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Dynamic Traffic Light Sequence Algorithm Using RFID

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Abstract: **Problem statement:** Traffic congestion and tidal flow management were recognized as major problems in modern urban areas, which have caused much frustration and loss of man hours. **Approach:** In order to solve the problem an intelligent RFID traffic control has been developed. It has circumvented or avoided the problems that usually arise with systems such as those, which use image processing and beam interruption techniques. RFID technology with appropriate algorithm and data base were applied to a multi vehicle, multi lane and multi road junction area to provide an efficient time management scheme. A dynamic time schedule was worked out for the passage of each column. **Results:** The simulation has shown that, the dynamic sequence algorithm has the ability to intelligently adjust itself even with the presence of some extreme cases. The real time operation of the system emulated the judgment of a traffic policeman on duty, by considering the number of vehicles in each column and the routing proprieties. **Conclusions/Recommendations:** RFID together with Internet and GSM technologies are anticipated to create a revolution in traffic management and control systems. The data base contains online statistical information, which can be used by operators and planners to develop better models in the future.

Key words: RFID, traffic control, ubiquitous network, traffic management

INTRODUCTION

The operation of standard traffic lights which are currently deployed in many junctions, are based on predetermined timing schemes, which are fixed during the installation and remain until further resetting. The timing is no more than a default setup to control what may be considered as normal traffic. Although every road junction by necessity requires different traffic light timing setup, many existing systems operate with an over-simplified sequence. This has instigated various ideas and scenarios to solve the traffic problem. To design an intelligent and efficient traffic control system, a number of parameters that represent the status of the road conditions must be identified and taken into consideration.

Most of the present intelligent traffic lights are sensor based with a certain algorithm that controls the switching operation of the system[1,2]. This approach considers the traffic to be moving smoothly and hence does not require any management or monitoring of traffic conditions. When some unpredictable situation develops, or when congestion occurs, there is no proper way of dealing with such development.

A more elaborate approach has been introduced to overcome these problems. It employs real-time traffic flow monitoring with image tracking systems[3,4]. Although this method can give a quantitative description of traffic flow[5], it involves several limitations. The processing in real time on a large scale may present prohibitive requirements. Some common problems involved in image processing system include False Acceptance Rate (FAR) and False Rejection Rate (FRR). Normally, in case of jam-packed traffic, the computer vision results in erroneous detection[3].

The sensor based traffic light control on the other hand may require sensors that operate with a line of sight detection, which may present difficulty in detecting vehicles that pass through blind spots detection range.

MATERIALS AND METHODS

Experimental setup: A model of the system has been set up to simulate the actual design of a novel RFID based traffic control using Cisco appliance and AeroScout RFID active tag. The layout is shown schematically in Fig. 1.

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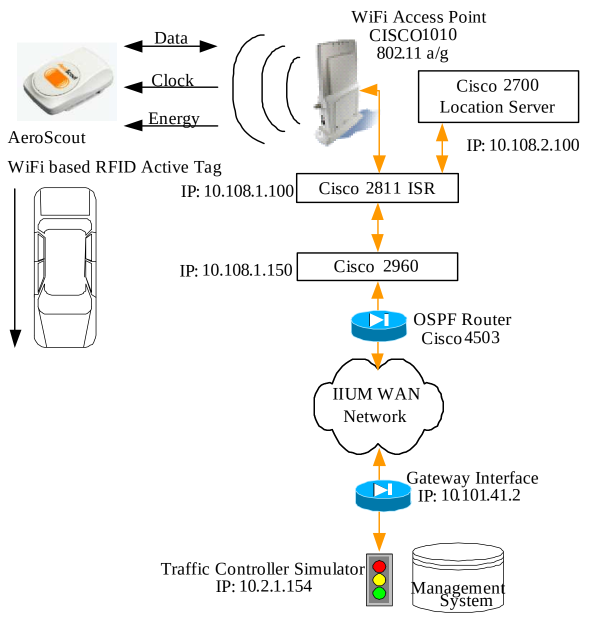


Fig. 1: Model of the RFID based traffic control system

The intelligent traffic control system consists of four main parts: the AeroScout RFID tags, the Cisco access point, the Cisco location server and IIUM Wide Area Network (WAN). The first simulates the moving vehicles; the second detects the RFID tags, the third acts as RFID software and fourth simulate the ubiquitous environment.

