# Green time period optimization at signalized intersection in Town of Pernik

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**Abstract**. Green time period optimization is essential issue about delay time reduction at signalized intersection. The features of traffic flows are variables in rush and other period of day. Optimal values of green time are that guarantee minimum of delay time. It can be accepted that the values that guarantee that in rush period is can be use in others periods of day. The main issue is being considered in paper is green time period optimization at signalized intersection for minimum delay time according to traffic flows features in rush period. That include comparison between three options of movement diagram and two option of phases for the chosen intersection in Town of Pernik. The application of result will make a lot of benefits both for the traveling and for the environment.

## 1. Introduction

In the last years in urbans number of vehicles have been increasing bringing seriously problems at social, environmental and economic levels. The main problem is increase delay time at intersections at greater rate. That influence of travel time of travelers (drivers and passengers), travel cost, fuel consumption, etc. That problems are traditionally solved by optimizing to minimizing total delays for vehicles. In case that approach is not efficient requires decision related to new road capacity, intelligent traffic system in new approach of traffic management, intersection reconstruction in new shape and more levels.

In this paper optimizing by minimizing total delay time for vehicle are presented for isolated intersection. Approaches used are described in [1] and [2].

## 2. Prerequisites and means for solving the problem

One of the busiest intersections on the territory of the town of Pernik is the four-approach junction of "Yuri Gagarin" Boulevard, "St. St. Cyril i Methodii" Street and "Pyrvi Mai" in the quarter of Dimova Mahala. Intersection of traffic flows is regulated by traffic lights. The transport link between the districts "Dimova Mahala", "Tvardi livadi", "Beli breg" and "Humni dol" is at the crossroads. A scheme of the junction is shown in Figure 1. After observation, it was found that during the evening peak hour of the day, the loading of cars at the crossroads in question was high. For some of the streams, a queue length of cars that interferes with the normal operation of the junction is formed.

The intersection in question consists of four approaches. Approach 1 (from "Yuri Gagarin" Boulevard) is a single canvas and separate traffic lanes for straight and left, each lane of 3,75 meters. Approach 2 on which the traffic road (from "Pyrvi Mai") is a two-way roadway and consists of two traffic lanes of 3.75 m width and a total gauge of 7,5 m, which in the area of the junction do not increase their number. Approaches 3 and 4 (from "St. St. Cyril i Methodii" Street) are with one canvas and separate traffic lanes for straight, right and separate traffic lane for the turning left flows, each strip of 3,75 meters.

For the purpose of the study, the approaches of the junction were designated as shown in Figure 2.

Using described algorithms in [1] and [2] requires input data wherefore were examined the following parameters for features of traffic flows crossing the intersection: queues length for all approaches; traffic light cycle and phases' durations; intensity of traffic flows; saturation flows for all traffic lanes. Technical devices of traffic research, described in [3] and [4], were used for collection of some of these data.

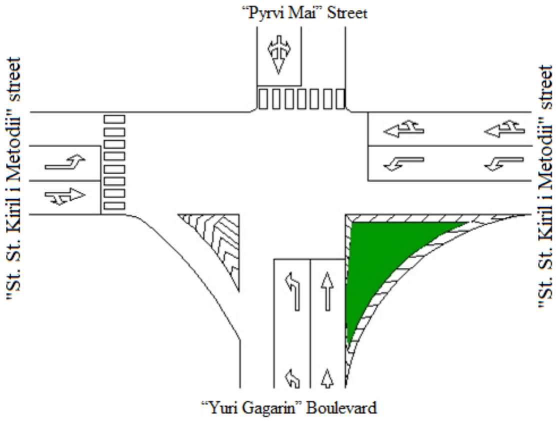


**Figure 1.** Intersection scheme.

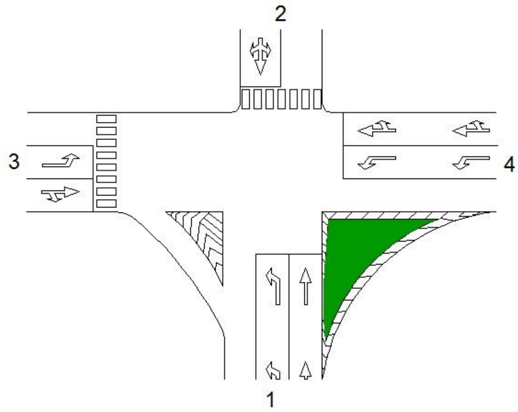


**Figure 2.** Intersection's approaches numbering.

The results of survey are shown in Table 1, Table 2, Table 3, Table 4, Figure 3, and Figure 4.

