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HUPMOBILE

PRE-FEASIBILITY STUDY OF ADAPTIVE TRAFFIC LIGHTS IN CITY OF TALLINN

HUPMOBILE – Holistic Urban and Peri-urban Mobility
City of Tallinn, 2022

Imprint

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Authors:	Kristiina Oll (Civitta Eesi AS), Dago Antov (Stratum OÜ), Margus Nigol (Stratum OÜ), Viljar Nurme (Trafiction OÜ)
Contributors:	Liivar Luts (City of Tallinn), Ralf-Martin Soe (ITL Digital Lab)
Layout:	Laura Sarlin, Union of the Baltic Cities Sustainable Cities Commission
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Project note

The EU co-funded project **HUPMOBILE – Holistic Urban and Peri-urban Mobility** (2019–2021) brings together municipalities, universities and other expert organisations in their efforts to develop a holistic approach to the planning, implementation, optimisation and management of integrated, sustainable mobility solutions in the Baltic Sea port cities.

The carried-out activities enable major urban mobility stakeholders such as city authorities, as well as infrastructure providers and transport providers to assess and integrate innovative mobility options into their mobility management plans and policies. The developed HUPMOBILE framework allows the planning and implementation of well-functioning interfaces and links in urban- and peri-urban transport considering the different transportation flows in the local context.

Within HUPMOBILE, partner cities plan, test and implement innovative sustainable urban mobility for both people and goods (i.e. freight, cargo logistics and delivery), which are easily adaptable for follower cities. These include greener urban logistics and combinations of goods- and passenger traffic, intelligent traffic systems-based services, tools for stakeholder participation, and new tools for transportation mobility management and Mobility-as-a-Service (MaaS).

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SUMMARY

Although traffic light control solutions have been known in the world for more than 100 years, it is in recent decades that new, innovative solutions have been found. Most of them are related to new possibilities of collecting real-time traffic data according to users of different modes of transport and of employing these data to optimize traffic management. These solutions are often referred to as adaptability. The aim of this project is to analyse the possibilities of applying adaptability in Tallinn and to share the obtained results with other cities in the Baltic Sea region.

The implementation of the analysis “Pre-feasibility study of Adaptive Traffic Management in Tallinn” was funded by the Interreg Baltic Sea Programme within the HUPMOBILE project.

The realization of possible new adaptive applications is, of course, quite a labour-intensive and resource-intensive activity. Consequently, before making such decisions, it is necessary to carefully analyse which adaptability priorities are practicable, as well as which techniques these applications require.

In the present study, the existing practices of the city in the application of adaptability have been analysed (on the road called Reidi tee); a pilot project was carried out at the intersection of the streets Kopli, Sitsi and Tööstuse, where traffic light control priority was applied to the tram; data were collected on the experience of other cities comparable to Tallinn in many ways; and the possible outcome of adaptive management of some potential traffic corridors was analysed.

As a result of this study, some general proposals were formulated to increase the adaptability of traffic light control in Tallinn in the future.

First, it is important to emphasize that possible priorities and goals for an adaptive solution should support the overall mobility policies and objectives of the city. This means that even if (similar to the results presented in this study) the adaptation of an intersection or corridor does not have an overall significant effect (for example, a total reduction in waiting times for all modes of transport), then, for transport policy purposes (for example, comprehensive promotion of cycling or public transport may be identified as one of those purposes), it may still be expedient to implement an adaptive solution. Such examples are also given in this report, which deals with the practices of other cities; for instance, the priority and favour of public transport has often been applied, precisely for transport policy reasons.

It follows from the foregoing that it is also possible **to set requirements for the technology used**, including which modes of transport and/or groups of road users need to be detected by sensors. This is certainly necessary if a priority is to be given to a particular group or direction of road users. However, this does not mean that it is not necessary to identify traffic flows from other groups or directions when implementing one priority or another. This is necessary if the aim is also to assess the overall performance of an intersection or if there are any limits to the priority solution, so as not to paralyse non-priority traffic to a large extent. In addition to modifying the traffic light program, there are other functions when using sensors, such as regular monitoring of traffic flows. In this case, too, it may be expedient to use sensors.

Adaptability as a modern traffic management concept should definitely be considered as the primary option for traffic management of all new and reconstructed objects. However, in general, the principle of an adaptive solution is that **each solution is relatively unique** and standard solutions are difficult to design. Therefore, it is always a matter of the so-called “tailoring”, to which analogies can only be applied to a limited extent.

The results of the present study clearly showed that **the implementation of adaptive solutions can have a significant effect, depending on the objectives of implementation, either a) for the priority of some modes of transport or b) to reduce the overall waiting time.** This was confirmed by the results of the present study for the road Reidi tee already in use, the results of the pilot project carried out and the experience of other cities, as well as theoretical calculations for several traffic corridors.

1. DESCRIPTION OF THE METHODOLOGY APPLIED

The aim of this study was to conduct a pre-feasibility study of adaptive traffic management in Tallinn together with adaptive traffic management testing (hereinafter *mini-pilot*) in a real traffic environment.

The objective of the study was to get an overview of different adaptive traffic management systems from around the world and to evaluate the possibility of their application on the example of Tallinn. The study also had to provide a reasoned assessment of whether adaptive traffic management improves infrastructure capacity and to test the operation of the proposed solution in real traffic in the form of a mini-pilot project.

Based on the project objectives, the project was implemented in **six stages** (see Figure 1).

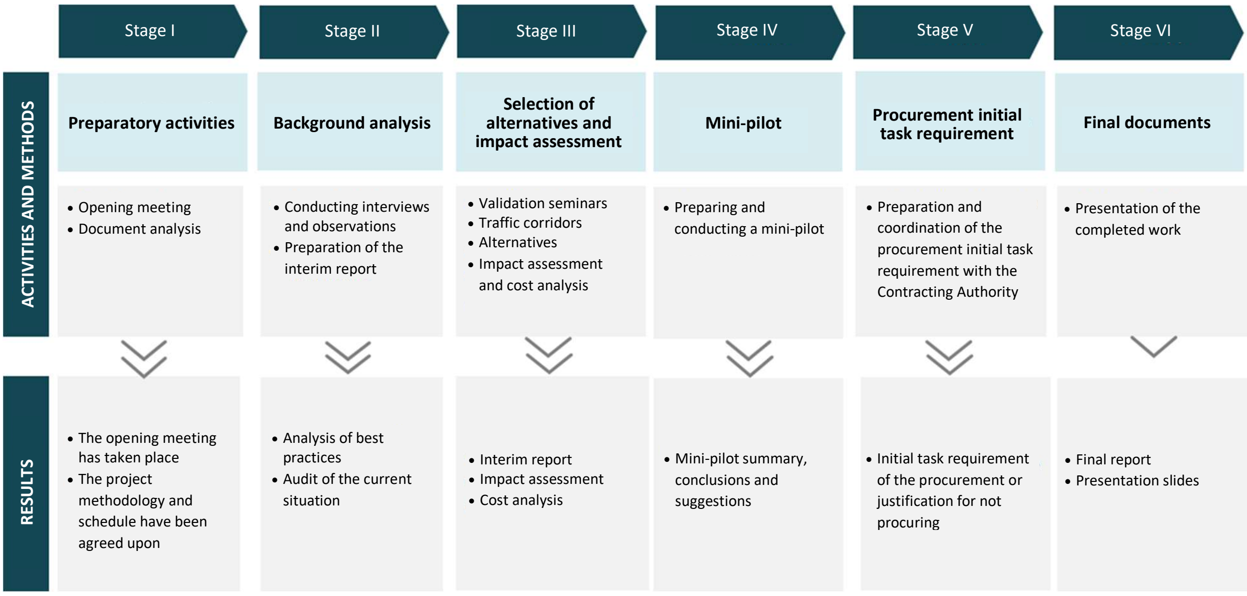

FIGURE 1. OVERVIEW OF THE METHODOLOGICAL PLAN AND RESULTS OF THE PROJECT

In the **first stage**, the preparatory activities required for a successful project took place, such as an opening meeting and a document analysis, during which the current situation and the main bottlenecks were identified.

In the **second stage**, a background analysis was carried out, including an analysis of best practices and the current situation. The analysis of foreign countries looked at four cities (Tampere, Copenhagen, Skopje and Białystok) and the adaptive solutions implemented in those. To perform the analysis, information was collected using a questionnaire and, if necessary, additional data queries were made. Information was also collected from manufacturers offering adaptive solutions in the above-mentioned cities (see "Annex 1. Methodology and results of the analysis of foreign practices"). As part of the analysis of the current situation, an audit of the adaptive solution implemented on the road Reidi tee was carried out (see "Annex 2. Audit methodology and results for the road Reidi tee").

In the **third stage**, traffic corridors and alternatives to be analysed were identified and their impacts and costs assessed. In the traffic corridors to be analysed, priorities were defined as follows: on the road Tartu maantee, the tram as the priority; on the road Smuuli tee, heavy vehicles as the priority; on the road Peterburi tee, heavy vehicles as the priority; and the roads Tammsaare tee, Ehitajate tee and Kadaka tee without a specific priority system, only for the purpose of increasing general traffic throughput. In the case of the corridors analysed, the effect of adaptability on the traffic flow was modelled and the potential time-saving for road users was estimated. The cost of the investment needed to achieve the adaptability of each corridor was also assessed (see Chapter "Possible corridors for implementing adaptive solutions in Tallinn").

During the **fourth stage**, a mini-pilot was carried out to evaluate the performance of adaptive solutions operating in a real-world environment. Within the framework of the mini-pilot, thermal sensors were installed at the intersection of the streets Kopli, Tööstuse, Sitsi and Paljassaare (+ the tramway) to give priority to trams, and the effect on traffic flow was observed during one month (see "Annex 3. Mini-pilot methodology and results" for more details).

In the **fifth stage**, the initial task requirement for the procurement of an adaptive traffic management system was prepared (see "Annex 4. Technical specification of the adaptive traffic management system for the city of Tallinn for procurement" for more details), and in the **last, sixth stage**, the final documents were prepared and introduced to the Contracting Authority.

2. IMPLEMENTATION OF ADAPTIVE SOLUTIONS IN THE CITY OF TALLINN

This chapter presents assessments of the application of adaptive solutions in the city of Tallinn, including the most important conclusions from the analysis of foreign practice, the audit of the road Reidi tee and the results of the mini-pilot.

2.1. STARTING POINTS FOR DEVELOPING ADAPTIVE SOLUTIONS

2.1.1. LESSONS LEARNT FROM THE ANALYSIS OF FOREIGN PRACTICE

The analysis of foreign countries looked at four cities (Tampere, Copenhagen, Skopje and Białystok) and the adaptive solutions implemented in those. To perform the analysis, information was collected using a questionnaire and, if necessary, additional data queries were made. Information was also collected from manufacturers providing adaptive solutions in these cities.

Priority systems are used in all those cities:

- In Tampere, priorities have been set for emergency vehicles, public transport and also for cyclists.
- In Copenhagen, priority systems have been set up for public transport (an advantage for buses in a bus priority system traffic lights, an adaptive *ImFlow* system, a green light time transmission system for buses and lorries).
- In Skopje, a priority system has been set up for emergency vehicles and public transport. Rescue vehicles are given priority through the OMNIA "green route" application. The priority of public transport is checked through the communication between UTOPIA and the public transport system (provided by a third party). GPS location for both rescue vehicles and public transport. For rescue vehicles, OMNIA prepares the green corridor solution on a given route. The public transport priority is implemented by making full use of UTOPIA's adaptation strategies.
- In Białystok, priority is given to public transport. On-board computers are used on buses. In addition, regular monitoring of traffic flows is carried out by using sensors (*Sitraffic Scala*, available from *Siemens*). According to the city, provision of this solution was a good decision and produced a positive result. The system has been implemented throughout the urban area and it focuses on traffic management. The traffic situation is much better and travel time was reduced by more than 15% without significantly extending the queue in terms of congestion on the non-priority road.

Summarizing the current practices and future visions of these cities, it can be said that

- all those cities have experience with adaptive solutions, and this is generally considered to be positive. The cities have plans to expand these systems;
- the traffic light equipment used varies, but none of the cities expressed the opinion that the traffic light equipment they have purchased does not work or has proved to be unreliable or ineffective;
- the cities have worked closely with equipment suppliers prior to the introduction of such new traffic light systems in order to avoid problems with the setting up of the equipment;
- in all those cities, clear priorities have been set for what the traffic light system must allow for or which modes of transport are expected to be prioritized. In most cases, they relate to the priority of public transport or non-motorized road users;
- based on the experience of these other cities, it can be stated that in addition to the ordinary traffic light management, one of the important functions of traffic light systems is the monitoring of traffic flows, which makes it possible to draw important conclusions about traffic developments and trends and forecast traffic problems that may arise in the future.

2.1.2. LESSONS LEARNT FROM THE AUDIT OF THE ROAD REIDI TEE

A prerequisite for the operation of an adaptive traffic light control system is the availability of very good sensor information. A sufficient number of sensors have been designed and installed on Reidi tee. Traffic load data is obtained from several sensors (pre-sensors for the departing direction of the previous intersection, sensors for the approaching direction of an intersection).

However, in the course of the audit, it was concluded that the greatest impact on the discrepancies in the expected operation of the traffic light control system of Reidi tee is caused by the sensors, more precisely the incorrect information obtained from them (also the lack of information). The Flir TrafiOne sensors, which were designed to be used and which according to the technical specification are of a very high standard and innovative (combining the conventional video detection with thermal imager), caused problems in actual performance. Thus, the question is, which traffic flow sensors should be used? Due to accuracy and low interference, the use of inductive sensors gives good results, but their failure in case of high traffic flows (durability from 2 to 5 years) must be taken into account. However, reinstalling inductive sensors is resource-intensive and disrupts traffic. Therefore, the designer has discarded this sensor type. In the long run, the reduction of metal parts in vehicle construction must also be taken into account, which reduces the possibility of inductive vehicle detection. Good results in vehicle detection have been obtained with ultrasonic sensors, but these sensors are sensitive to the chlorides used in our road environment in winter. At first glance, it seems that in the future the most widely used type of sensor will be the video sensor, which has the greatest possibilities of software application, but it also requires designing the road environment in accordance with the specifics of the sensor (interfering shadows, reflections, etc.). **The authors of this study recommend that traffic light practitioners work more closely together to find a suitable type of sensor.**

Some shortcomings in the implementation of the traffic light system were caused by the novelty of the application of adaptive traffic light control in Estonia. The designer could not foresee all possible aspects or ask the supplier of the traffic light control system about them in particular. The authors of this study also found it difficult to assess the compliance of the operation of the traffic light programs with the design, because in the section from Jõe street to the road Narva maantee, the traffic light control software prepares each optimal work program on the basis of the sensor information, taking into account the matrix of protection times given in the project. Observations showed that the traffic light control software was constantly changing the length of phases in the traffic light program, but in some cases it was not clear or rational. This happened more often on the arms leaving the port area, where the problem seemed to be skipping phases, which did not coincide with the principles of adaptability of the traffic light control software.

Should the adaptive traffic light control system applications be provided on the same platform, and in which locations? **Given the cost and complexity of the system, the auditor does not see the feasibility of using a similar platform at intersections with low traffic load and at intersections with large differences between the traffic load on the different arms of the intersection.** In the interest of a more rational use of resources, it would make sense to use an actuated traffic light control system at such intersections, which would allow such traffic lights to better meet the needs of the traffic flow (e.g. skipping the directions with no traffic).

The adaptive control system should be used especially in high-load areas, where the sensor-based system is able to divide the phases and the cycle length between the traffic flows on an adaptive basis (e.g. Liivalaia street).

With regard to variable-message signs (VMS), the inadequacy of their angle of visibility was remarked on – if the information displayed on the sign was visible from a distance, it was not visible up close, and vice versa. In future procurements, the adequacy of the angle of visibility should be paid attention to in the technical specifications.

2.1.3. LESSONS LEARNT FROM THE MINI-PILOT

Within the framework of the mini-pilot, ThermiCam thermal sensors were installed at the intersection of the streets Kopli, Tööstuse, Sitsi and Paljassaare (+ tramway) to give priority to trams, and priority traffic light programs were developed. The trams thus received priority according to the priority program, regardless of the traffic light phase at the intersection. At the tram stop Sitsi, the standing time of the trams at the stop was taken into account when creating the priority, as the stop is located directly before an intersection. In addition, the existing TrafiCam video sensors at the intersection were used to count vehicles at the stop line as the vehicle entered the intersection. Counting data were used in the tailor-made Smart Intersection traffic light programs. According to the data received from the counting sensors, green light time was continuously optimized between the different traffic directions, thus providing more green light time to the busier directions. The organization and results of the mini-pilot are detailed in the annexes to the report (see Annex 3. Mini-pilot methodology and results).

Tram detection and vehicle counting with the sensors selected for this purpose worked. As these are sensors that may be affected by different weather conditions to some extent, it would be reasonable to test such an intersection for a period of one year, going through all seasons in Estonia and some properly performed maintenance periods. After that, complete certainty in terms of performance could be achieved. However, if thermal and/or video sensors start to give false signals, re-use of inductive sensors embedded in the road surface can be considered.

The tram priority programs worked in an exemplary manner. The connection speed of the trams between two stops increased significantly. **The prioritization of trams did not have a significant impact on car traffic.** Waiting times increased in some directions, decreased in others and remained the same in some. This can be seen as a benefit of the Smart Intersection traffic light program, which redistributed green light time between directions based on the actual need.

Pedestrians were given the opportunity to cross the road after pressing the pedestrian call button. However, many pedestrians "forgot" to push the button and waited for the green light longer than necessary. Better information for pedestrians or the introduction of pedestrian sensors would be helpful.

It is certainly possible and highly recommended to extend the piloted adaptive traffic management system to other areas in Tallinn. In particular, it could be extended to isolated intersections that have already been tested in this mini-pilot, but also to traffic corridors, the performance of which it is reasonable to test further with a subsequent pilot.

2.2. POSSIBLE CORRIDORS FOR IMPLEMENTING ADAPTIVE SOLUTIONS IN TALLINN

2.2.1. CORRIDORS TO BE ANALYSED

In order to assess the feasibility and expediency of implementing adaptive solutions in Tallinn, six corridors were selected in cooperation with the contractors and the Transport Department of Tallinn (seeTable 1), where the implementation of adaptability would have somewhat different priorities and objectives. In the case of route selection, corridors were searched where:

- it would be possible to identify a specific priority (such as heavy vehicle traffic or trams) or
- these would be relatively congested routes where the expected effect could be significant.

It is necessary to add that the selected routes do not represent an exhaustive list of possible adaptive traffic light solutions. In the future, other routes can be considered, but to a large extent also individual isolated intersections, where a positive effect due to adaptability can also be expected.

TABLE 1. POSSIBLE CORRIDORS FOR IMPLEMENTING ADAPTIVE SOLUTIONS IN TALLINN

ROUTE	SECTION	POSSIBLE PRIORITY	POSSIBLE EFFECT	POTENTIAL “SUFFERER”	REMARKS
Peterburi tee	Linna piir-Tartu mnt	Heavy vehicle traffic, tram	Reducing waiting times for heavy vehicles and increasing the smoothness of traffic flow	Secondary directions	The road will be undergoing reconstruction
Tartu mnt	Lubja-Liivalaia	Tram	Reduction of waiting times for trams	All car traffic	Tram traffic is slow in this section
Tammsaare tee	Tondi-Kadaka tee	Reduction of waiting times	These are congested intersections at peak times – the positive effect of adaptability is not clear	Other traffic directions	High traffic load, but it is somewhat difficult to define principles; in particular, off-peak adaptability should be considered
Ehitajate tee /Rannamõisa tee	Kadaka tee-Kakumäe (Selver)	Reduction of waiting times	These are congested intersections at peak times – the application of adaptability is questionable		Uneven load, continuation of previous sections
Kadaka tee/pst	Ehitajate tee-Tähetorni	Reduction of waiting times	Reduction of total waiting times	In the absence of turning lanes, the effect of adaptability is small	Uneven load, relatively many unnecessary waiting times
Smuuli	Suur-Sõjamäe - Narva mnt/Pirita	Heavy vehicle traffic	Reducing waiting times for heavy vehicles and increasing the smoothness of traffic flow	Secondary directions	

2.2.2. IMPACT ASSESSMENT METHODOLOGY

In the present study, the impact of possible adaptive corridors has been assessed using two different methods, depending on whether the corridor has a priority for certain modes of transport or not.

IMPLEMENTATION OF AN ADAPTIVE SOLUTION TOGETHER WITH THE IMPLEMENTATION OF PRIORITY

For the corridors where the implementation of a clear priority has been considered (priority for heavy vehicle traffic on the roads Peterburi tee and Smuuli tee and priority for tram traffic on the road Tartu maantee), the impact assessment is based on certain assumptions:

- taking into account the actual daily traffic flows and the share of a specific type of traffic flow (for which priority is sought) in it;
- expecting the priority system to give the priority traffic flow (depending on location, either heavy vehicles or tram) early green light (a maximum of five seconds) if the priority vehicle would otherwise reach the intersection before the green light goes on, or green light delay (also up to five seconds) if the priority vehicle would otherwise not be able to cross the intersection with the time that the green light is on. However, in the event of such early green light or green light delay, it must be borne in mind that the green light time in other directions should not fall below the permitted minimum.

Thus, the priority directions always have a certain advantage, but at the same time the extent to which such a change leads to an increase in the waiting time for other directions (usually secondary directions) has been assessed.

It is important to point out that this calculation is to some extent a preliminary estimate, as **it is possible and necessary to develop a specific solution for each individual intersection when implementing actual systems**, as a result of which the actual waiting times may differ from the ones given in this study. As the present study **is** rather a **preliminary assessment** of possible solutions, it is a generalization that would give a general answer to whether and where the situation could change as a result of the application of adaptability. In addition, it is important to mention that **the implementation of the priority principle cannot depend on the change in waiting times alone**; it also depends on transport policy decisions, in which, despite certain changes in the traffic situation, it is still necessary to give preference to some modes of transport.

IMPLEMENTING AN ADAPTIVE SOLUTION WITHOUT IMPLEMENTING A PRIORITY

For the remaining corridors, the impact of the adaptive solution has been assessed, where no particular mode of traffic or direction is directly preferred, **but the potential effect arises precisely from better adaptability.** This means that instead of relatively rigid traffic light solutions, a situation has been assessed on a daily basis in which the change in waiting times is primarily due to the implementation of more flexible programs.

Here, the impact assessment is methodologically based on the data of the Tallinn traffic model (traffic flows and waiting times). The traffic model software (*Cube Voyager*) has a function that, based on the volume of the modelled traffic flows, automatically calculates the optimal traffic light program for the intersection on the basis of the current traffic load. Using this function, two situations have been compared in the present study – before and after. “Before” means a situation in which the intersection operates on the basis of previously planned and implemented traffic light programs. In the “after” situation, the traffic light program is created according to the actual modelled distribution of traffic flows.

The traffic model also provides waiting times per car, which are used as a basis for estimating changes in daily waiting times. In addition to the above, it should be borne in mind that since the model operates on a network in which the best route for each vehicle is “searched” for the given situation, the traffic load values in the “before” and “after” situations given for reference in this study are slightly different. This conditionally describes a situation in which some drivers may choose a different route if an adaptive solution is implemented at the intersection, which has increased their waiting time. However, the changes in the traffic volume are not very large.

When performing the analysis, each corridor was modelled separately. This means that the result reflects a situation in which only the adaptive solution of a given corridor has been implemented in the street network of the city at a time. If such corridors are implemented at the same time, the outcome may change to some extent as a result.

CITY INFORMATION SYSTEMS USED IN THE ANALYSIS

In carrying out this project, the authors made significant use of the information layers and sources of the city itself. Mainly the following data were relied on:

- the existing traffic light programs,
- public transport movement data (*Thoreb*),
- the city traffic monitoring system data,
- the traffic light sensor data,
- other sources.

These data are generally adequate and can be used in the present and similar studies. However, there were some problems, particularly in the following aspects:

- The structure of the datasets is patchy and there are often problems with dealing with different datasets in one package. This requires relatively high data processing skills and resources. This problem affected not only this project but also the interests of the city itself and opportunities for similar analyses. Consequently, it is necessary to consider further developments that would make the data easier to use.
- Unfortunately, there occurred also situations in which some sensors or the system as a whole did not work for a period of time, so this project also required time adjustments for the reference period. These problems only emerged during data processing and not before the start of the project phase.

Based on the above, the following proposals can be made:

- Continue to develop the traffic monitoring system of the city, significantly expanding the number and locations of counting points. It is particularly important to include counting facilities that include pedestrians, cyclists and other modes of transport.
- Start developing an urban mobility data system that would allow for easy and user-friendly analysis and cross-use of different datasets. Based on the experience gained in this project, special emphasis could be placed on the data of traffic light programs, where the existing use is rather complicated and labour-intensive.

The above is especially important for the traffic specialists of the city to make better decisions.

2.2.3. RESULTS OF CORRIDOR ANALYSIS

The following is a summary of the analysis of adaptive corridors. More detailed calculations by corridors are provided in “Annex 5. Results of the implementation of adaptive solutions for specific corridors”. The corridor analysis mainly used two key quantitative indicators: 1) total waiting time as an annual average daily sum, for all directions combined (minutes per twenty-four hours); and 2) economic impact.

