Model of demand order method of traffic lights phases

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Abstract. The traffic light has a significant role in controlling vehicles stream in urban road networks. This traffic light is install at an intersection of an urban road network consisting of four sections. Sometimes, the southern section is close because it is use as an area to hold the folk festivals. The intersection requires a new traffic light schedule that is different from the usual situation. The behavior of traffic light states is model using the Petri net. For model verification and validation, the invariants and simulation are used. The control system of the traffic light phases implements Demand Order Method (DOM). The purpose of this control system is to create an automatic system of the traffic light schedule. It is base on the demand order of each section to get the green signal. The control system is able to create the appropriate traffic light phases schedule, mainly when the southern section is closed. It proves that the DOM is an applicable system.

1. Introduction
Commonly, the traffic lights serve separate the different vehicle traffic stream and prevent conflicts. It is due to the safety of travel and efficiency reason [1, 2]. Traffic light schedule has grouped into two categories. They are fixed time strategy and the actuated time strategy or responsive traffic strategy. The fixed time strategy has based on historical data. This most straightforward signaling control system assumes that the volume of the passing vehicles on the road is constant. The responsive strategy is a real-time system, it uses detectors to calculate the actual traffic stream [3].

This study was done at an intersection consisting of four sections with the horizontal geometric grade. It applies to the left-hand vehicle traffic. It introduces the Demand Order Method (DOM) of traffic lights schedule. It is base on the demand of the phase orders. It is different from the Fixed Order Method (FOM). There may not be a queue of vehicles in a section when the traffic is very low or a section is closed. The sensors in this section are not necessary to activate the green signal [4]. The signal that needs to be activate is the green signal in the next section where a queue of vehicles exists. In other words, the green signal in the initial section keeps on active until another section sends the request.

The traffic lights remain active in the fixed order/ sequence of phases of sections when the traffic lights schedule applies a fixed time strategy. Hence, it has not correlated with both the actual traffic volume entering the intersection and the real event on each section. This research aim is to investigate
the traffic lights phases using Demand Order Method (DOM). Is it an efficient method to create an automatic system of the traffic light schedule, primarily while the folk festival was held?

The contribution of this paper is to create an automatic control system of the traffic light schedule. It uses Demand Order Method (DOM) of each section to get the green signal. We can use an artificial sensor system while no vehicle sensor is install. The periodic setting of a token to appear on a place of the artificial sensor causes this system to turn into the initial system as the Fixed Order Method (FOM). So, we can turn off the switch in a closed section. Automatically, the traffic lights change into just three-phases from the original four-phases.

Commonly, the standard of traffic lights cycle has three states i.e., green, yellow, red. The behavior of the traffic lights states can be model by Discrete Event Systems (DES). The system can formulate the sequences of the events/ states occurring at the set time intervals [3, 4]. DES can be realize using Petri Net [5]. It can build a sequence of events design on traffic lights states. The design system can offer representations of conflict of the situations from various resources, synchronization of events and schedules, and multiple constraints that shall be prioritized [6]. Petri net design also can be attach to time. That is the Time Place Petri Net (TPPN).

Many previous researchers have done the study on the dynamics of system behavior using Petri net. Adzkiya D [5] built the model and simulations of traffic lights behavior using Petri nets. Bordon J, Mraz M, and Moskon M [7] used Petri nets and fuzzy logic methods to address unknown kinetic data for the quantitative modeling of the biological systems. Dotoli M and Fanti MP [8] reviewed the red Petri net to model, simulate, and build the schedule of the production systems. Mohammadi M and Mukhtar M [11] represented the supply chain management using Petri nets. It was used for a business process modeling of an integrated information system. Dong H and Li X [12] wrote research entitled the fault diagnosis for substation with redundant protection configuration. Its fault diagnosis was based on the time-sequence of the fuzzy Petri-net. Kurniawan F, Sajati H, and Dinaryanto O [13] researched about adaptive traffic controller. It was based on the pre-timed system.

2. Research method

For the modeling method of the behavior of traffic lights states, it is used Petri net with Place-time. Each state of the traffic light is equipped with the time interval or duration. The schedule of the traffic lights phases using Demand Orders Method (DOM).

2.1. Basic and p-time Petri net

The basic Petri net is realized using the four-pair of elements i.e., places, transitions, arcs, and tokens [14]. A Petri Net is a graph attached with the direction of arcs and weight. Petri net uses places for presenting the events and transitions for the firing of the changed events. The place is described with circle/ ellipse and transition by box/ square. In the following is the formal definition of the Petri net structure [14].

