

# Conceptual Design of Intelligent Traffic Light Controller

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## **Abstract**

*More than a few aspects should be taken into consideration when drawing up plans for a traffic light system. If the planners disregard some of these aspects, the traffic light might be not just ineffective, but even more – it might harm the flow of the traffic, might increase the carbon emission and the severest – it might cause vehicle accidents. With the aim of confronting this challenging objective, we suggest in this paper a scheme for a functional intelligent traffic light system model.*

**Keywords:** *Traffic light, State Machine, Inductive Detector Loops*

## **1. Introduction**

Traffic lights have been turning out to be more sophisticated since their invention at 1868 [1]. The new generation of traffic lights is called "intelligent traffic lights" and it contains digital electronic units derived from common computers [2]. Traffic lights are one of the oldest safety apparatus for transportation [3]; however, traffic lights can have both positive and negative effects on transportation safety; particularly traffic lights can increase the chances for rear end vehicle accidents [4]. Computed collision detection simulations can help deciding whether to install a traffic light in a questionable intersection [5,6]. Yet, when the new autonomous vehicles will be widespread, these decisions may be changed [7,8,9].

## **2. Traffic Light Model**

We consider an intersection of two roads and a controllable traffic light system is in charge of the lights on all of the intersection corners. In Israel most of the major roads are North-South; therefore we consider the North-South road as the major road and the East-West road as a minor road. Accordingly, we gave the North-South road triple time period.

In countries where the traffic goes on the right side of the road, the right turns are easier; because they do not interfere with the traffic from the opposite direction. In Israel vehicles go on the right side of the road; therefore, the left turns are more problematic. There are two possibilities what to do when the left turns get the green light:

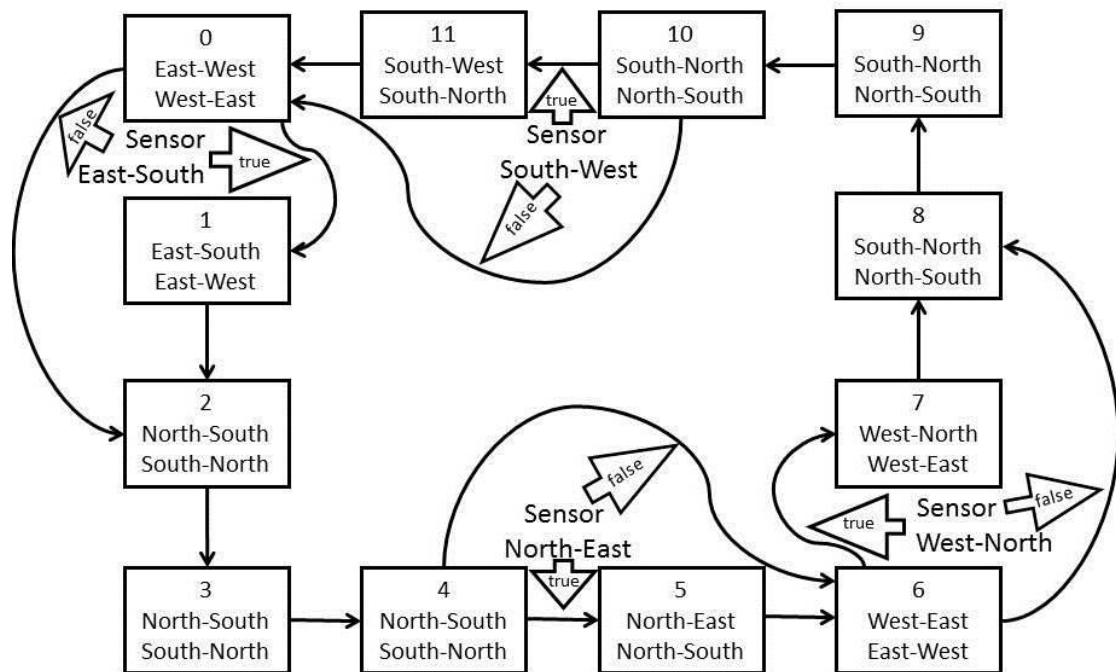
Let two left turns from opposite directions to go together as they will not intrude into each other's path.

Let the traffic comes from one side and goes straight or goes left to be in motion together.

We have chosen the second option.

As the traffic of the left turns is usually sparse, we consider Inductive Detector Loops [10,11] installed under of the left turn lanes pavement. If the detector does not indicate a vehicle in the turn left lane, the green light for this turn will be skipped in this iteration.