TABLE 2. TOTAL DAILY WAITING TIMES AT INTERSECTIONS WITH THE EXISTING AND AN ADAPTIVE SOLUTION

CORRIDOR	INTERSECTION	TOTAL WAITING TIME, MIN/24HRS				PRIORITY
		existing	adaptive	change[1]		
				min	%	
Ehitajate tee	Õismäe tee	1,6838	1,5952	–886	–5.3%	ad[2]
	Kadaka tee	3,2251	2,9311	–2,940	–9.1%	ad
Kadaka tee/pst	Akadeemia tee	4,7387	3,9697	–7,690	–16.2%	ad
	Mustamäe tee	1,2915	1,1657	–1,258	–9.7%	ad
	Tähetorni	7,754	6,087	–1,667	–21.5%	ad
	Mäepealse	6,781	7,175	394	5.8%	ad
	Ehitajate tee	3,2251	2,7739	–4,512	–14.0%	ad
Tammsaare tee	Kadaka tee	3,2251	3,1576	–675	–2.1%	ad
	Mustamäe tee	2,6200	3,4981	8,781	33.5%	ad
	Ehitajate tee	1,3972	1,0277	–3,695	–26.4%	ad
	Laki	4,596	3,904	–692	–15.1%	ad
	Sõpruse pst	1,24119	8,0804	–4,3315	–34.9%	ad
	Nõmme tee	2,0412	1,5234	–5,178	–25.4%	ad

[1] *A negative result indicates a decrease in waiting time and a positive result indicates an increase in waiting time.*

[2] ad *- means implementing a fully adaptive solution at the intersection instead of the existing program selection.*

	Tondi	5,1895	6,4835	1,2940	24.9%	ad
Smuuli tee	Punane	6,642	6,897	255	3.8%	Heavy vehicle traffic (–15.4 min per 24 hrs)
	Narva mnt	2,749	2,709	–40	–1.5%	Heavy vehicle traffic (–25.1 min per 24 hrs)
Peterburi tee	Mustakivi	7,213	7,290	77	1.1%	Heavy vehicle traffic (–28.3 min per 24 hrs)
	Smuuli	9,186	9,030	–156	–1.7%	Heavy vehicle traffic (–63.7 min per 24 hrs)
Tartu mnt	Liivalaia	1,2539	1,2561	22	0.2%	Tram (–23 min per 24 hrs)
	Kreutzwaldi	3,845	3,150	–696	–18.1%	Tram (–17.4 min per 24 hrs)
	Laulupeo	7,026	5,691	–1,336	–19.0%	Tram (–18.5 min per 24 hrs)
	Odra/Türnpu	1,1408	1,1631	223	2.0%	Tram (–17.5 min per 24 hrs)
	Lubja	7,756	6,744	–1,012	–13.1%	Tram (–18.6 min per 24 hrs)

It can be seen from the table that the expected results of the implementation of adaptive solutions are varied. As a rule, for those corridors where a priority for a particular mode of transport has been applied, the total waiting time at the intersection as the sum of all directions is greater than the existing waiting time, or no significant change is expected, as the priority is applied to only a few modes of transport. A small difference can be seen on the road Tartu maantee in terms of tram priority where, however, the total waiting time has been reduced at three intersections, which is primarily due to the fact that together with the tram priority (early green light or green light delay), vehicles moving along Tartu maantee also gain a certain advantage.

It is necessary to emphasize that while the analysis of the priority system of the roads Peterburi tee, Smuuli tee and Tartu maantee is based on the existing solution, including the existing traffic volume values, for the remaining corridors also possible changes in traffic loads have been taken into account, caused by the application of the adaptive solution. This means that the adaptive solution of one corridor or another also changes the distribution of traffic flows to some extent. In addition, at some very busy intersections, the change in waiting time is primarily due to a change in off-peak waiting time.

The results of the corridor analysis show that the implementation of adaptability or the priority of a mode of transport reduces or increases the travel time of different modes of transport.

Savings in travel time is the greatest benefit of investing in transport infrastructure for each user. The value of time, which enables us to convert savings in time into economic benefits, is calculated for:

- car users,
- public transport users (trams, buses),
- heavy vehicles.

The travel time values of car and public transport users are calculated as follows[3]:

- 0.214 EUR/min (according to prices in 2020) for work travel and commuting (from home to work),
- 0.086 EUR/min (according to prices in 2020) for non-work travel.

The following distribution of travel is expected for Tallinn: 35% work travel and 65% non-work travel. On the basis of these assumptions, the time value is calculated to be 7.74 EUR/h (according to prices in 2020). The value of travel time for heavy vehicles is calculated according to the average hourly labour cost in the transport sector, which in 2020 was 12.15 euro per hour[4], i.e. 0.203 EUR/min.

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[3] Feasibility and technical framework study for a rail bound (light rail or tram) connection from RB Ülemiste passenger terminal to Ten-T core network Tallinn Passenger Port, p. 206
Final Report of the Rail Baltica Global Project Cost-Benefit Analysis, p. 147

[4] PA001: AVERAGE GROSS WAGES (SALARIES), LABOUR COST, HOURS ACTUALLY WORKED AND NUMBER OF EMPLOYEES BY ECONOMIC ACTIVITY SECTION (QUARTERLY); Transportation and Storage, 2020

Although vehicle traffic flows were modelled in the adaptive corridor analysis, they can be converted to passenger numbers by using average vehicle occupancy rates:

- passenger car occupancy 1.25 people per car,
- tram occupancy 63 people per tram,
- bus occupancy 30 people per bus,
- heavy vehicle occupancy 1 person per heavy vehicle.

The following table shows the time saved per year by corridors and intersections and the financial estimate of the value of the time saved. (Negative values mean an increase in the time of passing through an intersection.)

TABLE 3. TIME SAVED AT INTERSECTIONS AND ESTIMATED FINANCIAL VALUE OF THE TIME SAVED

Corridor	Intersection	Total time saved (hrs/year)		Value of time saved (€/year)	
		At the intersection	In the corridor	At the intersection	In the corridor
Ehitajate tee	Õismäe tee	8,728 h	37,671 h	68,025 €	293,614 €
	Kadaka tee	28,944 h		225,589 €	
Kadaka tee/pst	Akadeemia tee	82,401 h	157,866 h	642,679 €	1,231,268 €
	Mustamäe tee	13,478 h		105,118 €	
	Tähetorni	17,868 h		139,361 €	
	Mäepealse	–4,227 h		–32,965 €	
	Ehitajate tee	48,346 h		377,076 €	
Tammsaare tee	Kadaka tee	7,237 h	345,957 h	56,443 €	2,698,269 €
	Mustamäe tee	–94,078 h		–733,756 €	
	Ehitajate tee	39,640 h		309,169 €	
	Laki	7,420 h		57,873 €	
	Sõpruse pst	464,089 h		3,619,638 €	
	Nõmme tee	55,471 h		432,643 €	
	Tondi	–133,823 h		–1,043,742 €	
Smuuli tee	Punane	–1,903 h	–1,432 h	–14,308 €	–9,993 €
	Narva mnt	471 h		4,315 €	
Peterburi tee	Mustakivi	–810 h	439 h	–5,507 €	5,868 €
	Smuuli	1,249 h		11,376 €	
Tartu mnt	Liivalaia	8,012 h	85,362 h	61,975 €	661,304 €
	Kreutzwaldi	18,932 h		146,692 €	
	Laulupeo	30,907 h		239,547 €	
	Odra/Türnpu	2,343 h		18,052 €	
	Lubja	25,168 h		195,038 €	

On the other hand, building adaptive solutions requires certain investment. The table below (Table 4) shows the construction costs and annual maintenance costs (excluding VAT) of all the corridors and intersections analysed. The cost of building an intersection includes the design of the intersection, the sensors to be installed and sensor installation work at the intersection, and the *Smart Intersection* software and programming required for the operation of the sensors.

TABLE 4. CONSTRUCTION COSTS FOR CORRIDORS AND INTERSECTIONS

CORRIDOR	CORRIDOR COST	INTERSECTION	INTERSECTION COST	ESTIMATED MAINTENANCE AND TROUBLESHOOTING COSTS (PER YEAR)
Ehitajate tee	49,000 €	Õismäe tee	19,500 €	195 €
		Kadaka tee	29,500 €	
Kadaka tee/pst	107,500 €	Akadeemia tee	24,500 €	699 €
		Mustamäe tee	22,000 €	
		Tähetorni	17,000 €	
		Mäepealse	14,500 €	
		Ehitajate tee	29,500 €	
Tammsaare tee	166,500 €	Kadaka tee	29,500 €	655 €
		Mustamäe tee	27,000 €	
		Ehitajate tee	17,000 €	
		Laki	19,500 €	
		Sõpruse pst	27,000 €	
		Nõmme tee	22,000 €	
		Tondi	24,500 €	
Smuuli tee	65,500 €	Punane	39,000 €	208 €
		Narva mnt	26,500 €	
Peterburi tee	68,000 €	Mustakivi	29,000 €	221 €
		Smuuli	39,000 €	
Tartu mnt	149,500 €	Liivalaia	43,000 €	593 €
		Kreutzwaldi	29,500 €	
		Laulupeo	22,000 €	
		Odra/Türnpu	27,000 €	
		Lubja	28,000 €	

The cost of installing the sensors does not take into account the costs that the contractors consider necessary to carry out the work at intersections even without adaptive solutions or with the solutions that already exist there. It is therefore assumed that:

- the traffic light controllers for all intersections are modern;
- the crossings have pedestrian call buttons that can be activated;
- the intersections have enough spare pipes, i.e. no excavation work is required; and
- the intersections have enough metal structures to which sensors can be attached.

If the above preconditions are not met, additional investments are needed. For example, if the reserve pipes have collapsed or fully in use (impassable), the additional design of each intersection, together with the approvals of the network operators and the excavation permit, will cost up to 10,000 euro per intersection. The cost of excavation work at a particular intersection depends on the scope of the work and the need for road pavement restoration.

Supervision of excavation work will be approx. 2,000 euro per intersection. It is also necessary to take into account the additional time, which would be about 1.5 to 2 years from the design.

In case of stop line sensors to be installed at intersections, the following have been taken into account:

- always one stop line sensor in the direction straight ahead, regardless of the number of lanes;
- a stop line sensor in the direction of the right turn with a separate traffic light (if there is no traffic light in the direction of the right turn, no sensor is considered);
- a stop line sensor in the direction of the left turn with a separate traffic light (a separate stop line sensor is not considered for turning left from the direct lane (i.e. there is no separate left-turn lane), so there is only one sensor for the direct lane).

At intersections where the priority is set for a certain category of vehicle (tram or heavy vehicle), the installation of additional detection sensors is considered as follows:

- In order to ensure the priority of the tram in the corridor of Tartu maantee, the installation of tram detection sensors at both ends of the corridor. In addition, each intersection has tram stop line sensors in both directions.
- In the corridors of Smuuli tee and Peterburi tee, the installation of detection sensors for heavy vehicles at each intersection.

According to experts, the development of adaptive solutions should not lead to a significant increase in maintenance costs. The maintenance of one video or thermal sensor takes an average of 5 minutes a year and it must be maintained twice a year. It takes an average of 6 minutes a year per intersection to find and repair faults. In addition, with the introduction of Smart Intersection programs, for example, the maintenance costs associated with controllers could even be reduced by not having to manually configure traffic light programs to such an extent. However, it should be borne in mind that when it comes to introducing new technology, maintenance costs may initially be significantly higher due to the need to further configure and adjust the particular solution.

IMPACT ON THROUGHPUT

In the case of modelled corridors, the effect on throughput is marginal. In the case of corridors where the priority system was not implemented, the model also takes into account a certain redistribution of traffic flows, so that there are no significant additional throughput problems (congestion) at the intersections analysed.

No significant throughput problems occurred for the corridors where the priority system was applied, either, because the priority system analysed has been planned for the main route. The traffic volume and the ensuing throughput problems of the secondary directions are much less serious. However, it is possible that the situation on the main route may improve to some extent as a whole due to the implementation of the priority principle. Yet, this has not been taken into account in the present analysis, as its effectiveness depends to a large extent on the actual traffic light solution. On the other hand, the solution presented in the present analysis requires only a relatively small change (1 to 5 seconds) of green light time, and this also depends on the priority vehicle being in the vicinity of the intersection at an appropriate moment. Such situations do not actually occur in every cycle and in some hours of the day it is quite infrequent. Even though the solution would be realized at the expense of the secondary direction, its impact on throughput can be assessed as modest or marginal.

IMPACT ON NON-MOTORIZED ROAD USERS

The present study is based on the view that the situation of non-motorized road users will not change when the potential impact of the adaptability of the corridors is assessed. This means that all crossing options available, as well as the required lengths of traffic light phases, will work even after adaptability is applied. It is possible, though, that when implementing adaptive solutions, situations may arise where, for example, pedestrians have to press the pedestrian call button to cross the road, which is not necessary in the current situation or during certain periods of time. Also, at certain times, when the priority of one mode of transport or another is applied, situations may arise (but not necessarily) in which, for example, waiting times for pedestrians or secondary directions increase to some extent. But this should not lead to situations in which they are not provided with the necessary green light time, the priority system creates undesirable problems for other road users (such as public transport), or the queues that form block traffic at other intersections. Avoidance of such situations must be ensured when creating detailed traffic light programs.

IMPACT OF NEW TECHNOLOGIES

This analysis is based primarily on the situation in which reliable and dependable technology is used to implement the adaptive solutions under analysis. In particular, sensors detecting vehicles and non-motorized road users have been considered, because in principle the traffic light controllers and the control system in Tallinn already have the capacity to implement adaptability to a greater extent. In other words, this analysis reflects a situation in which the application of adaptability would already be possible in the short term, using known technology. It cannot be ruled out, though, that other devices may also be used in the future. It is also possible that the prices of the equipment may change significantly.

IMPACT ON ROAD TRAFFIC SAFETY

However, in view of the future, traffic light solutions, including adaptive solutions, are likely to have some other implications and opportunities. These include increasing road traffic safety through traffic light equipment and new technologies, as well as other possible priorities, such as a much higher preference for non-motorized traffic, or adapting traffic light programs according to environmental impacts (i.e. taking into account pollution loads) or weather conditions.

Some of the so-called smart solutions aimed at increasing road traffic safety, even though still experimental, are already being implemented in real traffic situations (see, for example, www.bercman.com). As the main solution, additional warning systems (flashing lights, etc.) have been implemented for drivers, which are only activated when a vulnerable road user is actually in the danger zone. Preliminary research has shown that such solutions have a significant impact on improving safety. Their implementation can easily go hand in hand with adaptive traffic light solutions.

However, when assessing the overall impact of the application of adaptability on road traffic safety, there may be some setbacks, particularly in the early stages of implementation. These are primarily due to the fact that in ordinary situations, road users are used to a certain solution at the intersection. Among other things, they have learned the sequence of phases and often also operate on the basis of this knowledge. Thus, the use of a non-standard solution, which may no longer have such specific parameters, may lead to an increase in road user error. Therefore, an increase in the number of accidents in the initial phase of implementation cannot be ruled out.

Adequate information for road users will certainly reduce this potential risk. The dangers described here will also subside over time, as road users (such as pedestrians or cyclists) learn that a different solution is now in place and the pedestrian call button must be pressed to cross the road. Of course, the best solution would be detection of pedestrians waiting for a green light without any action on their part (pressing a button). Unfortunately, today we cannot be sure that this solution (although it exists) would work smoothly. Also, local conditions can be limiting for these solutions, such as the lack of a waiting area for pedestrians wishing to cross the road, and misidentification and registration of those pedestrians who pass through the waiting area but do not actually want to cross the road. In the current situation, therefore, the safest solution is still the pedestrian call buttons. Yet, it should be added that even if they are used, it would certainly be necessary to signal to the pedestrian that his “wish” to cross the road has been registered and that a green traffic light will soon come on. At the same time, problems may arise when the call buttons do exist but do not work at the moment, so the pedestrian is given incorrect information. Such situations could also be alleviated by informing the pedestrian that the opportunity to cross the road is coming soon.

OTHER POTENTIAL IMPACTS

A separate question is to what extent new technologies and modes of transport may affect the performance of adaptive solutions in the future. Examples of such technologies are self-driving vehicles, bicycle sharing, scooter rental, taxi platforms, etc.

It is necessary to mention at once that the impact of various technologies and solutions on adaptability is varied. While, for example, self-driving vehicles have a high potential to contribute to the acquisition of the information needed to implement adaptability, some developments (such as taxi platforms) do not participate to the same extent, because they are conventional motor vehicles in the general sense. A similar example would be rental bicycles, which are technically equivalent to conventional bicycles. Their role grows when they bring about a significant change in the distribution of modes of transport and a decision is made to give priority to such a mode of transport, but this in turn requires political agreements and decisions.

However, it is precisely the development of self-driving vehicles (not only full driving automation (SAE level 5), but also those self-driving vehicles that can collect, transmit and use traffic information) that has the greatest potential to support most adaptive solutions today (primarily stationary sensors). For instance, vehicles with this capability could be used as one possible source of data for analysis of the distribution of traffic flows on the road network or traffic characteristics (e.g. speed, waiting times, stoppages, etc.). To a certain extent, such capacity already exists in a certain category of public transport vehicles (mainly vehicles in the Tallinn public transport system), but there are still great opportunities for development here. The same problem applies to pedestrians, bicycles and, for example, non-motorized means of transport – information about these is scarce and there are few very good detection solutions.

ANNEXES

ANNEX 1. METHODOLOGY AND RESULTS OF THE ANALYSIS OF FOREIGN PRACTICES

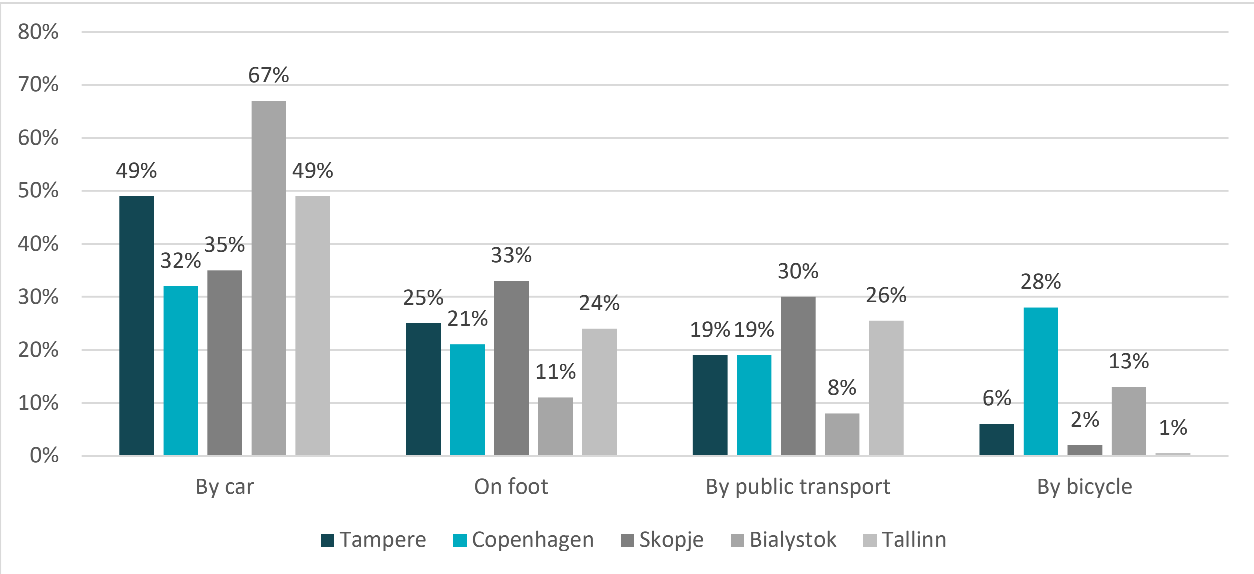
The analysis of foreign countries looked at four cities (Tampere, Copenhagen, Skopje and Białystok) and the adaptive solutions implemented in them. To perform the analysis, information was collected using a questionnaire and, if necessary, additional data queries were made. Information was also collected from manufacturers providing adaptive solutions in these cities.

GENERAL DATA

The traffic light systems of four cities (Tampere, Copenhagen, Skopje, Białystok) and the adaptive systems used in them are examined below.

	TAMPERE	COPENHAGEN	SKOPJE	BIAŁYSTOK	
Territory (km²)	523.4	179.8	571.5	102	159
Inhabitants	226,696	794,200	546,824 (2016)	296,958 (2020)	438,341 (2021)
Length of street network (km)	n/a	759	350	705	1,006 (2010)
Level of car ownership	n/a	n/a	400 cars per 1,000 inhabitants	347 cars per 1,000 inhabitants	481 cars per 1,000 inhabitants

MOBILITY RESEARCH



The highest levels of car traffic are in Białystok and Tampere, where 67% and 49% of road users use cars as their primary means of transport, respectively. In the example of Skopje, traffic by car, on foot and by public transport is relatively evenly distributed between 30 and 35%. In terms of cycling, Copenhagen stands out, with 28% of all travel being made by bicycle.

INTERSECTIONS AND PEDESTRIAN CROSSINGS

		TAMPERE	COPENHAGEN	BIAŁYSTOK	TALLINN
Intersections	Fixed	0	295		167
	Actuated	150	90		215
	Adaptive	25	15	129	5
	Total	175	400	129	387
Regulated pedestrian crossings	Fixed	0	135		35
	Actuated	15	10		61
	Adaptive	0	0	10	2
	Total	15	145	10	98

TECHNICAL DETAILS

	TAMPERE	COPENHAGEN	SKOPJE	BIAŁYSTOK	TALLINN
Sensors	Inductive sensors at each intersection, some radar and infrared sensors	FLIR TrafiCam, Thermicam, TrafiOne (100+), Smart Micro Radar (25), ViSense bicycle counters (18), road-side-units (50), bicycle counters with screen (27)	Inductive loops	3,304 inductive, SafeWalk, TrafiOne, Multiline detectors	inductive sensors, TrafiCam, TrafiOne
Traffic signal controllers			SWARCO ITC-2	C900V, sXH	EC-1, ITC-2, ITC-3
Traffic control centre software	RMS central system (Dynniq)	Dynniq RMS; Technolution MobiMaestro	SWARCO Utoopia, OMNIA	Siemens	OMNIA, OmniVue
Connection of controllers to the centre	100%	400 (401st)	77 TLC	86 intersections are centrally controlled	100%
Traffic light software features			Monitoring of traffic lights, traffic sensors, cameras, variable-message signs, notification of problems and maintenance, modification of traffic light programs, enabling a “green route” for priority vehicles, managing a “calendar scenario”	Traffic light monitoring, maintenance, program modification, signal group monitoring, sensor status monitoring	Traffic light monitoring, maintenance, program modification, signal group monitoring, sensor status monitoring

PRIORITIES

Priority systems are used in all four cities concerned:

- In **Tampere**, priorities have been set for emergency vehicles, public transport and also for cyclists.
- In **Copenhagen**, priority systems have been set up for public transport (an advantage for buses in a bus priority system, an adaptive ImFlow system, a green light time transmission system for buses and lorries).
- In **Skopje**, a priority system has been set up for emergency vehicles and public transport. Rescue vehicles are given priority through the OMNIA "green route" application. The priority of public transport is checked through the communication between UTOPIA and the public transport system (provided by a third party). GPS location for both rescue vehicles and public transport. For rescue vehicles, OMNIA prepares the green corridor solution on a given route. The public transport priority is implemented by making full use of UTOPIA's adaptation strategies.
- In **Białystok**, priority is given to public transport. On-board computers are used on buses. In addition, regular monitoring of traffic flows is carried out by using sensors (Sitraffic Scala, available from Siemens). According to the city, provision of this solution was a good decision and produced a positive result. The system has been implemented throughout the urban area and it focuses on traffic management. The traffic situation is much better and travel time was reduced by more than 15% without significantly extending the queue in terms of congestion on the non-priority road (see https://www.tomtom.com/en_gb/traffic-index/bialystok-traffic).
- In **Tallinn**, priorities have been set for public transport and pedestrians / non-motorized road users. Increasing overall capacity on main roads is a priority.

DEVELOPMENTS AND FUTURE PLANS

TAMPERE	COPENHAGEN	SKOPJE	BIAŁYSTOK
Increasing adaptability (tram), new ITS solution, VMSs, automatic bollards.	Bicycle – reduce the average travel time and the number of stops by 10%. Pedestrian – inner city traffic lights with enough green light time to reduce stops in the middle of the road, the cycle length should not exceed 80 sec. Public transport – reduce the average travel time during peak hours by 5–20%, increase reliability by 10%. Car/truck – reduce the average travel time in certain sections by 5%, increase the reliability of travel time during peak hours by 10%, reduce the number of stops on priority road networks by 10%.	Plans include expanding the system to include 110 centralized TLCs, multiple VMSs, and a traffic monitoring video detection system, all integrated under OMNIA. The priority for public transport is to take advantage of UTOPIA's ability to give buses selective and absolute priority through communication between the PT AVL and OMNIA systems. The next step is to introduce a multimedia application for the information system for citizens.	All new solutions are planned to be connected to the system and at the same time, new functions are planned to be implemented in the city. Since March 2021, the latest version of Sitraffic Scala 8.1 has been used.

ANNEX 2. AUDIT METHODOLOGY AND RESULTS FOR THE ROAD REIDI TEE

INTRODUCTION

The audit is intended to provide an independent assessment of road safety solutions in the road design and construction process, based on actual road safety experience, taking into account the circumstances and knowledge of road accidents and the results of similar solutions, as well as the results of road safety research and practice in other countries, with a view to minimizing the number and severity of road accidents.

The performance of the developed solution after the completion of the object is also assessed during the audit.

GENERAL INFORMATION

TABLE 5. CONSTRUCTION PROJECT/SITE

Project/site:	Reidi tee in the section from Jõe street to Russalka intersection
Project compiled by:	K-Projekt AS
Job no:	T04920
Person responsible for the project/site:	Taavi Agasild
Representative of the Contracting Authority:	Reio Vesiallik, Margus Kuusmann

TABLE 6. AUDITOR

Name of contractor:	Stratum OÜ
Job no:	T001-2021
Auditor:	Margus Nigol, professional qualification certificate 116857 30.11.2016, road safety audit and assessment
Experts involved, their competencies and tasks:	Tarmo Sulger, Erik Dejev
Audit phase:	2, 3, 4 – main project (ITS management), pre-opening, post-opening audit
Time of the execution of work:	10.03.2021 – 19.07.2021
Time of field work:	03. - 06.2021

TABLE 7. PREVIOUS AUDITS

Audit phase:	Road safety audit of the main project
The Contractor:	Stratum OÜ
Job no:	
Auditor:	Tarmo Sulger
Experts involved, their competencies and tasks:	

DESCRIPTION

PROPOSED SOLUTION

General information

The project presents the principles of ITS management of the road Reidi tee. An adaptive traffic light control system is designed for intelligent traffic management. Traffic light control principles, strategies, protection times, sensor placement principles and fixed traffic light programs are presented for the intersections included in the scope of the project.

In addition to traffic light management, the project addressed the use of variable traffic signs (VMS), the construction of a road weather station, urban video recording systems, traffic surveillance cameras, intersection cameras and pedestrian/cyclist counting points.

