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The Norwegian Traffic Light Models and Its Modifications Using The Basic Petri Net

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Abstract. The Norwegian traffic lights were more complicated than the traffic signals standard type. The implementation in the real-world abled to reduce time delay of travel, although it applied without using seven-segments as the countdown timer to present the time stop remaining. The other type that had similarity was the modification of the Norwegian model. The purpose of this paper was to examine both Petri net models and their advantages to reduce the travel delays. As the method of validation and verification of traffic lights model, we used basic Petri net simulation and invariants. For the model simulation method, we used Petri net simulator 2.0. The Norwegian traffic lights model and its modification were the appropriate types for the implementation in urban road net. The driver had the same response to both Norwegian traffic lights and its modification which was delayed two seconds on the standard type. The simulation result showed that the implementation of Norwegian traffic lights and its modification could decrease the travel delay better when compared to those using the standard type.

INTRODUCTION

The main reason for traffic lights usage is to provide efficient and safe for the persons and goods transportation [1]. These also offer the advantages better time sharing to the road users coming from different directions of arms of an intersection. While properly installed, the signals of traffic lights propose some of the benefits. As an example, It can improve the performance of an intersection capacity. However, when poorly designed, traffic signals can cause excessive delays [2]. Traffic lights of road intersections are as the main control measures implemented in the urban networks. It is quite evident that the efficiency of traffic control directly depends on the relevance of the employed control methodologies [1]. These have become a major topic of ITS (Intelligent Transportation System) research.

Many kinds of traffic lights variance on the world. The standard type applies three colours of lights, i.e., green, yellow/ amber, and red. The sequence of states/ events are green as the first step, yellow as the second, red as the third, and return to the green signal as the initial state becomes a cycle of traffic lights [3].This paper aims to investigate the advantages of the traffic lights that apply the Norwegian model and its modification to reduce the travel delays. It also compares the travel delay simulation at the intersection that involves the Norwegian traffic lights and the standard type.

Our study had modelled the behaviour of traffic lights using the Petri net method as one of several mathematical modelling languages to express the discrete event dynamic of a distributed systems. A Petri net was a directed and bipartite graph. One of its manifestations was the basic Petri net which was not enclosed by the time of the state or the coloured token [4], [5]. In this paper, the time interval of a state used the representation of the number of tokens in the places that occur. It was displayed implicitly. Why the reason, because we want to display a simple model. Complicated models were often elusive and useless.

Many research had written the model using traffic lights standard style. The Modelling and Its Analysis of Traffic Light Control Systems. It used timed coloured Petri net. This was the research of [6]. The paper of [7] was the Modeling Ring-Barrier Traffic Controllers. It implemented colored timed stochastic Petri nets. It must be attached by the seven-segments board to present the time stop remaining for vehicles queue to reduce the time delay of travelling. The concept of adaptive traffic control that synchronized with density. This was the way out to minimize the duration of the waiting time of vehicles. This was the paper of [8]. Architecture-Driven Integration of Modeling Languages for Design of Software-Intensive Systems was the research of [4]. It talked about modelling traffic lights using Petri net. [5] had modelled traffic light using Petri net. He also presented the simulation. The study of traffic vehicles delayed at a signalized intersection. It was integrated to the railway doorstop, it was the paper of [9].

THE BASIC PETRI NET

The Definition of Petri Net

For the first time, the Petri net had been developed by C.A. Petri in the early 1960s. Petri net is one tool to model Discrete Event System (DES) [5]. The Petri net event is related to the transition. An event must meet some initial states first to occur. An event and a state are each represented by a transition and a place. The place of input must satisfy the initial state which implies the transition is to be enabled and ready to execute/ fire. After the transition execution occurs then the state will change, and it is expressed at the place of output.