The state machine for this traffic light is depicted in Figure 1.

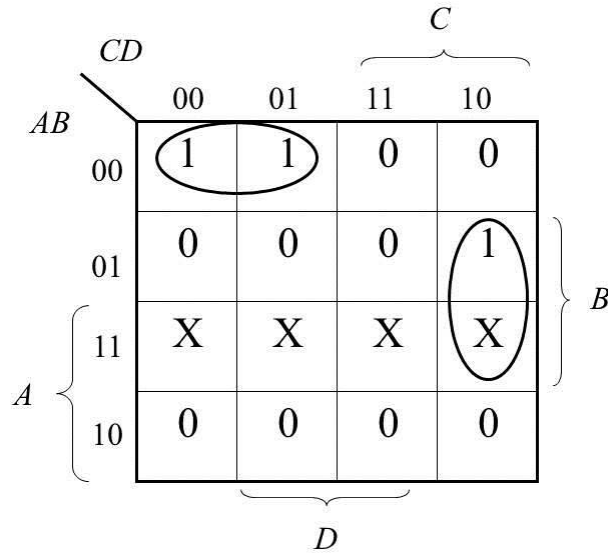


**Figure 1. Description of the States in the Traffic Light**

### 3. Controlling the Lights According to the States

The lights are decided only according to the states [12]. The inputs from the Inductive Detector Loops have an effect only on the next state decision. This is actually the different of Mealy machines [13] and Moore machines [14]. In Mealy machines, the input has a direct effect on the output, whereas in Moore machines the input affects the output only through the selection of the states. In view of that, our machine is a Moore machine.

We use Karnaugh maps [15] to find the simplest functions for implementing these circuits. As can be seen in Figure 1, we have 12 states numbered from 0 to 11, so we need  $\lceil \log_2 12 \rceil$  flip-flops to implement this state machine i. e. we need four flip-flops. We have denoted these flip-flops as A, B, C, D. Four flip-flops will give us 16 states but as a matter of fact, only the first 12 states are needed. The other states are considered as "don't care" as denoted by "X". We have considered green light as "1" and red light as "0".



**Figure 2. Karnaugh Map for East-West Direction**

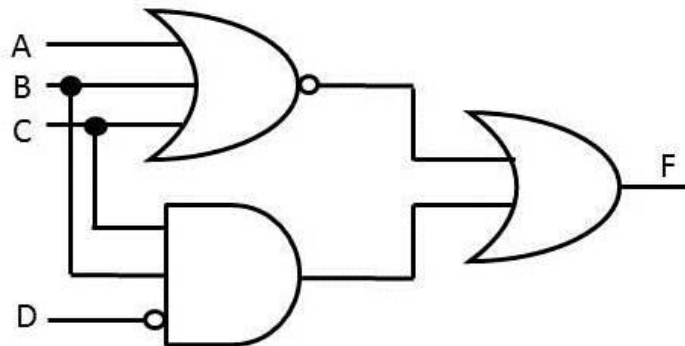
The first traffic light we take is for the East-West direction. The Karnaugh map for this direction is depicted in Figure 2 and according to this map the minimized Boolean function for this direction is

$$\text{East - West} = \overline{A}B\overline{C} + B\overline{C}\overline{D}$$

According to De Morgan's laws it can be also expressed as:

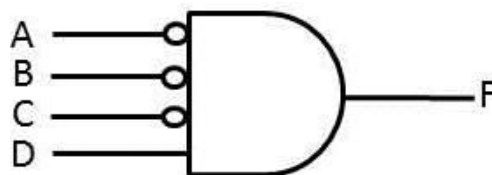
$$\text{East - West} = \overline{A + B + C} + B\overline{C}\overline{D}$$

The implementation of this Boolean function can be found in Figure 3.



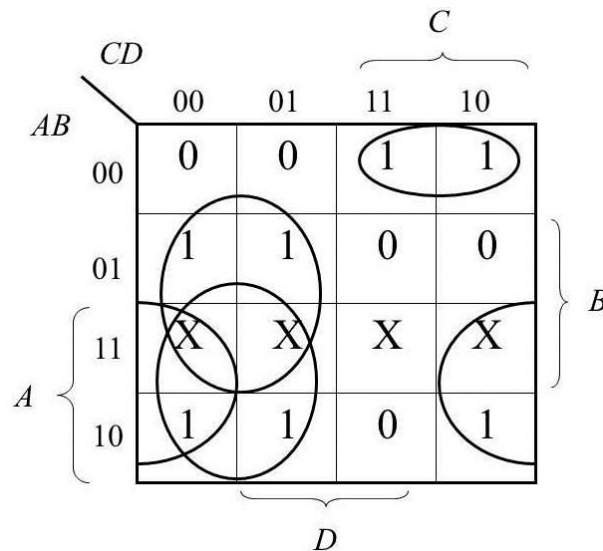
**Figure 3. Gate Implementation for the Circuit of East-West Direction**