A precondition was that the traffic light controllers are fully and in all respects compatible with the traffic light control system used in Tallinn, enables coordination and adaptive control and connection to the traffic light control centre.

Design criteria

The Transport Department of Tallinn issued design criteria as the initial task requirement for the designer.

Design criteria of the Transport Department of Tallinn for Construction of Reidi tee in the section from Jõe street to Russalka intersection for preparation of technical design

Requirements for project design (excerpt from traffic light management and ITS solutions section)

1. *Design in the project all intersections of the planned road as intersections regulated with traffic lights.*
2. *Take into account the route of heavy duty vehicles from the Port of Tallinn to Tallinn ring road via the road Peterburi tee, and provide a solution for traffic lights (during peak hours) to regulate the merging of heavy duty vehicles into city traffic.*
3. *Plan the locations of public transport and its stops in accordance with the requirements and specify the locations further with the Transport Department of Tallinn. Where possible, design stops along the main road in accordance with the principle of the so-called closed pocket, separating them from the rest of the carriageway with a physical safety island.*
4. *Design the intersection of non-motorized traffic with the roads at the Russalka monument on different levels (mainly the direction of Kadriorg).*
5. *During the design, calculate the perspective traffic flows of the traffic junction and their directions and present the corresponding capacity calculations.*
6. *Model the traffic flows and changes of the entire planned road and intersections (incl. the load of the road Narva maantee up to Jõe street from the Russalka intersection with public transport priority on Narva maantee).*
7. *In the project, design the basic construction-time traffic scheme for the main construction stages together with the number of lanes and their width. Include the indication of possible detours and the work required to increase traffic on those.*
8. *Indicate in the design the dimensions of the traffic control road elements and the width of the lanes in the area between the intersections at least every 30 cm of each drawing, and at intersections, bends and changes in lane width in significant cross-sections, but at least every 15 m.*
9. *To regulate traffic flows, design VMSs (variable-message signs) on the road Pirita tee up to Rummu tee and on the road Narva maantee from Valge street to the Russalka intersection.*

The design criteria issued are given below:

Design requirements for traffic lights and variable message signs (VMS)

1. *For all new traffic light sites, design and implement fully adaptive traffic light control or at least five different traffic light programs which take into account changes in traffic volume over time. Coordinate the designed traffic light programs with the traffic light programs at neighbouring intersections. Appropriate schedules for the scope of the project shall be provided.*
2. *The required distance from the centre axis of the traffic light post to the edge of the carriageway shall ensure that the traffic light head is not closer than 0.5 m to the carriageway (2.0 m along the carriageway from the end of the safety island in the direction of traffic). The location of the traffic light post on the pavement shall provide the minimum width required for mechanical cleaning of the pavement.*
3. *For adaptive traffic light control, sensors (inductive loops, compact inductive sensors, infrared, ultrasonic, radar or video detectors) for both main and secondary traffic directions, which take into account the specifics of a particular object shall be designed.*
4. *For traffic light sites, communication connection between traffic light controllers and connection of intersection controllers with traffic light control centre shall be designed and implemented. The interconnection and the connection to the traffic light control centre shall be designed and constructed via a cable line to the nearest communication well connected to the traffic light control centre or to the intersection controller connected to the existing traffic light control centre. If it is not possible to establish a cable line, provide for the use of devices required for Internet connection / mobile communication in the controller.*
5. *Cable runs shall be constructed underground, in plastic conduits. Sensor (communication) cables and traffic light cables shall be placed in separate pipes (one 27x1.5 cable per pipe).*
6. *The control cable for traffic lights controlled from the same controller shall be designed and constructed as a ring feeder.*
7. *The use of equipment designed as traffic light controllers, which is fully and in all respects compatible with the traffic light control system used in Tallinn, shall enable coordination, adaptive control and connection to the traffic light control centre.*
8. *Only LED lights may be installed during the construction and reconstruction of traffic lights. The electrical parameters of traffic light equipment shall be compatible with the traffic light control technology used in Tallinn.*
9. *For pedestrian traffic lights, an acoustic signal with traffic direction and traffic control information shall be used to distinguish traffic lights. It must be possible to adjust the power of the acoustic signal over time, depending on the background noise, and to switch it off. For pedestrian traffic lights with a green light call, the pedestrian call buttons together with the direction of travel and traffic control information shall be used.*

The requirements for traffic lights and traffic signs in the technical parameters shall apply to VMS, together with the differences arising from the specifics of VMS.

Designed solution

SWARCO OMNIVUE software is used in the Tallinn traffic light control centre to manage traffic light controllers. All designed solutions are compatible with it.

To determine the performance of the designed solution, the principles of traffic light control systems described in the project were followed:

- **fixed control** – the principle of a traffic light control system, according to which the change in daily traffic volumes is forecasted and on the basis of which fixed-time traffic light programs are designed;
- **actuated control** – the principle of a traffic light control system, in which the maximum and minimum phase durations are determined and a traffic light program is established according to the information received from sensors;

- **adaptive control** – the principle of a traffic light control system, which monitors the movement of groups of vehicles in the area between intersections and forecasts their arrival at intersections, analyses the current traffic light cycle according to the arrival of vehicles, and decides whether and how to change it.

According to the meeting held on 14.10.2016 regarding Reidi tee, it was decided that "traffic control of Reidi tee should be provided as adaptive" (minutes of the Reidi tee meeting on 14.10.2016).

In the initial design phase, it was also established that the traffic light control software Swarco OmniVue is suitable for fixed and actuated control, but not for adaptive control. However, the technical specifications required full compatibility with the existing system. Due to the limitations, Swarco UTOPIA software, which enables adaptive traffic light control, was chosen as the basis for the development of the adaptive traffic light control system in the project.

The next-generation OMNIA software, which integrates both OMNIVUE and UTOPIA traffic light control systems, was used to integrate the adaptive traffic light control software UTOPIA with the existing traffic light control software OMNIVUE.

The introduction of OMNIA also allows the centre to manage both variable-message signs and other ITS solutions (parking arrangements, road weather stations, etc.).

To perform traffic light control on the road Reidi tee, 6 interconnected traffic light controllers were constructed, which control a total of 11 different traffic light sites. The following table shows the groupings of traffic light intersections in relation to traffic light controllers.

TABLE 8. INTERSECTIONS CONTROLLED BY TRAFFIC LIGHT CONTROLLERS ON REIDI TEE

TRAFFIC LIGHT CONTROLLER SYMBOL	INTERSECTIONS CONTROLLED BY TRAFFIC LIGHT CONTROLLER	
	Symbol	Location of the intersection
FJK1	EF1	Reidi tee – Jõe tn – Ahtri tn – Lootsi tn
FJK2	EF2	Reidi tee JK PK 3+90
	EF3	Reidi tee – Uus - Sadama tn
FJK3	EF4	Reidi tee – Petrooleumi tn
	EF5	Reidi tee JK PK 10+40
FJK4	EF6	Reidi tee – Pikksilma tn
	EF7	Reidi tee JK PK 14+80
FJK5	EF8	Reidi tee – Narva mnt
FJK6	EF9	Narva mnt JK PK 19+20
	EF10	Narva mnt – Pirita tee
	EF11	Pirita tee JK

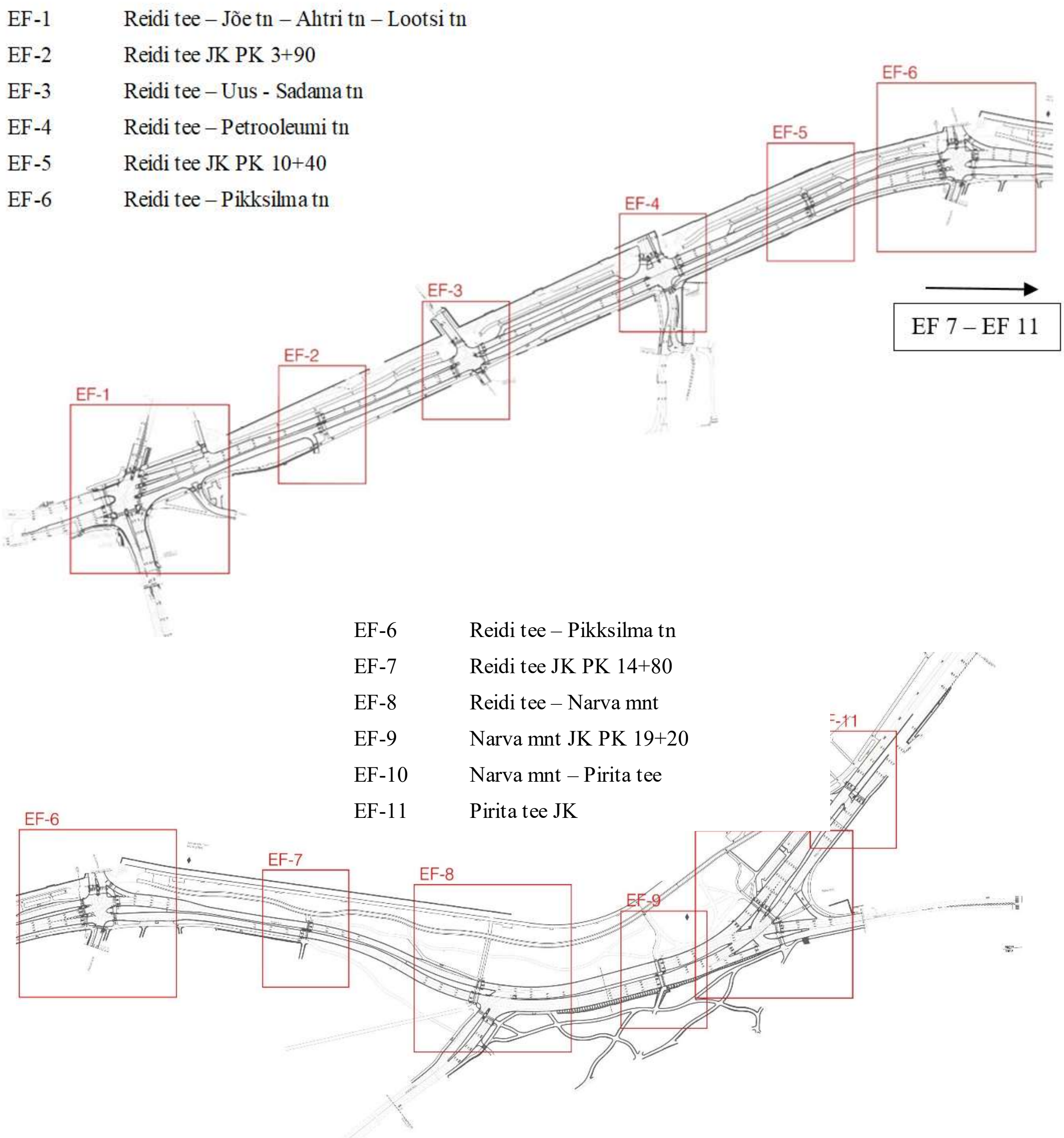


FIGURE 2. ***LOCATION OF TRAFFIC LIGHT SITES***

<u>Traffic light sensors and their installation</u>

The sensors were designed and installed in front of each arm leading to the intersection, for assessing the approaching traffic flow and making decisions based on this information.

Sensors were also designed and installed at the departing directions to assess the distribution of turns and to obtain information on the emptying flow at the intersection. The information received from each departing direction sensor is used as information from the previous sensor for the next intersection.

The Reidi tee project provided for Flir TrafiOne sensors for vehicle detection, which combine the conventional video detection with thermal imager. The resulting information is theoretically more reliable than a conventional video sensor (a thermal imager can detect vehicles regardless of the weather – complete darkness, shadows, sun, etc.).

FIGURE 3. ***FLIR TRAFIONE SENSOR***

In addition to the TrafiOne sensors, information from the sensors of the Tallinn monitoring system is used for the operation of the Reidi tee traffic light control system, which was also integrated with the OMNIA software.

The push-buttons selected as pedestrian sensors are such that, in accordance with the design criteria, they can also be used to distinguish traffic lights with an acoustic signal together with direction of travel and traffic control information. The push-buttons have a built-in audible signal as well as a signal light to indicate the need to cross the road. In addition to push-buttons, Flir TrafiOne video sensors operating in parallel are used to detect pedestrians and cyclists. If the video sensor detects a non-motorized road user, the registration signal on the push-button also lights up. If the video sensor does not detect a non-motorized road user, the light permitting the non-motorized road user to cross will be activated by pressing the push button. The video sensor makes crossing easier for cyclists who do not have to get off the bicycle to press a button.

Traffic light control

The project provides fixed traffic light programs for the morning and evening peak hours, which are applied in the event of a sensor-based system failure. The adaptive traffic light program is not described in detail in the project. The adaptive traffic light management system program was developed in collaboration with the OMNIA traffic light system supplier.

No errors or mistakes were detected in the fixed traffic light programs.

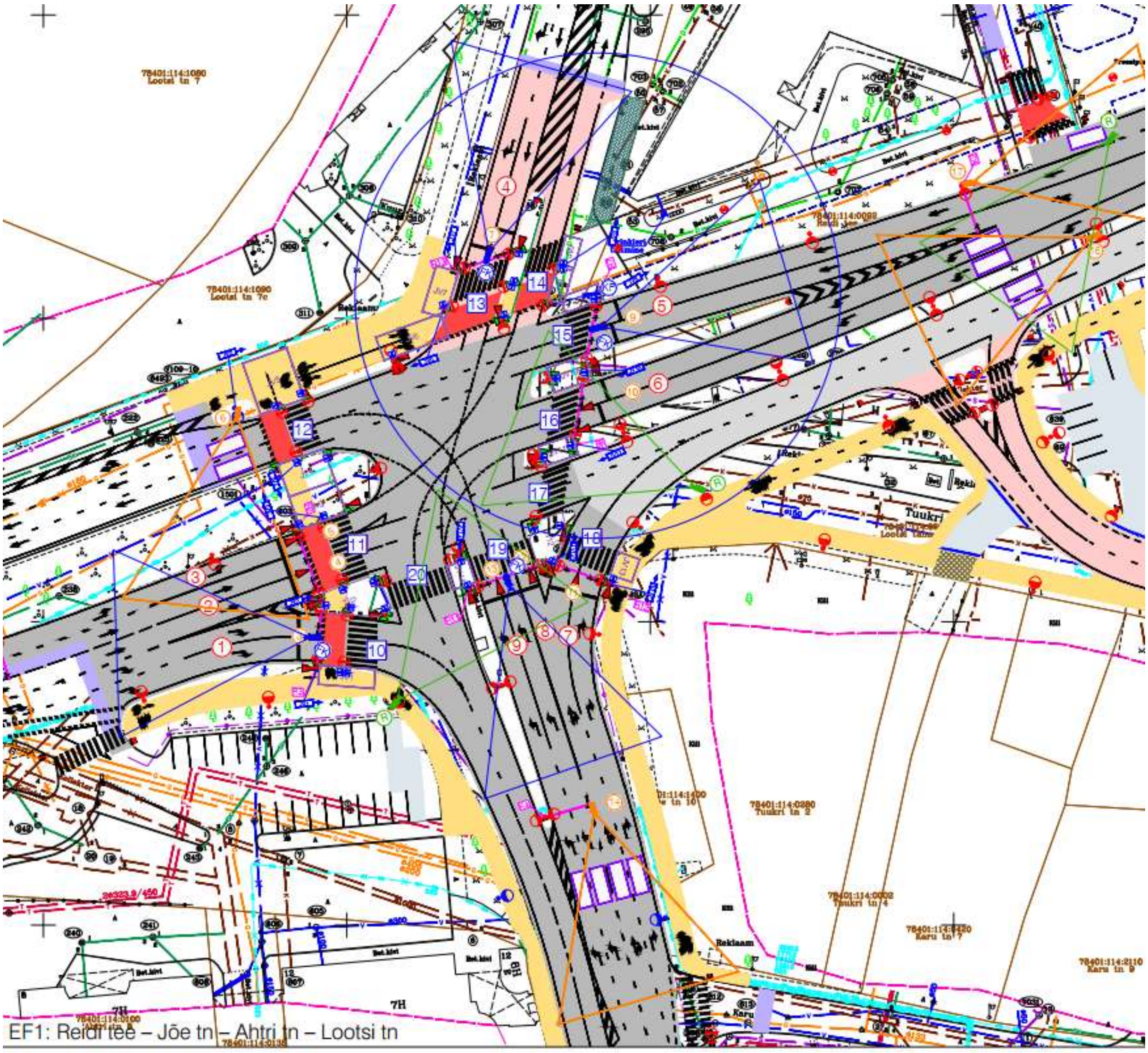
The calculation of protection times is based on the “Methodological Guide for Calculating the Throughput of Intersections” prepared by Tiit Metsvahi in 2001, according to which the protection times of vehicles are calculated at a departure speed of 8 m/s. The duration of the yellow light is 3 seconds. Before turning off, the green light flashes for 2 seconds for vehicles and for 4 seconds for pedestrians. The protection times have been calculated correctly, no errors were detected.

PERFORMANCE OF THE DESIGNED SOLUTION AFTER OPENING TO TRAFFIC

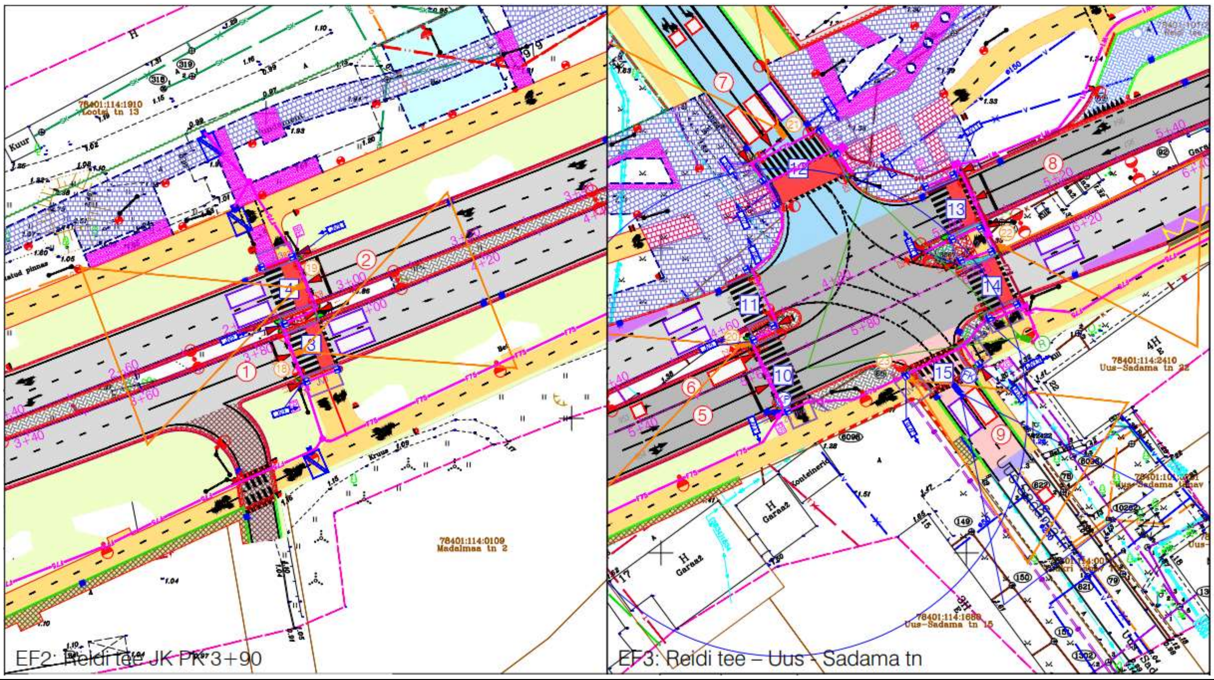
In order to assess the performance of the Reidi tee traffic light control system, several visual observations were carried out in the period from February to March 2021. Observations were carried out at different times (peak hours, off-peak hours, the so-called quiet time in the evening).

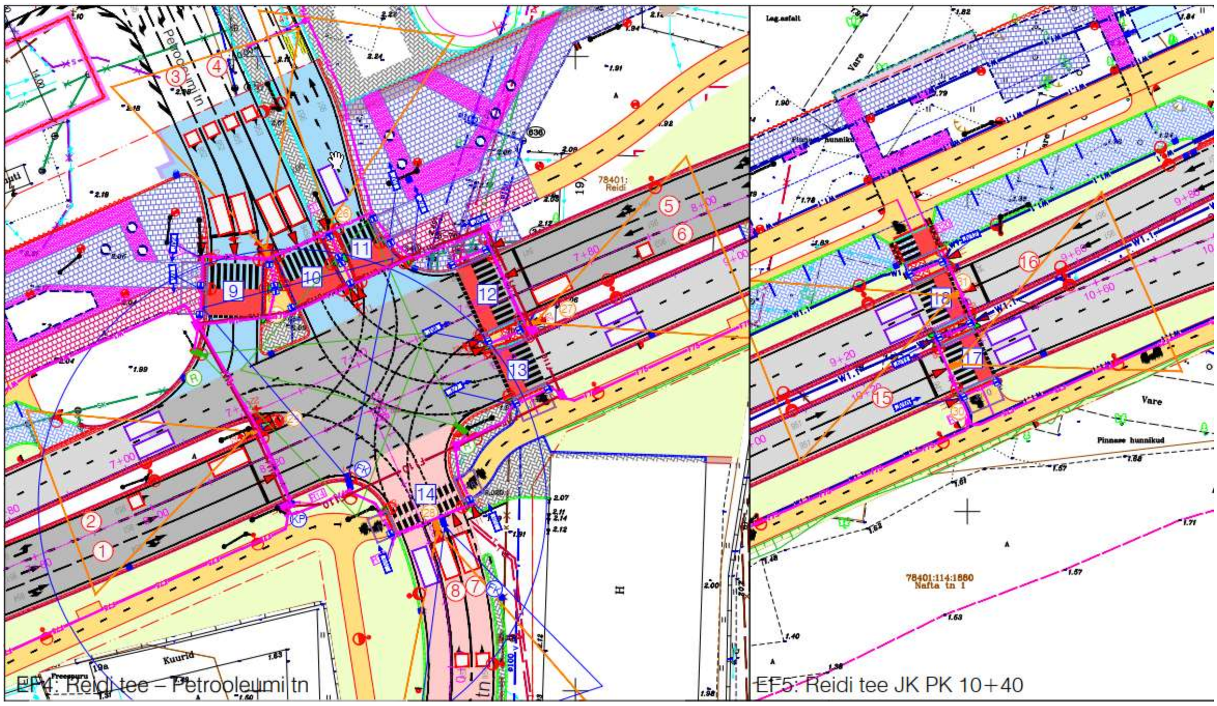
FIGURE 4. ***LOCATIONS OF OBSERVATION CAMERAS***

PROBLEMS IDENTIFIED

<table>
<tr><td>Traffic light site no.:</td><td>FJK1 (EF1)</td><td>Reidi tee – Jõe tn – Ahtri tn – Lootsi tn</td></tr>
<tr><td>General description:</td><td colspan="2">EF1 is the starting point for the adaptive section from Jõe street to the road Narva maantee.</td></tr>
<tr><td colspan="3">
EF1: Reidi tee – Jõe tn – Ahtri tn – Lootsi tn</td></tr>
<tr><td>Observations:</td><td colspan="2">In the whole project area, the adaptive traffic light system works best at this intersection. The length of the traffic light cycle actually changes according to the traffic load at the different arms of the intersection. If a longer queue of vehicles starts to build up on an arm, the traffic light software will extend the time of the light that allows this direction to move forward. The length of the traffic light cycle changed during the observations by ~10 seconds.