Definition 1. Petri net is 4-tuple (P, T, A, w) [10]. P is a finite set of places, $P = \{p_1, p_2, \ldots, p_n\}$, $n \in N_+$ / positive natural numbers. T is a finite set of transitions, $T = \{T_1, T_2, \ldots, T_m\}$, $m \in N_+$. A is an arc set, $A \subseteq (P \times T) \cup (T \times P)$. w is as weight function, $w : A \rightarrow \{1, 2, 3, \ldots\}$.

Definition 2. A marking Petri net is PN = (P, T, A, w, *Mo*). $Mo : P \rightarrow N_+$ is the initial marking [5], [10], [11].

Definition 3. A marking Petri net is PN = (P, T, A, w, *M*). The total function $M : P \rightarrow N_+$ is the marking [10], [11].

The Petri Net Properties

The design models must correct. It must satisfy a set of desirable properties [5],[6],[10], [11]. The most common required properties of the Petri net are as the following.

1. *Reachability*: The transition firing of a Petri Net will generate a sequence of markings that are reached with the change of token distribution flow. A marking of *Mn* is reachabled or can be reached from the initial marking *Mo* if there exists a sequence of transitions firing that transform from *Mo* to *Mn*. This denotes that the sequence marking $Mn \in R(N, Mo)$ [5].
2. *Reversibility*: the Petri Net model must be able to return to the initial marking or state [5].
3. *Boundedness*: A Petri Net is called k-bounded if the number of tokens that exist in each place should not continue to grow indefinitely. This should not exceed k for any reachabled marking from *Mo* , k is a non-negative integer [5].
4. *Safeness*: A Petri net is said to be safe if it is 1-bounded [11].
5. *Liveness:* A live Petri net guarantees deadlock free [11]. At least there is an enabled transition**.**

THE TRAVEL DELAYS

The improper traffic scheduling causes traffic light signals to be ineffective in regulating the intersections flow, resulting in delays, and have the lower intersection performance levels. The travel delay caused Vehicle Operating Cost (VOC) to be high. According to [8], the waiting time for all vehicles arriving at the time t_d is $\omega(t_d)$. The Eq. (1) is the formula.

$$\omega(t_d) = d(t_d) \times (t_o - t_d) \tag{1}$$

Which $d(t_d)$ = traffic density (traffic volume) when the time t_d, t_o = the vehicles departure time, and t_d = the vehicle arrival time at the intersection.

The total waiting time of all vehicles arriving while the red signals turn on is $\hat{\omega}(t_o)$. The formula is in Eq. (2).

$$\hat{\omega}(t_o) = \sum_{t=t_o-T}^{t_o-1} d(t) \times (t_o - t) \quad (2)$$

Which $d(t)$ = traffic density (traffic volume) when the time t .

THE TRAFFIC LIGHTS MODELING METHOD

The standard traffic lights always lighted up in a fixed order. They had a sequence of a state as a loop cycle. The standard signals in most countries usually changed in the following order [3]:

1. Red lights indicated the vehicles drivers to stop.
2. Green lights meant the driver could start driving their vehicles.
3. Yellow lights informed the drivers ready to stop because the lights will turn red soon.

In the type of Norwegian traffic lights had one stage more, i.e. red-yellow that lighted simultaneously. This fourth stage suggested that the vehicle driver should prepare to start driving. This stage can substitute the seven-segment as countdown timers for presenting the time stoped remaining of the vehicle's movement. This way can reduce the time delay of travel of vehicles [9]. The modification of the Norwegian traffic lights changed the fourth stage into a light yellow colour only after the red signal elapsed.

The Norwegian Traffic Lights Model and Its Modification

The simple model of the traffic lights schedule of an intersection consisted of two phases. It applied fixed time strategy. Phase 1 was as the north-south signals. The traffic lights of phase 2 stood for east-west signals. We assumed that the schedule had solved the conflict of traffic flows. In this paper, the marking of the Petri net model can be 1 or 0 only. It meant that the signals were turned on or off.