The traffic light of the East-South direction is much easier, because it has a green light only when the state is "1". Therefore, there is no need for Karnaugh map for this direction and it can be implemented straightforwardly to detect just when the combination of ABCD is 0001 as can be seen Figure 4.



**Figure 4. Gate Implementation for the Circuit of East-South Direction.**

Unlike the traffic light of the East-South direction, the traffic light of the North-South direction has several states that bring about a green light. These states are detailed in Figure 1 and they were put in the Karnaugh map in Figure 5 so as to minimize the Boolean function.

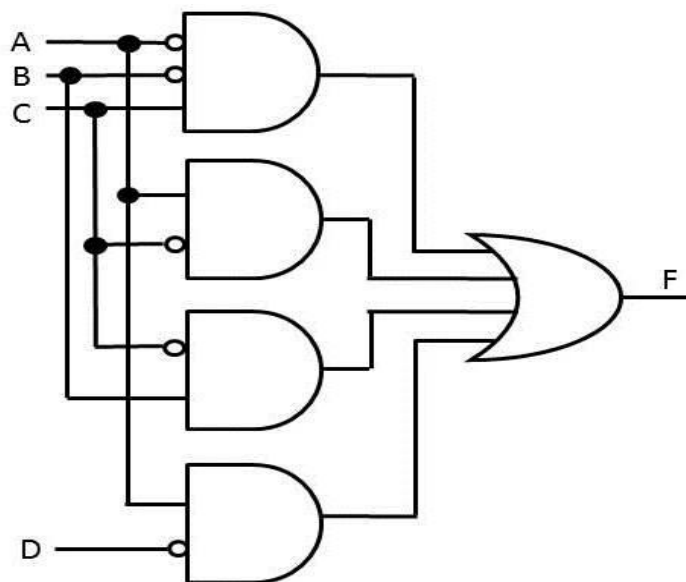


**Figure 5. Karnaugh Map for North-South Direction.**

According to the Karnaugh map in Figure 5, the Boolean function for the North-South direction is:

$$\text{North - South} = B\bar{C} + A\bar{C} + A\bar{D} + \bar{A}\bar{B}C$$

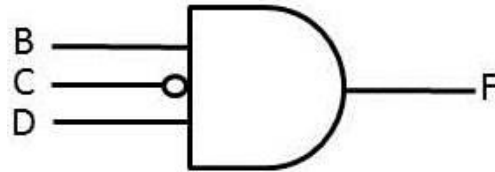
The implementation of this Boolean function can be found in Figure 6.



**Figure 6. Gate Implementation for the Circuit of North-South Direction.**

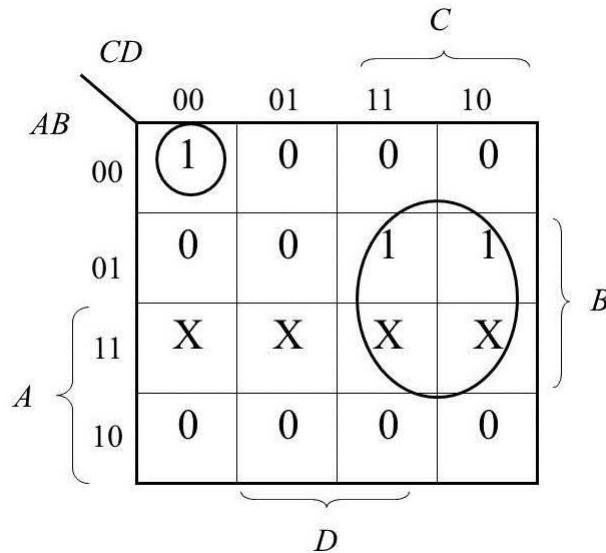
The traffic light of the North-East direction is pretty similar to the traffic light of the East-South direction. It has a green light only when the state is "5". Therefore,

there is no need for Karnaugh map for this direction and it can be implemented straightforwardly to detect just when the combination of ABCD is 0101; however, since the values 1101 for ABCD are defined as "don't care", we can uncomplicatedly see that flip-flop A can be omitted from the circuit of the North-East direction's traffic light and we actually has to check for the combination 101 for only BCD. The implementation can be seen Figure 7.