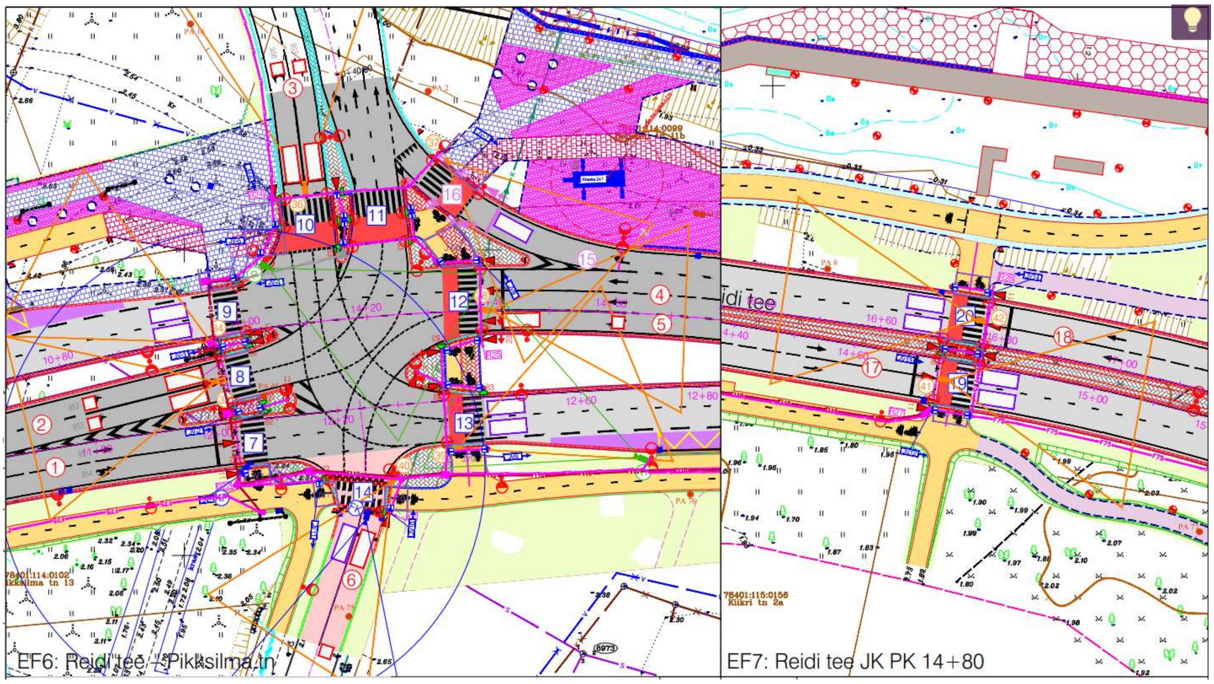
In terms of traffic management, it might be pointed out that the distribution and branching of lanes is confusing when approaching the intersection on Reidi tee from the direction of Pirita, as the second lane branches into two, causing confusion for drivers and sudden manoeuvres. Left-turn lanes should be like expansion of the direct lanes. The current traffic management is apparently designed keeping in mind the large share of the left turn of Reidi tee – Jõe street, which will increase even more in the future.</td></tr>
<tr><td>Assessment:</td><td colspan="2">The level of performance of the intersection is good.</td></tr>
</table>

<table>
<tr><td>Traffic light site no.:</td><td>FJK2 (EF2, EF3)</td><td>Reidi tee JK PK3+90; Reidi tee-Uus-Sadama tn</td></tr>
<tr><td>General description:</td><td colspan="2">EF3 – operates on an adaptive basis, the traffic light control software distributes the signal permitting advancement according to sensor information.
EF2 – pedestrians receive a signal permitting advancement according to a push-button or presence detector.</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Observations:</td><td colspan="2">There are sometimes problems with registering secondary directions and finding a place for a signal permitting their advancement. In some cases the signal permitting advancement of a secondary direction is received immediately, but in other cases, in order to give that signal, the group of vehicles that has just arrived at the intersection on the priority road is slowed down, while during the time between groups, the secondary direction is also waiting for a signal permitting advancement, although it would be practical to allow secondary direction movement during this time between the groups on the priority road.
Extending the light permitting advancement of the secondary direction works well enough, although there are sometimes incomprehensible extensions.
Situations were also identified when pedestrians were given a green light despite no one pressing a pedestrian call button to cross the road Reidi tee. Green lit for 43 seconds and vehicles approaching from the priority directions were waiting.
Such anomalies did not occur all the time, and it was even more difficult to understand what caused them (why the sensors gave false information to the traffic light software).
On the Uus-Sadama arm, vehicles that had just been started and began driving from the parking lots in the immediate vicinity of the intersection were not always detected. It is likely that the Flir TrafiOne sensor could not detect an object of the same temperature as the environment.</td></tr>
<tr><td>Assessment:</td><td colspan="2">Needs readjustment (correspondence of sensor information to the actual traffic situation).</td></tr>
</table>

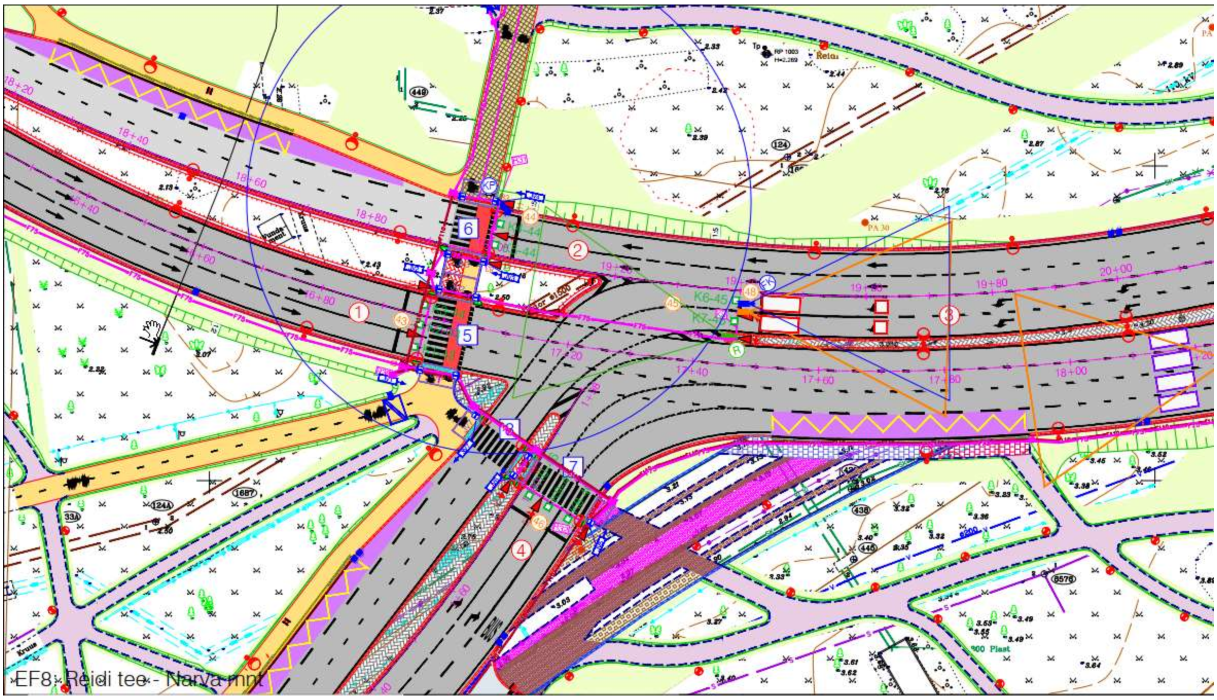
<table>
<tr><td>Traffic light site no.:</td><td>FJK3 (EF4, EF5)</td><td>Reidi tee-Petrooleumi tn; Reidi tee JK PK10+40;</td></tr>
<tr><td>General description:</td><td colspan="2">EF4 – operates on an adaptive basis, the traffic light software distributes the signal permitting advancement according to sensor information.
EF5 – pedestrians receive a signal permitting advancement according to a push-button or presence detector.</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Observations:</td><td colspan="2">Similar situations with previous intersections.

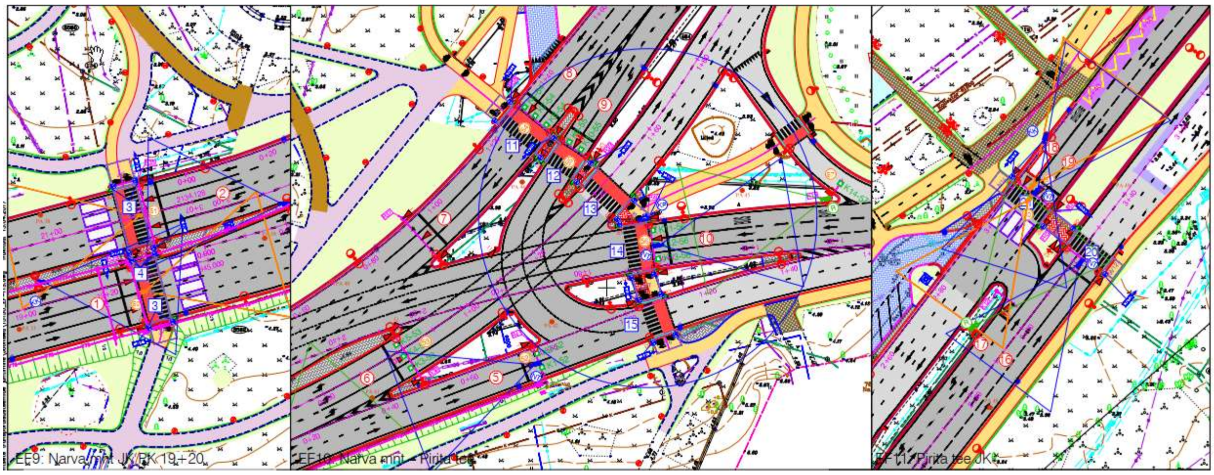
On 01.03.2021, the 3rd group of traffic lights (right turn from the port to Reidi tee) gave a green light to one vehicle for 20 seconds, while the vehicles in the main direction were waiting. A red light was also given for the non-conflicting direction going out of the city with the right turn, as the pedestrian traffic light group for crossing Reidi tee was also activated, although there were no pedestrians.</td></tr>
<tr><td>Assessment:</td><td colspan="2">Needs readjustment.</td></tr>
</table>

Traffic light site no.:	FJK4 (EF6, EF7)	Reidi tee-Pikksilma tn; Reidi tee JK PK14+80;
General description:	EF6 – operates on an adaptive basis, the traffic light software distributes the signal permitting advancement according to sensor information. EF7 – pedestrians receive a signal permitting advancement according to a push-button or presence detector.	



Observations:	There are sometimes problems with registering secondary directions and finding a place for a signal permitting their advancement. In some cases the signal permitting advancement of a secondary direction is received immediately, but in other cases, in order to give that signal, the group of vehicles that has just arrived at the intersection on the priority road is slowed down, while during the time between groups, the secondary direction is also waiting for a signal permitting advancement, although it would be practical to allow secondary direction movement during the time between the groups on the priority road. An observation on 01.03.2021 identified one vehicle turning to Reidi tee and the green light time was 39 s long. After that, the road users following the 6th group of traffic lights (from Pikksilma street) started moving. In total, road users waited for about **70 seconds** for the green light to come on. On previous occasions, when combinations of vehicles arrived in Tallinn by ship at 15.30 and there were vehicles manoeuvring, the 3rd group of traffic lights (for road users moving from the direction of the port) gave 6 to 12 s of green (in most cases 6 s). Extending the light permitting movement of a secondary direction generally works well.
Assessment:	Requires readjustment (correspondence of sensor information to the actual traffic situation).

Traffic light site no.:	FJK5 (EF8)	Reidi tee-Narva mnt
General description:	EF8 – operates on an adaptive basis, the traffic light software distributes the signal permitting advancement according to sensor information.	
		
Observations:	EF8 – no deviations from the designed solution were found.	
Assessment:	EF8 – the level of performance of the intersection is good.	

Traffic light site no.:	FJK6 (EF9, EF10, EF11))	Narva mnt JK PK19+20; Narva mnt-Pirita tee; Pirita tee JK)
General description:	Narva maantee JK PK19 + 20 gives pedestrians the opportunity to cross a very wide carriageway in one traffic light phase. At the same time, it is necessary to find a resource for vehicles so that the previous Russalka intersection would not be blocked during the long waiting period. An innovative phase distribution solution has been used to reduce the likelihood of a pedestrian waiting to cross the carriageway on a safety island in the middle of the road. On both threads a green light comes on. Pedestrians start crossing the carriageway. After 12 seconds, pedestrians have passed 12 x 1.2 = 14.4 m, i.e. crossed one of the carriageway threads. After pedestrians have crossed the first thread of the carriageway, the traffic light for this thread turns red. The light on the second thread indicating the possibility of passing is green for 20 seconds. Within 20 seconds, the pedestrian crosses 28 m. At the moment the red light comes on, the pedestrian has another 4.4 m of the carriageway to cross. To ensure the safety of pedestrian crossings, protection time is provided, which ensures that pedestrians can cross the road safely from the last moment the green light flashes, i.e. the time required to cross 14.4 m.	
		
Observations:	<u>EF9</u> – regulated pedestrian crossing, bicycle crossing works in both directions as designed in the project. <u>EF10</u> – there is no presence sensor for detecting the flow of vehicles approaching on the road Pirita tee, with the intention of making a left turn to Narva maantee towards Lauluväljak. There is only a sensor further away from the intersection, but even after crossing this sensor, it is possible to head for the left turn. Therefore, it is not possible to skip this traffic light phase. During the observation (25.02.), the exact same traffic light program operated between 15.30 and 23.30, which means that it was a fixed program.	
Assessment:	<u>EF9</u> and <u>EF11</u> – the level of performance of the intersection is good. The EF9 as well as all other regulated pedestrian crossings could have the information that the pedestrian (and the cyclist) can be detected without pressing the push-button. During the observations, no road users who knew about it were detected, and everyone did press the push-button (including the audit team). The public transport priority system worked as designed in the project.	

	EF10 – consider the need for a left-turn manoeuvre presence sensor to skip the left-turn manoeuvre, as well as verify that the traffic light program used outside of peak hours is optimal (a fixed program appeared to be running at the time of observation). During the observation periods, no risk of congestion described in the project was detected.

Object:	Variable-message signs	Throughout the section
General description:	Variable-message signs (VMS) have too narrow a viewing angle. If the information displayed on them is visible from a distance, it is not visible at close range, and vice versa. The VMSs used are very sensitive to the installation angle.	
 		
Observations:	When driving behind a heavy vehicle, the driver does not see the traffic sign with variable message or the information displayed on it, because the heavy vehicle (also a bus) in front hides it from view. Getting closer, drivers will notice the VMS but still fail to read the information on it, because from a sharper angle, the information displayed on the sign is not visible.	
Assessment:	In future procurements, include the minimum angle of visibility in the technical description, which ensures the visibility of the information to the road user at different distances.	

AUDIT SUMMARY

The Reidi tee traffic light project was drawn up on the basis of an adaptive traffic light control system. The goal of the city in designing an adaptive traffic light control system was mostly related to Tallinn Old City Harbour situated in the immediate vicinity of the road Reidi tee. The traffic flows generated by the port are uneven considering the nature of its operation.

After opening Reidi tee to traffic, it has often been heard that road users are outraged that the coordinated management of Reidi tee (the so-called green wave) is not working properly at all. It has not been communicated to road users that this is not a case of coordinated control but adaptive control, which has to calculate the phase distribution and also the cycle length of intersections according to the traffic load on the arms of the intersections. Traffic load data is obtained from several sensors (pre-sensors for the departing direction of the previous intersection, sensors for the approaching direction of an intersection).

A prerequisite for the operation of an adaptive traffic light control system is the availability of very good sensor information. A sufficient number of sensors have been designed and installed during the implementation of the project.

However, in the course of the audit, it was concluded that the greatest impact on the discrepancies in the expected operation of the traffic light control system of Reidi tee is caused by the sensors, more precisely the incorrect information obtained from them (also the lack of information).

The adaptive control system relies on good sensor information. Problems with the Flir TrafiOne sensors used in the audited project have been repeatedly mentioned in this report, so the question arises as to which traffic flow sensors should be used. Due to accuracy and low interference, the use of <u>inductive sensors</u> gives good results, but their failure (in 2 to 5 years) in case of high traffic flows must be taken into account. Reinstalling inductive sensors is resource-intensive and disrupts traffic. Therefore, the designer has discarded this sensor type. In the long run, the reduction of metal parts in vehicle construction must also be taken into account, which reduces the possibility of inductive vehicle detection. Good results in vehicle detection have been obtained with ultrasonic sensors, but these sensors are sensitive to the chlorides used in our road environment in winter. At first glance, it seems that in the future the most widely used type of sensor will be the video sensor, which has the greatest possibilities of software application, but it also requires designing the road environment in accordance with the specifics of the sensor (interfering shadows, reflections, etc.). The auditor recommends that traffic light practitioners work more closely together to find the appropriate type of sensor.

Innovative Flir TrafiOne sensors have been used, which combine the conventional video detection with thermal imager. Unfortunately, the audit found that several disturbances in the traffic light control system of Reidi tee were caused by sensors (e.g. the problem with the detection of vehicles on the Uus-Sadama arm of the Reidi tee and Uus-Sadama intersection).

Some shortcomings in the implementation of the traffic light system were caused by the novelty of the application of adaptive traffic light control in Estonia. The designer could not foresee all possible aspects or ask the supplier of the traffic light control system about them in particular. It was also difficult for the auditor to assess the compliance of the operation of the traffic light programs with the design, because in the section from Jõe street to the road Narva maantee, the traffic light control software prepares the optimal work program each time on the basis of the sensor information, taking into account the matrix of protection times given in the project. Observations showed that the traffic light control software did change the length of phases in the traffic light program, but in some cases it was not clear or rational. This happened more often on the arms leaving the port area, where the problem seemed to be skipping phases, which does not coincide with the principles of adaptability of the traffic light control software.

Should the adaptive traffic light control system applications be provided on the same platform, and in which locations? Given the cost and complexity of the system, the auditor does not see the feasibility of using a similar platform at intersections with low traffic load or at intersections with large differences between the traffic load on the different arms of the intersection. In the interests of a more rational use of resources, it would make sense to use an <u>actuated</u> traffic light control system at such intersections, which would allow such traffic lights to better meet the needs of traffic flow (e.g. skipping the directions with no traffic).

The adaptive control system should be used especially in high-load areas, where the sensor-based system is able to divide the phases and the cycle length between the traffic flows on an adaptive basis (e.g. Liivalaia street).

The problem with variable-message signs (VMS) is the inadequacy of their angle of visibility – if the information displayed on the sign was visible from a distance, it was not visible up close, and vice versa. In future procurements, the adequacy of the angle of visibility should be paid attention to in the technical specifications.

The project has been prepared and implemented at a good level. The smooth operation of the intersection EF 1 (Jõe street – Ahtri street – Lootsi street – Reidi tee) and the regulated pedestrian crossing EF9 (Narva maantee JK PK19 + 20) whose innovative operation should be highlighted. Despite some problems, the general traffic situation has improved and the service level has increased. During peak hours, it is worth considering the implementation of a coordinated traffic light system on Reidi tee.

The auditor, Margus Nigol, confirms that this audit of the Reidi tee traffic light control system project has been carried out independently and objectively.

The observations and problems described in the audit reflect the situation in the period from February to April 2021. It is known that improvement and adjustment works took place on the Reidi tee section even after this period, and some problems have been solved.

ANNEX 3. MINI-PILOT METHODOLOGY AND RESULTS

THE INITIAL TASK REQUIREMENT OF THE MINI-PILOT

During the performance of the mini-pilot, the Contractor was responsible for installing at one intersection in the mini-pilot area additional counter sensors and equipment necessary for the mini-pilot project; for creating traffic light programs with an adaptive traffic control mode for this intersection (on the basis of information received from sensors and data layers); and for reconfiguring the traffic lights of the intersection to use this program. If necessary, the solution developed had to be combined with the existing traffic light controllers in the pilot area. In addition, an assessment had to be made as to whether the piloted adaptive traffic management system could be extended to other areas in Tallinn.

The intersections proposed by the Contracting Authority for the mini-pilot were as follows:

- **The intersection of the streets Kopli, Tööstuse, Sitsi and Paljassaare (+ tramway).** The prioritization of public transport (tram) by adaptive traffic light control (and thereby increasing tram connection speed) can be piloted.
- **The intersection of the streets Petrooleumi and Tuukri.** Adaptability can be piloted by receiving information from traffic light controllers and sensors at neighbouring intersections through the traffic light control centre (considering that the system must continue to operate in the event of communication problems).
- **The intersection of the streets Pärnu maantee, Vääna and Hiiu.** Adaptability can be piloted if the railway is closed (the main goal is to avoid congestion at the intersection).

PLANNING OF MINI-PILOT

In cooperation with the Contracting Authority, the intersection of the streets **Kopli, Tööstuse, Sitsi and Paljassaare (+ tramway)** was selected as the piloted intersection, on the basis of the following considerations:

- **Prioritizing public transport is promising** – the more road users use public transport, the more economically the road network of the city can be used.
- **The selected intersection is equipped with modern hardware and software** enabling the introduction of new and innovative solutions without prior investment in the modernization of the intersection.
- **The junction is partially equipped with stop line call sensors,** which makes it possible to achieve the goal of the mini-pilot by adding sensors according to the procurement conditions.
- Due to the existing sensors, it is possible to develop and fully implement adaptive traffic light programs.

The **aim** of the mini-pilot was to:

- pilot the prioritization of tram traffic and thereby **increase tram connection speed through adaptive traffic light control**,
- pilot the transition to adaptive traffic light control for the entire intersection on the basis of counting data.

Based on the results of the mini-pilot, it was planned **to find answers to the following questions**:

- To what extent does the priority of tram traffic work with the selected sensors and methodology?
- To what extent do adaptive traffic light programs work at the intersection?
- To what extent do adaptive traffic light programs work with the selected sensors?
- What is the impact on tram connection speed in this section upon implementation of the mini-pilot?

- What is the effect on the connection speed of other vehicles upon implementation of the mini-pilot?

When planning the mini-pilot, the following activities were planned to be performed:

- **To add pre-sensors in both directions to give priority to the tram**. To choose from radar, video or thermal sensors.
- As the tram stop in the direction of Kopli is too close to the intersection to give priority to the tram based on tram detection alone, it was necessary **to find the optimal time for the tram to stay at the stop in the direction of Kopli**, to estimate the time of tram arrival at the intersection and give priority to as many trams as possible.
- **To use the counting data of the existing vehicle video sensors** to compile adaptive traffic light programs for the intersection.
- **To compile adaptive traffic light programs for *Smart Intersection* with variable cycle length and optimized continuous green light time.**

MINI-PILOT ACTIVITIES AND DESCRIPTION OF THE SOLUTION

When designing the mini-pilot, sensor selection (tram detection) was performed on the basis of the following criteria:

- performance – excluding sensors that, based on past experience, were not expected to operate under the given conditions, such as infra-red sensors, radar sensors with certain parameters, magnetic sensors, etc.;
- financial suitability – excluding sensors that were not allowed by the project budget and schedule, such as inductive sensors that would have required excavation;
- novelty – excluding sensors previously used in similar conditions, such as video sensors (TrafiCam), lower resolution thermal sensors (TrafiOne).

The choice was made between a higher resolution and therefore “far-sighted” thermal sensor (ThermiCam) and a high-resolution sensor based on object tracking radar technology, capable of three-dimensional (3D) resolution. Due to time constraints, thermal sensors were chosen because they showed better detection accuracy than the radar sensors.

In the direction of the city centre, the thermal sensor detected a tram at a distance of approximately 150 m from the intersection, which is the optimal distance for the tram to reach the intersection without significantly slowing down or accelerating, with the green light given to it through priority. **In the direction of Kopli**, a tram was detected upon arrival at the stop and the priority generation process was started 18 seconds after the tram was detected, on the basis of previous mappings which show that 67% of trams stay at a stop for 10 to 20 seconds. The exact time, 18 seconds, was determined by visual inspection. The trams that left earlier had to wait a green light for a few seconds. Trams that stayed at the stop longer (more than 20 seconds) were detected by the stop line sensor and received their green light as non-priority according to the phase sequence of the intersection traffic light program.

According to the prepared program, the tram was given priority at any time, provided that it was detected by the pre-sensors. The priority given to one direction did not automatically call the priority to the other direction, but if necessary, the priorities of both tram directions could take place simultaneously. Once the tram had been given priority, a second priority in the same direction was given after 90 seconds in order not to unduly reduce the chances of other road users crossing the intersection. Depending on the transport policy, the time between priorities may be extended or reduced. The 90-second gap in priority did not mean that the second tram, which reached the intersection immediately after the priority tram, had to wait 90 seconds. The second tram was detected by a stop line video sensor at the intersection and given a green light according to the phase sequence of the traffic light program. Quite often there occurred also situations in which two trams in the direction of Kesklinn–Kopli crossed the intersection under the same priority.

Adaptive traffic light programs for the *Smart Intersection* were also prepared for the intersection, which controlled the traffic flows of the other vehicles according to the data received from the counting sensors. The counting data of the existing vehicle video sensors was used for this purpose. The traffic light program worked with a variable cycle length. The minimum cycle length was 70 seconds and the maximum was 120 seconds. According to the data received from the counting sensors, there was a continuous optimization of the green light time between the different traffic directions.

There was a certain sequence of phases in the traffic light program (with the exception of the tram priority, which came at any point in time based on the tram being detected). The green light for the vehicle and the pedestrian came on only when the sensor had detected the vehicle or the pedestrian had pressed the call button. When there were no road users in some direction, the particular phase was missed. Pedestrians who did not press the call button could not cross the road. Due to the tram priority and the Smart Intersection program, no road user "automatically" received a green light together with some non-conflicting direction.

MINI-PILOT RESULTS

The mini-pilot was carried out, i.e. pre-sensors were used and an adaptive traffic light program was applied, from 13.07.2021 to 30.08.2021.

The results of the pilot project were evaluated using the so-called before-and-after method. The following parameters were used as main evaluation criteria:

- **Tram travel time between the stops of Maleva and Sitsi**:
  - The data come from Tallinn City Government data stock (the so-called Thoreb data), in which the entry and exit of trams at stops is registered. The data were processed by directions, i.e. the basis for the tram travel time in the direction of the city centre was the departure time from the stop Maleva and arrival at the stop Sitsi, and in the direction of Kopli it was the tram departure from the stop Sitsi and arrival at the stop Maleva.
  - In addition, the duration of the stay of the tram at the stop Sitsi was determined for both the before and after situation.
- **Waiting times for cars and pedestrians at traffic lights at the intersection:**
  - Data from the Tallinn traffic light system were used, i.e. data on the frequency of traffic crossing the tramway as well as the length of green light and red light time were used, which made it possible to determine waiting times for directions by 15-minute periods.
  - Pedestrian movement was assessed by random observation. The adaptive solution implemented a variant where pedestrians receive a green traffic light only when they have pressed the call button. Thus, in addition to the above, the number of situations in which pedestrians could not cross the road because they had not pressed the button was assessed via video recording.

In the present study, the before-period was **28.06.2021 to 02.07.2021**, and the after-period was **28.07.2021 to 03.08.2021**.

Impact on tram traffic

The average tram travel times in the before and after periods between the stops Maleva and Sitsi are shown in the following tables.

TABLE 9. AVERAGE TRAM TRAVEL TIMES BETWEEN THE STOPS MALEVA AND SITSI IN THE SO-CALLED BEFORE-PERIOD

DATE	AVERAGE TRAVEL TIME PER TRAM (HRS:MIN:SEC)
Maleva > Sitsi	
2021-06-28	00:02:14
2021-06-29	00:02:16
2021-06-30	00:02:15
2021-07-01	00:02:10
2021-07-02	00:02:09
Average	**00:02:13**
Sitsi > Maleva	
2021-06-28	00:02:06
2021-06-29	00:02:06
2021-06-30	00:01:59
2021-07-01	00:02:03
2021-07-02	00:02:03
Average	**00:02:04**

TABLE 50. AVERAGE TRAM TRAVEL TIMES BETWEEN THE STOPS MALEVA AND SITSI IN THE SO-CALLED AFTER-PERIOD

DATE	AVERAGE TRAVEL TIME PER TRAM (HRS:MIN:SEC)
Maleva > Sitsi	
2021-07-28	00:01:54
2021-07-29	00:01:52
2021-07-30	00:01:52
2021-07-31	00:01:45
2021-08-01	00:01:46
2021-08-02	00:01:46
2021-08-03	00:01:49
Average	**00:01:49**
Sitsi > Maleva	
2021-07-28	00:01:56
2021-07-29	00:01:52
2021-07-30	00:01:54
2021-07-31	00:01:47
2021-08-01	00:01:45
2021-08-02	00:01:51
2021-08-03	00:01:55
Average	**00:01:51**

The tram travel times by hours in the before and after period are shown in the following figures.