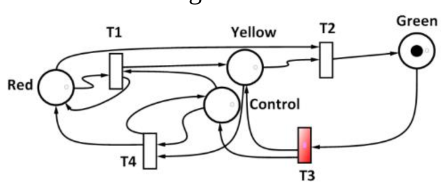


FIGURE 1. The Norwegian traffic lights Petri net model of the east arm that presented horizontally. A token existed in the green place, and the transition T_3 enabled ready for firing after the time interval of the green signal had passed. It had an extra place as the control place.

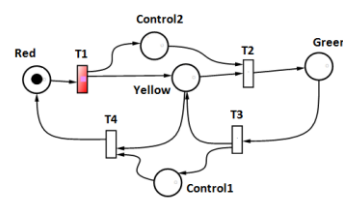


FIGURE 2. The Modification of Norwegian traffic lights Petri net model of the east arm. A token existed in red place, and transition T_1 will enable after the time interval of the red place had passed. It had two extra places as the control place.

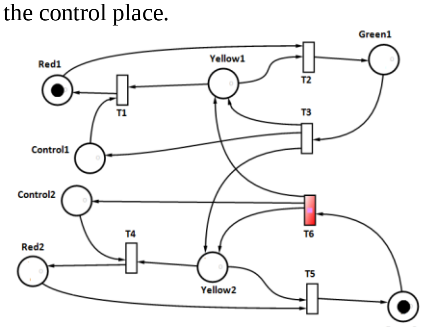


FIGURE 3. The two phases of Norwegian traffic lights Petri net model. The place Red1, Yellow1, and Green1 stood for Red north-south, Yellow north-south, and Green north-south. The signals Red2, Yellow2, and Green2 represented Red east-west, Yellow east-west, and Green east-west. A token existed in each place Green2 and Red1 that meant the green signals of the east-west was turned on while the red signal of north-south was lighted.

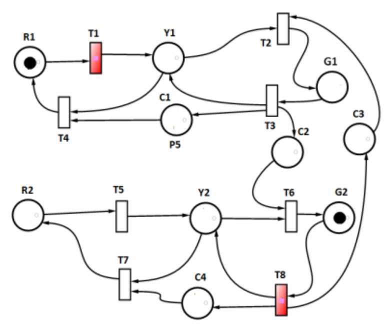


FIGURE 4. Two phases of modification of Norwegian traffic lights Petri net model. The red transition T_1 and T_8 were enabled and ready for a fire. The place R1, Y1, and G1 stood for Red north-south, Yellow north-south, and Green north-south. The signals R2, Y2, and G2 represented as Red east-west, Yellow east-west, and Green east-west.

Places Invariants

The traffic lights schedule should not allow conflicting of the traffic movement, the state should be able to serve all signal phases, and it must be able to return to the initial state [6]. The methods to analyze the Petri net model properties were 1. Invariants. 2. Occurrence Graph, and 3. Simulation [6]. In this paper was presented invariants and simulation result only used Petri net Simulator 2.0. The place-invariants as one of Petri net properties guaranteed that the firing of the enable transitions will not vary.

$$2.M(Green)+M(Yellow)+M(Red)+M(Control)=2 \qquad \text{(Iv-1)}$$

The invariant (Iv-1) asserted that the token available in four places Green, Yellow, Red, and Control of Norwegian traffic lights model in Fig. 1. We must multiply by two to the marking of the Green place. The invariant (Iv-1) equalled to two. It presented that while the Green signal turned on, a token existed in place Green and there was not a token available in three places, i.e., Yellow, Red, or Control.