Definition 1. A Petri net structure is four-pair elements. \(N = (P, T, \text{Pre}, \text{Post})\) [14].

Places is \(P = \{p_1, p_2, p_3, \ldots p_n\}\). Transition is \(T = \{t_1, t_2, t_3, \ldots t_m\}\). P and T have finite elements.

\(\text{Pre}: (P \times T) \rightarrow N^+\) is the input function. It depicted with a directed arc from place to transition. The Post: \((T \times P) \rightarrow N^+\) is the output function. It realized by a directed arc from the transition to place. \(N^+\) integer is non-negative.

Definition 2. A basic Petri net is \(PN = (N, Mo)\), which \(N\) is a Petri net, and \(Mo\) is the initial value.

The dynamics of event changes in Petri net are reflect by a sequence of marking from \(Mo\) to \(Mn\). Several enable transitions to play the role for the fire of a previous state and change to the next state. The transition \(t \in T\) is enable if places \(p \in P\) as all inputs of transition \(t\) has the number of tokens greater than or equal to the weight of the arc connecting place \(p\) to transition \(t\) \((M(p) \geq \text{Pre}(p,t))\) while \(p \in P\). Events that are modeled by the state of Petri net also can have a time interval [4].

Definition 3. A P-Time of Petri net is a pair \((PN; Ip)\). \(PN\) is the symbol of a Petri net attached using the initial state. \(Ip\) is the function of time. \(Ip: P \rightarrow (\mathbb{Q} + \{0\}) \times (\mathbb{Q} + \{\infty\})\).
The interval of time $I_p = [\alpha, \beta]$ connecting with $0 \leq \alpha \leq \beta$. It is the static interval of time to symbolize the duration while a token that exists in a place $P$ is ready for firing/triggered by a transition. Before $\alpha$ and after $\beta$, a token in a place is non-available, or it is call as a dead token. The value $\alpha$ is the minimum period, and $\beta$ is the maximum period. A fixed interval of time of the traffic lights signal is represent when the minimum period is equal to the maximum period [4].

2.2. The properties of the Petri net
The correctness of the model design must be verify and validated using several Petri net functional properties. The reachability reflects that the marking $M_n$ must be reachable from $M_0$ by a firing sequence of transitions that converts from $M_0$ to $M_n$. It means $M_n \in R(N, M_0)$. The reversibility means that the model is possible to reversible to the initial state. The boundedness shows that the number of tokens in each place will not more than $k$ for any marking that can be reach from $M_0$, $k$ is positive integers. The safeness represents that the Petri net $(N, M_0)$ is 1-bounded [14]. The liveness on Petri Net is guarantees that the model will not meet the deadlock [4, 14].

![Figure 1](image1.png)

Figure 1. The signalized intersection is the southern gate of Madiun city.

This massive size intersection has four sections. The traffic stream of all section moves in two directions, entering and leaving the intersection. The northern section is the main road of Madiun-Nganjuk city. The eastern section is Basuki Rahmad road, southern section is Yos Sudarso road, and the west section is western ring road of Madiun city. It is the left-hand traffic. The stream of northern and western sections are allowed to Turn Left On Red (LTOR). All sections have a heavy traffic stream except for the south section.

2.3. Invariants
The traffic signals must be error-free features. It has no deadlocks and has no schedule for conflicting traffic movements. It can serve all phases of the sections and shall able to return to the initial state [5]. For the verification and validation of the model, it can employ the invariants, simulations, or event graphs.

The invariant represents the marking of the place of the model. They are “1” or “0” only. Those mean the signals turn on or off, respectively. Place controls in the model do not include in the invariants.:

$$M(G_i) + M(Y_i) + M(R_i) = 1$$

Invariant (1)
Invariant (1) states that there is only one signal in one section turn-on of the three signals $G_i, Y_i,$ and $R_i$, $i=1,2,3,4$. Invariant (2) indicates that the travel schedule of the conflicting traffic movements does not exist. If it is available a token in place $R_i$, there must be a token in either one of the three places $G_j, Y_j$, or $R_j$ while $i, j=1,2,3,4$ and $i \neq j$.

$$M(G_i) + M(Y_i) + M(R_i) = M(R_j) \text{ while } M(R_j) = 1 \quad \text{Invariant (2)}$$

Invariant (3) is added with an intermediation place $S$ for phase changes. A token exists in place $S$ while all red signals occurred.