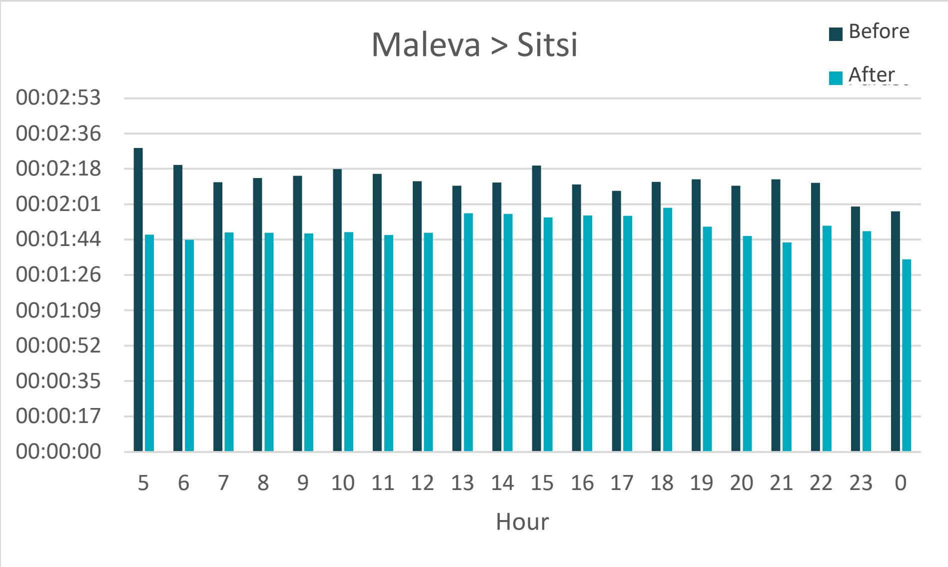


FIGURE 5. TRAM TRAVEL TIMES TO KOPLI IN THE BEFORE AND AFTER PERIOD

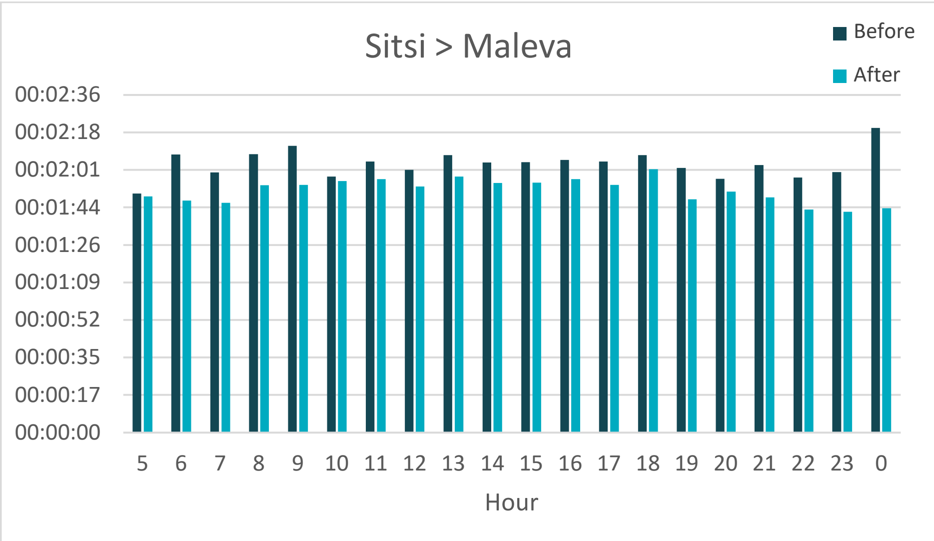


FIGURE 6. TRAM TRAVEL TIMES TO THE CITY CENTRE IN THE BEFORE AND AFTER PERIOD

Thus, as a result of the pilot, the travel time of trams in the section in question was significantly reduced after the application of the adaptive traffic light solution. The average results are shown in the table below.

TABLE 11. CHANGES IN THE AVERAGE TRAVEL TIME BETWEEN THE STOPS MALEVA AND SITSI IN THE SO-CALLED AFTER-PERIOD

DATE	AVERAGE TRAVEL TIME PER TRAM (HRS:MIN:SEC)
Maleva > Sitsi	
Before	2:13
After	1:49
Difference	**00:24**
Sitsi > Maleva	
Before	2:04
After	1:51
Difference	**00:12**

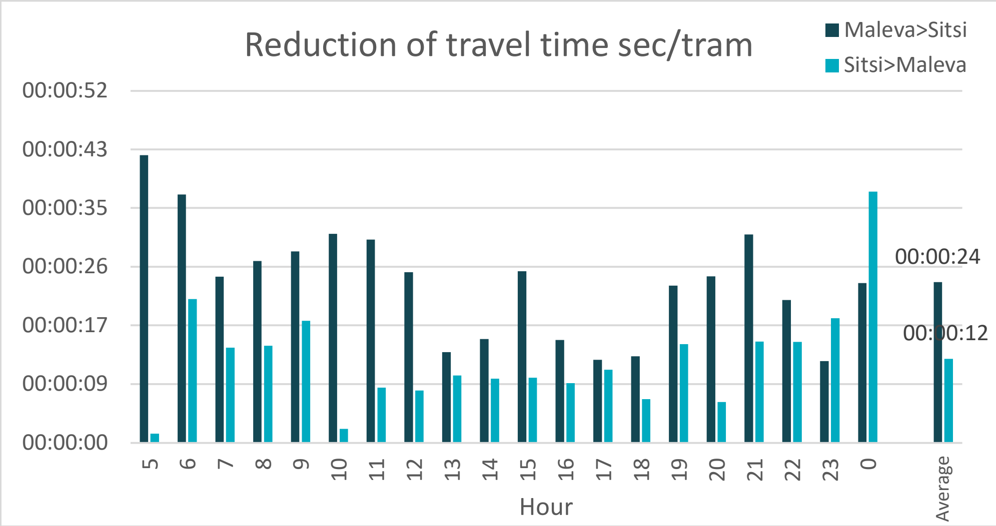


FIGURE 7. THE CHANGE IN TRAM TRAVEL TIME AFTER THE APPLICATION OF THE ADAPTIVE TRAFFIC LIGHT SOLUTION

In order to apply the best possible adaptive traffic light program, the average standing times of the tram at the stop Sitsi, both before and after, have been determined in this study on the basis of the aforementioned data.

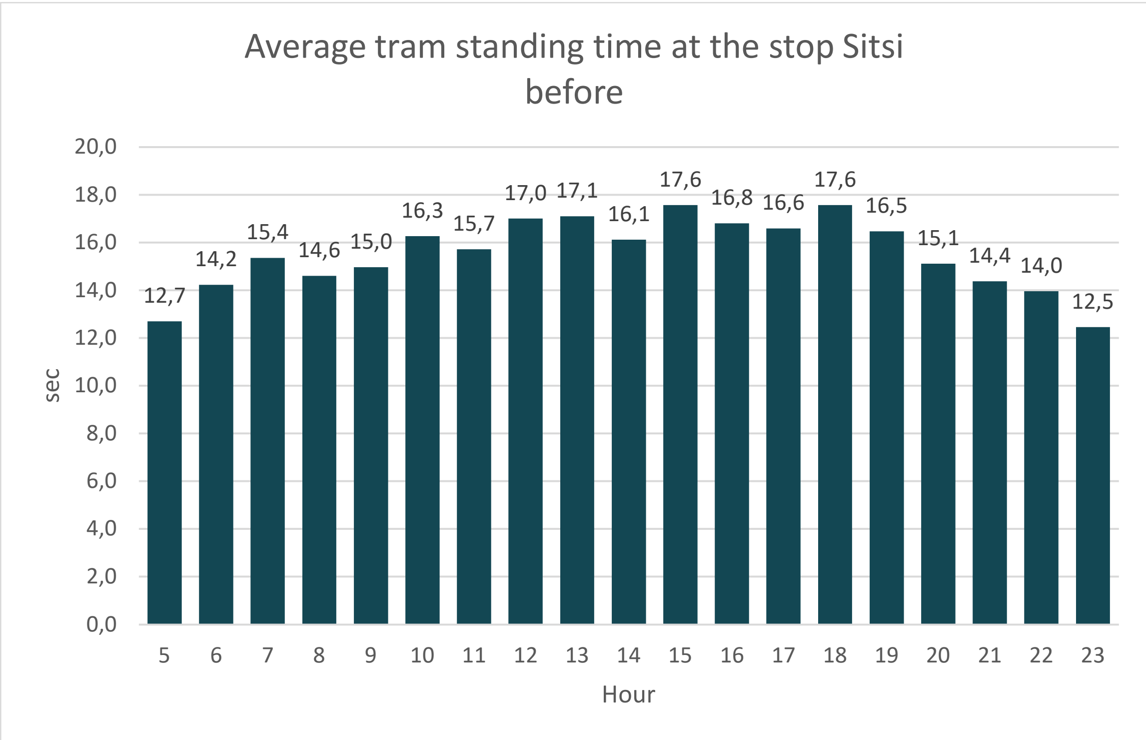
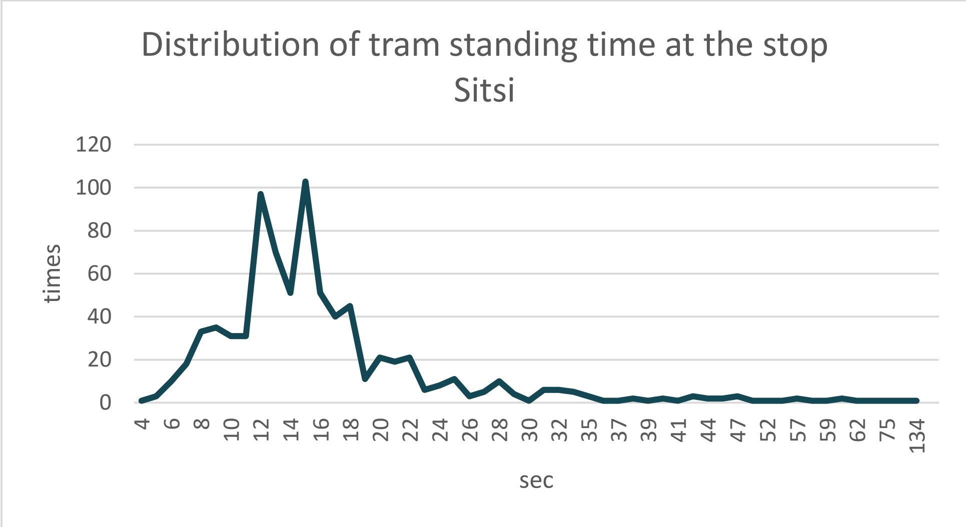


FIGURE 8. DURATION OF THE TRAM STANDING TIME AT THE STOP SITSI IN THE SO-CALLED BEFORE-SITUATION



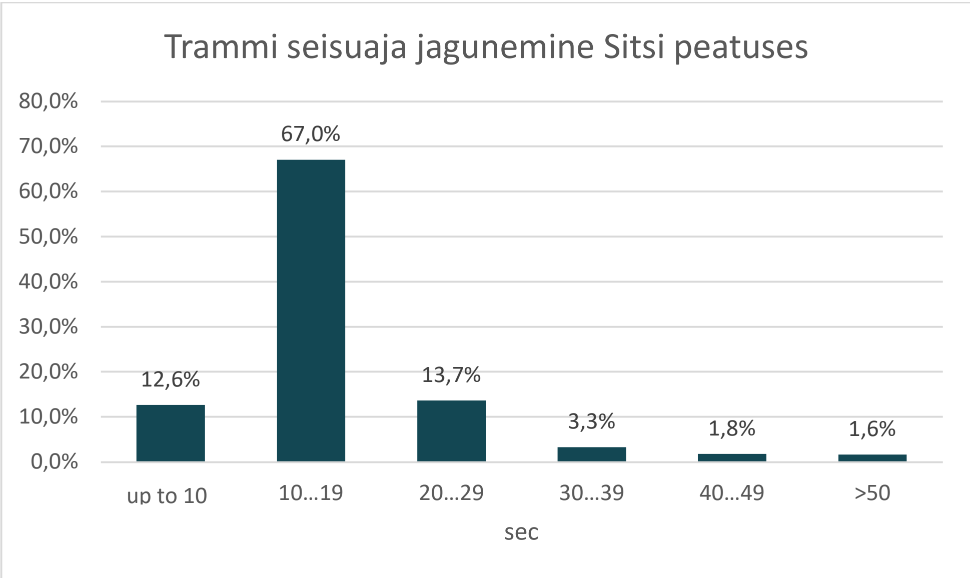


FIGURE 9 DISTRIBUTION OF THE TRAM STANDING TIME AT THE STOP SITSI

Thus, it can be said that in about 2/3 of the cases the tram stood at the stop Sitsi for 10 to 20 seconds. In 13% of the cases, the duration of the standing time was up to 10 seconds or 20 to 30 seconds. Standing times of more than 30 seconds were recorded in approximately 7% of cases.

The average standing time of the tram at the stop did not change significantly even in the so-called after-situation.

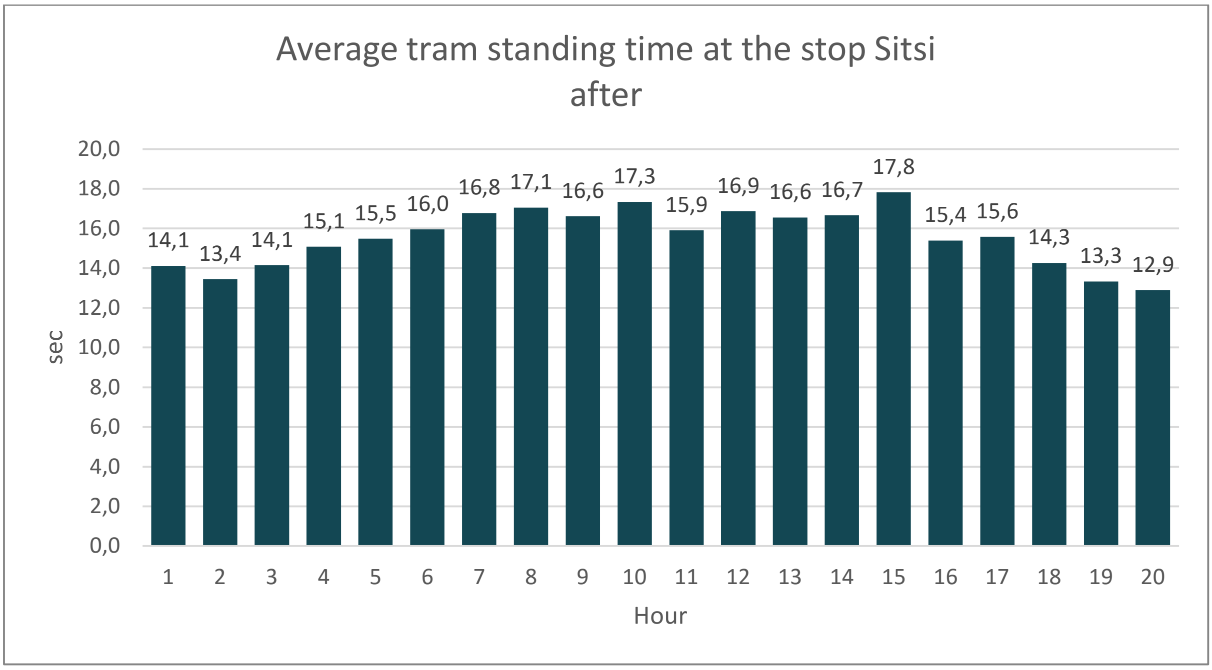


FIGURE 10. THE AVERAGE STANDING TIME OF THE TRAM BY HOURS AFTER THE APPLICATION OF THE ADAPTIVE SOLUTION

The estimated cost of constructing the solution needed to achieve the effects described above is 30,000 euros (including all the necessary sensors, the smart intersection program and the construction cost).

Impact on car traffic

This analysis for determining the waiting times for car traffic is based on directions 5, 7, 12 and 13 that cross the tramway and may be affected by the implementation of the tram priority system.

Data from 29 June to 3 July 2021 have been taken into account as the before-period and from 29 July to 3 August 2021 as the after-period. Per day, the period from 7.00 to 22.00 has been taken into account, when the traffic lights were on, as a rule.

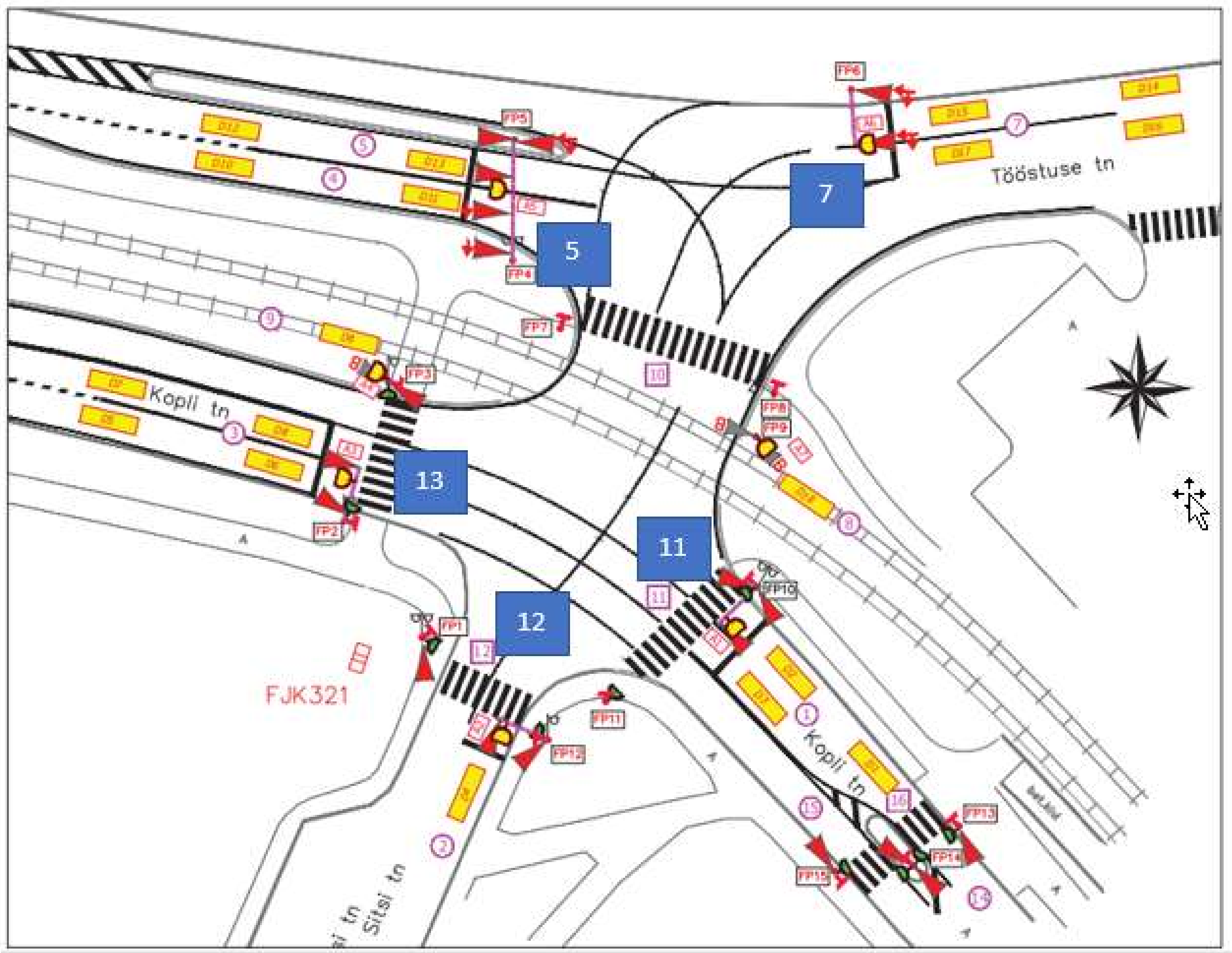


FIGURE 12. TRAFFIC DIRECTION MARKING

The following table shows the average waiting times per vehicle over 15-minute periods, averaged over the entire observation period.

Average waiting time per vehicle in the before and after situation, and the difference:

PERIOD	AFTER DIRECTION				BEFORE DIRECTION				AFTER DIRECTION			
	5	7	12	13	5	7	12	13	5	7	12	13
07:00:00	32.4	11.5	8.6	20.4	34.5	10.4	38.4	20.1	–2.1	1.1	–29.8	0.4
07:15:00	45.2	9.0	6.4	4.9	37.7	6.2	43.3	17.0	7.5	2.8	–36.8	–12.1
07:30:00	32.5	7.7	7.7	6.3	28.4	6.0	66.3	12.0	4.1	1.7	–58.6	–5.6
07:45:00	29.6	7.2	17.3	15.5	25.5	4.9	51.4	11.8	4.1	2.3	–34.1	3.7
08:00:00	37.2	11.2	9.5	13.9	28.2	6.2	42.2	11.6	9.0	5.0	–32.7	2.3
08:15:00	42.2	9.7	13.3	17.0	34.4	8.5	49.0	14.0	7.9	1.2	–35.7	3.0
08:30:00	27.4	8.7	19.3	9.2	24.9	6.0	36.4	9.6	2.5	2.7	–17.1	–0.4
08:45:00	38.7	7.0	9.9	16.6	17.0	6.3	55.3	9.1	21.6	0.7	–45.4	7.5
09:00:00	26.5	10.5	22.0	17.8	16.2	7.6	40.4	11.0	10.3	2.9	–18.4	6.8
09:15:00	31.0	7.4	13.2	13.8	18.8	6.0	50.5	11.2	12.2	1.4	–37.3	2.6
09:30:00	25.0	5.7	14.0	12.9	19.4	6.0	48.8	10.5	5.5	–0.3	–34.8	2.5

09:45:00	26.0	7.6	12.9	10.8	19.0	5.7	40.0	10.7	6.9	1.8	−27.1	0.1
10:00:00	22.2	6.3	12.5	8.3	19.4	5.8	48.5	11.2	2.8	0.6	−36.0	−2.8
10:15:00	22.2	5.8	12.7	13.0	16.7	5.4	62.8	12.3	5.5	0.4	−50.1	0.7
10:30:00	18.0	6.2	12.4	10.0	15.4	5.8	–	10.8	2.6	0.4	12.4	−0.8
10:45:00	19.8	6.2	11.6	12.3	14.2	5.7	38.8	10.3	5.6	0.5	−27.2	2.0
11:00:00	19.5	5.2	11.4	13.9	14.9	5.2	47.1	9.8	4.6	−0.1	−35.7	4.2
11:15:00	16.9	5.1	9.1	13.0	13.2	5.3	44.8	10.2	3.8	−0.2	−35.7	2.8
11:30:00	25.4	5.2	9.6	10.3	12.9	5.3	64.8	10.4	12.4	−0.1	−55.2	−0.1
11:45:00	17.7	4.8	10.2	12.0	11.4	4.7	65.4	10.0	6.3	0.1	−55.1	1.9
12:00:00	13.0	4.8	10.8	10.5	13.9	4.8	50.0	8.7	−0.8	0.0	−39.2	1.8
12:15:00	15.0	4.9	9.1	10.9	12.0	5.1	44.9	9.7	3.0	−0.2	−35.8	1.2
12:30:00	15.8	4.7	9.4	6.4	11.0	4.8	51.3	9.4	4.9	−0.1	−41.9	−3.0
12:45:00	14.7	4.8	9.7	10.0	11.8	4.8	53.6	9.5	3.0	−0.1	−43.8	0.5
13:00:00	18.2	5.1	9.9	10.5	11.0	4.3	65.0	10.6	7.1	0.8	−55.1	−0.2
13:15:00	17.6	4.4	9.1	8.7	12.3	4.8	65.5	11.5	5.4	−0.4	−56.3	−2.8
13:30:00	17.6	4.9	12.4	12.4	13.2	4.5	50.0	11.5	4.4	0.4	−37.6	0.9
13:45:00	16.9	5.1	18.9	12.2	12.4	4.7	–	10.5	4.5	0.3	18.9	1.7
14:00:00	14.4	4.6	10.8	10.1	11.2	5.4	56.3	11.0	3.2	−0.8	−45.5	−0.9
14:15:00	14.8	4.3	13.1	11.7	12.5	4.5	56.3	10.4	2.4	−0.2	−43.2	1.2
14:30:00	14.2	4.7	11.1	11.1	10.2	5.0	64.3	9.6	3.9	−0.3	−53.2	1.5
14:45:00	15.7	5.4	10.2	11.9	11.7	5.0	50.2	10.4	4.0	0.4	−40.0	1.6
15:00:00	14.9	4.7	11.6	14.3	11.2	4.8	53.7	9.7	3.7	−0.1	−42.0	4.7
15:15:00	13.6	5.2	10.7	8.0	10.8	5.1	47.9	10.9	2.8	0.2	−37.2	−2.9
15:30:00	14.8	4.6	12.6	10.6	9.6	4.8	46.5	9.9	5.2	−0.2	−33.9	0.7
15:45:00	18.9	4.5	14.4	10.8	9.4	4.7	49.4	10.7	9.4	−0.2	−35.0	0.1
16:00:00	12.5	5.2	14.6	10.9	9.0	4.9	57.9	9.7	3.5	0.3	−43.2	1.2
16:15:00	12.5	4.9	12.2	9.1	8.3	4.2	70.0	9.7	4.2	0.7	−57.8	−0.5
16:30:00	13.7	4.2	14.1	8.8	8.9	4.3	53.6	7.5	4.8	−0.1	−39.5	1.3
16:45:00	13.2	4.4	18.1	8.6	10.3	4.3	56.6	8.8	2.9	0.1	−38.5	−0.2
17:00:00	17.4	4.6	15.0	11.2	8.5	4.1	45.5	8.8	8.8	0.5	−30.4	2.4
17:15:00	17.5	4.0	17.2	10.2	9.0	4.1	37.5	9.2	8.5	−0.1	−20.3	1.0
17:30:00	13.8	4.6	13.1	11.2	9.9	4.2	56.3	10.3	3.9	0.5	−43.2	0.9
17:45:00	13.3	4.2	12.8	14.6	8.9	4.1	57.3	11.6	4.3	0.1	−44.5	3.0
18:00:00	15.2	4.6	17.4	15.7	8.0	4.9	53.1	13.9	7.2	−0.4	−35.8	1.7
18:15:00	19.5	4.5	16.4	11.8	10.7	4.4	40.9	10.2	8.7	0.1	−24.5	1.6
18:30:00	18.3	4.7	14.8	12.8	10.6	4.7	42.6	8.4	7.7	0.0	−27.7	4.5
18:45:00	18.6	4.5	13.5	13.2	10.9	4.8	26.7	8.9	7.6	−0.3	−13.2	4.3
19:00:00	20.5	4.9	14.8	13.7	9.9	4.9	56.3	15.6	10.7	0.0	−41.4	−1.8
19:15:00	24.6	5.1	13.5	14.8	10.3	5.4	45.1	14.5	14.3	−0.3	−31.7	0.3
19:30:00	25.4	5.3	16.0	15.0	10.2	5.9	39.5	16.8	15.2	−0.7	−23.5	−1.8
19:45:00	21.4	5.9	13.8	18.0	12.1	5.6	36.1	14.8	9.3	0.2	−22.3	3.2
20:00:00	26.8	5.7	13.4	17.1	9.1	6.5	35.6	12.2	17.7	−0.8	−22.2	4.9
20:15:00	23.9	6.9	16.3	13.9	13.3	6.2	37.0	14.3	10.6	0.7	−20.8	−0.4
20:30:00	27.1	6.8	15.2	15.1	11.1	6.0	35.4	11.9	16.0	0.7	−20.2	3.2
20:45:00	28.7	6.0	18.5	12.1	13.2	5.6	32.3	15.1	15.5	0.3	−13.8	−3.0
21:00:00	23.7	7.4	14.1	15.5	12.0	6.5	30.3	17.9	11.8	1.0	−16.2	−2.5

21:15:00	28.1	6.8	17.7	19.3	15.8	6.8	35.0	17.3	12.3	0.0	−17.3	1.9
21:30:00	28.6	7.8	22.9	16.9	17.7	7.7	36.5	16.5	10.9	0.1	−13.6	0.3
21:45:00	30.3	7.2	19.7	25.7	18.8	7.6	34.4	19.4	11.4	−0.3	−14.7	6.3
Average	**21.7**	**5.9**	**13.4**	**12.6**	**14.5**	**5.5**	**48.1**	**11.7**	**7.1**	**0.4**	**−33.1**	**0.9**

Thus, it can be stated on the basis of the calculations that the average waiting times for car traffic per vehicle increased by about 7 seconds for direction 5, the increase was very small in directions 7 and 13 (less than 1 second per car), but the average waiting time for direction 12 decreased significantly.