**Table 1.** Average queue length.

| Flow № | Average queue lengths $Q_{av}$ (PCU) |
|---|---|
| Flow 1-2 | 4,40 |
| Flow 1-3 | 16,10 |
| Flow 2-3, 2-1, 2-4 | 5,13 |
| Flow 3-1, 3-4 | 86,26 |
| Flow 3-2 | 3,27 |
| Flow 4-2, 4-3 | 26,07 |
| Flow 4-1 | 23,40 |

**Table 2.** Intensity by approaches at intersection.

| Approach № | Intensity $I_a^f$ (PCU/s) |
|---|---|
| Approach 1 | 0,31 |
| Approach 2 | 0,09 |
| Approach 3 | 0,34 |
| Approach 4 | 0,34 |

**Table 3.** Saturation flows for traffic lanes.

| Flow № | Saturation flow $I_p^f$ (PCU/s) |
|---|---|
| Flow 1-2 | 0,41 |
| Flow 1-3 | 0,19 |
| Flow 2-3, 2-1, 2-4 | 0,40 |
| Flow 3-1, 3-4 | 0,52 |
| Flow 3-2 | 0,41 |
| Flow 4-2, 4-3 | 0,47 |
| Flow 4-1 | 0,46 |

The traffic flows passes in three phases (Figure 3). Cycle length is 75 s. Intergreen time ($t_{ti}$) for all of phases is 5 s. Green time ($t_{gi}$) duration is 18 s for first phase, 22 s for second phase and 20 s for the third phase (Figure 4).

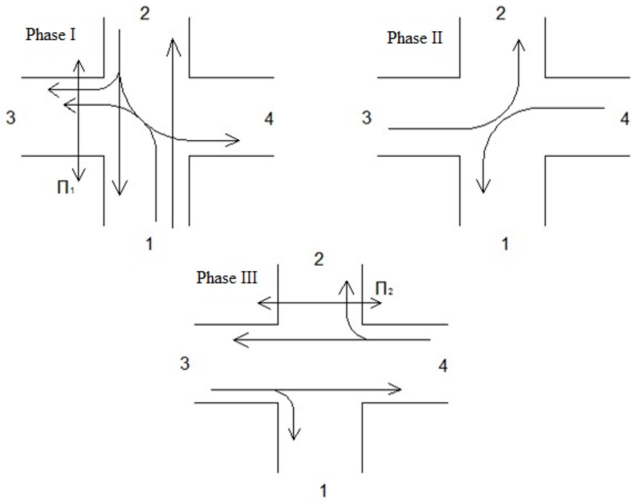


**Figure 3.** Phase signal diagram.

**Table 4.** Phase time duration.

| Phase № | Duration (s) |
|---|---|
| Phase I | 23 |
| Phase II | 27 |
| Phase III | 25 |

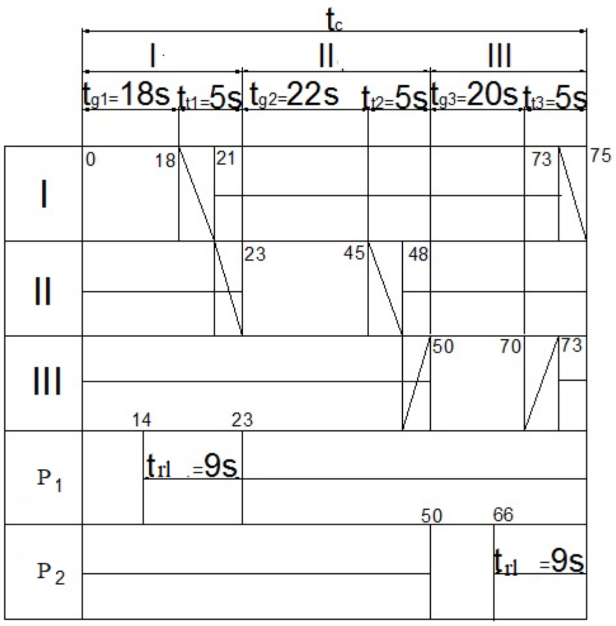


**Figure 4.** Time-Space diagram.

After the observation and measurements, it is clear that at the intersection there are problems with the accumulation of the most cars under flow 3-1, 3-4 running right and to the right from the busiest direction "St. St. Kiril and Metodii" boulevard. After it, there is a flow of 4-2, 4-3, and a flow of 4-1. One way to solve this problem is by optimizing the green signal times of each phase by the method described in [2]. The goal is to optimize the green signal duration of each phase, so minimizing total delay of all the junction flows.