$$\sum_{i=1}^{4} [M(G_i) + M(Y_i)] + M(S) = 1 \quad \text{Invariant (3)}$$

**Figure 2.** The traffic light Petri net model with four phases.

The phase in a traffic light cycle is a number of vehicle travel scheduling models in several sections of an intersection. The goal is to avoid conflict with the flow of traffic from different directions. Phase 1 has signal places $G_1$ (Green1), $Y_1$ (Yellow1), $R_1$ (Red1), and $C_1$ (Control1). It is similar in phase 2, phase 3, and phase 4. The place $S$ is the intermediation place to build the phases demand order. Place controls get information from vehicular detectors about the vehicles that are queuing up the earliest between sections that stop due to the red signal. The traffic light applies the fixed time strategy at the predefined time. Transition $t_4$ is enabled and ready to fire. The information that there exists queuing up early in section 2 is obtained in place $C_2$. Section 2 is served by phase 2. All signals are red while a token is in place $S$. This is the time interval to clear the intersection of the remaining traffic stream. The sequence of traffic lights is not fixed. It can change any time according to the request.

3. Results and discussion

The systems that implement Demand Orders Method (DOM) are always looked the same as the Fixed Order Method (FOM) of traffic signals while the regular traffic. It very rarely the order of phases signals of the traffic signal is changed, except when the number of vehicles is very low as it situation that happened at midnight or while its fluctuations are very high. The second factor, the number of vehicles passing in the first cycle is high, but in the second cycle is low. This fluctuation can occur when there is a traffic light setting at the nearest intersection that is not coordinated.

First, it is assume a token in the place control appears periodically using a virtual vehicular sensor. Furthermore, the verification and validation of the Petri net model can be done. The results showed that the model meets all properties. All states can be reached from the initial state, the marking can
return to the initial state, the number of tokens at all places does not exceed $k$ ($k$ is the positive integers), the model is safe, and never meets deadlock. The model also satisfies all invariants.

### 3.1. Simulation result

The traffic light simulation is similar to an occurrence graph. It illustrates the schedule of each signal in all phases with the interval time of the event. The simulation and occurrence graph can replace the Petri net properties partially.

![Figure 3. The simulation results of a cycle of the traffic light that has four phases.](image)

When the green signal, a token exists in places G1, G2, G3 or G4 while the time interval $\tau_1 + \tau_2$, $\tau_5 + \tau_6$, $\tau_9 + \tau_{10}$, or $\tau_{13} + \tau_{14}$, respectively. The places Y1, Y2, Y3, or Y4 contain a token while the yellow signal. It happens when the time interval $\tau_3$, $\tau_7$, $\tau_{11}$, or $\tau_{15}$, respectively. A token available in place S when all signals are red while the interval time $\tau_4$, $\tau_8$, $\tau_{12}$, or $\tau_{16}$, respectively. The places controls are not available in the simulation.

Table 1. is the traffic light schedule of the intersection. The sections 2 and 3 require longer green time intervals than others due to the high traffic volume. Regarding the huge size of the intersection, all red signals for all sections are six seconds. The southern section is often closed due to the folk festival. The green signal in the south section is not required when it happens. There is no traffic coming from it, and the vehicles originated from other sections are forbidden to enter. The traffic light schedule involves three phases only.

| Phases | Green | Inter Green | Red | Cycle |
|--------|-------|-------------|------|-------|
|        | Green | Yellow      | All red | Cycle |
| 1. South | 21    | 3           | 6     | 105   | 129  |
| 2. West  | 21    | 3           | 6     | 105   | 129  |
| 3. North | 24    | 3           | 6     | 102   | 129  |
| 4. East  | 27    | 3           | 6     | 99    | 129  |

3.2. Traffic lights schedule while a folk festival held

There are six different possible cyclic orders of the traffic lights phases when it implements a Fixed Order Method (FOM) with four phases. There is the phases order: (1). South – West – North – East, (2). South – West – East – North, (3). South – North – East – West, (4). South – North – West – East, (5). South – East – North – West, and (6). South – East – West – North.

In Table 2., several possible orders of traffic light phases due to the implementation of Demand Order Method (DOM). It can use the permutation formula while it is not assumed as a cyclical order of phases.

In Table 2, there are the orders/sequences of the active sections. There are four possibilities when only a section is active. This happens when there is no queue of vehicles in the other sections exists. There are twelve possible orders while two sections are active. There are twenty-four possible orders of the sections in a cycle if it exists three or four active sections.