**Figure 7. Gate Implementation for the Circuit of North-East Direction.**

The traffic light for the West-East direction is fairly similar to the traffic light of the East-West direction. They gives a green light in the same states, except of state "1" that was replaced by state "7" in the West-East direction.



**Figure 8. Karnaugh Map for West-East Direction.**

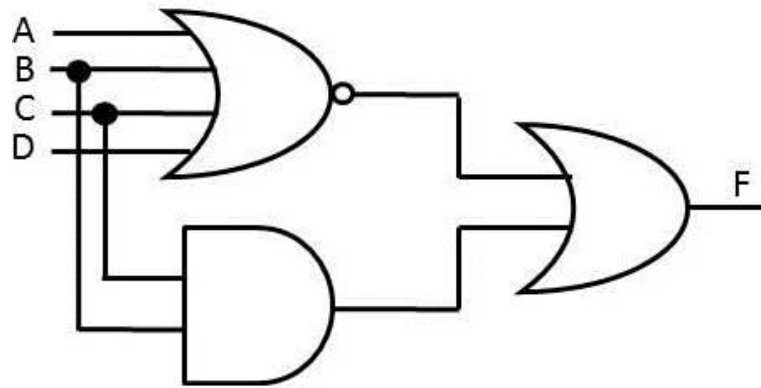
The Karnaugh map for the West-East direction is depicted in Figure 8. According to this map the minimized Boolean function for the West-East direction is expressed by this Boolean expression:

$$\text{West} - \text{East} = \overline{A}\overline{B}\overline{C}\overline{D} + BC$$

According to De Morgan's laws it can be also expressed as:

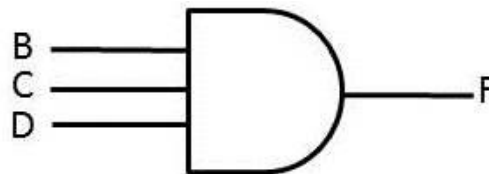
$$\text{West} - \text{East} = \overline{A} + B + C + \overline{D} + BC$$

The implementation of this Boolean function can be found in Figure 9.



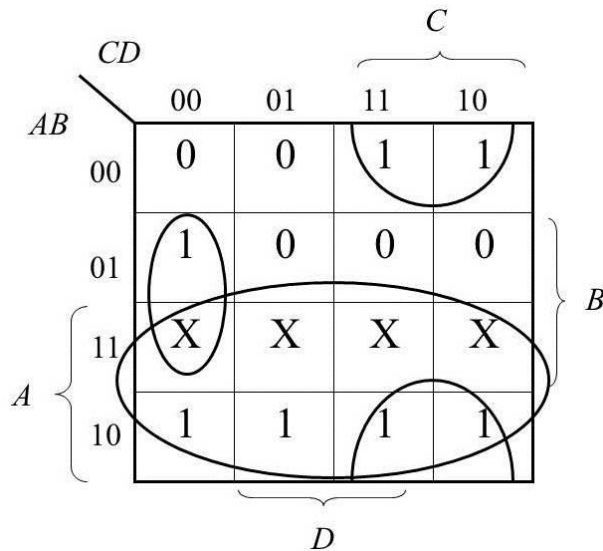
**Figure 9. Gate Implementation for the Circuit of West-East Direction.**

Like the other left turn traffic lights detailed below, the traffic light of the West-North direction is unfussy. It has a green light only when the state is "7". Therefore, again we do not make a Karnaugh map for this direction and it can be implemented straightforwardly to detect just when the combination of ABCD is 0111; however, like the West-North direction, there a set of value of ABCD which is defined as "don't care" that can help us to minimize the function. If the values of ABCD are 1111, we do not care about the result of the function, so we can uncomplicatedly see that here again flip-flop A can be omitted from the circuit of the West-North direction's traffic light and we actually has to check for the combination 111 for only BCD. The implementation can be seen Figure 10.



**Figure 10. Gate Implementation for the Circuit of West-North Direction.**

Like the traffic light of the North-South direction, the traffic light of the South-North direction has seven states that bring about a green light. These states are detailed in Figure 1 and they were put in the Karnaugh map in Figure 11 so as to minimize the Boolean function.