## 3. Results and discussion

They were appreciated three different variants of number of phases and phase signal diagrams – optimizing the green times of current time-spacing diagram; calculation of the delay time at the junction for passing the vehicles in four phases and calculation of delay time at the junction when passing vehicles in three different phases than existing ones.

### *3.1. Optimizing the green times of current time-spacing diagram*

The maximum duration of the traffic light cycle shall be determined in accordance with the requirements set out in [7], namely 90 seconds when the three-phase traffic is omitted. The minimum cycle time is determined according to the minimum green signal time. It takes 8 seconds in view of the traffic flow parameters for features and the possibility of pedestrian crossing in the individual phases. The cycle change step should be taken to be the minimum duration of one phase when passing by road vehicles as defined in [7]. According to this, the cycle will change from 49 to 87 seconds at an interval of 8 seconds while preserving the intergreen times for each phase.

Using the optimize algorithms in [1], we need to combine traffic flows by gathering the queue lengths, the incoming car's intensity and the saturation flows by each phase. For phase I we collect queue lengths, intensity and saturation flows of traffic flow 1-2, flow 1-3 and flows 2-3, 2-1, 2-4. For phase II of traffic flows 3-2 and 4-1. For phase III of traffic flows 3-2 and 4-1. The resulting queue lengths values are shown in Table 5, vehicle Intensity in Table 6, and saturation flow in Table 7.

The results of optimizing the duration of the traffic light phases at different cycle time values are shown in Table 8 and Figure 5.

**Table 5.** Average queue length.

| Phase № | Average queue lengths $Q_{av}$ (PCU) |
|---|---|
| Phase I | 25,63 |
| Phase II | 26,67 |
| Phase III | 112,33 |

**Table 6.** Intensity by phases.

| Phase № | Intensity $I_a^f$ (PCU/s) |
|---|---|
| Phase I | 0,39 |
| Phase II | 0,68 |
| Phase III | 0,68 |

**Table 7.** Saturation flows by phases.

| Phase № | Saturation flow $I_p^f$ (PCU/s) |
|---|---|
| Phase I | 0,60 |
| Phase II | 0,87 |
| Phase III | 0,98 |

**Table 8.** Results of optimizing the duration of the traffic light phases at different cycle time values.

| $t_c$ (s) | Phase's duration (s) | | | $T_{w\min}$ (h) |
|---|---|---|---|---|
| | Phase I | Phase II | Phase III | |
| 39 | 8 | 8 | 8 | 15,80 |
| 47 | 8 | 8 | 16 | 12,40 |
| 55 | 8 | 10 | 22 | 12,52 |
| 63 | 10 | 12 | 26 | 12,67 |
| 71 | 14 | 14 | 28 | 13,15 |
| 79 | 14 | 16 | 34 | 13,55 |
| 87 | 16 | 20 | 36 | 14,07 |

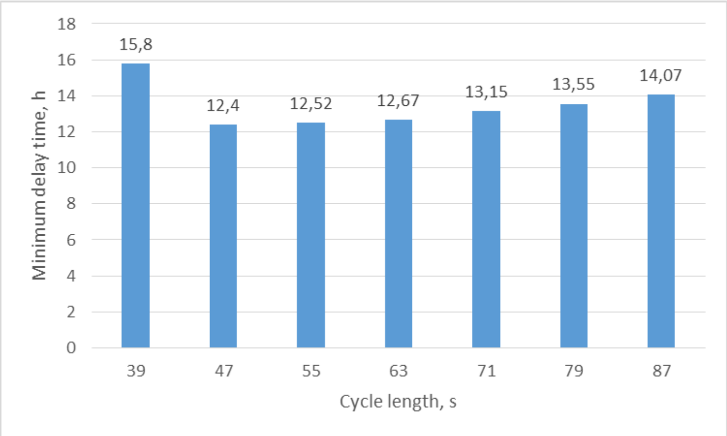


**Figure 5.** Delay time at different cycle time values.

It can be seen that with any change in cycle time with the specified step, the delay time tends to decrease as the minimum is reached at 47 second cycle time. After this step each successive increase in waiting time. With the corresponding green signal timing distribution, the minimum waiting time for all traffic flows at the junction is 12,40 hours for crossing the junction of the vehicles in the evening peak period.

