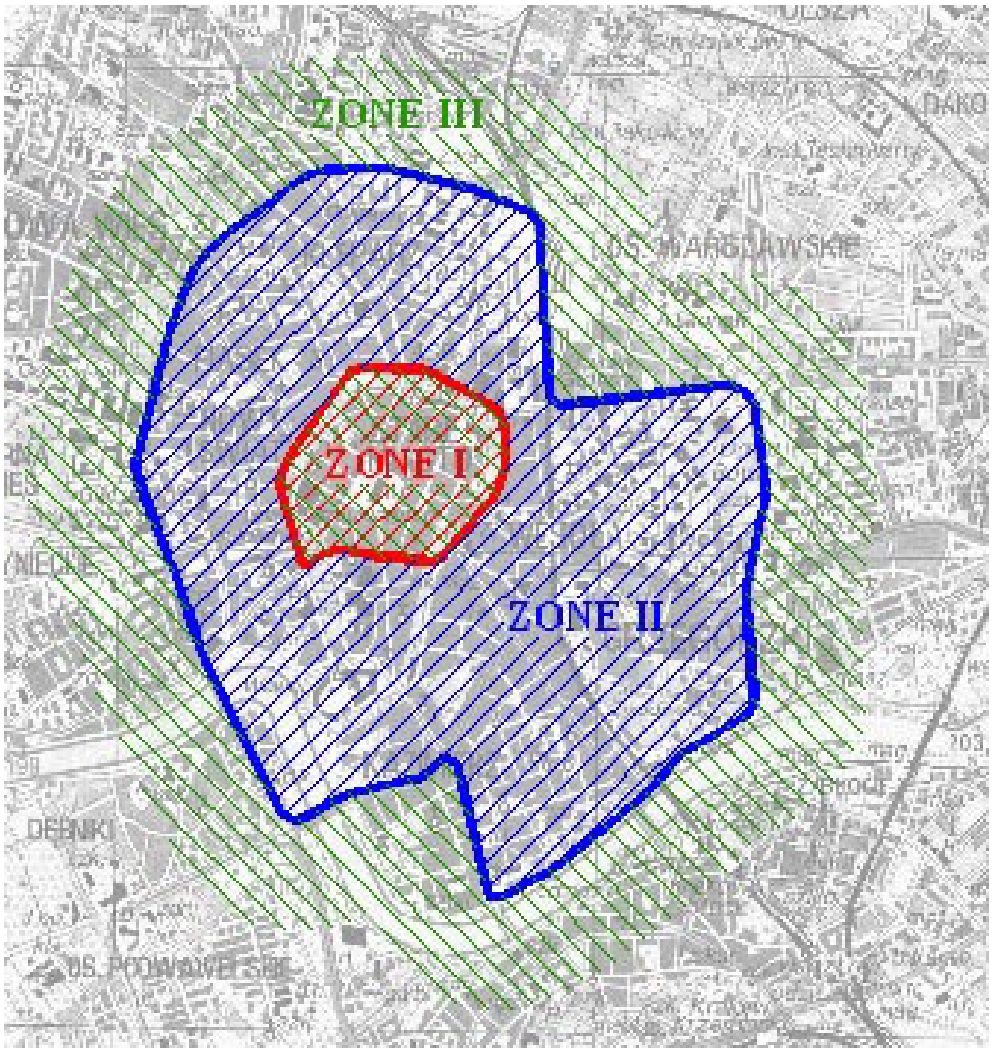


Figure 3: Range of tram stops location's zones in Kraków.

4 STATISTICAL ANALYSIS OF TRAM'S TIME LOST ON STOP

4.1 Measurement's sample and basic analysis of tram's time lost on stop

Measurements were led in typical workday, in afternoon rush hours time (13^{00} – 17^{00}), on three tram lines (by persons inside vehicles), and additionally on two stops (by persons staying on stops, outside vehicles). With the aim of assuring enough precision, during measurements there were used radio controlled clocks. There were recorded moments of starting opening door, starting closing the last opened door and time of departure from stop. As a result, there were obtained three important parameters: running time, alighting and boarding time and time lost by tram before departure from stop.

Overall, there were recorded 1340 results of time lost by tram after finishing alighting and boarding passengers, but before departure from stop, with range from 1 [s] to 204 [s]. The mean value for all results was 12 [s], and the estimated value of standard deviation was 17 [s]. Distribution of tram's time lost is highly concentrated in 0. However, the hypothesis of an exponential distribution is refused by a Kolmogorov-Smirnov test [2]. In Figure 4, additional to the exponential distribution (black solid line) a Gamma distribution with corresponding

mean value and standard deviation is fitted (red dashed line) to the empirical distribution of time lost. The Gamma distribution matches the empirical results much better. However, a χ^2-test of goodness of fit rejects also the hypothesis of Gamma-distribution. Furthermore, a logarithmic normal distribution is fitted (blue dot-dashed line). Also in this case the hypothesis of a normal distribution of the logarithms of time lost is rejected by a Kolmogorov-Smirnov test.