In Table 3, there are three-phases scheduling when the folk festival held. The south section was closed. It was 30 seconds faster than four-phases traffic lights. Traffic lights on the southern section
were always in the red signal all, It happened because a token still existed in place R1. This was done by turning off the control C1 of the Petri net model in Figure 2. It meant that the southern section never made a green signal request. Therefore, the existence of the signal in the south section was ignored. There were six possibilities of the active sections order of a cycle of the traffic signal. They were North – East – West (N – E – W), North – West – East (N – W – E), East – North – West (E – N – W), East – West – North (E – W – N), West – North – East (W – N – E), and West – East – North (W – E – N).

Table 2. The schedule of the phases of the traffic lights using demand order method (DOM)

| Phases | The order of the active section in a cycle of traffic lights | The Number of Order |
|--------|-------------------------------------------------------------|---------------------|
| 1. One | S, N, E, and W                                               | 4                   |
| 2. Two | S – N, S – E, and S – W                                      | 3                   |
|        | N – S, N – E, and N – W                                      | 3                   |
|        | E – S, E – N, and E – W                                      | 3                   |
|        | W – S, W – N, and W – E                                      | 3                   |
| 3. Three | S – N – E, S – N – W, S – E – N, S – E – W, S – W – N, S – W – E | 6                   |
|        | N – S – E, N – S – W, N – E – S, N – E – W, N – W – S, N – W – E | 6                   |
|        | E – S – N, E – S – W, E – N – W, E – N – S, E – W – N, E – W – S | 6                   |
|        | W – N – E, W – N – S, W – E – S, W – E – N, W – S – E, W – S – N | 6                   |
| 4. Four | S – N – E – W, S – N – W – E, S – E – N – W, S – E – W – N, S – W – N – E | 6                   |
|        | E, and S – W – E – N                                         | 6                   |
|        | N – S – E – W, N – S – W – E, N – E – S – W, N – E – W – S, N – W – S – E | 6                   |
|        | E, and N – W – E – S                                         | 6                   |
|        | E – S – N – W, E – S – W – N, E – N – W – S, E – N – S – W, E – W – N – S | 6                   |
|        | S, and E – W – S – N                                         | 6                   |
|        | W – N – E – S, W – N – S – E, W – E – S – N, W – E – N – S, W – S – E – N | 6                   |
|        | N, and W – S – N – E                                         | 6                   |

This method can not be done on the Petri net model that implements Fixed Order Method (FOM) of traffic signals phases. Petri net models that apply the Fixed Sequence Method or Fixed Order Method (FOM) in each phase must have four different intermediation places on a four-phases traffic signal system. Hence, the existence of the signal of all sections can’t be ignored.

Figure 4. The traffic light Petri net model with four phases that implements the Fixed Order Method (FOM).
The sequence of phases is South – West – North – East (S – W – N – E). Its composition becomes a cycle of the traffic light. While compared to Figure 2, this requires four intermediation places, namely S1, S2, S3, and S4. However, this model does not require place control as a vehicle detector. The duration of all signals based on the time that has been defined first by the authorities.

The Petri net model of the fixed order method requires Invariant (4)

$$\sum_{i=1}^{4} \{M(Gi) + M(Yi) + M(Si)\} = 1$$  \hspace{1cm} \text{Invariant (4)}$$

**Figure 5.** The occurrence graph (OG) of the traffic lights using four phases that implements the Fixed Order Method (FOM) and fixed time strategy of all signals.

The sequence of phases is South – West – North – East (S – W – N – E). The initial is node 1 when the signal G1, R2, R3, and R4 turn on. It is in the time interval [0, 21]. Node 2 happens when the time interval [21, 24] and the signal Y1, R2, R3, and R4 turn on simultaneously. Node 3 states that the S1 and all red signals turn on when the time interval [24, 30]. The next node is similar until it reaches the interval of a traffic light cycle, that is 129 seconds. At nodes 3, 6, 9, and 12, there are two signals those change, while at the other nodes only a signal.

### 3.3. The implementation effect of Demand Order Method (DOM)

The implementation of Demand Order Method (DOM) becomes very useful when the southern section is closed. It can create the traffic systems that usually apply four-phases of traffic lights to systems that is used three-phases automatically. The time interval of a cycle becomes shorter when it uses three phases instead of four phases of the traffic lights. When traffic volume in a section is low or no vehicle
queues, the system may prioritize another section that exists heavy traffic in it. The traffic light must have four phases although the southern section is closed when it is applied the Fixed Order Method (FOM).