When the token did not present in the place Green, a token must exist in two places of three places Yellow, Red, or Control. There were three kinds of the options. The first option, when a token existed in place Yellow and place Control. It meant that both the control and yellow signal turned on. The second, while a token presenced in place control and red signal. This indicated that the control and red signal turned on. The third, when a token existed in place yellow and place red. This represented that both the yellow and red lights turned on.

$$M(Green)+M(Yellow)+M(Red)=1 \qquad \text{(Iv-2)}$$

$$M(Green)+M(Control1)+M(Red)+M(Control2)=1 \qquad \text{(Iv-3)}$$

The invariant (Iv-2) and invariant (Iv-3) stood for the modification of Norwegian traffic lights model in Fig. 2. Invariant (Iv-2) told us that there was one signal only that lighted up of three signals, i.e., green, yellow or red. The invariant (Iv-3) indicated that there was a token existed one place only of four places, i.e., Green, Control1, Red, or Control2.

$$M(R1)+M(R2)=1 \qquad \text{(Iv-4)}$$

$$M(G1)+M(C1)+M(G2)+M(C2)=1 \qquad \text{(Iv-5)}$$

$$2.M(G1)+M(Y1)+2.M(G2)+M(Y2)=2 \qquad \text{(Iv-6)}$$

The invariant (Iv-4), invariant (Iv-5), and invariant (Iv-6) stood for the synchronized of two phases of Norwegian traffic lights in Fig. 3. The invariant (Iv-4) indicated that must be one of two signals turned on, i.e., the Red signal of north-south or Red signal of east-west. The invariant (Iv-5) asserted that a token must exist in one place of four places, i.e., Green north-south, C1, Green east-west, or C2. The invariant (Iv-6) had written that while Green north-south signal turned on, it must turn off in the three signals, i.e., the Yellow north-south, Green east-west, and Yellow east-west signals. While Green east-west signal turned on, it must turn off in the three signals, i.e., the Green north-south, Yellow north-south and Yellow east-west signals. The Yellow signals of the north-south traffic lights and east-west traffic lights must turn on simultaneously while the Red north-south and the Red east-west turned off. The invariant (Iv-6) was for both the Petri net model of Norwegian traffic lights and its modification.

$$M(Gi)+M(Yi)+M(Ri)=1 \qquad i=1,2 \qquad \text{(Iv-7)}$$

$$M(Ri)+M(Yi)+M(Ri)=1 \qquad i=1,2 \qquad \text{(Iv-8)}$$

$$2.M\ (R1) + M\ (Y1) + 2.M\ (R2) + M\ (Y2) = 2 \qquad \text{(Iv-9)}$$

Started from the invariant (Iv-7) up to invariant (Iv-9) stood for the synchronized of two phases of modification of Norwegian traffic lights in Fig. 4. The place controls were not included in the invariants.

Invariant (Iv-7) referred to invariant (Iv-2). While $i=1$ was written for north-south traffic lights, and $i=2$ was provided to east-west traffic lights.

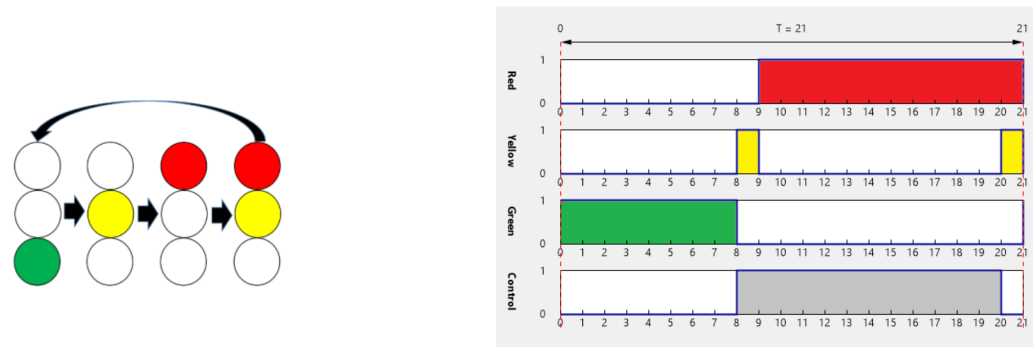
Invariant (Iv-8) while $i= 1$ told us that there was one signal only that lighted up of three signals, i.e. Red north-south, Yellow north-south, and Red east-west. Invariant (Iv-8) when $i=2$ indicated that there was one signal only that lighted up of three signals, i.e., Red east-west, Yellow east-west, and Red north-south.