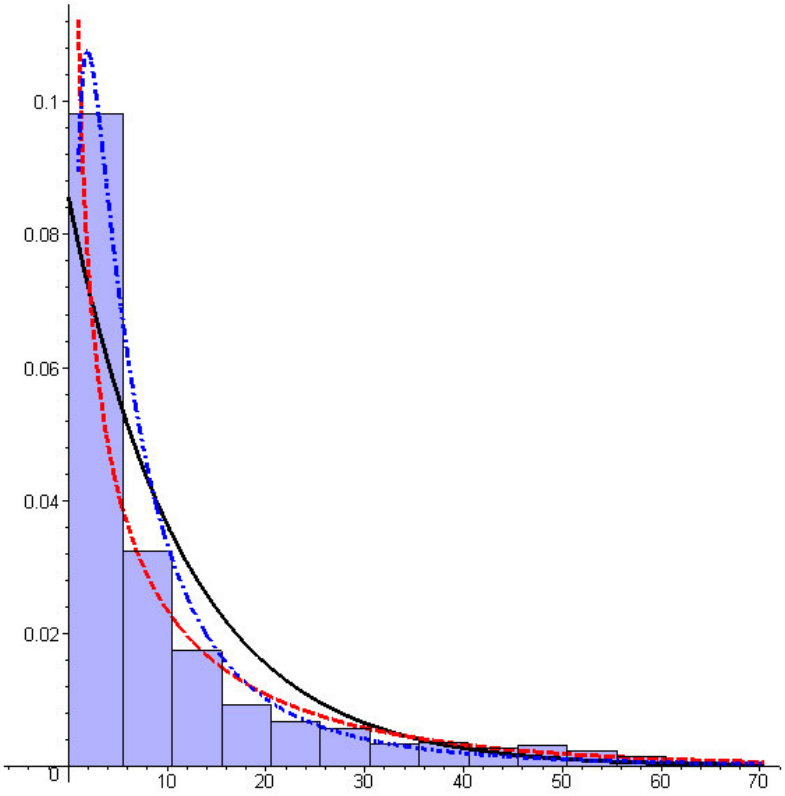


Figure 4: Distribution of tram time lost on stop and fitted distributions (total sample).

There were taken into consideration results for five types of stops, five stop locations in relation to the nearest intersection (no results are available for stops with Location IV – located far side non-signalized intersection – this is a very seldom solution), and three stop locations in relation to the part of the city. The mean values, median and values of standard deviations differ for different considered cases. For example – the mean values are from 4 to 27 [s], values of standard deviation – from 3 to 21 [s]. At Table 1 there are presented the basic parameters of obtained sample, divided for three groups of described cases: types of stops, way of stops location in relation to the nearest intersection and part of the city.

Stop	Sample	Range	Mean value	Median	Standard deviation
	[-]	[s]	[s]	[s]	[s]
TYPES OF TRAM STOPS					
Single tram stop located in the middle part of street	330	1 – 123	7	3	14
Single tram stop located on the separated track	448	1 – 69	8	4	11
Double tram stop located in the middle part of street	66	1 – 59	14	5	15
Double tram stop located on the separated track	118	1 – 110	27	21	19
Double tram and bus stop located on the separated tram-bus lane	378	1 – 204	15	8	21
POSSIBLE TRAM STOP LOCATIONS IN RELATION TO THE NEAREST INTERSECTION					
Far side signalized intersection	377	1 – 110	7	5	9
Near side signalized intersection (without priority for trams)	605	1 – 204	19	12	21
Near side signalized intersection (with priority for trams)	96	1 – 56	7	2	11
Near side non-signalized intersection	84	1 – 20	4	3	3
Mid block	178	1 – 19	4	3	3
POSSIBLE TRAM STOP LOCATIONS IN RELATION TO THE ZONE OF THE CITY					
Close city centre – first ring	192	1 – 123	16	6	21
Wide city centre – second ring	646	1 – 204	15	8	19
Outside city centre	502	1 – 69	7	3	10
OVERALL					
ALL CASES	**1340**	**1 – 204**	**12**	**5**	**17**

Table 1: Parameters of time lost by trams before departure from stops.

Those results give the information, that there is the possibility of separating groups of main factors, that have influence onto value of time lost on stops and finally onto disturbances of tram line operation. Namely, the three most significant factors are: type of stop, way of stop location in relation to the nearest intersection and part of the city. The boxplots in Figures 5, 6 and 7 show again the empirical distribution properties of time lost corresponding to the above factors.