The system rises as Fixed Order Method (FOM) if the token in all control places is set to appear periodically and in a fixed order. This simple automatic system doesn’t require a vehicle detector.

Table 3. The schedule of three phases of traffic lights

| Phases | Green  | Inter Green | Yellow | All red | Red  | Cycle |
|--------|--------|-------------|--------|---------|------|-------|
|        |        |             |        |         |      |       |
| 1. North | 24     | 3           | 6      | 72      | 99   |       |
| 2. East  | 27     | 3           | 6      | 69      | 99   |       |
| 3. West  | 21     | 3           | 6      | 75      | 99   |       |

It refers to Table 3. The time interval of a traffic light cycle is 99 seconds. The time interval of a traffic light cycle becomes shorter because it only consists of three phases. The travel delay for all vehicles crossing the intersection decreases and the performance of the intersection becomes better. By definition, travel delay is the travel time difference between two different places when the traffic stops to a smooth flow state. The vehicle movement being stopped due to the congestion or traffic light signal settings.

The performance of an intersection is assessed by the average travel delay of all vehicles that cross it. The performance of the intersection is low when the average travel delay is high. Conversely, the intersection performance is at a good level while the average travel delay is low. The best time interval of a traffic light cycle is proportional to the average travel delay of all vehicles on systems that implement a fixed time strategy.

It usually applies all reds in all sections with an interval of 3 seconds for a small intersection. This time interval is used to empty the intersection of the remaining vehicle flow that has not finished crossing. This also affects the value of travel delay. The effect is inversely proportional.

The stream of the vehicle becomes rapid when we look macroscopically. There are a lot of wasted times and costs when we review microscopically. The vehicles that will pass through the southern section must look for the alternative roads to reach their destination. The travel time usually becomes longer as the longer route. The folk festivals shall be held in particular places that do not interfere with the stream of traffic based on the reason that the number of vehicles is always increasing.

4. Conclusion

Based on the analysis of the Petri net model, the Demand Order Method (DOM) is an applicable system. This automatic system is not more complicated when compared to the Fixed Order Method (FOM). Both are different when traffic is low or no vehicle queues in a section and when the southern section is closed. In heavy but stable traffic streams, both have the same performance. The Demand Order Method (DOM) is an efficient method to create an automatic system of the traffic light schedule, primarily while the folk festival was held.

Future research is about the actual signaling intersection of traffic light schedules based on expert systems such as fuzzy logic. This is very urgent because the volume of vehicles increases continuously.

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References

[1] IHC M 1997 (Jakarta: Dir. of Highways of Road Development City)
[2] Tamin O Z 2000 Transport Planning & Modeling (Bandung: ITB Publisher)
[3] Huang Y S & Chung T H 2010 Mod. & analysis of traffic light control use TCPN (Intechopen)
[4] Soares M 2010 Architecture-driven integration of modeling languages (Netherlands: Delft)
[5] Adzkiya D 2008 Modeling traffic light using petri net & its simulation Thesis (Surabaya: ITS)
[6] Cassandras C G and Lafortune S 1999 Introduction to DESs. The Int. Series on Dynamic DES (Norwell Massachusetts USA: Kluwer Academic Publishers)
[7] Bordon J, Moskon M, and Mraz M 2016 Overcoming unknown kinetic data for quantitative modeling of biological systems using fuzzy logic and Petri nets researchgate
[8] Dotolia M and Fanti M P 2006 Urban traffic model via TCPN Con. Eng. Prac. 14 (10): 1213-29.
[9] Aalst W M P V D 1995 Petri net based scheduling (Dept. of Math. & Comp. Sci: Eindhoven Univ of Tech)
[10] Bozek A 2012 Using TCPN for modeling (Rzeszow Univ. of Tech. Poland. Intechopen)
[11] Mohammadi M and Mukhtar M 2012 Business process modelling languages in designing integrated information System for supply chain management JJASEIT: 2 464-67.
[12] Dong H and Li X 2013 Fault diagnosis for substation with redundant protection configuration based on time-sequence fuzzy petri-net TELKOMNIKA 11: 231-240.
[13] Kurniawan F, Sajati H, and Dinaryanto O 2016 Adaptive traffic controller based on pre-timed system TELKOMNIKA 14: 56–63.
[14] Murata T 1989 Petri Net: Properties, Analysis, & Applications Proc. of IEEE. 77: 541-90.