The differences in traffic load in the before and after periods are shown in the following figure.

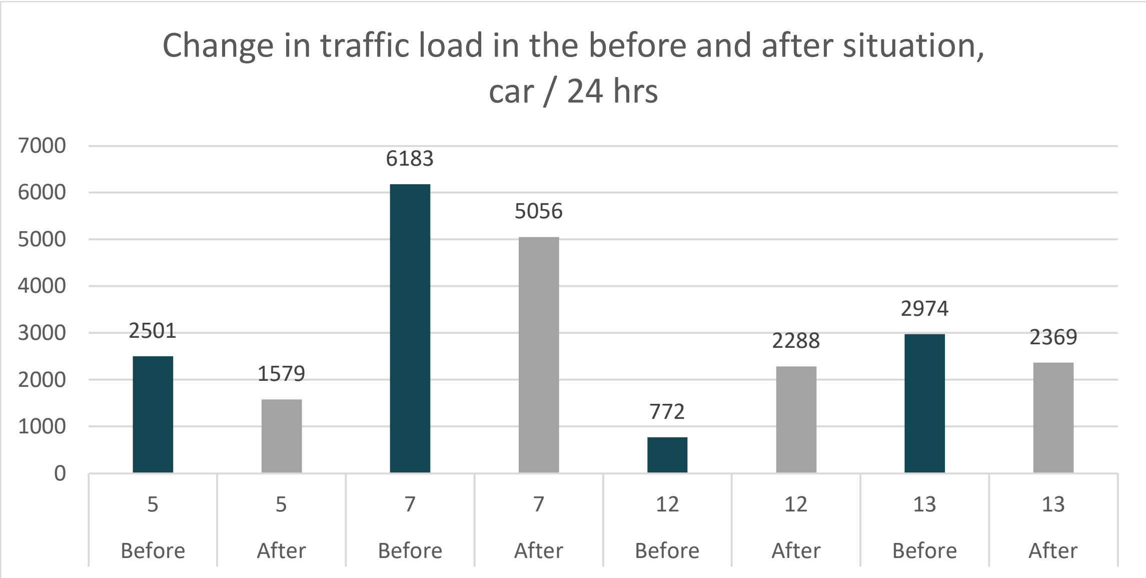


FIGURE 32. DIFFERENCES IN TRAFFIC LOAD IN THE BEFORE AND AFTER PERIODS

Impact on pedestrian traffic

In the case of pedestrian traffic, no waiting times have been set because the number of pedestrians is not counted. However, in the present study, the number of situations after the application of the adaptive traffic light solution has been additionally determined by means of video recording. The main problem is that the so-called before-solution gave pedestrians the green light without the need to press the call button, but in the case of the new solution, pedestrians always need to register their wish to cross the road by pressing the call button.

In the after-situation, this caused some confusion, as obviously not all pedestrians were used to it and did not understand the need for it.

Video detection identified situations in which:

- pedestrians could not cross the road because they had not pressed the button,
- the call button was pressed several times.

The results were as follows:

	THE BUTTON WAS PRESSED (NO. OF TIMES)	PEDESTRIANS WAITED BUT DID NOT PRESS THE BUTTON
Morning peak hour	11	3
Evening peak hour	24	6

Other observations

At the beginning of the adaptive solution, some dangerous situations occurred, probably largely because road users were not yet used to the new solution. These were mainly related to the fact that drivers were still trying to cross the tramway in front of the tram at the last moment. This is more likely due to the fact that drivers are used to a certain solution, rather than to the fact that the new solution is problematic. However, when applying adaptability, the solutions that road users are accustomed to may not work. Getting used to a new solution will certainly help overcome such problems. It is also important that observations of the operation of the intersection be carried out immediately after the implementation of the new solutions and that the solutions be adjusted accordingly.

CONCLUSIONS

It is certainly possible and even highly recommended to extend the piloted adaptive traffic management system to other areas in Tallinn. In particular, it could be extended to isolated intersections that have already been tested in this mini-pilot, but also to traffic corridors, the performance of which it is reasonable to test further with a subsequent pilot.

Thermal pre-sensors and stop line video sensors worked very well during this one-month mini-pilot. It would be reasonable to test such an intersection for the duration of one year, through all Estonian seasons and some properly performed maintenance periods. After that, complete certainty in terms of performance could be achieved. However, if thermal and/or video sensors start to give false signals, re-use of inductive sensors embedded in the road surface can be considered.

ANNEX 4. TECHNICAL SPECIFICATION OF THE ADAPTIVE TRAFFIC MANAGEMENT SYSTEM FOR THE CITY OF TALLINN FOR PROCUREMENT

The following technical specification is based on the technical specifications used in Tallinn to design traffic light systems, which have been supplemented according to the potential need to construct adaptive solutions. During the preparation of the technical specification, the suitability of the technical specifications used for it have not been assessed according to other needs (not related to adaptive solutions) arising during the design of the intersection.

1. The energy supply of the traffic light sites shall be designed for a two-tariff electricity meter, single-phase.
2. Cable runs shall be constructed underground, in plastic conduits with a diameter of at least 75 mm. Sensor (communication) cables and traffic light cables should be placed in separate pipes (one 27x1.5 cable per pipe). For the subsequent construction or improvement of an adaptive traffic light control system, two spare conduits shall be added into each section of the cable run and remain empty after the construction is finished. It is allowed to use plastic conduits with a ring stiffness class of at least SN8 and service life of at least 50 years guaranteed by the manufacturer. When designing cable runs, the need to replace and supplement cables shall be taken into account. To better achieve this, the cable route shall be designed with smooth turning radii and, if necessary, additional cable manholes shall be used near traffic light posts.
3. The control cable for traffic lights controlled from the same controller shall be designed and constructed as a ring feeder. If this is not cost-effective, or reasonable or possible considering the geometry of the intersection, the use of a single cable run is permitted as an exception. In this case, the solution shall be additionally approved by the Transport Department of Tallinn.
4. The use of equipment designed as traffic light controllers, which is fully and in all respects compatible with the traffic light control system used in Tallinn, shall enable coordination, adaptive control and connection to the traffic light control centre.
5. The opening and location of the traffic light post terminal block shall comply with the conditions given in diagram 2. The design of traffic light posts shall provide ventilation and rain proofing of the post. The materials used for manufacturing the posts shall ensure a stable fastening of the traffic control devices to the post and a rigid fastening of the post to the footing (foundation). In the case of posts simultaneously used for street lighting, at least two service hatches shall be designed for each post.
6. The required distance from the centre axis of the traffic light post to the edge of the carriageway shall ensure that the traffic light head (including the visor) is not closer than 0.5 m to the carriageway (2 to 2.5 m along the carriageway from the end of the safety island in the direction of traffic). The location of the traffic light post on the pavement shall provide the minimum width required for mechanical cleaning of the pavement. The load-bearing structure of the traffic control device shall not be located on the footpath part of a cycle and pedestrian track.
7. For all new traffic light sites, smart intersection adaptive traffic light programs (such as Swarco Smart Intersection or equivalent) using counting data shall be designed and implemented. These programs should change the length of the green light phase on the basis of the results of the counting, thus providing a permissive green light for the direction where more vehicles are counted. If this is not possible, actuated traffic light control or at least four different traffic light programs that take into account changes in traffic loads over time shall be implemented. In the presence of neighbouring intersections (even if they are being constructed at the same time), the traffic light programs designed shall be coordinated with the traffic light programs of the neighbouring intersections. Appropriate schedules for the scope of the project shall be provided.
8. For the purpose of adaptive traffic light control, sensors capable of accurate vehicle counting (e.g. TrafiCam video sensor, ThermiCam thermal sensor or inductive sensor or equivalent) shall be designed at the stop lines of all traffic directions approaching an intersection.

For actuated traffic light control, sensors (inductive loops, compact inductive sensors, infrared, radar or video detectors) that correspond to both main and secondary traffic directions and take into account the specifics of a particular object shall be designed. It is recommended that sensors which can implement both adaptive and actuated traffic light control (for example, video sensor TrafiCam, thermal sensor ThermiCam or inductive sensor or equivalent) be used. In addition to the call buttons with buzzers, also thermal sensors TrafiOne or equivalent shall be designed for actuated control to detect pedestrian and non-motorized road users. Calls of the thermal sensors detecting non-motorized users shall be designed with "recall" capability for cancelled demand. All directions and vehicles requiring/needing priority (public transport, heavy vehicles, bicycles, etc.) shall be equipped with either pre-sensors (e.g. ThermiCam thermal sensor, Smartmicro radar, inductive sensor or equivalent) or priority system equipment, and traffic light programs shall be developed which, in accordance with the established traffic policy, give priority to designated vehicles.

9. For traffic light sites, communication connection between traffic light controllers and connection of intersection controllers with traffic light control centre shall be designed and implemented. The interconnection and the connection to the traffic light control centre shall be designed and constructed via a cable line to the nearest communication well connected to the traffic light control centre or to the intersection controller connected to the existing traffic light control centre. If it is not possible to establish a cable line, provide for the use of devices required for Internet connection / mobile communication in the controller. The design of mobile communication is only permitted if the establishment of an on-line connection is not possible or it is economically extremely costly.
10. When constructing and reconstructing traffic light sites, only LED traffic lights may be installed. The electrical parameters of traffic light equipment shall be compatible with the traffic light control technology used in Tallinn.
11. For pedestrian traffic lights, an acoustic signal with traffic direction and traffic control information shall be used to distinguish traffic lights. It shall be possible to adjust the power of the acoustic signal over time, depending on the background noise, and to switch it off. For pedestrian traffic lights with a green light call, the pedestrian call buttons together with traffic direction and traffic control information shall be used.
12. All equipment and installations of the traffic light site shall be suitable for operation in the temperature range from –40 °C to +50 °C.
13. To ensure the uniform, prompt and economical construction and maintenance of traffic light sites, the materials and products listed below shall be used.
    13.1. Power cable: MCMK or at least equivalent.
    13.2. Control cables: MCMO (27/19/12) x 1.5. (When designing, the need for reserve cable cores at least 10% shall be taken into account.)
    13.3. Traffic light head connection cables: PPJ (5/4) X 1.5.
    13.4. Communication cables and sensor connection cables: fiber-optic cable, VMOHBU 5(10) x 2 x 0.5 or equivalent.
    13.5. Sensor inductive frame wire: MKEM – 2.5 or at least equivalent.
    13.6. The type of traffic light heads shall be Futurit LED Slim or equivalent, with a lens diameter of 210 mm (tolerance up to 1%) and a light transmitting part of the lenses of at least 185 mm (tolerance up to 1%). Traffic light heads with a shiny housing are prohibited.
    13.7. The traffic light head shall be fixed in such a way that the distance between the outer surface (curvature) of the traffic light carrier or traffic light post and the centre of the mounting beam in the traffic light head housing does not exceed 110 mm (see diagram 3, dimension A).
    13.8. The traffic light heads shall be rotatable at least 75 degrees about the centre of the mounting beam (see diagram 3, dimension B) even when the traffic light head is attached to a post, cantilever or portal.
    13.9. Traffic light heads shall have high impact resistance (EN 60598-1, EN 12368).
    13.10. Traffic light heads shall have a high degree of weather resistance (*water- and dust-proof* (IP55) – EN60529; *equals class IV acc.* to EN12368).

13.11. Traffic light heads shall have high temperature resistance (EN60068-2-30) from –40 °C to +60 °C; high vibration resistance (EN60068-2-64) and high resistance to large temperature fluctuations (EN60068-2-14).

13.12. Traffic light heads shall have a CE safety certificate.

13.13. Traffic light head housing shall be made of UV-resistant polycarbonate, with a matt (non-gloss/non-reflective) outer surface.

13.14. Traffic light heads shall be equipped with visors for each LED element and masks shall be located between the lens (glass) and the LED light source, protected from external weather conditions.

13.15. Traffic light controller: ITC-3 or ITC-3 Mini (SWARCO) or equivalent or newer models with Smart Intersection and Smart Corridor capability.

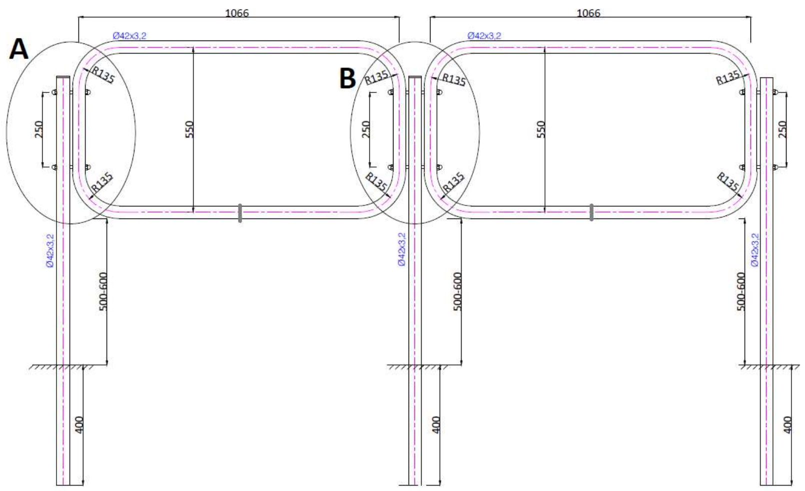
13.16. Traffic light posts made of metal pipe with a diameter of 114 mm and a wall thickness of 2.5 mm with RBJ-3 bases (the metal part must be hot galvanized with zinc in accordance with EVS-EN 1461 and powder-coated (colour code RAL7016)).

13.17. Cantilevers with corresponding legs (type U I-V designed in Finland) or at least equivalent modernized constructions. The metal part shall be hot galvanized with zinc according to EVS-EN 1461 and powder-coated (colour code RAL7016).

13.18. Portals with corresponding bases, type according to the opening (type I-IX designed in Finland) or at least equivalent modernized constructions. The metal part shall be hot galvanized with zinc according to EVS-EN 1461 and powder-coated (colour code RAL7016).

14. At the two opposite diagonal corners of the intersection, the locations of the intersection cameras shall be designed at maximum height (to minimize soiling) and mounting opposite the direction of the sun shall be avoided as much as possible. Wiring with 2x CAT6 to the traffic light control cabinet from both cameras shall be designed.
15. Portals shall be designed for all traffic directions (in exceptional cases, cantilevers in such a way that it is possible to install monitoring sensors above all lanes), and the traffic light control cabinet with communication cable conduits to ensure readiness to install monitoring sensors, information boards, direction signs, traffic signs, traffic light heads, additional cameras, etc. During design, the use of materials, equipment or installations not mentioned in the above conditions shall be additionally approved by the Transport Department of Tallinn.
16. Changes to the project and/or materials during construction shall be approved by the Transport Department of Tallinn.
17. The design shall be submitted for approval to the Transport Department of Tallinn.
18. These technical specifications shall be valid for 2 (two) years.

DIAGRAM 1. DRAWINGS OF PEDESTRIAN GUIDES



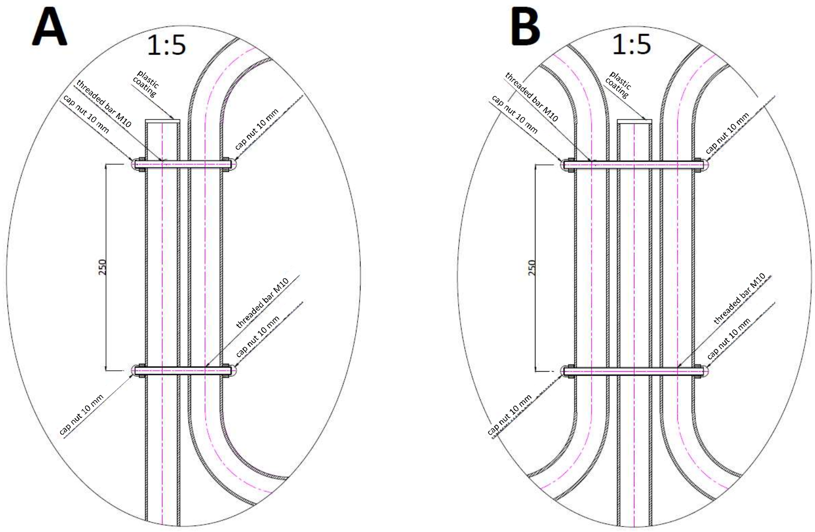


DIAGRAM 2. THE OPENING AND LOCATION OF THE TRAFFIC LIGHT POST TERMINAL BLOCK

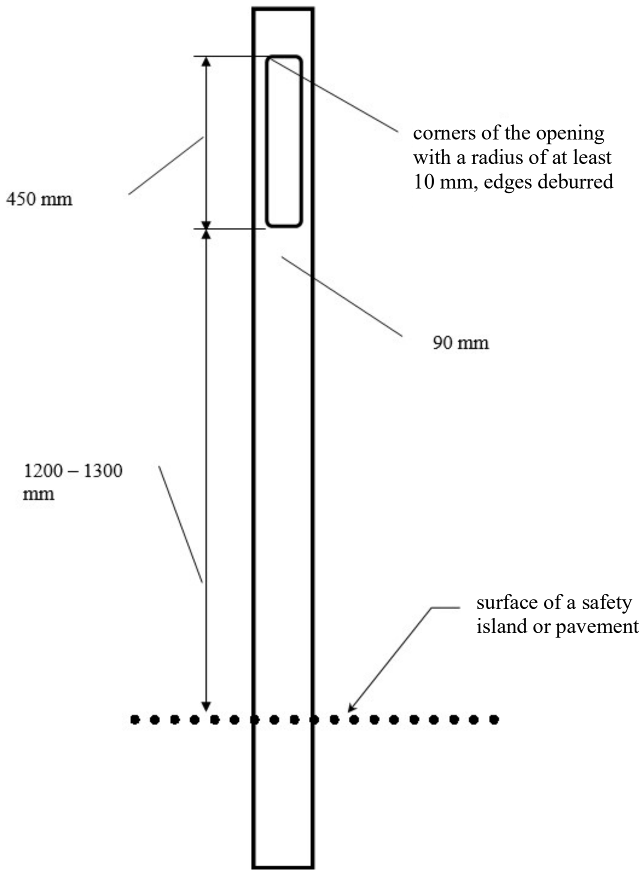
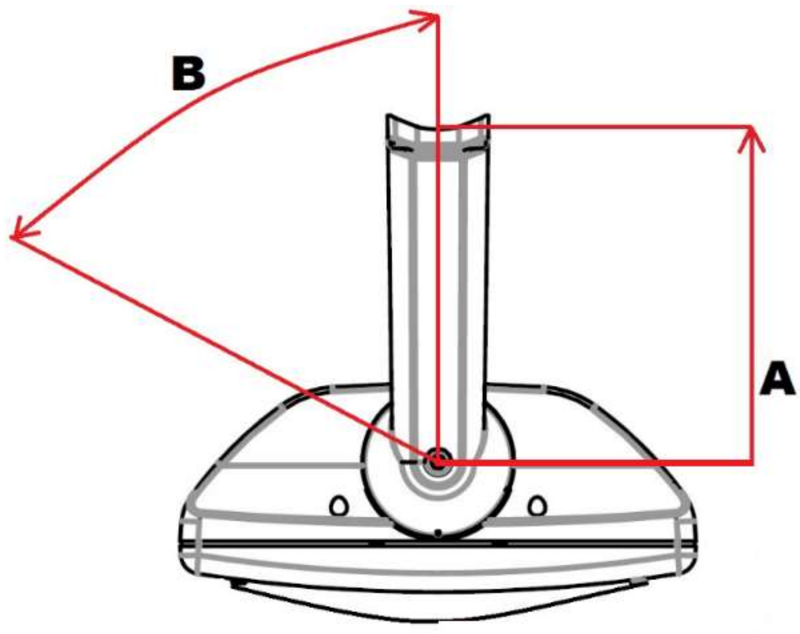


DIAGRAM 3. ADDITIONAL REQUIREMENTS FOR TRAFFIC LIGHTS


B
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ANNEX 5. RESULTS OF THE IMPLEMENTATION OF ADAPTIVE SOLUTIONS FOR SPECIFIC CORRIDORS

PETERBURI TEE

J. SMUULI TEE

TABLE 12. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF PETERBURI TEE AND J. SMUULI TEE IN THE MAIN DIRECTION (PETERBURI TEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		HEAVY VEHICLE WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. truck	sec/truck	sec/hour	sec/truck	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	799	77	22	1,083	20	987	–96	12.6	9,070	11.4	8,264	–806
7	1,947	162	68	2,723	62	2,475	–248	15.3	2,7275	13.9	2,4796	–2,480
8	2,047	235	99	3,949	90	3,590	–359	14.6	2,6502	13.3	2,4093	–2,409
9	1,581	270	113	4,538	103	4,125	–413	13.3	1,7495	12.1	1,5904	–1,590
10	1,452	252	106	4,235	96	3,850	–385	13.3	1,5932	12.1	1,4483	–1,448
11	1,601	280	79	3,938	72	3,588	–350	11.1	1,4639	10.1	1,3338	–1,301
12	1,494	203	57	2,855	52	2,601	–254	11.9	1,5300	10.8	1,3940	–1,360
13	1,661	240	68	3,375	62	3,075	–300	11.7	1,6608	10.6	1,5132	–1,476
14	1,674	244	69	3,431	63	3,126	–305	11.7	1,6678	10.6	1,5196	–1,483
15	1,832	231	65	3,248	59	2,960	–289	12.0	1,9266	11.0	1,7553	–1,713
16	2,253	226	95	3,798	86	3,453	–345	14.9	3,0267	13.6	2,7515	–2,752
17	1,868	136	57	2,286	52	2,078	–208	15.5	2,6822	14.1	2,4383	–2,438
18	1,347	79	33	1,328	30	1,207	–121	15.8	1,9982	14.3	1,8165	–1,817
19	1,016	50	14	703	13	641	–63	13.3	1,2881	12.1	1,1736	–1,145
20	699	41	12	577	11	525	–51	13.2	8,677	12.0	7,905	–771
21	451	30	8	422	8	384	–38	13.1	5,498	11.9	5,010	–489
TOTAL	2,3722	2,756	15.4	4,2487	14.0	3,8664	–3,823	13.5	2,82891	12.3	2,57414	–2,5478

TABLE 13. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF PETERBURI TEE AND J. SMUULI TEE IN THE SECONDARY DIRECTION (J. SMUULI TEE)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME				
		Existing		Adaptive		Difference
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	472	15.3	7,241	16.6	7,857	616
7	1,150	16.8	1,9330	18.3	2,1087	1,757
8	1,209	16.8	2,0323	18.3	2,2171	1,848
9	934	16.8	1,5696	18.3	1,7123	1,427
10	858	16.8	1,4416	18.3	1,5726	1,311
11	946	15.3	1,4509	16.6	1,5744	1,235
12	883	15.3	1,3539	16.6	1,4692	1,152
13	981	15.3	1,5053	16.6	1,6334	1,281
14	989	15.3	1,5171	16.6	1,6462	1,291
15	1,082	15.3	1,6603	16.6	1,8016	1,413
16	1,331	16.8	2,2368	18.3	2,4402	2,033
17	1,104	16.8	1,8546	18.3	2,0232	1,686
18	796	16.8	1,3373	18.3	1,4589	1,216
19	600	15.3	9,208	16.6	9,991	784
20	413	15.3	6,335	16.6	6,874	539
21	266	15.3	4,087	16.6	4,435	348
TOTAL	**1,4014**	**16.1**	**2,25798**	**17.5**	**2,45734**	**1,9937**