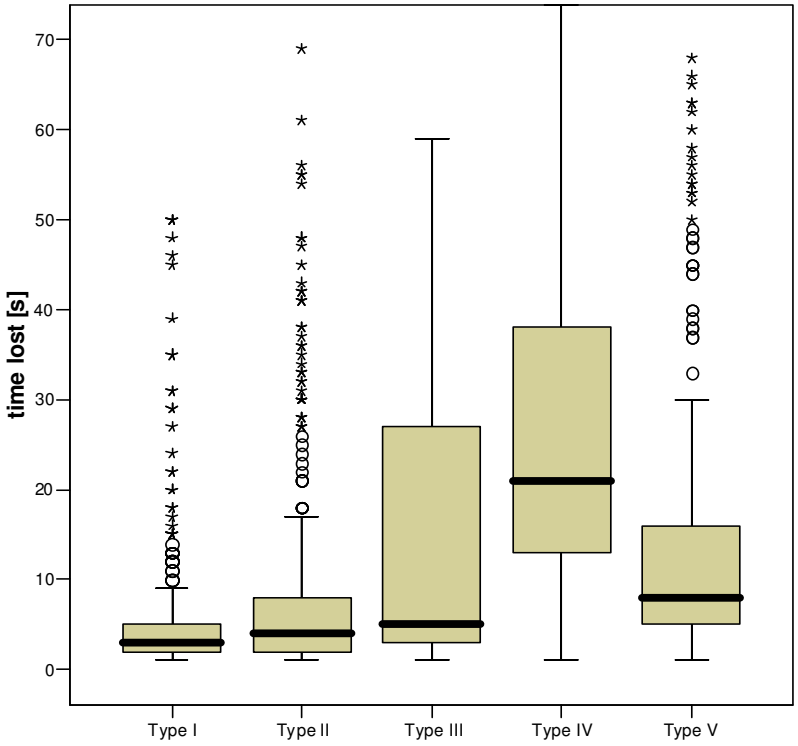


Figure 5: Boxplot of time lost in dependence on type of stop.

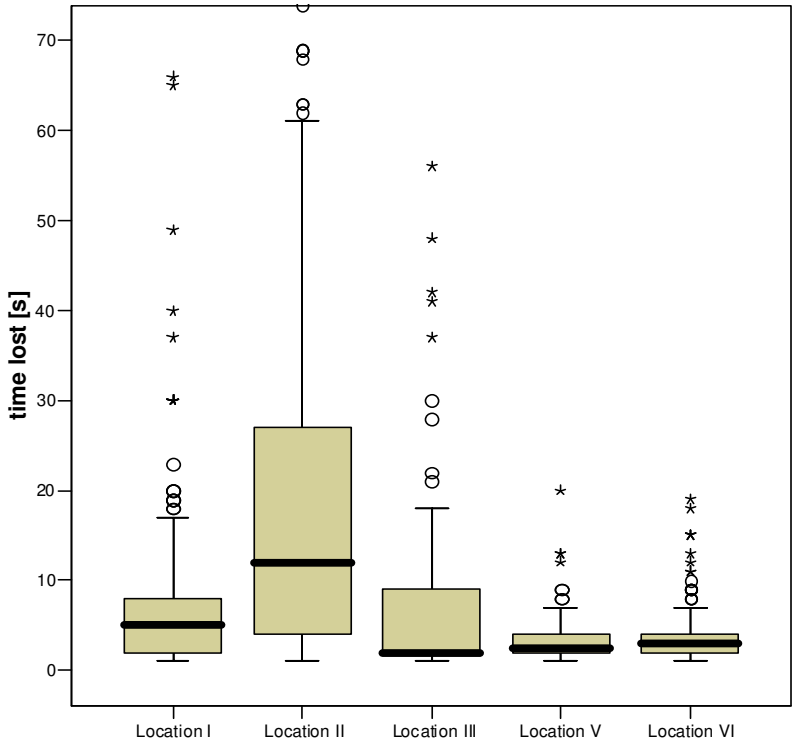


Figure 6: Boxplot of time lost in dependence on stop location (in relation to nearest intersection).