The location server acts as the microcontroller of the traffic signal. It will collect the location and tagging time of the data from reader. This information is sent to the management system via Internet. The management system using intelligent algorithm will then send suitable instructions to control the traffic.

Dynamic traffic sequence algorithm: An algorithm for the control of the traffic sequence that can change dynamically the priority and easy to implement is written to facilitate the efficient traffic control at certain junction. This also can be extended to multiple junction control. It is based on an automatic intelligent selection of traffic sequence in a multilane traffic flow. The multilane traffic flow is shown in Fig. 2.

The A1, A2 and A3 represent vehicle moving from A direction which A1 is moving to the west, A2 is moving forward and A3 is moving to the east. The orientation is similarly applied to the vehicle moving from B, C and D direction.

Figure 3 shows an example of how the algorithm works. Assuming A, B, C and D are traffic column in which A from south can go forward, east or west, with timing slot that is dynamically determine according to the number of vehicle for each route. The same sequence is then shifted to B, C then D.

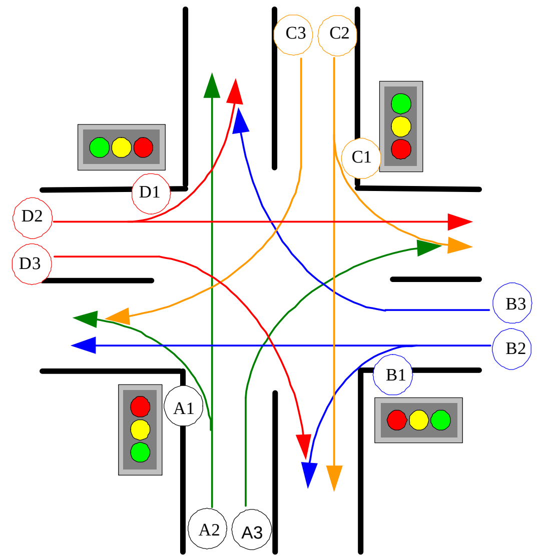
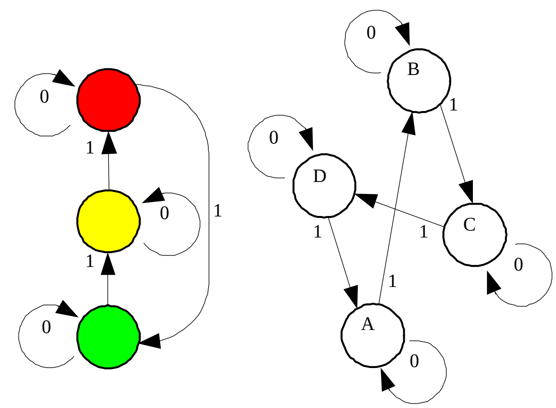


Fig. 2: Multilane traffic sequence flow



Next state	0	1
R	R	G
Y	Y	R
G	G	Y

Next state	0	1
A	A	B
B	B	C
C	C	D
D	D	A

Fig. 3: Traffic light state diagram

The decision process for the intelligent traffic control depends on the real time information as provided by the RFID system. The data is also recorded and saved in the centralized management database. A number of readers are deployed to detect and count the vehicle at each junction. The reader captures the time-in for each vehicle passing within its range. The practical arrangement and the location of the readers around the junction are shown in Fig. 4. The captured information such as location (l_n) and time-in (t_n) for each vehicle are saved as a tag reference table ID

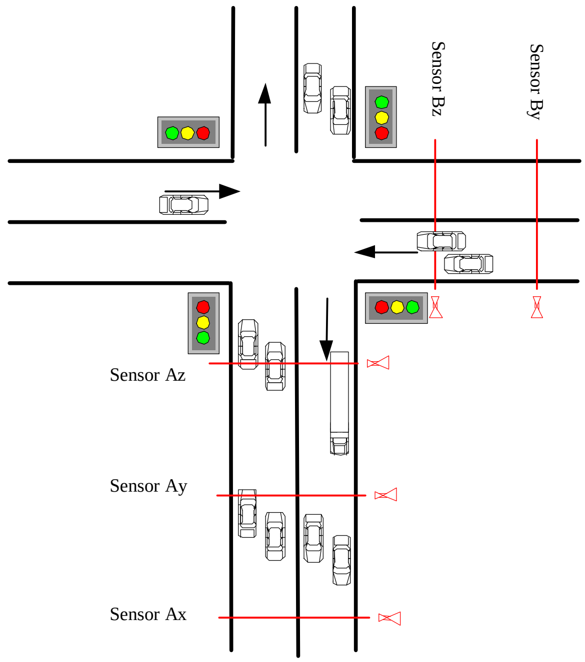


Fig. 4: RFID Reader reading range

ID: <Location (l_n)>:<Time-in (t_n)>

Theoretically, the waiting time at each junction is same as defined in Table 1. This algorithm can change the sequence dynamically depending on the real time situation at the specific junction with respect to situations that currently exist in other junctions of the surrounding area. If, for example the accepted waiting time at each junction is 90 sec, the period for Green and Yellow states may probably be 30 sec at each junction.