Invariant (Iv-9) informed us that while a token available in place R1 or Red north-south signal turned on, it must turn off in the three signals, i.e., the Red east-west, Yellow north-south, and Yellow east-west signals. While Green east-west signal turned on, it must turn off in the three signals, i.e., the Green north-south, Yellow north-south, and Yellow east-west signals. The Yellow signals of the north-south traffic lights and east-west traffic lights must turn on simultaneously while the Red north-south and the Read east-west turned off.

The synchronized traffic lights must build the schedule of travel and can avoid conflict flow for both traffic north-south and east-west. All had been presented in the invariant (Iv-1) up to the invariant (Iv-9) for both Norwegian traffic lights and its modification Petri net model.

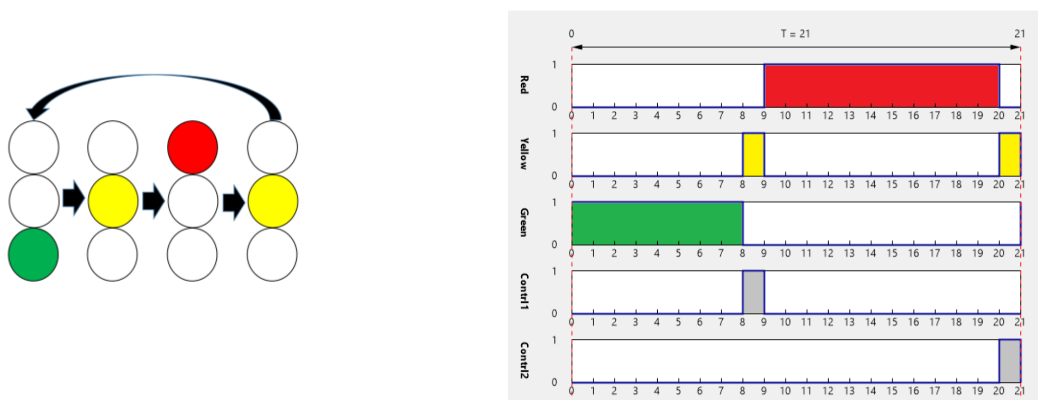
The Simulation of The Traffic Lights Petri Net Model

The traffic lights in Fig. 5., Fig. 6., and Fig. 7. applied 63 seconds for a time cycle. A step represented for 3 seconds. The time interval of Green signal was eight multiplied by three whose value equalled twenty-four seconds. The time interval for the yellow signal was three seconds and twelve steps or thirty-six seconds were the time interval for red signals.



A B

FIGURE 5. a. The sequence of signals that were lighted of Norwegian traffic lights, and b. Simulation result of Norwegian traffic lights signals schedules of the east-west signal/ arm of an intersection.



A B

FIGURE 6. a. The sequence of signals was lighted of modification of Norwegian traffic lights. b. The simulation result of modification of Norwegian traffic lights of the east-west signal/ arm of an intersection. The red signals turned on for eleven steps or thirty-three seconds.

TABLE 1. The Two Phases of The Norwegian Traffic Lights Schedule

Phases	Green	Inter Green		Red	Cycle
		Yellow	All red		
	Seconds				
SN	27	3	3	33	63
EW	24	3	3	36	63

RESULT AND DISCUSSION

This research implemented Passenger Car Unit (PCU). This was the measurement standard metric that used in transportation engineering to assess the traffic rate of the number of vehicles that passed on the road. This was the effect of traffic variables if it was compared to a single passenger car. The typical values of PCU were as the following. 1. The Low Vehicle (LV), such as passenger cars, oplet, microbus, pick-up, and sedans. 2. The Heavy Vehicle (HV), for example, buses, trucks that had two, or three axles. 3. The motorcycle (MC), and 4. The unmotorized vehicle (UM), those were like pedicab, bicycle, horse carriage and so on [3]. The equivalent value of a heavy vehicle is equal to 1,3 up until three, the low vehicle is one, a motor vehicle equals one fifth, and an unmotorized vehicle was equal to zero, or its value was ignored. It was assumed that the arrival of the vehicle for the simulation had a normal distribution for every three seconds and the departure while the green signal had a negative exponential distribution.