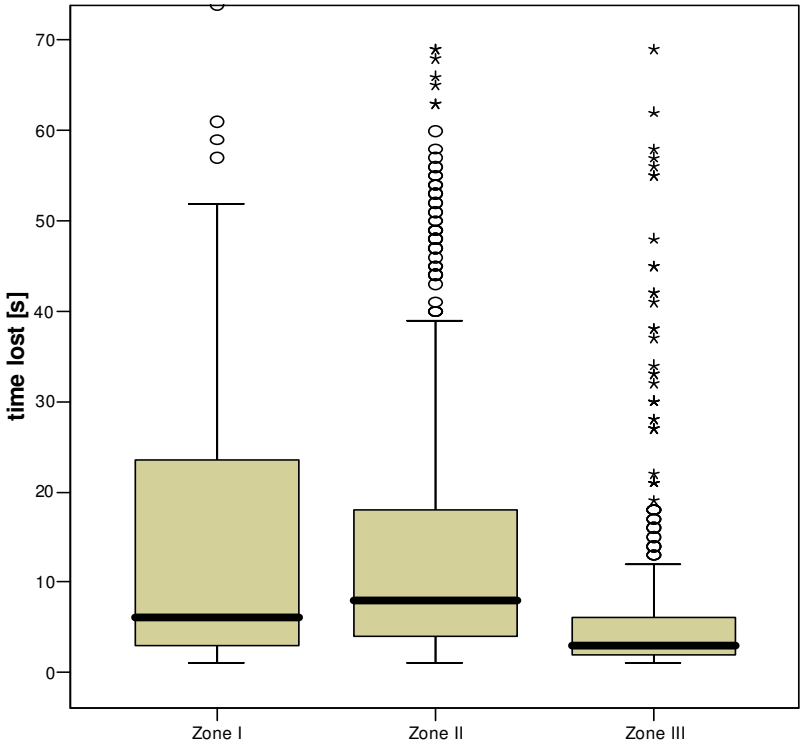


Figure 7: Boxplot of time lost in dependence on stop location (in relation to zone of the city).

4.2 Type of stop influence onto tram's time lost before departure from stops

In Figure 5, some differences between time lost parameters for various types of tram stops can be seen. The result of a Mann-Whitney test shows that there is no significant difference between the distributions of time lost between double stops for trams located in the middle part of street and separated double common tram-bus stops (Types III and V, respectively). For this reason, these both types are merged.

From Figure 5 a comparable result with respect to Types I and II (both types of single stops – located in the middle part of street and on separated track) can be supposed. However, a Mann-Whitney test refuses the hypothesis of identical distributions. On the other hand, comparison tests like a *t*-test would show, that there are no significant differences between the mean values of time lost on both types of single stops. By the lack of normal distribution such tests are not evident. Nevertheless, from now on the latter types are merged, too. The result is a new classification of tram stop types, presented in Table 2 and Figure 8.

The results of multiple comparison tests like the Kruskal-Wallis test show that mean values for those three cases are significantly different from each other, at the 95,0 % confidence level. Those results confirm the sense of tram's stops classification by types.

Finally, there are three types of tram stops, for which there are significant differences of tram's time lost on stop. The best situation (the smallest mean value of time lost) clearly is in case of single stops, where there is no problem with influence of other trams (or buses).

Type of stop	Sample	Range	Mean value	Median	Standard deviation
	[-]	[s]	[s]	[s]	[s]
Single tram stop	778	1 – 123	8	3	12
Double tram stop, non-separated track Double tram-bus stop, separated lane	444	1 – 204	15	8	20
Double tram stop, separated track	118	1 – 110	27	21	19
ALL CASES	**1340**	**1 – 204**	**12**	**5**	**17**

Table 2: Tram's time lost on stop depending on type of stop.

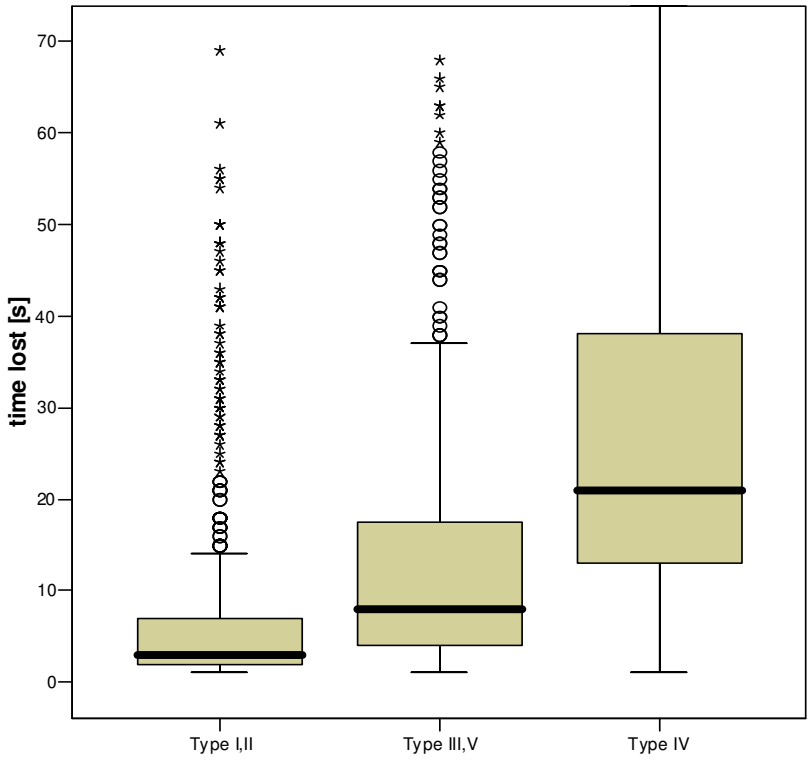


Figure 8: Boxplot of time lost in dependence on type of stop.