In reality, the state of traffic condition and congestion change with time. Hence, the timing for a Yellow state can be fixed at 3 sec which is long enough for a driver to stop. The Green state at B represents as BG while Yellow state at B represents as BY and it is applicable to other parameter e.g., CG, DG, CY and DY. The waiting time for example can be computed for a state A as:

$$A_{wait} = BG + CG + DG + AY + BY + CY + DY$$
$$A_{wait} = BG + CG + DG + 4(3s)$$
$$A_{wait} = BG + CG + DG + 12s$$

where

$$A_{wait} \neq B_{wait} \neq C_{wait} \neq D_{wait}$$

Table 1: Waiting time at each state

State	Waiting time at each state
A	AY + BG + BY + CG + CY + DG + DY
B	BY + CG + CY + DG + DY + AG + AY
C	CY + DG + DY + AG + AY + BG + BY
D	DY + AG + AY + BG + BY + CG + CY

Table 2: Captured time-in

Vehicle	Sensor A_x	Sensor A_y	Sensor A_z
Vehicle 1	Tx_1	Ty_1	Tz_1
Vehicle 2	tx_2	Ty_2	Tz_2
Vehicle 3	tx_3	Ty_3	Tz_3
Vehicle 4	tx_4	Ty_4	Tz_4
…	…	…	…
Vehicle n	tx_n	ty_n	tz_n

Table 3: Collected vehicles speed databases

Database of the Speed of Moving Vehicles

A_xA_y	A_yA_z	B_xB_y	B_yB_z	C_xC_y	C_yC_z	D_xD_y	D_yD_z
v_{11}	v_{21}	v_{11}	v_{21}	v_{11}	v_{21}	v_{11}	v_{21}
v_{12}	v_{22}	v_{12}	v_{22}	v_{12}	v_{22}	v_{12}	v_{22}
v_{13}	v_{23}	v_{13}	v_{23}	v_{13}	v_{23}	v_{13}	v_{23}
…	…	…	…	…	…	…	…
v_{1P}	v_{2P}	v_{1P}	v_{2P}	v_{1P}	v_{2P}	v_{1P}	v_{2P}

v: Speed of the vehicles between two readers; l: Location of the RFID reader; t: Time tagged the RFID tag at the particular reader; n: Number of reader; P: Total number of vehicles traveling between two readers

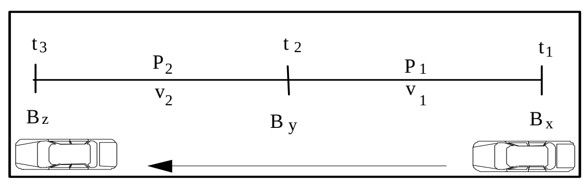


Fig. 5: Reader reading the passing through tag

The Green state timing of AG, BG, CG and DG at each junction can be different from each other because it depends on the congestion conditions and the queue length.

If no vehicles are detected at a particular state, then the sequence automatically proceed to the next state. On the other hand if number of vehicle in a congested state along queue is high, the system will check the condition of other junction and determine a compromising time for maximum efficiency in relieving the congestion. This will allow a reasonable balance for the overall waiting time.

The decision takes into account real-time data at surrounding junction as well as statistically compiled data for a specific time of the day and day of the week and may even consider weather the data coincide specific event. Figure 5 shows that how the measurement process of time-in were collected when the vehicles entering the reading range of the reader located at Bx, By and Bz.