After optimizing the green phase times, the waiting time decreases by 3,29 hours from the current 15,69 hours.

*3.2. Calculation of the delay time at the junction for passing the vehicles in four phases*

The junction configuration and traffic flow intensity values provide a basis for identifying four trafficking phases, aiming at a safe passage of vehicles from each approach.

In this case we use an algorithm describe in [2] for calculating cycle length and green tame duration. After that we gone optimized that value with an algorithm presented in [1].

Determined phases are that shown in Figure 6. To provide an extra time reserve when crossing the conflict zones between cars of different phases, intermediate times are foreseen. It is the duration between the end of the green period of one traffic stream and the start of the green period of a following released conflicting or partially conflicting traffic stream. In this way, it is ensured that the time taken for the last vehicle to arrive from the junction flows to pass the conflict zone with the outgoing flows from the next phase before the first vehicle reaches it. A schematic of the conflict zones in the defined phase signal diagram is shown in Figure 7. For each of them the duration of the intermediate time is determined in use the German method reached with the Japan researchers [5]. Values for clearance speed and entrance time we accept the presented in [6].

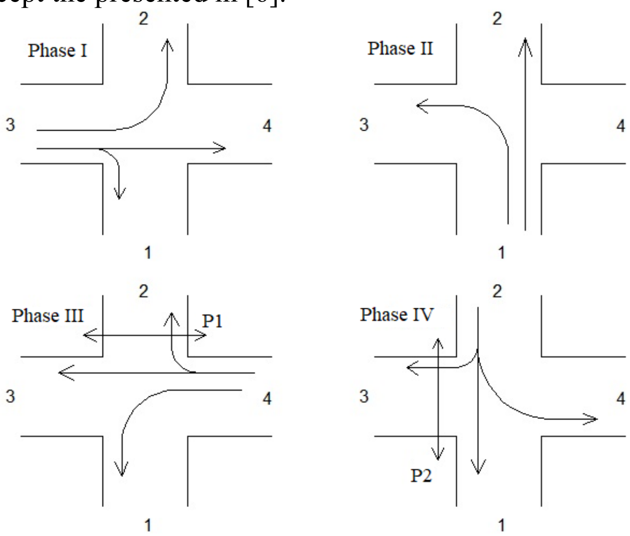


**Figure 6.** Phase signal diagram.

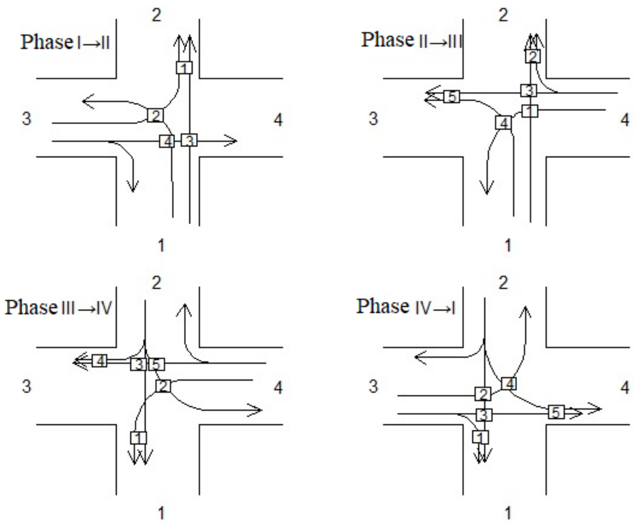


**Figure 7.** Schematic of the conflict zones in the defined phase signal diagram.

The intergreen time adjacent to the corresponding phase is the largest calculated value for the relevant conflict zones. It needs to be an integer in seconds. Ensuring the resulting values requires rounding to the larger integer. The adjacent intergreen times to the relevant phase are: 7 s for phase I; 5 s for phases II and III and 3 s for phase IV.

According to algorithm described in [2] it needed to calculate saturation flows for each phases. This is done for flows that are only passed through the appropriate phase. For phase I, these are flows 3-1, 3-2 and 3-4, for phase II these are flows 1-2 and 1-3, for phase III these are flows 4-1, 4-2 and 4-3, for phase IV, these are flows 2-1, 2-3 and 2-4. Result about saturation flows are: 1,0 PCU/s for phase I, II and III; 0,5 PCU/s for phase IV.

Needed green time for all traffic flows cross the junction through the evening rush period is 4212 seconds. That shows the time is not enough for vehicles passing in this period. Decision in this case is intersection reconstruction for change the shape and increase capacity.