4.3 Tram stop location's influence onto time lost before departure from stops

There are some differences between time lost parameters for various tram stop's locations, in relation to the nearest intersection. Figure 6 shows that there are comparable results of the distributions of time lost for stops located mid block, far side signalized intersections and near side non-signalized intersections, and also near side signalized intersections, when priorities in traffic lights for trams are not assured. Only mean value for stops located near side signalized intersections, without priorities in traffic lights for trams (Location II), differs clearly from the other mean values (see also [1], [3]). The new classification of tram stop locations is presented at Table 3 and Figure 9.

Stop location in relation to the nearest intersection	Sample	Range	Mean value	Median	Standard deviation
	[-]	[s]	[s]	[s]	[s]
Near side signalized intersection (without priority for trams)	605	1 – 204	19	12	21
Other tram's stop locations	735	1 – 110	6	3	8
ALL CASES	**1340**	**1 – 204**	**12**	**5**	**17**

Table 3: Tram's time lost on stop depending on type of stop.

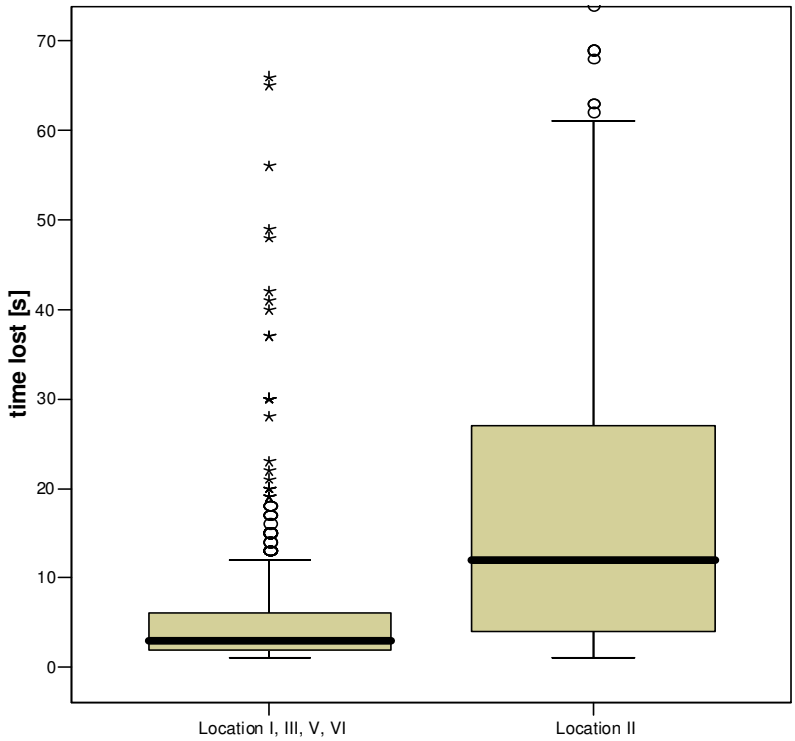


Figure 9: Boxplot of time lost in dependence on stop location (in relation to nearest intersection).

Clearly, in case of stops situated near side signalized intersections, without priorities in traffic lights for trams, there are the largest values of time lost. The values of time lost for other locations are nearly the same and much smaller.

4.4 City zone's influence onto time lost by trams before departure from stops

There are also differences between time lost parameters for various tram stop's locations, in relation to the zone of the city. The result of a Mann-Whitney test shows, that there is no significant difference between the distributions of time lost for stops located in close and wide city centre. In contrast, the distribution for stops located outside city centre differs from the other cases. The new classification of tram stop locations in relation to the zone of the city is presented at Table 4.

Stop location in relation to the zone of the city	Sample	Range	Mean value	Median	Standard deviation
	[-]	[s]	[s]	[s]	[s]
Close and wide city centre	838	1 – 204	15	7	19
Outside city centre	502	1 – 69	7	3	10
ALL CASES	**1340**	**1 – 204**	**12**	**5**	**17**

Table 4: Tram's time lost on stop depending on zone of the city.

With respect to this new classification, a Mann-Whitney test shows highly significant, that there is an influence of tram stop location (in relation to the zone of the city) onto time lost before departure. This result confirms the sense of tram's stops classification by location in relation to the zone of the city. But this zone's influence onto time lost values is smaller than in cases of tram stop type or stop location in relation to neighbourly intersection.