MUSTAKIVI

TABLE 14. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF PETERBURI TEE AND MUSTAKIVI STREET IN THE MAIN DIRECTION (PETERBURI TEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		HEAVY VEHICLE WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. truck	sec/truck	sec/hour	sec/truck	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	612	61	8	408	7	356	–53	5.9	3,268	5.2	2,846	–422
7	1,492	149	27	1,074	23	925	–149	6.4	8,591	5.5	7,398	–1,193
8	1,568	157	28	1,129	24	972	–157	6.4	9,033	5.5	7,778	–1,255
9	1,211	121	22	872	19	751	–121	6.4	6,976	5.5	6,007	–969
10	1,112	111	20	801	17	690	–111	6.4	6,407	5.5	5,517	–890
11	1,227	123	16	819	14	713	–106	5.9	6,548	5.2	5,703	–845
12	1,145	114	15	764	13	665	–99	5.9	6,111	5.2	5,322	–788
13	1,272	127	17	849	15	740	–110	5.9	6,794	5.2	5,917	–877
14	1,282	128	17	856	15	745	–110	5.9	6,847	5.2	5,963	–883
15	1,403	140	19	937	16	816	–121	5.9	7,493	5.2	6,526	–967
16	1,726	173	31	1,243	27	1,070	–173	6.4	9,942	5.5	8,561	–1,381
17	1,431	143	26	1,030	22	887	–143	6.4	8,243	5.5	7,098	–1,145
18	1,032	103	19	743	16	640	–103	6.4	5,944	5.5	5,118	–826
19	778	78	10	519	9	452	–67	5.9	4,156	5.2	3,619	–536
20	535	54	7	357	6	311	–46	5.9	2,859	5.2	2,490	–369
21	346	35	5	231	4	201	–30	5.9	1,845	5.2	1,607	–238
TOTAL	**1,8173**	**1,817**	**7.0**	**1,2632**	**6.0**	**1,0934**	**–1,698**	**6.2**	**1,01056**	**5.3**	**8,7473**	**–1,3583**

TABLE 15. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF PETERBURI TEE AND MUSTAKIVI STREET IN THE SECONDARY DIRECTION (MUSTAKIVI)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME				
		Existing		Adaptive		Difference
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	333	26.7	8,880	28.4	9,453	573
7	811	37.4	3,0280	39.6	3,2127	1,846
8	852	37.4	3,1836	39.6	3,3777	1,941
9	658	37.4	2,4588	39.6	2,6088	1,499
10	605	37.4	2,2582	39.6	2,3959	1,377
11	667	26.7	1,7793	28.4	1,8941	1,148
12	622	26.7	1,6604	28.4	1,7675	1,071
13	692	26.7	1,8460	28.4	1,9651	1,191
14	697	26.7	1,8604	28.4	1,9805	1,200
15	763	26.7	2,0360	28.4	2,1674	1,314
16	938	37.4	3,5040	39.6	3,7176	2,137
17	778	37.4	2,9052	39.6	3,0823	1,771
18	561	37.4	2,0949	39.6	2,2226	1,277
19	423	26.7	1,1292	28.4	1,2020	728
20	291	26.7	7,769	28.4	8,270	501
21	188	26.7	5,012	28.4	5,336	323
TOTAL	9,876	32.3	3,19102	34.3	3,39001	1,9899

TARTU MAANTEE

LIIVALAIA

TABLE 16. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND LIIVALAIA STREET IN THE MAIN DIRECTION (TARTU MAANTEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		TRAM WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. tram	sec/tram	sec/hour	sec/tram	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	524	22	15.3	337.5	12.8	282	–55.0	18.0	9,006.0	12.8	6,441.8	–2,564.2
7	1,259	36	20.0	720.0	16.8	605	–115.0	20.0	2,4450.3	16.8	2,0545.0	–3,905.3
8	1,323	38	20.0	760.0	16.8	639	–121.4	20.0	2,5706.1	16.8	2,1600.2	–4,105.8
9	1,025	32	20.0	640.0	16.8	538	–102.2	20.0	1,9854.1	16.8	1,6682.9	–3,171.1
10	940	28	20.0	560.0	16.8	471	–89.4	20.0	1,8234.1	16.8	1,5321.7	–2,912.4
11	1,037	32	15.3	490.9	12.8	411	–80.0	18.0	1,8045.9	12.8	1,2907.8	–5,138.0
12	968	30	15.3	460.2	12.8	385	–75.0	18.0	1,6839.8	12.8	1,2045.2	–4,794.6
13	1,075	32	15.3	490.9	12.8	411	–80.0	18.0	1,8722.1	12.8	1,3391.6	–5,330.6
14	1,083	32	15.3	490.9	12.8	411	–80.0	18.0	1,8868.7	12.8	1,3496.4	–5,372.3
15	1,186	36	15.3	552.3	12.8	462	–90.0	18.0	2,0649.6	12.8	1,4770.3	–5,879.3
16	1,422	40	20.0	800.0	16.8	672	–127.8	20.0	2,7640.0	16.8	2,3225.3	–4,414.7
17	1,211	38	20.0	760.0	16.8	639	–121.4	20.0	2,3458.2	16.8	1,9711.4	–3,746.8
18	872	26	20.0	520.0	16.8	437	–83.1	20.0	1,6915.5	16.8	1,4213.7	–2,701.8
19	662	24	15.3	368.2	12.8	308	–60.0	18.0	1,1452.0	12.8	8,191.4	–3,260.6
20	463	24	15.3	368.2	12.8	308	–60.0	18.0	7,878.9	12.8	5,635.6	–2,243.3
21	299	16	15.3	245.4	12.8	205	–40.0	18.0	5,083.5	12.8	3,636.1	–1,447.4
TOTAL	**1,5348**	**486**	**17.6**	**8,564**	**14.8**	**7,184**	**–1,380.3**	**19**	**2,82805**	**15**	**2,21817**	**–6,0988.2**

TABLE 17. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND LIIVALAIA STREET IN THE SECONDARY DIRECTION (LIIVALAIA–PRONKSI)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME					QUEUE	
		Existing		Adaptive		Difference	Existing	Adaptive
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour	m	m
6	866	22.5	1,9480.4	24.5	2,1212	1,732	16.2	17.7
7	2,110	13.9	2,9302.3	16.8	3,5456	6,153	44.0	48.3
8	2,218	13.9	3,0807.3	16.8	3,7277	6,470	46.2	50.8
9	1,713	13.9	2,3794.0	16.8	2,8791	4,997	35.7	39.3
10	1,573	13.9	2,1852.6	16.8	2,6442	4,589	32.8	36.1
11	1,735	22.5	3,9033.9	24.5	4,2504	3,470	32.5	35.4
12	1,619	22.5	3,6425.2	24.5	3,9663	3,238	30.4	33.1
13	1,800	22.5	4,0496.8	24.5	4,4096	3,600	33.7	36.7
14	1,814	22.5	4,0813.7	24.5	4,4442	3,628	34.0	37.0
15	1,985	22.5	4,4665.9	24.5	4,8636	3,970	37.2	40.5
16	2,385	13.9	3,3125.0	16.8	4,0081	6,956	49.7	54.7
17	2,024	13.9	2,8113.4	16.8	3,4017	5,904	42.2	46.4
18	1,460	13.9	2,0272.3	16.8	2,4530	4,257	30.4	33.4
19	1,101	22.5	2,4771.1	24.5	2,6973	2,202	20.6	22.5
20	757	22.5	1,7042.3	24.5	1,8557	1,515	14.2	15.5
21	489	22.5	1,0995.8	24.5	1,1973	977	9.2	10.0
TOTAL	2,5649	18	4,60992	20.5	5,24649	6,3657		

KREUTZWALDI

TABLE 18. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND KREUTZWALDI STREET IN THE MAIN DIRECTION (TARTU MAANTEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		TRAM WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. tram	sec/tram	sec/hour	sec/tram	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	619	22	9.5	209.2	7.6	166	–42.8	10.3	6,133.8	7.6	4,513.3	–1,620.5
7	1,490	36	11.3	405.0	8.9	320	–85.0	11.3	1,6360.6	8.9	1,2926.9	–3,433.7
8	1,567	38	11.3	427.5	8.9	338	–89.7	11.3	1,7200.9	8.9	1,3590.9	–3,610.1
9	1,213	32	11.3	360.0	8.9	284	–75.6	11.3	1,3285.1	8.9	1,0496.9	–2,788.2
10	1,113	28	11.3	315.0	8.9	249	–66.1	11.3	1,2201.2	8.9	9,640.4	–2,560.7
11	1,228	32	9.5	304.2	7.6	242	–62.2	10.3	1,2290.6	7.6	9,043.5	–3,247.0
12	1,146	30	9.5	285.2	7.6	227	–58.3	10.3	1,1469.2	7.6	8,439.1	–3,030.0
13	1,273	32	9.5	304.2	7.6	242	–62.2	10.3	1,2751.2	7.6	9,382.5	–3,368.7
14	1,282	32	9.5	304.2	7.6	242	–62.2	10.3	1,2851.0	7.6	9,455.9	–3,395.1
15	1,404	36	9.5	342.3	7.6	272	–70.0	10.3	1,4063.9	7.6	1,0348.4	–3,715.5
16	1,684	40	11.3	450.0	8.9	356	–94.4	11.3	1,8495.0	8.9	1,4613.3	–3,881.7
17	1,433	38	11.3	427.5	8.9	338	–89.7	11.3	1,5696.8	8.9	1,2402.4	–3,294.4
18	1,032	26	11.3	292.5	8.9	231	–61.4	11.3	1,1318.8	8.9	8,943.3	–2,375.6
19	783	24	9.5	228.2	7.6	182	–46.7	10.3	7,799.6	7.6	5,739.1	–2,060.6
20	546	24	9.5	228.2	7.6	182	–46.7	10.3	5,366.1	7.6	3,948.4	–1,417.7
21	353	16	9.5	152.1	7.6	121	–31.1	10.3	3,462.2	7.6	2,547.6	–914.7
TOTAL	**1,8166**	**486**	**10.4**	**5,035**	**10.8**	**3,991**	**–1,044**	**10.8**	**1,90746**	**8.3**	**1,46032**	**–4,4714**

TABLE 19. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND KREUTZWALDI STREET IN THE SECONDARY DIRECTION (KREUTZWALDI)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME					QUEUE	
		Existing		Adaptive		Difference	Existing	Adaptive
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour	m	m
6	46	27.5	1,277.8	29.5	1,371	92.9	1.1	1.1
7	113	23.5	2,657.7	27.2	3,082	424.6	3.1	3.3
8	119	23.5	2,794.2	27.2	3,241	446.4	3.2	3.5
9	92	23.5	2,158.1	27.2	2,503	344.8	2.5	2.7
10	84	23.5	1,982.0	27.2	2,299	316.7	2.3	2.5
11	93	27.5	2,560.4	29.5	2,747	186.2	2.1	2.3
12	87	27.5	2,389.3	29.5	2,563	173.8	2.0	2.1
13	97	27.5	2,656.4	29.5	2,850	193.2	2.2	2.4
14	97	27.5	2,677.2	29.5	2,872	194.7	2.2	2.4
15	107	27.5	2,929.9	29.5	3,143	213.1	2.4	2.6
16	128	23.5	3,004.4	27.2	3,484	480.0	3.5	3.7
17	109	23.5	2,549.9	27.2	2,957	407.4	2.9	3.2
18	78	23.5	1,838.7	27.2	2,132	293.8	2.1	2.3
19	59	27.5	1,624.9	29.5	1,743	118.2	1.4	1.5
20	41	27.5	1,117.9	29.5	1,199	81.3	0.9	1.0
21	26	27.5	721.3	29.5	774	52.5	0.6	0.6
TOTAL	**1,377**	**25.4**	**3,4940**	**28.3**	**3,8960**	**4,019**		

LAULUPEO

TABLE 20. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND LAULUPEO STREET IN THE MAIN DIRECTION (TARTU MAANTEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		TRAM WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. tram	sec/tram	sec/hour	sec/tram	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	924	22	9.5	209.2	7.6	166	–42.8	11.6	1,0430.5	7.6	6,822.1	–3,608.4
7	2,234	36	13.9	500.0	11.3	405	–95.0	13.9	3,0530.9	11.3	2,4730.0	–5,800.9
8	2,349	38	13.9	527.8	11.3	428	–100.3	13.9	3,2099.0	11.3	2,6000.2	–6,098.8
9	1,817	32	13.9	444.4	11.3	360	–84.4	13.9	2,4791.7	11.3	2,0081.3	–4,710.4
10	1,667	28	13.9	388.9	11.3	315	–73.9	13.9	2,2768.8	11.3	1,8442.7	–4,326.1
11	1,840	32	9.5	304.2	7.6	242	–62.2	11.6	2,0900.2	7.6	1,3669.8	–7,230.3
12	1,717	30	9.5	285.2	7.6	227	–58.3	11.6	1,9503.3	7.6	1,2756.2	–6,747.1
13	1,907	32	9.5	304.2	7.6	242	–62.2	11.6	2,1683.4	7.6	1,4182.1	–7,501.3
14	1,922	32	9.5	304.2	7.6	242	–62.2	11.6	2,1853.1	7.6	1,4293.1	–7,560.0
15	2,104	36	9.5	342.3	7.6	272	–70.0	11.6	2,3915.7	7.6	1,5642.2	–8,273.5
16	2,525	40	13.9	555.6	11.3	450	–105.6	13.9	3,4513.9	11.3	2,7956.3	–6,557.6
17	2,147	38	13.9	527.8	11.3	428	–100.3	13.9	2,9292.1	11.3	2,3726.6	–5,565.5
18	1,547	26	13.9	361.1	11.3	293	–68.6	13.9	2,1122.3	11.3	1,7109.1	–4,013.2
19	1,171	24	9.5	228.2	7.6	182	–46.7	11.6	1,3263.3	7.6	8,674.9	–4,588.4
20	813	24	9.5	228.2	7.6	182	–46.7	11.6	9,125.1	7.6	5,968.3	–3,156.8
21	525	16	9.5	152.1	7.6	121	–31.1	11.6	5,887.6	7.6	3,850.8	–2,036.8
TOTAL	**2,7210**	**486**	**11.7**	**5,663**	**9.4**	**4,553**	**–1,110**	**12.8**	**3,41681**	**9.5**	**2,53906**	**–8,7775**

TABLE 21. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND LAULUPEO STREET IN THE SECONDARY DIRECTION (LAULUPEO)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME					QUEUE	
		Existing		Adaptive		Difference	Existing	Adaptive
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour	m	m
6	106	27.5	2,925.0	29.5	3,138	212.7	4.9	5.2
7	259	20.0	5,183.7	23.5	6,084	900.0	13.0	14.0
8	272	20.0	5,450.0	23.5	6,396	946.2	13.6	14.8
9	210	20.0	4,209.3	23.5	4,940	730.8	10.5	11.4
10	193	20.0	3,865.8	23.5	4,537	671.2	9.7	10.5
11	213	27.5	5,861.0	29.5	6,287	426.3	9.8	10.5
12	199	27.5	5,469.3	29.5	5,867	397.8	9.1	9.8
13	221	27.5	6,080.6	29.5	6,523	442.2	10.1	10.9
14	223	27.5	6,128.2	29.5	6,574	445.7	10.2	11.0
15	244	27.5	6,706.7	29.5	7,194	487.8	11.2	12.0
16	293	20.0	5,860.0	23.5	6,877	1,017.4	14.7	15.9
17	249	20.0	4,973.4	23.5	5,837	863.4	12.4	13.5
18	179	20.0	3,586.3	23.5	4,209	622.6	9.0	9.7
19	135	27.5	3,719.4	29.5	3,990	270.5	6.2	6.6
20	93	27.5	2,558.9	29.5	2,745	186.1	4.3	4.6
21	60	27.5	1,651.0	29.5	1,771	120.1	2.8	3.0
TOTAL	**3,151**	**23.6**	**7,4229**	**26.3**	**8,2969**	**8,741**		

ODRA/TÜRNPU

TABLE 22. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND THE STREETS ODRA AND TÜRNPU IN THE MAIN DIRECTION (TARTU MAANTEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		TRAM WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. tram	sec/tram	sec/hour	sec/tram	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	980	22	12.3	269.5	10.0	221	–48.9	10.2	9,783.3	10.0	9,610.3	–173.0
7	2,371	36	8.9	320.0	6.8	245	–75.0	8.9	2,0758.6	6.8	1,5893.3	–4,865.3
8	2,493	38	8.9	337.8	6.8	259	–79.2	8.9	2,1824.7	6.8	1,6709.6	–5,115.2
9	1,928	32	8.9	284.4	6.8	218	–66.7	8.9	1,6856.3	6.8	1,2905.6	–3,950.7
10	1,770	28	8.9	248.9	6.8	191	–58.3	8.9	1,5481.0	6.8	1,1852.6	–3,628.4
11	1,952	32	12.3	392.0	10.0	321	–71.1	10.2	1,9603.3	10.0	1,9256.6	–346.7
12	1,822	30	12.3	367.5	10.0	301	–66.7	10.2	1,8293.2	10.0	1,7969.6	–323.6
13	2,024	32	12.3	392.0	10.0	321	–71.1	10.2	2,0338.0	10.0	1,9978.3	–359.7
14	2,040	32	12.3	392.0	10.0	321	–71.1	10.2	2,0497.2	10.0	2,0134.6	–362.5
15	2,233	36	12.3	441.0	10.0	361	–80.0	10.2	2,2431.8	10.0	2,2035.1	–396.8
16	2,680	40	8.9	355.6	6.8	272	–83.3	8.9	2,3466.7	6.8	1,7966.7	–5,500.0
17	2,279	38	8.9	337.8	6.8	259	–79.2	8.9	1,9916.3	6.8	1,5248.4	–4,667.9
18	1,642	26	8.9	231.1	6.8	177	–54.2	8.9	1,4361.5	6.8	1,0995.5	–3,366.0
19	1,243	24	12.3	294.0	10.0	241	–53.3	10.2	1,2440.3	10.0	1,2220.3	–220.0
20	862	24	12.3	294.0	10.0	241	–53.3	10.2	8,558.9	10.0	8,407.5	–151.4
21	557	16	12.3	196.0	10.0	160	–35.6	10.2	5,522.2	10.0	5,424.6	–97.7
TOTAL	**2,8877**	**486**	**10.6**	**5,154**	**8.4**	**4,107**	**–1,047**	**9.5**	**2,70133**	**8.3**	**2,36609**	**–3,3525**

TABLE 23. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND THE STREETS ODRA AND TÜRNPU IN THE SECONDARY DIRECTION (ODRA/TÜRNPU)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME					QUEUE	
		Existing		Adaptive		Difference	Existing	Adaptive
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour	m	m
6	528	25.0	1,3195.7	27.0	1,4251	1,055.7	11.0	11.9
7	1,286	27.2	3,5013.4	31.3	4,0194	5,180.5	37.5	40.2
8	1,352	27.2	3,6811.7	31.3	4,2258	5,446.6	39.4	42.3
9	1,044	27.2	2,8431.5	31.3	3,2638	4,206.7	30.5	32.6
10	959	27.2	2,6111.7	31.3	2,9975	3,863.5	28.0	30.0
11	1,058	25.0	2,6440.9	27.0	2,8556	2,115.3	22.0	23.8
12	987	25.0	2,4673.7	27.0	2,6648	1,973.9	20.6	22.2
13	1,097	25.0	2,7431.8	27.0	2,9626	2,194.5	22.9	24.7
14	1,106	25.0	2,7646.5	27.0	2,9858	2,211.7	23.0	24.9
15	1,210	25.0	3,0255.9	27.0	3,2676	2,420.5	25.2	27.2
16	1,454	27.2	3,9581.1	31.3	4,5438	5,856.4	42.4	45.4
17	1,234	27.2	3,3592.7	31.3	3,8563	4,970.3	36.0	38.6
18	890	27.2	2,4223.4	31.3	2,7808	3,584.1	26.0	27.8
19	671	25.0	1,6779.5	27.0	1,8122	1,342.4	14.0	15.1
20	462	25.0	1,1544.1	27.0	1,2468	923.5	9.6	10.4
21	298	25.0	7,448.4	27.0	8,044	595.9	6.2	6.7
TOTAL	**1,5637**	**26.2**	**4,09182**	**29.2**	**4,57123**	**4,7941**		

LUBJA

TABLE 24. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND THE STREETS ODRA AND TÜRNPU IN THE MAIN DIRECTION (TARTU MAANTEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		TRAM WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. tram	sec/tram	sec/hour	sec/tram	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	1,168	22	12.3	269.5	10.0	221	–48.9	11.7	1,3370.5	10.0	1,1492.3	–1,878.2
7	2,829	36	11.3	405.0	8.9	320	–85.0	11.3	3,1417.6	8.9	2,4823.8	–6,593.8
8	2,974	38	11.3	427.5	8.9	338	–89.7	11.3	3,3031.2	8.9	2,6098.8	–6,932.5
9	2,300	32	11.3	360.0	8.9	284	–75.6	11.3	2,5511.7	8.9	2,0157.4	–5,354.3
10	2,111	28	11.3	315.0	8.9	249	–66.1	11.3	2,3430.1	8.9	1,8512.7	–4,917.4
11	2,328	32	12.3	392.0	10.0	321	–71.1	11.7	2,6791.2	10.0	2,3027.7	–3,763.5
12	2,173	30	12.3	367.5	10.0	301	–66.7	11.7	2,5000.7	10.0	2,1488.7	–3,512.0
13	2,414	32	12.3	392.0	10.0	321	–71.1	11.7	2,7795.3	10.0	2,3890.7	–3,904.6
14	2,433	32	12.3	392.0	10.0	321	–71.1	11.7	2,8012.8	10.0	2,4077.7	–3,935.1
15	2,664	36	12.3	441.0	10.0	361	–80.0	11.7	3,0656.8	10.0	2,6350.2	–4,306.6
16	3,197	40	11.3	450.0	8.9	356	–94.4	11.3	3,5516.3	8.9	2,8062.2	–7,454.0
17	2,717	38	11.3	427.5	8.9	338	–89.7	11.3	3,0142.8	8.9	2,3816.6	–6,326.3
18	1,958	26	11.3	292.5	8.9	231	–61.4	11.3	2,1735.8	8.9	1,7173.9	–4,561.8
19	1,481	24	12.3	294.0	10.0	241	–53.3	11.7	1,7001.8	10.0	1,4613.5	–2,388.3
20	1,027	24	12.3	294.0	10.0	241	–53.3	11.7	1,1697.1	10.0	1,0053.9	–1,643.2
21	663	16	12.3	196.0	10.0	160	–35.6	11.7	7,547.1	10.0	6,486.9	–1,060.2
TOTAL	3,4437	486	10.6	5,716	8.4	4,602	–1,113	11.4	3,88659	9.4	3,20127	–6,8532

TABLE 25. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TARTU MAANTEE AND THE STREETS ODRA AND TÜRNPU IN THE SECONDARY DIRECTION (ODRA/TÜRNPU)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME					AVERAGE QUEUE	
		Existing		Adaptive		Difference	Existing	Adaptive
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour	m	m
6	99	25.0	2,486.7	27.0	2,686	198.9	8.3	9.0
7	242	23.5	5,689.2	27.2	6,598	908.9	26.3	28.3
8	255	23.5	5,981.4	27.2	6,937	955.6	27.6	29.7
9	197	23.5	4,619.7	27.2	5,358	738.1	21.3	23.0
10	181	23.5	4,242.8	27.2	4,921	677.8	19.6	21.1
11	199	25.0	4,982.7	27.0	5,381	398.6	16.6	17.9
12	186	25.0	4,649.7	27.0	5,022	372.0	15.5	16.7
13	207	25.0	5,169.4	27.0	5,583	413.6	17.2	18.6
14	208	25.0	5,209.9	27.0	5,627	416.8	17.4	18.8
15	228	25.0	5,701.6	27.0	6,158	456.1	19.0	20.5
16	274	23.5	6,431.4	27.2	7,459	1,027.5	29.7	32.0
17	233	23.5	5,458.4	27.2	6,330	872.0	25.2	27.1
18	168	23.5	3,936.0	27.2	4,565	628.8	18.2	19.6
19	126	25.0	3,162.0	27.0	3,415	253.0	10.5	11.4
20	87	25.0	2,175.4	27.0	2,349	174.0	7.3	7.8
21	56	25.0	1,403.6	27.0	1,516	112.3	4.7	5.1
TOTAL	**2,947**	**26.2**	**7,1300**	**29.2**	**7,9904**	**8,604**		

TAMMSAARE TEE

KADAKA TEE

TABLE 26. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND KADAKA TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,895	0.28	527	2,051	0.25	516	156	–0.03	–11
7	4,618	0.68	3,131	4,998	0.61	3,066	380	–0.06	–66
8	4,855	0.71	3,461	5,255	0.64	3,389	400	–0.07	–72
9	3,750	0.55	2,065	4,059	0.50	2,021	309	–0.05	–43
10	3,444	0.51	1,742	3,727	0.46	1,705	284	–0.05	–36
11	3,797	0.56	2,117	4,110	0.50	2,073	313	–0.05	–44
12	3,543	0.52	1,844	3,835	0.47	1,805	292	–0.05	–39
13	3,940	0.58	2,279	4,264	0.52	2,231	324	–0.06	–48
14	3,970	0.58	2,315	4,297	0.53	2,266	327	–0.06	–48
15	4,345	0.64	2,772	4,703	0.58	2,714	358	–0.06	–58
16	5,344	0.78	4,193	5,784	0.71	4,105	440	–0.07	–88
17	4,430	0.65	2,882	4,795	0.59	2,822	365	–0.06	–60
18	3,195	0.47	1,499	3,458	0.42	1,467	263	–0.04	–31
19	2,410	0.35	853	2,608	0.32	835	198	–0.03	–18
20	1,658	0.24	404	1,794	0.22	395	137	–0.02	–8
21	1,070	0.16	168	1,158	0.14	164	88	–0.01	–4
TOTAL	5,6263	0.57	3,2251	6,0896	0.52	3,1576	4,633	–0.15	–675