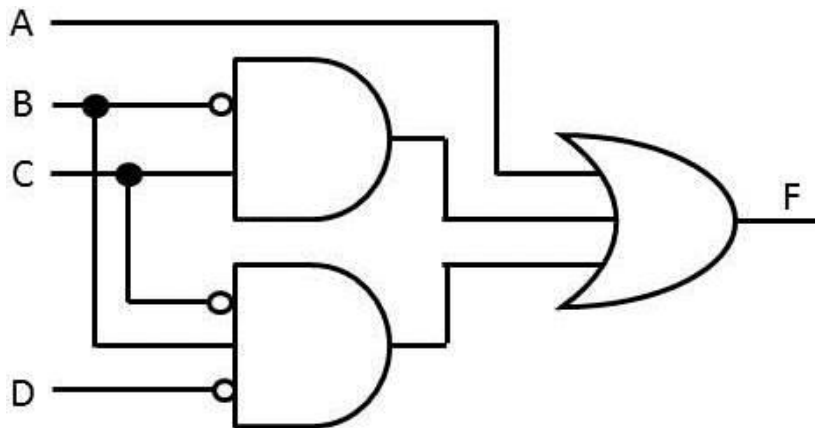


**Figure 11. Karnaugh Map for South-North Direction.**

According to the Karnaugh map in Figure 11, the Boolean function for the South-North direction is:

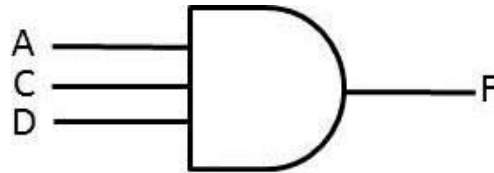
$$\text{South - North} = A + \bar{B}C + B\bar{C}\bar{D}$$

The implementation of this Boolean function can be found in Figure 12.



**Figure 12. Gate Implementation for the Circuit of South-North Direction.**

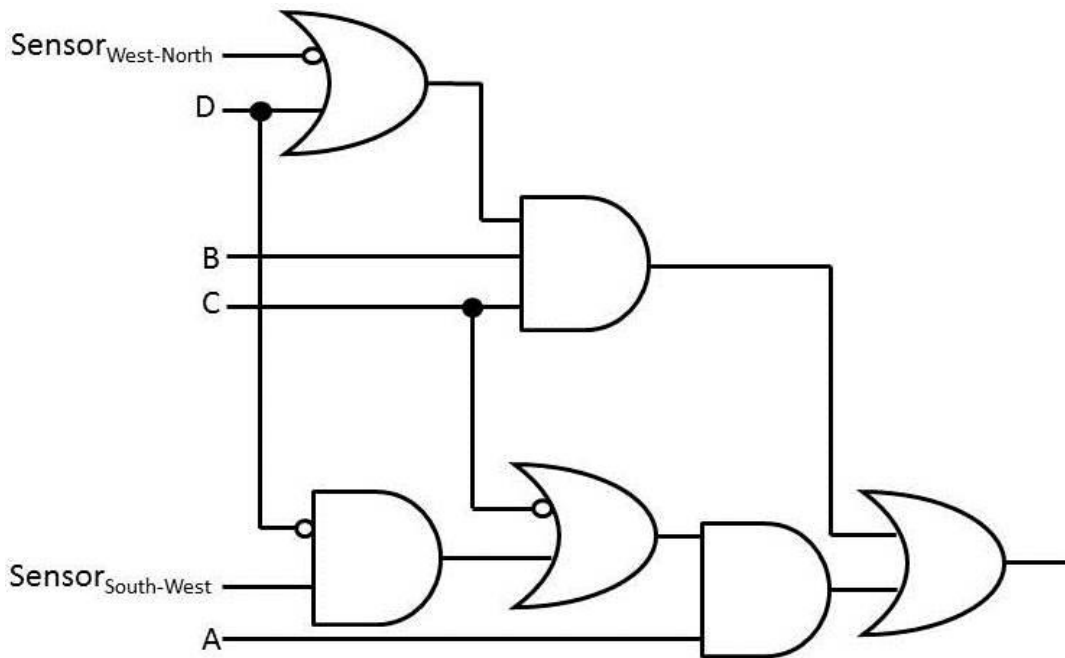
The last traffic light is for the South-West direction. It has just one state that brings about a green light – state "11". Therefore, again we a Karnaugh map for this direction is not necessary and it can be implemented straightforwardly to detect just when the combination of ABCD is 1011; however, like the West-North direction and the North-East direction, there a set of value of ABCD which is defined as "don't care" that can help us to minimize the function. If the values of ABCD are 1111, we do not care about the result of the function, so unlike the West-North direction and the North-East direction where flip-flop A could be omitted, in the South-West direction we can clearly see that flip-flop B is the flip-flop that can be omitted from the circuit of the traffic light and we actually has to check for the combination 111 for only ACD. The implementation can be seen Figure 13.