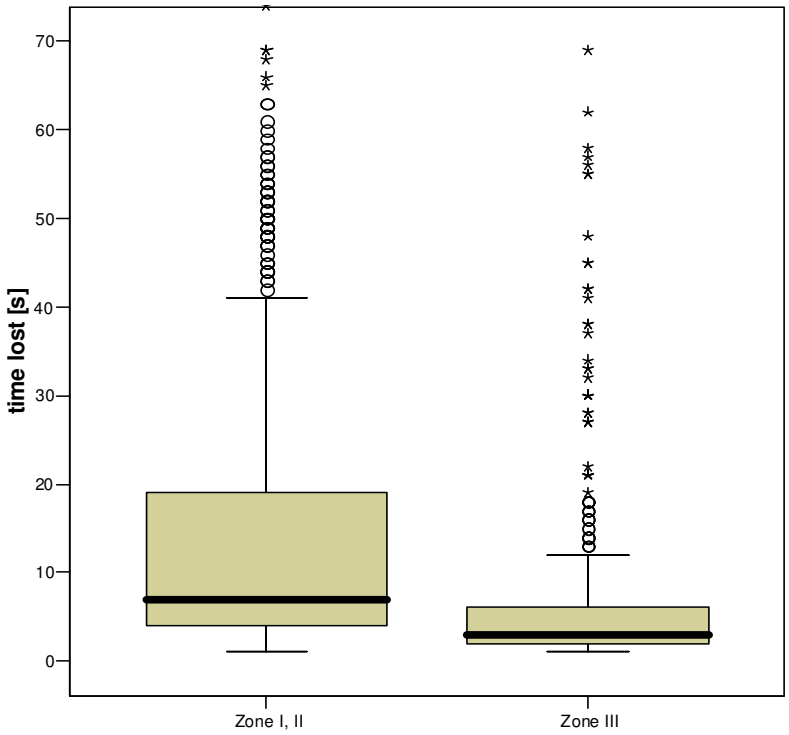


Figure 10: Boxplot of time lost in dependence on stop location (in relation to part of the city).

Clearly, there are bigger values of time lost in case of stops located in the city centre, it is probably an effect of large density of intersections and relatively short stopping spaces.

4.5 Both – type and location of stop influence onto tram's time lost before departure from stops

Two factors, namely type of stop and stop location in relation to the nearest intersection have strong influence onto time lost. There is the possibility to make a new classification of time lost, on basis of those two factors, operating together. As a result of their interactions, there are five new cases, which are presented in Table 5. The results of multiple comparison tests, done for this new classification, show that there is a significant difference between the distributions of time lost for all considered cases. Especially, as a result of a Kruskal-Wallis test, for the considered cases, there is a significant difference amongst the medians (95,0 % confidence level).

This analysis gives the conclusion, that the combination of type of stop and location in relation to the nearest intersection has big influence onto time lost by trams before departure from stops. There are five different cases, that are characterized by various parameters of time lost distributions.

Type of stop and stop location in relation to the nearest intersection	Sample	Range	Mean value	Median	Standard deviation
	[-]	[s]	[s]	[s]	[s]
Single tram stop located near side signalized intersection (without priorities in traffic lights for trams) **Case 1**	282	1 – 123	13	6	18
Single tram stop other locations **Case 2**	496	1 – 56	5	3	6
Double tram stop, on non-separated track and double tram-bus stop on separated lane located near side signalized intersection (without priorities for trams) **Case 3**	205	1 – 204	22	15	25
Double tram stop on non-separated track and double tram-bus stop on separated lane other locations **Case 4**	239	1 – 110	8	5	11
Double tram stop located on separated track near side signalized intersection (without priorities in traffic lights for trams) **Case 5**	118	1 – 110	27	21	19
ALL CASES	**1340**	**1 – 204**	**12**	**5**	**17**

Table 5: Tram's time lost on stop depending on type of stop and stop location in relation to the nearest intersection.

Adding the third factor, which is location in relation to zone of the city does not improve the classification. The influences of factors begin to mix one another. As a result such an extended classification is less functional. So, the classification of five cases, based on type of stops and location in relation to the nearest intersection can be recommended.