For aim of optimization without reconstruction we accept for cycle length the maximum permissible traffic light cycle time determined in accordance with the requirements set out in [7], namely 120 seconds when a four-phase is omitted.

In this acceptance the green time period are calculated as follows: for phase I - 31 s; for phase II – 27 s; for phase III – 31 s and for phase IV – 11 s.

For calculating delay time according algorithm describe in [1] we needed to collect values for queue length for flows in each phases. Collected values for $Q_{av}$ are: for phase I – 89,53 PCU; for phase II – 20,5 PCU; for phase III – 49,47 PCU and for phase IV – 5,13 PCU.

Phase's duration and total delay time are shown in Table 9.

**Table 9.** Results of phase's duration and total delay time.

| $t_c$ (s) | Phase's duration (s) | | | | $T_{w\min}$ (h) |
|---|---|---|---|---|---|
| | Phase I | Phase II | Phase III | Phase IV | |
| 120 | 38 | 32 | 36 | 14 | 9,48 |

Four phases variant application decreases total delay time about 40 %.

*3.3. Calculation of delay time at the junction when passing vehicles in three different phases than existing ones*

To determine the number and type of phases of flows across the intersection, we chose the busiest legs to separate them in separate phases, and those with lower metrics to unify them in one phase. Legs 3 and 4 will pass into two separate phases, the intensity of these two approaches is 0,34 PCU/s. Legs 1 and 2 will pass through a common phase, their total intensity is 0,39 PCU/s.

The phases are as follows: continuing movement to the right, straight and left streams of approach 3 form Phase I, there is no leakage of pedestrian movement; continuing to the straight, right and left flows of approach 4 form a phase II in which the pedestrian movement of approach 2, parallel to the leg 3 and 4, is also omitted; continuing movement straight, right, left flows of approach 1 and 2 form a phase III in which the pedestrian movement of leg 3 is parallel to legs 1 and 2. The phase signal diagram is shown in Figure 8. A schematic of the conflict zones in the defined phase signal diagram is shown in Figure 9. For each of them the duration of the intergreen time is determined according to algorithm presented in [2]. The values are as follows: for phase I – 9 s; for phase II – 5 s; for phase III – 3 s.