**Figure 13. Gate Implementation for the Circuit of South-West Direction.**

#### 4. Next State of the Traffic Light System

The next state functions are more complicated because we have four input lines and four flip-flops, so in total we have eight lines entering into the circuit functions, which are too much for a Karnaugh map. So, we will have to minimize the functions by the Boolean Algebraic laws.



**Figure 14. Gate Implementation for the Circuit of Next Value for Flip-Flop A**

The first next function we take is the next value for flip-flop A. We consider standard Edge-Triggered D flip-flop, so the function is:

$$A_{\text{next}} = \overline{A}BC\overline{D} \cdot \text{Sensor}_{\text{West-North}} + \overline{A}BCD + A\overline{B}\overline{C}\overline{D} + A\overline{B}C\overline{D} + A\overline{B}C\overline{D} \cdot \text{Sensor}_{\text{South-West}}$$

The first product in this function assumes that the current state is 6; however, adding states 7, 14 and 15 will make no harm, because from state 7 we always go to state 8 regardless of the sensors and in state 8 flip-flop A should contain "1". States 14 and 15 do not exist, so we don't care what the value of flip-flop A will be in these non-exist states, therefore we can minimize the first product to:

$$BC \cdot \text{Sensor}_{\text{West-North}}$$

The second product assumes that the current state is 7, but again we can add state 15 that do not exist and this addition will help us to minimize the product to:

$$BCD$$

The third and the fourth products assume that current state is either 8 or 9. Here, we can add state 12 and state 13 that do not exist and by this to minimize the third and the fourth products to:



$$A\bar{C}$$

The last product assume that the current state is 10; however, adding states 8, 12 and 14 will make no harm, because from state 8 we always go to state 9 regardless of the sensors and in state 9 flip-flop A should contain "1". States 12 and 14 do not exist, so we don't care what the value of flip-flop A will be in these non-existent states, therefore we can minimize the first product to:

$$A\bar{D} \cdot \text{Sensor}_{\text{South-West}}$$

Consequently, the next function of A should be:

$$A_{\text{next}} = BC \cdot \overline{\text{Sensor}_{\text{West-North}}} + BCD + A\bar{C} + A\bar{D} \cdot \text{Sensor}_{\text{South-West}} =$$

$$A_{\text{next}} = BC(\text{Sensor}_{\text{West-North}} + D) + A(\bar{C} + \bar{D} \cdot \text{Sensor}_{\text{South-West}})$$

We are not interested in the delay of the logic gates and the number of level that we should be passed until getting the result, because anyway the clock cycle is very long – few seconds; therefore, we focus on minimizing the number of gates, even if the result is more level of gates and an extra delay time. The implementation of this function can be found in Figure 14.

Unfortunately here again we do not have enough space in this paper to detail all the next state functions; however, the chosen next state function can clearly point up the system configuration.

## 5. Conclusions

Vehicular safety equipment is divided into two general categories. The equipment within the vehicle [16,17,18] and equipment in the vehicle environment [19,20]. Traffic lights are one of the most important safety equipment in the second category. New approaches for traffic light configurations have been recently suggested [21]. These approaches can be implemented in a dedicated chip [22] or in a remote manner [23] and can have many benefits for many objectives like better traffic flow [24,25] or carbon emissions mitigation [26]. Our proposition in this paper can help traffic light designers drawing up plans for more efficient traffic lights.

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In addition, Dr. Wiseman has been teaching in many institutes including Bar-Ilan University, The Hebrew University of Jerusalem, Israel Aircraft Industry, Holon Institute of Technology and Jerusalem College of Technology.

Dr. Wiseman has been supervising many graduate students and an interesting point is that Albert Einstein is Dr. Wiseman's academic great-great-grandfather (*i.e.* the advisor of the advisor of the advisor of Dr. Wiseman's advisor).

Dr. Wiseman has collaborated with other partners and received research grants to run an active laboratory from inter alia Sun Microsystems, Intel, Polak Foundation and the Open University.

Dr. Wiseman is an international expert who has reviewed and evaluated several large projects of the European Union, Israel Science Foundation, MB Logic and more. Dr. Wiseman's papers have been published in many venues around the world.