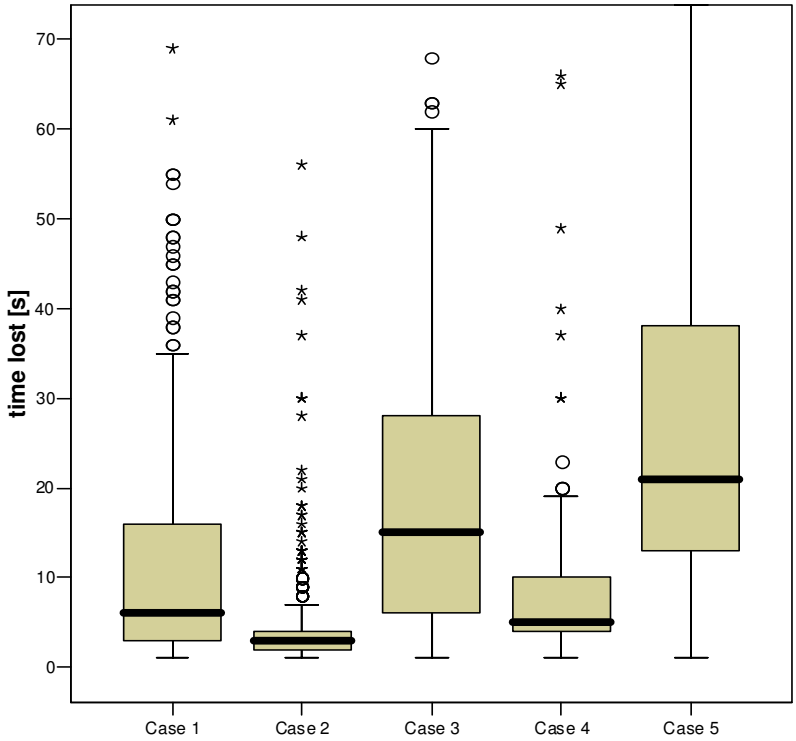
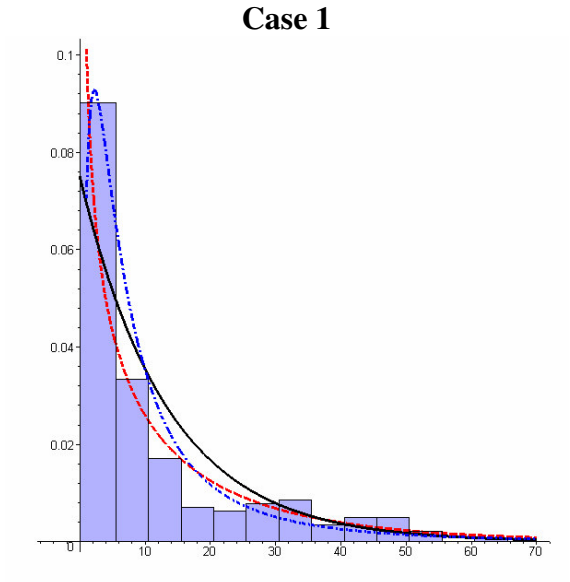
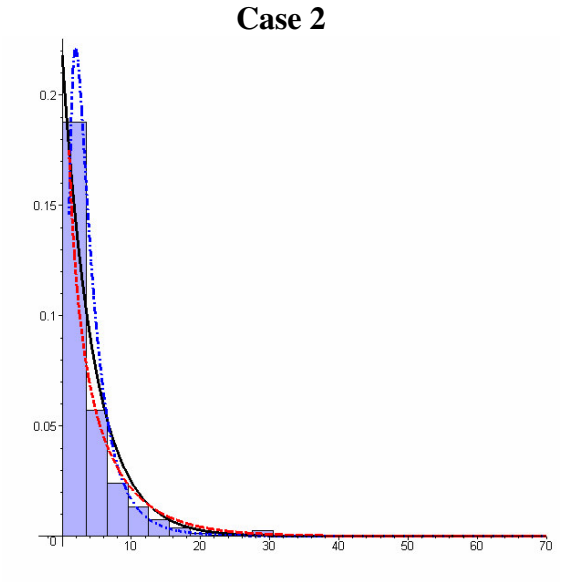


Figure 11: Boxplot of time lost in dependence on type of stop and stop location in relation to the nearest intersection.

For the five described cases of time lost, distributions were fitted. From the large group of possible distributions, finally there were taken into consideration Exponential, Gamma and Logarithmic Normal distribution. The best results of corresponding χ^2-tests of goodness of fit are obtained for the Gamma-distribution, which is not rejected for cases 1, 3 and 5. Log-Normal distribution is not rejected for cases 3 and 5 and Exponential distribution is not rejected for case 3. In remaining cases (2 and 4) there is no statistically significant fitting of any presented distributions.