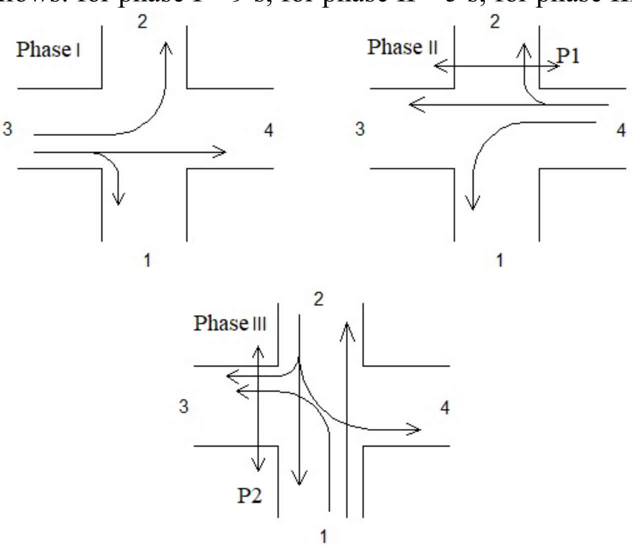


**Figure 8.** Phase signal diagram.

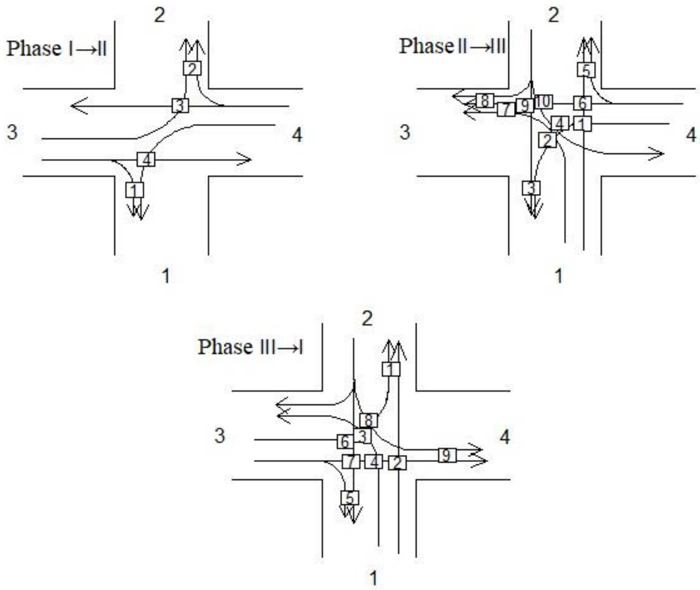


**Figure 9.** Schematic of the conflict zones in the defined phase signal diagram.

Calculating saturation flows for each phases is once again follow the algorithm presented in [2]. This is done for flows that are only passed through the appropriate phase. For phase I, these are flows 3-1, 3-2 and 3-4, for phase II these are flows 4-1, 4-2, 4-3 for phase III, these are flows 1-2, 1-3, and 2-1, 2-3, 2-4. The calculated values for saturation flows are: 1,0 PCU/s for phases I and II, 1,5 PCU/s for phase III.

Needed green time in this case is 3384 s. Determined value for cycle length is 283 s. This is inconsistent with the requirements set out in the [7] – 90 seconds about three phases signal diagram. This again highlights the necessity of re-engineering the junction to increase capacity.

Following the same aim - optimizing without reconstruction – we accepted for cycle length duration 90 s in accordance with [7]. In this case calculated green time period for each phases is: 27 s for phases I and II, 19 s for phase III.

For calculating total delay time we again collect the values about queue lengths for flows pass in separated phases. Collected values for Qav are as follows: for phase I – 89,53 PCU; for phase II – 49,47 PCU; for phase III – 25,63 PCU.

Phases duration and total delay time is shown in Table 10.

**Table 10.** Results of phase's duration and total delay time.

| $t_c$ (s) | Phase's duration (s) | | | $T_{w\min}$ (h) |
|---|---|---|---|---|
| | Phase I | Phase II | Phase III | |
| 90 | 36 | 32 | 22 | 9,35 |

Three different phases than existing ones variant decrease total delay time above 40 %.

*3.4. Comparison of the results obtained*

The results of the phase optimization and the duration of the traffic light phases at the crossing considered at different cycle time values are shown in Table 11 and Figure 10. It can be seen that with each of the optimizations made, the total delay time tends to decrease, as the minimum is achieved with three-phase adjustment different phases than existing ones and a 90 second cycle time. With the corresponding green signal timing, the minimum delay time for all flows at the junction is 9,35 hours.

**Table 11.** Comparison of the result obtained.

| *Variants* | $t_c$ *(s)* | $T_{w\min}$ (h) |
|---|---|---|
| Current | 75 | 15,69 |
| Optimized current | 47 | 12,40 |
| Four phases | 120 | 9,48 |
| Three phases different for existing once | 90 | 9,35 |

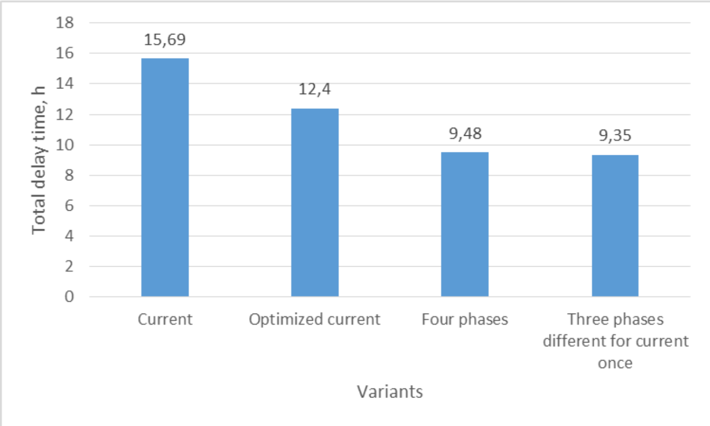


**Figure 10.** Result of optimization of green time period at signalized intersection in Town of Pernik.

## 4. Conclusions

The basic aim in this paper - optimization of green time period at signalized intersection in Town of Pernik – have been achieved. Examined variants of traffic oversight are shown different results but implementation of which one different than existing one will be better for decrease negative of reached traffic flows in evening rush period at this intersection. The best result are given in three phases dissimilar than current. This variant for passes flows through the crossroad will decrease the total delay time above 40 %. This is expected to decrease travel time, fuel consumption and the harmful components in the exhaust gases almost such values.

For more benefits and availability of resources of Municipality of Pernik that intersections must be re-engineering for change the shape (mean roundabout) or make the one more level for flows of "St. St Ciril i Metodii" street direction.


## 5. Acknowledgements

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