For simulation, we were referring to the east arm of a signalized intersection at Jombang city. The flow of the vehicle was moving in one direction entering the intersection. While dawn, the degree of saturation (DS) was about 0,5. At normal state, the unsaturated degree was $0 < DS \leq 1$. The degree of saturation less than or close to 0.5 meant that on every green signal illuminated in a traffic light cycle, there was no queue of vehicles remaining due to unfinished to cross the intersection. In peak hours, while the degree of saturation (DS) was greater than 0.5 up until approaching one meant that there was the queue of the vehicles left because not yet finished to cross the intersection. When it was greater than one meant that the volume of passing vehicles had exceeded the capacity of the road and congestion occurred.

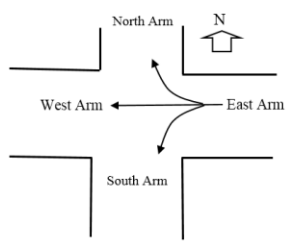


FIGURE 7. The flow of traffic of east arm of an intersection at Jombang city which implemented the standard type and without the countdown timer board.

The Norwegian traffic lights can reduce travel time delay. So too, for modification of Norwegian traffic lights style. But the traffic light must have an all red time interval. It was used to guarantee the safety of all road users. The all red signals were for three seconds only to make clear space at the intersection of the remaining vehicles and to ensure safety to avoid traffic flow conflicts.

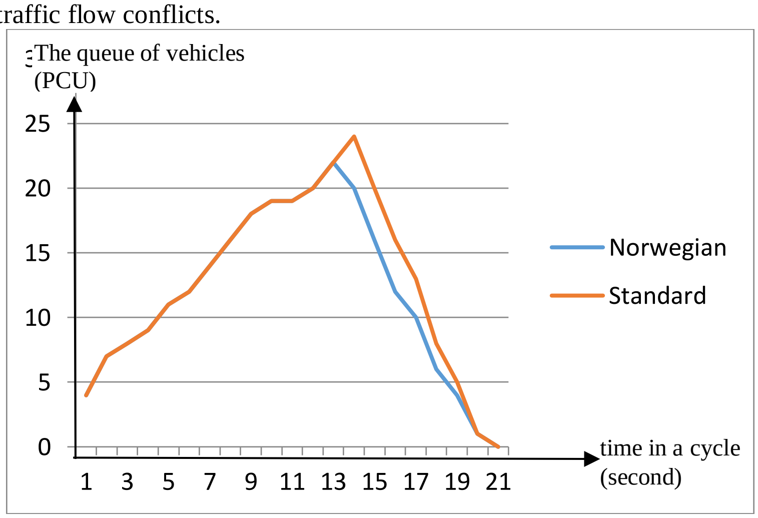


FIGURE 8. The queue of vehicles implementing 63 seconds for a time cycle of traffic lights. A step in the figure represented for 3 seconds. The vehicle queue of east arm raised when the red signal lighted up and went down when the green was on. The peak queue of vehicles on signalling that implemented traffic lights of a standard type were higher when compared to the

simulation of the Norwegian system. This happened because of a delay of two seconds to restart the trip after the red signal was over

Based on observations of its real-world implementation, Norwegian traffic lights and its modifications had a similar effect on the behavior of the driver to restart their travel after being stopped by a red signal. The response meant that drivers already knew the meaning of a simultaneous yellow-red signal while Norwegian traffic lights were applied, or a single yellow signal that lighted up after the red signal passed when modified Norwegian traffic lights were used. The Norwegian traffic lights partially applied to road traffic in Semarang city. The modification of Norwegian traffic lights, its implementation on the road traffic in the city of Madiun - east Java- Indonesia, and many cities such as the Jombang city applied traffic lights with the standard type.