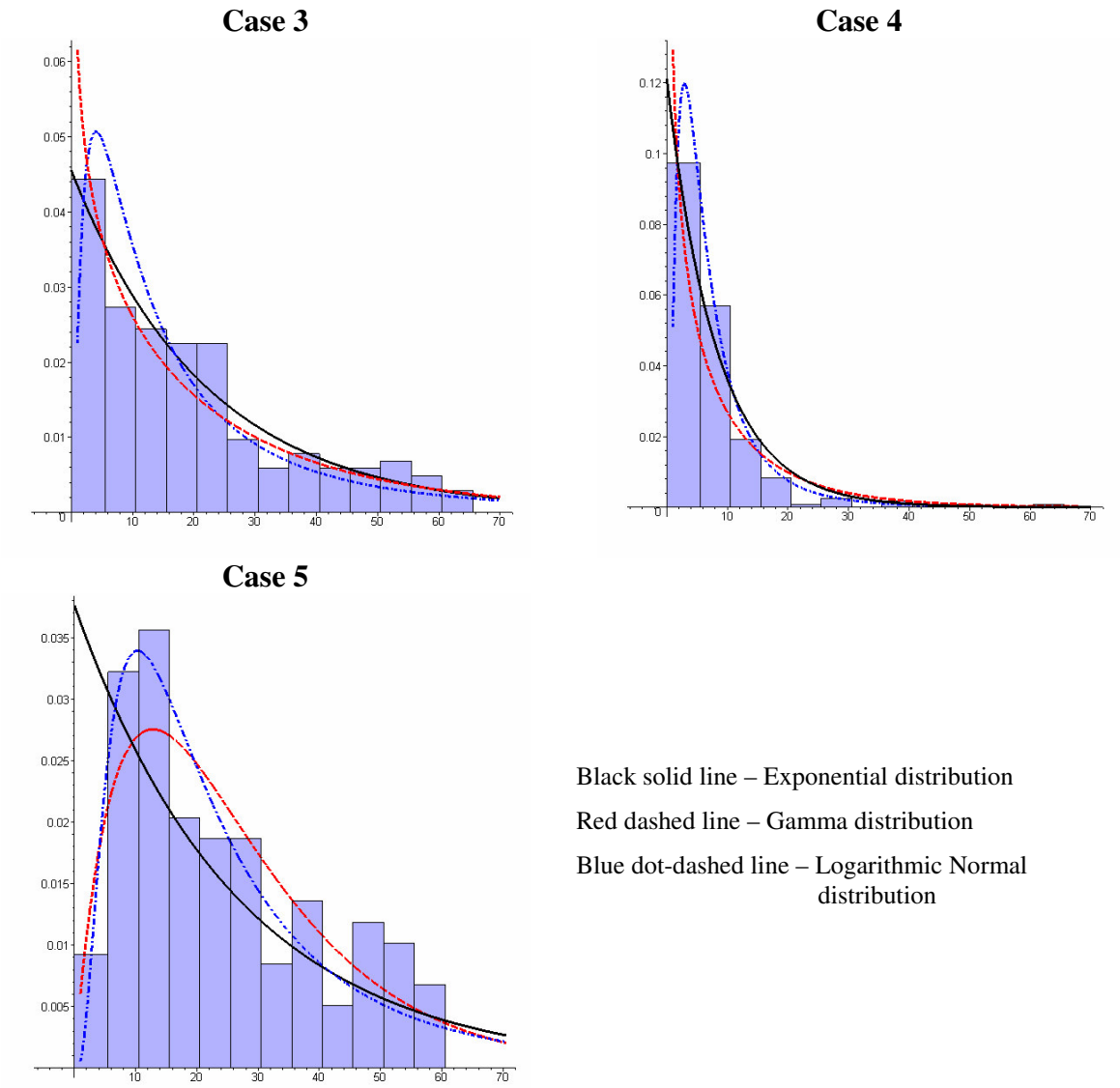


Figure 12: Fitted distributions of time lost in dependence on type of stop and stop location in relation to the nearest intersection.

5 GENERAL CONCLUSIONS

As consequence of the statistical considerations the following conclusions can be drawn.

1) Time lost by trams after finishing alighting and boarding passengers, but before departure from stop is an important part of tram line operation. Sum of all times, lost by tram on all stops on line, could be essential for line operation.

2) There is the possibility of separating factors, that have influence onto value of time lost on stops and finally onto disturbances of tram line operation. Those factors are: type of stop, and way of stop location in relation to the nearest intersection and the part of the city.

3) The best dividing factor is common influence of type of stop, and way of stop location, in relation to the nearest intersection. The way of stop location in relation to the part of the city could be treated as extra factor.

4) The highest mean value and value of standard deviation of time lost on stop is reached in case of double tram stops located on separated track near side signalized intersections without priorities in traffic lights for trams. This can be a result from lack of possibility of two trams departure during one green signal phase (not enough green signals for trams).

5) Tram stops should be situated near side the intersections with priorities for trams. If there is no possibility to assure the priority in traffic lights for trams, it is much better to locate stop far side intersection.

6) Single stops are generally less susceptible for high values of time lost than double stops, but in cases of large public transport vehicles traffic the latter are necessary.

References:

1. S. Brandt S, *Data Analysis. Statistical and Computational Methods for Scientists and Engineers*, Springer-Verlag, New York, 1999.
2. J. R. Cogdell, *Modeling Random Systems*, Pearson Education Inc., Upper Saddle River, NJ, 2004.
3. M. Dobosz, Wspomagana komputerowo statystyczna analiza wyników badań, *Akademicka Oficyna Wydawnicza EXIT*, Warszawa, 2001.
4. A. Rudnicki, *Jakość komunikacji miejskiej*, Zeszyty Naukowo-Techniczne Oddziału SITK w Krakowie, Zeszyt nr 71, Kraków 1999.

This paper is involved with **CIVITAS – CARAVEL** project:
„Clean and better transport in cities"
The project has received research funding from
the **Community's Sixth Framework Programme**.
The paper reflects only the author's views and the Community is
not liable for any use that may be made of the information
contained therein.