MUSTAMÄE TEE

TABLE 27. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND MUSTAMÄE TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,511	0.28	428	1,795	0.32	572	284	0.04	144
7	3,683	0.69	2,544	4,375	0.78	3,396	692	0.09	853
8	3,872	0.73	2,812	4,599	0.82	3,754	728	0.09	942
9	2,990	0.56	1,677	3,552	0.63	2,239	562	0.07	562
10	2,746	0.52	1,415	3,262	0.58	1,889	516	0.06	474
11	3,028	0.57	1,720	3,597	0.64	2,296	569	0.07	576
12	2,826	0.53	1,498	3,357	0.60	2,000	531	0.07	502
13	3,142	0.59	1,851	3,732	0.66	2,472	590	0.07	620
14	3,166	0.59	1,880	3,761	0.67	2,511	595	0.07	630
15	3,465	0.65	2,252	4,116	0.73	3,007	651	0.08	755
16	4,261	0.80	3,406	5,062	0.90	4,548	801	0.10	1,142
17	3,533	0.66	2,342	4,197	0.74	3,126	664	0.08	785
18	2,548	0.48	1,218	3,026	0.54	1,626	479	0.06	408
19	1,922	0.36	693	2,283	0.41	925	361	0.04	232
20	1,322	0.25	328	1,571	0.28	438	248	0.03	110
21	853	0.16	136	1,013	0.18	182	160	0.02	46
TOTAL	4,4868	0.58	2,6200	5,3299	0.66	3,4981	8,431	1.04	8,781

EHITAJATE TEE

TABLE 28. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND EHITAJATE TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,306	0.17	229	1,458	0.12	168	152	–0.06	–60
7	3,182	0.43	1,357	3,554	0.28	998	371	–0.15	–359
8	3,346	0.45	1,500	3,736	0.30	1,103	390	–0.15	–397
9	2,584	0.35	895	2,886	0.23	658	302	–0.12	–237
10	2,373	0.32	755	2,650	0.21	555	277	–0.11	–200
11	2,617	0.35	918	2,922	0.23	675	305	–0.12	–243
12	2,442	0.33	799	2,727	0.22	587	285	–0.11	–212
13	2,715	0.36	988	3,032	0.24	726	317	–0.12	–261
14	2,736	0.37	1,003	3,055	0.24	738	319	–0.13	–266
15	2,994	0.40	1,201	3,344	0.26	883	349	–0.14	–318
16	3,683	0.49	1,817	4,112	0.32	1,336	430	–0.17	–481
17	3,053	0.41	1,249	3,410	0.27	918	356	–0.14	–331
18	2,202	0.30	650	2,459	0.19	478	257	–0.10	–172
19	1,661	0.22	370	1,854	0.15	272	194	–0.08	–98
20	1,143	0.15	175	1,276	0.10	129	133	–0.05	–46
21	737	0.10	73	823	0.07	54	86	–0.03	–19
TOTAL	3,8774	0.36	1,3977	4,3298	0.24	1,0277	4,525	–0.82	–3,700

LAKI

TABLE 29. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND LAKI STREET

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	955	0.08	75	1,157	0.06	64	201	–0.02	–11
7	2,328	0.19	446	2,819	0.13	379	490	–0.06	–67
8	2,448	0.20	493	2,963	0.14	419	516	–0.06	–74
9	1,891	0.16	294	2,289	0.11	250	398	–0.05	–44
10	1,736	0.14	248	2,102	0.10	211	366	–0.04	–37
11	1,915	0.16	302	2,318	0.11	256	403	–0.05	–45
12	1,787	0.15	263	2,163	0.10	223	376	–0.04	–40
13	1,986	0.16	325	2,405	0.11	276	418	–0.05	–49
14	2,002	0.16	330	2,423	0.12	280	422	–0.05	–50
15	2,191	0.18	395	2,652	0.13	336	461	–0.05	–60
16	2,694	0.22	598	3,262	0.16	508	567	–0.07	–90
17	2,234	0.18	411	2,704	0.13	349	470	–0.05	–62
18	1,611	0.13	214	1,950	0.09	181	339	–0.04	–32
19	1,215	0.10	122	1,471	0.07	103	256	–0.03	–18
20	836	0.07	58	1,012	0.05	49	176	–0.02	–9
21	539	0.04	24	653	0.03	20	114	–0.01	–4
TOTAL	2,8368	0.16	4,596	3,4343	0.11	3,904	5,974	–0.12	–693

SÕPRUSE PUIESTEE

TABLE 30. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND SÕPRUSE PUIESTEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	2,527	0.80	2,029	2,842	0.46	1,321	315	–0.34	–708
7	6,158	1.96	1,2051	6,925	1.13	7,845	767	–0.82	–4,205
8	6,475	2.06	1,3320	7,281	1.19	8,672	807	–0.87	–4,649
9	5,001	1.59	7,946	5,624	0.92	5,173	623	–0.67	–2,773
10	4,593	1.46	6,702	5,165	0.84	4,363	572	–0.61	–2,339
11	5,064	1.61	8,148	5,695	0.93	5,305	631	–0.68	–2,844
12	4,725	1.50	7,096	5,314	0.87	4,619	589	–0.63	–2,476
13	5,254	1.67	8,770	5,908	0.97	5,710	654	–0.70	–3,061
14	5,295	1.68	8,908	5,954	0.97	5,799	660	–0.71	–3,109
15	5,795	1.84	1,0669	6,516	1.07	6,946	722	–0.78	–3,723
16	7,126	2.26	1,6136	8,014	1.31	1,0505	888	–0.95	–5,631
17	5,908	1.88	1,1093	6,644	1.09	7,222	736	–0.79	–3,871
18	4,261	1.35	5,768	4,791	0.78	3,755	531	–0.57	–2,013
19	3,214	1.02	3,281	3,614	0.59	2,136	400	–0.43	–1,145
20	2,211	0.70	1,553	2,486	0.41	1,011	275	–0.30	–542
21	1,427	0.45	647	1,604	0.26	421	178	–0.19	–226
TOTAL	7,5032	1.65	1,24119	8,4379	0.96	8,0804	9,347	–4.63	–4,3315

NÕMME TEE

TABLE 31. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND NÕMME TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	2,093	0.16	334	2,435	0.10	249	342	–0.06	–85
7	5,100	0.39	1,982	5,935	0.25	1,479	835	–0.14	–503
8	5,362	0.41	2,191	6,239	0.26	1,635	877	–0.15	–556
9	4,141	0.32	1,307	4,819	0.20	975	678	–0.11	–331
10	3,803	0.29	1,102	4,426	0.19	823	622	–0.10	–280
11	4,194	0.32	1,340	4,880	0.20	1,000	686	–0.11	–340
12	3,913	0.30	1,167	4,554	0.19	871	640	–0.11	–296
13	4,351	0.33	1,442	5,063	0.21	1,076	712	–0.12	–366
14	4,385	0.33	1,465	5,102	0.21	1,093	717	–0.12	–372
15	4,799	0.37	1,755	5,584	0.23	1,310	785	–0.13	–445
16	5,902	0.45	2,654	6,867	0.29	1,981	966	–0.16	–673
17	4,893	0.37	1,824	5,694	0.24	1,362	801	–0.13	–463
18	3,528	0.27	949	4,106	0.17	708	577	–0.10	–241
19	2,661	0.20	540	3,097	0.13	403	435	–0.07	–137
20	1,831	0.14	255	2,131	0.09	191	300	–0.05	–65
21	1,181	0.09	106	1,375	0.06	79	193	–0.03	–27
TOTAL	6,2138	0.33	2,0412	7,2305	0.21	1,5234	1,0167	–0.51	–5,177

TONDI

TABLE 32. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF TAMMSAARE TEE AND TONDI STREET

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	2,283	0.37	849	2,476	0.43	1,053	193	0.05	204
7	5,564	0.91	5,039	6,035	1.04	6,251	471	0.13	1,213
8	5,850	0.95	5,569	6,345	1.09	6,910	495	0.14	1,340
9	4,518	0.74	3,322	4,900	0.84	4,122	382	0.11	800
10	4,150	0.68	2,802	4,500	0.77	3,477	351	0.10	674
11	4,575	0.74	3,407	4,962	0.85	4,227	387	0.11	820
12	4,270	0.69	2,967	4,631	0.79	3,681	361	0.10	714
13	4,747	0.77	3,667	5,148	0.88	4,550	401	0.11	883
14	4,784	0.78	3,725	5,189	0.89	4,621	405	0.11	896
15	5,236	0.85	4,461	5,678	0.97	5,535	443	0.12	1,074
16	6,439	1.05	6,747	6,983	1.20	8,371	544	0.15	1,624
17	5,338	0.87	4,638	5,790	0.99	5,754	451	0.13	1,116
18	3,849	0.63	2,412	4,175	0.72	2,992	326	0.09	580
19	2,904	0.47	1,372	3,149	0.54	1,702	246	0.07	330
20	1,998	0.33	649	2,167	0.37	806	169	0.05	156
21	1,289	0.21	270	1,398	0.24	335	109	0.03	65
TOTAL	6,7793	0.77	5,1895	7,3526	0.88	6,4385	5,733	2.18	1,2490

EHITAJATE TEE / RANNAMÕISA TEE

ÕISMÄE TEE

TABLE 33. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF EHITAJATE TEE AND ÕISMÄE TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,218	0.23	275	1,223	0.21	261	5	–0.01	–14
7	2,967	0.55	1,635	2,980	0.52	1,549	13	–0.03	–86
8	3,119	0.58	1,807	3,133	0.55	1,712	14	–0.03	–95
9	2,409	0.45	1,078	2,420	0.42	1,021	10	–0.03	–57
10	2,213	0.41	909	2,222	0.39	861	10	–0.02	–48
11	2,440	0.45	1,105	2,450	0.43	1,047	11	–0.03	–58
12	2,277	0.42	963	2,287	0.40	912	10	–0.02	–51
13	2,531	0.47	1,190	2,542	0.44	1,127	11	–0.03	–63
14	2,551	0.47	1,209	2,562	0.45	1,145	11	–0.03	–64
15	2,792	0.52	1,447	2,804	0.49	1,371	12	–0.03	–76
16	3,433	0.64	2,189	3,448	0.60	2,074	15	–0.04	–115
17	2,847	0.53	1,505	2,859	0.50	1,426	12	–0.03	–79
18	2,053	0.38	782	2,062	0.36	741	9	–0.02	–41
19	1,548	0.29	445	1,555	0.27	422	7	–0.02	–23
20	1,065	0.20	211	1,070	0.19	200	5	–0.01	–11
21	687	0.13	88	690	0.12	83	3	–0.01	–5
TOTAL	3,6149	0.47	1,6838	3,6306	0.44	1,5952	157	–5.66	–886

KADAKA TEE

TABLE 34. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF EHITAJATE TEE AND KADAKA TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,921	0.25	479	1,895	0.28	527	–26	0.03	48
7	4,682	0.61	2,846	4,618	0.68	3,131	–64	0.07	285
8	4,922	0.64	3,146	4,855	0.71	3,461	–67	0.07	315
9	3,802	0.49	1,876	3,750	0.55	2,065	–52	0.06	188
10	3,491	0.45	1,583	3,444	0.51	1,742	–48	0.05	159
11	3,850	0.50	1,924	3,797	0.56	2,117	–53	0.06	193
12	3,592	0.47	1,676	3,543	0.52	1,844	–49	0.05	168
13	3,994	0.52	2,071	3,940	0.58	2,279	–54	0.06	208
14	4,025	0.52	2,104	3,970	0.58	2,315	–55	0.06	211
15	4,405	0.57	2,520	4,345	0.64	2,772	–60	0.07	253
16	5,418	0.70	3,811	5,344	0.78	4,193	–74	0.08	382
17	4,492	0.58	2,620	4,430	0.65	2,882	–61	0.07	263
18	3,239	0.42	1,362	3,195	0.47	1,499	–44	0.05	137
19	2,443	0.32	775	2,410	0.35	853	–33	0.04	78
20	1,681	0.22	367	1,658	0.24	404	–23	0.03	37
21	1,084	0.14	153	1,070	0.16	168	–15	0.02	15
TOTAL	5,7041	0.51	2,9311	5,6263	0.57	3,2251	–778	–3.78	2,940

KADAKA TEE

AKADEEMIA TEE

TABLE 35. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF KADAKA TEE AND AKADEEMIA TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,209	0.64	775	1,247	0.52	649	39	–0.12	–126
7	2,945	1.56	4,601	3,039	1.27	3,854	94	–0.29	–747
8	3,096	1.64	5,086	3,195	1.33	4,260	99	–0.31	–825
9	2,391	1.27	3,034	2,468	1.03	2,541	76	–0.24	–492
10	2,196	1.17	2,559	2,266	0.95	2,144	70	–0.22	–415
11	2,422	1.28	3,111	2,499	1.04	2,606	77	–0.24	–505
12	2,260	1.20	2,709	2,332	0.97	2,269	72	–0.23	–440
13	2,512	1.33	3,348	2,593	1.08	2,805	80	–0.25	–543
14	2,532	1.34	3,401	2,613	1.09	2,849	81	–0.25	–552
15	2,771	1.47	4,073	2,859	1.19	3,412	88	–0.28	–661
16	3,408	1.81	6,161	3,517	1.47	5,161	109	–0.34	–1,000
17	2,825	1.50	4,235	2,916	1.22	3,548	90	–0.28	–687
18	2,037	1.08	2,202	2,102	0.88	1,845	65	–0.20	–357
19	1,537	0.82	1,253	1,586	0.66	1,050	49	–0.15	–203
20	1,057	0.56	593	1,091	0.46	497	34	–0.11	–96
21	682	0.36	247	704	0.29	207	22	–0.07	–40
TOTAL	**3,5881**	**1.32**	**4,7387**	**3,7026**	**1.07**	**3,9697**	**1,145**	**–6.72**	**–7,691**

MUSTAMÄE TEE

TABLE 36. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF KADAKA TEE AND MUSTAMÄE TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,040	0.20	211	1,074	0.18	191	35	–0.03	–21
7	2,534	0.49	1,254	2,618	0.43	1,132	84	–0.06	–122
8	2,664	0.52	1,386	2,752	0.45	1,251	89	–0.07	–135
9	2,057	0.40	827	2,126	0.35	746	68	–0.05	–81
10	1,889	0.37	697	1,952	0.32	629	63	–0.05	–68
11	2,083	0.41	848	2,153	0.36	765	69	–0.05	–83
12	1,944	0.38	738	2,009	0.33	666	65	–0.05	–72
13	2,161	0.42	913	2,233	0.37	824	72	–0.05	–89
14	2,178	0.43	927	2,251	0.37	837	73	–0.05	–90
15	2,384	0.47	1,110	2,463	0.41	1,002	79	–0.06	–108
16	2,932	0.57	1,679	3,029	0.50	1,515	98	–0.07	–164
17	2,431	0.47	1,154	2,512	0.41	1,042	81	–0.06	–112
18	1,753	0.34	600	1,811	0.30	542	58	–0.04	–58
19	1,322	0.26	341	1,366	0.23	308	44	–0.03	–33
20	910	0.18	162	940	0.16	146	30	–0.02	–16
21	587	0.11	67	606	0.10	61	20	–0.01	–7
TOTAL	**3,0869**	**0.42**	**1,2915**	**3,1896**	**0.37**	**1,1657**	**1,028**	**–1.22**	**–1,258**

TÄHETORNI

TABLE 37. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF KADAKA TEE AND TÄHETORNI STREET

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	879	0.14	127	576	0.17	100	–302	0.03	–27
7	2,141	0.35	753	1,405	0.42	591	–737	0.07	–162
8	2,251	0.37	832	1,477	0.44	653	–775	0.07	–179
9	1,739	0.29	496	1,141	0.34	390	–598	0.06	–107
10	1,597	0.26	419	1,047	0.31	329	–550	0.05	–90
11	1,761	0.29	509	1,155	0.35	400	–606	0.06	–109
12	1,643	0.27	443	1,078	0.32	348	–565	0.05	–95
13	1,827	0.30	548	1,198	0.36	430	–629	0.06	–118
14	1,841	0.30	557	1,208	0.36	437	–634	0.06	–120
15	2,015	0.33	667	1,322	0.40	523	–693	0.07	–143
16	2,478	0.41	1,008	1,625	0.49	791	–853	0.08	–217
17	2,055	0.34	693	1,348	0.40	544	–707	0.07	–149
18	1,482	0.24	360	972	0.29	283	–510	0.05	–77
19	1,117	0.18	205	733	0.22	161	–385	0.04	–44
20	769	0.13	97	504	0.15	76	–265	0.02	–21
21	496	0.08	40	325	0.10	32	–171	0.02	–9
TOTAL	**2,6091**	**0.30**	**7,754**	**1,7113**	**0.36**	**6,087**	**–8,978**	**0.19**	**–1,668**

MÄEPEALSE

TABLE 38. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF KADAKA TEE AND MÄEPEALSE STREET

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	736	0.15	111	732	0.16	117	–4	0.01	6
7	1,793	0.37	658	1,783	0.39	697	–11	0.02	38
8	1,886	0.39	728	1,874	0.41	770	–11	0.02	42
9	1,456	0.30	434	1,448	0.32	459	–9	0.02	25
10	1,337	0.27	366	1,330	0.29	387	–8	0.02	21
11	1,475	0.30	445	1,466	0.32	471	–9	0.02	26
12	1,376	0.28	388	1,368	0.30	410	–8	0.02	23
13	1,530	0.31	479	1,521	0.33	507	–9	0.02	28
14	1,542	0.32	487	1,533	0.34	515	–9	0.02	28
15	1,687	0.35	583	1,678	0.37	617	–10	0.02	34
16	2,075	0.42	882	2,063	0.45	933	–12	0.03	51
17	1,721	0.35	606	1,711	0.37	641	–10	0.02	35
18	1,241	0.25	315	1,233	0.27	333	–7	0.02	18
19	936	0.19	179	930	0.20	190	–6	0.01	10
20	644	0.13	85	640	0.14	90	–4	0.01	5
21	415	0.09	35	413	0.09	37	–2	0.01	2
TOTAL	2,1851	0.31	6,781	2,1722	0.33	7,175	–129	–3.06	394

EHITAJATE TEE

TABLE 39. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF KADAKA TEE AND EHITAJATE TEE

TIME	EXISTING			ADAPTIVE			DIFFERENCE		
	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total	vehicle/h	waiting time min/vehicle	waiting time min/total
6	1,895	0.28	527	1,463	0.31	454	–432	0.03	–74
7	4,618	0.68	3,131	3,565	0.76	2,693	–1,053	0.08	–438
8	4,855	0.71	3,461	3,748	0.79	2,977	–1,107	0.08	–484
9	3,750	0.55	2,065	2,895	0.61	1,776	–855	0.06	–289
10	3,444	0.51	1,742	2,659	0.56	1,498	–785	0.06	–244
11	3,797	0.56	2,117	2,931	0.62	1,821	–866	0.06	–296
12	3,543	0.52	1,844	2,736	0.58	1,586	–808	0.06	–258
13	3,940	0.58	2,279	3,041	0.64	1,960	–898	0.07	–319
14	3,970	0.58	2,315	3,065	0.65	1,991	–905	0.07	–324
15	4,345	0.64	2,772	3,354	0.71	2,384	–991	0.07	–388
16	5,344	0.78	4,193	4,125	0.87	3,606	–1,218	0.09	–587
17	4,430	0.65	2,882	3,420	0.72	2,479	–1,010	0.07	–403
18	3,195	0.47	1,499	2,466	0.52	1,289	–728	0.05	–210
19	2,410	0.35	853	1,860	0.39	733	–549	0.04	–119
20	1,658	0.24	404	1,280	0.27	347	–378	0.03	–56
21	1,070	0.16	168	826	0.17	145	–244	0.02	–24
TOTAL	5,6263	0.57	3,2251	4,3435	0.64	2,7739	–1,2828	0.35	–4,512

J. SMUULI TEE

PUNANE

TABLE 40. CHANGE IN WAITING TIMES WHEN IMPLEMENTING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF J.SMUULI TEE AND PUNANE STREET IN THE MAIN DIRECTION (J. SMUULI TEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		HEAVY VEHICLE WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. truck	sec/truck	sec/hour	sec/truck	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	160	16	11	436	10	405	–31	24.2	3,491	22.5	3,242	–249
7	391	39	27	1,063	25	987	–76	24.2	8,507	22.5	7,899	–608
8	411	41	28	1,118	26	1,038	–80	24.2	8,944	22.5	8,305	–639
9	317	32	22	863	20	802	–62	24.2	6,908	22.5	6,414	–493
10	291	29	20	793	18	736	–57	24.2	6,344	22.5	5,891	–453
11	321	32	22	874	20	812	–62	24.2	6,995	22.5	6,495	–500
12	300	30	20	816	19	758	–58	24.2	6,527	22.5	6,061	–466
13	333	33	23	907	21	842	–65	24.2	7,257	22.5	6,739	–518
14	336	34	23	914	21	849	–65	24.2	7,314	22.5	6,791	–522
15	368	37	25	1,001	23	929	–71	24.2	8,004	22.5	7,432	–572
16	452	45	31	1,230	29	1,143	–88	24.2	9,844	22.5	9,140	–703
17	375	37	26	1,020	24	947	–73	24.2	8,161	22.5	7,578	–583
18	270	27	18	736	17	683	–53	24.2	5,885	22.5	5,465	–420
19	204	20	14	555	13	515	–40	24.2	4,439	22.5	4,122	–317
20	140	14	10	382	9	354	–27	24.2	3,054	22.5	2,836	–218
21	90	9	6	246	6	229	–18	24.2	1,970	22.5	1,830	–141
TOTAL	**4,759**	**476**	**27.2**	**1,2955**	**25.3**	**1,2030**	**–925**	**24.2**	**1,03644**	**22.5**	**9,6240**	**–7,403**

TABLE 41. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF J. SMUULI TEE AND PUNANE STREET IN THE SECONDARY DIRECTION (PUNANE)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME				
		Existing		Adaptive		Difference
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	339	28.0	9,495	30.0	1,0163	669
7	826	28.0	2,3137	30.0	2,4766	1,629
8	869	28.0	2,4325	30.0	2,6038	1,713
9	671	28.0	1,8788	30.0	2,0111	1,323
10	616	28.0	1,7255	30.0	1,8470	1,215
11	679	28.0	1,9025	30.0	2,0365	1,340
12	634	28.0	1,7754	30.0	1,9004	1,250
13	705	28.0	1,9738	30.0	2,1128	1,390
14	710	28.0	1,9893	30.0	2,1294	1,401
15	777	28.0	2,1770	30.0	2,3304	1,533
16	956	28.0	2,6773	30.0	2,8659	1,885
17	793	28.0	2,2198	30.0	2,3761	1,563
18	572	28.0	1,6007	30.0	1,7134	1,127
19	431	28.0	1,2074	30.0	1,2924	850
20	297	28.0	8,306	30.0	8,891	585
21	191	28.0	5,359	30.0	5,737	377
TOTAL	**1,0066**	**28.0**	**2,81898**	**30.0**	**3,01750**	**1,9852**

NARVA MNT.

TABLE 42. CHANGE IN WAITING TIMES WHEN IMPLEMENTING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF J. SMUULI TEE AND NARVA MAANTEE IN THE MAIN DIRECTION (J. SMUULI TEE)

TIME	TRAFFIC VOLUME (vehicle/hour)		HEAVY VEHICLE WAITING TIME					OTHER TRANSPORT WAITING TIME				
			Existing		Adaptive		Difference	Existing		Adaptive		Difference
	Total	incl. truck	sec/truck	sec/hour	sec/truck	sec/hour	sec/hour	sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	357	36	5	335	5	284	−51	8.3	2,679	7.1	2,273	−406
7	869	87	13	816	11	692	−124	8.3	6,529	7.1	5,540	−989
8	914	91	14	858	12	728	−130	8.3	6,865	7.1	5,824	−1,040
9	706	71	11	663	9	562	−100	8.3	5,302	7.1	4,499	−803
10	648	65	10	609	8	516	−92	8.3	4,869	7.1	4,131	−738
11	715	71	11	671	9	569	−102	8.3	5,369	7.1	4,555	−813
12	667	67	10	626	9	531	−95	8.3	5,010	7.1	4,251	−759
13	742	74	11	696	10	591	−105	8.3	5,570	7.1	4,726	−844
14	747	75	11	702	10	595	−106	8.3	5,614	7.1	4,763	−851
15	818	82	12	768	10	652	−116	8.3	6,144	7.1	5,213	−931
16	1,006	101	15	944	13	801	−143	8.3	7,555	7.1	6,411	−1,145
17	834	83	13	783	11	664	−119	8.3	6,264	7.1	5,315	−949
18	601	60	9	565	8	479	−86	8.3	4,517	7.1	3,833	−684
19	454	45	7	426	6	361	−65	8.3	3,407	7.1	2,891	−516
20	312	31	5	293	4	249	−44	8.3	2,344	7.1	1,989	−355
21	201	20	3	189	3	160	−29	8.3	1,512	7.1	1,283	−229
TOTAL	1,0592	1,059	9.4	9,944	8.0	8,437	−1,507	8.3	7,9551	7.1	6,7498	−1,2053

TABLE 43. CHANGE IN WAITING TIMES WHEN APPLYING AN ADAPTIVE SOLUTION AT THE INTERSECTION OF J. SMUULI TEE AND NARVA MAANTEE IN THE SECONDARY DIRECTION (NARVA MAANTEE)

TIME	TRAFFIC VOLUME (vehicle/hour)	WAITING TIME				
		Existing		Adaptive		Difference
		sec/vehicle	sec/hour	sec/vehicle	sec/hour	sec/hour
6	207	12.4	2,578	14.1	2,917	339
7	505	12.4	6,282	14.1	7,109	827
8	531	12.4	6,605	14.1	7,474	869
9	410	12.4	5,101	14.1	5,773	671
10	376	12.4	4,685	14.1	5,302	616
11	415	12.4	5,166	14.1	5,846	680
12	387	12.4	4,821	14.1	5,455	634
13	431	12.4	5,360	14.1	6,065	705
14	434	12.4	5,402	14.1	6,112	711
15	475	12.4	5,911	14.1	6,689	778
16	584	12.4	7,270	14.1	8,226	957
17	484	12.4	6,028	14.1	6,821	793
18	349	12.4	4,346	14.1	4,918	572
19	263	12.4	3,278	14.1	3,710	431
20	181	12.4	2,255	14.1	2,552	297
21	117	12.4	1,455	14.1	1,647	191
TOTAL	6,149	12.4	7,6544	14.1	8,6616	1,0072