Based on the above reasons, we compared the results of a vehicle queue simulation applying a Norwegian traffic light to a signal system that implemented a standard type. The queue of vehicles on traffic systems that implemented standard systems and without a countdown timer had a delay of two seconds in initiating their forward movement. This delay did not occurred in signalling with Norwegian traffic lights or its modifications.

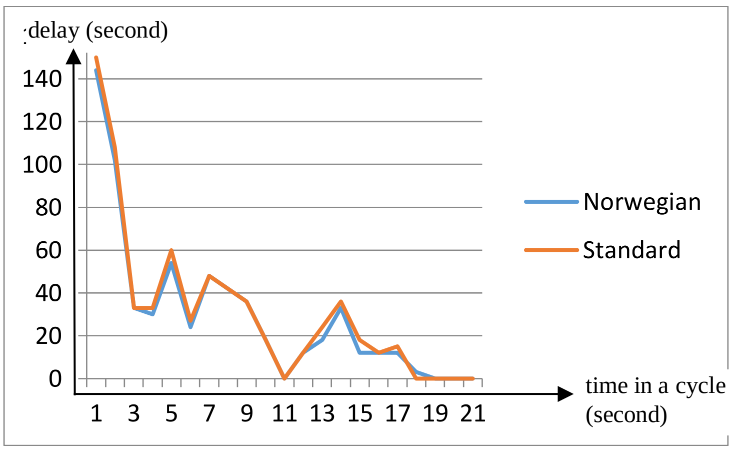


FIGURE 9. The vehicle travel delays of the east arm of an intersection at Jombang city. On the left side of the figure illustrated that the vehicles coming in the first three seconds had the highest delay. This vehicle arrived while the red signal lighted up. The next coming vehicle had a lower delay when compared to the earlier arriving vehicle. On the right side of the figure indicated a low delay because at that point the green signal was on. The travel delays on the systems that applied standard types were generally higher when compared to those simulations using Norwegian traffic lights. The vehicle entering the intersection when the signal was green, the delay was zero.

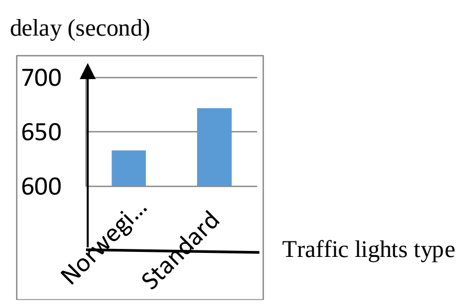


FIGURE 10. The total delays of all vehicles in a traffic light cycle of the east arm. On the left side applying the Norwegian system traffic lights appeared lower when compared to the right side using the standard type.

The implementation of various signalling of many types of traffic lights can be understood by road users. The efforts to reduce travel delays intended for efficiency. This should be followed the disciplinary behavior of all road users. The yellow signal after the green informed the driver to reduce the vehicle speed and immediately stopped it because the red signal was immediately on. A second yellow-red or yellow signal after a red signal indicated that the driver should be prepared for forwarding movement to travel to their respective destinations. The driver was not allowed to start the trip before the green signal light up. This was strictly forbidden.

CONCLUSION

We have presented Petri net models about the Norwegian traffic lights and its modification. The models become more complicated than standard traffic lights. We have analyzed the model using invariants and Petri net simulation methods. The implementation of the Norwegian system's traffic lights and its modifications can reduce the travel delays better when compared to those using standard type.

Nowadays, there has been grown various model of traffic light signals, travel guides, even traffic information through mobile phones that can be accessed at any time. It's all for the reasons of travel safety and efficiency.

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