The raw data from the readers is accumulated in the centralized database and arranged in a database table as shown in Table 2 and 3. The database also records the average speed of all vehicles traveling between two readers within the area of the controlled zone. Hence accumulated speed average in the area before reaching the traffic light for all area before reaching the traffic light is calculated as:

$$v_1 = \frac{l_2 - l_1}{t_2 - t_1}$$

$$\langle v_1 \rangle_{collect} = \left\langle |v_i|_{i=1}^{i=P} \right\rangle_{collect}$$

$$(v_1)_{avg} = \frac{\left\langle \sum_{i=1}^{i=P} v_i \right\rangle_{collect}}{P_1}$$

$$\langle v_{avg} \rangle_{collect} = \frac{\langle (v_1)_{avg} + (v_2)_{avg} \rangle_{collect}}{2}$$

$$v_{avg} = \frac{\sum_{i=1}^{i=2} (v_i)_{avg}}{2}$$

$$v_{avg} = \frac{\sum_{j=1}^{j=3} \frac{l_j - l_{j-1}}{t_j - t_{j-1}}}{P_2}$$

The average speed and the estimated information are important parameter in determining the proper routing of the traffic utilizing the intelligent algorithm for the traffic flow system.

The average acceleration and average speed of a vehicle which is moving from standstill after the traffic light turns green can be computed as:

$$a_{avg} = v_{avg} \frac{dv}{dt}$$

where, a_{avg} is the average acceleration.

In the case where other than RFID are used in the system such as image processing and traffic sensor, the algorithm proposed in this work will improve their performance by reducing the size of computational data since the size of RFID tag data only several bytes long and provides proper basis for the estimation assume in normal fuzzy logic analysis procedure discussed in[2,6,7].

The algorithm is required to process all the data captured from the moving vehicles which have been tagged with RFID tag. This algorithm examines the entire traffic environment and decides a procedure to control the switching process of the traffic lights, as shown in Fig. 3.

If this system senses an odd situation such as an accident that causes imbalance traffic flow, it would still be capable to control the traffic by allowing the appropriate junction manipulation. The decision makes use of the accumulated data saved in the centralized traffic management database. The system can learn from the accumulated decisions and can be produce an overall scenario of the traffic flow by identifying a variety of situation:

- Identify the junction with a longest queue
- Identify the busiest route
- Identify the routine traffic pattern at particular time and day
- Determine the most efficient sequence

The traffic controller algorithm is defined as follow:

```
If A1, A2, A3: G
    then B1: G until A1, A2, A3: Y

If only A3 not detected at B(z, y, x), then A3: Y
    then compare queue at C(x, y, z) and B(x, y, z)
    {
    if C(x, y, z) > B(x, y, z)
    then C1, C2:G until A1and A2: Y
    else C1, B1: G until A1 and A2: Y
    }
    then B1, B2, B3 start G

If only A2 not detected at C(z, y, x), then A2: Y
    {
    then D1, C1: G until A1and A2: Y
    }
    then B1, B2, B3 start G

If A1 not detected at D(z, y, x) AND
    If A2 not detected at C(z, y, x), then A1, A2: Y
    {
    then D1, C3: G until A3: Y
    }
    then B1, B2, B3 start G

If A2 not detected at C(z, y, x) AND
If A3 not detected at B(z, y, x) then A2, A3: Y
    then compare queue at C(x, y, z), B(x, y, z) and
    D(x, y, z)
    {
    if B(x, y, z) > C(x, y, z) and D(x, y, z)
    then B3, B1:G until A1:Y
    if C(x, y, z) > D(x, y, z) and B(x, y, z)
    then C1, C2:G until A1:Y
    if D(x, y, z) > B(x, y, z) and C(x, y, z)
    then D1, D2, D3:G until A1:Y
    }
    then B1,B2,B3 start G

If A1, A2, A3 not detected at A(x, y, z)
    then B1, B2, B3 start G
```

Table 4: Table for monitoring congested routing

Total number of moving vehicles from A(x, y, z) to		
B(z,y,x)	C(z,y,x)	D(z,y,x)
∑vehicle	∑vehicle	∑vehicle
Total number of moving vehicles from B(x, y, z) to		
A(z,y,x)	B(z,y,x)	C(z,y,x)
∑vehicle	∑vehicle	∑vehicle
Total number of moving vehicles from C(x, y, z) to		
D(z,y,x)	A(z,y,x)	B(z,y,x)
∑vehicle	∑vehicle	∑vehicle
Total number of moving vehicles from D(x, y, z) to		
A(z,y,x)	B(z,y,x)	C(z,y,x)
∑vehicle	∑vehicle	∑vehicle

The same algorithm is applied to states B, C and D in order to avoid long queuing times at congested lane, to provide an efficient flow rate to the most congested route (Table 4).

RESULTS

Model implementation: The model has been implemented successfully for the system shown schematically in Fig. 6. However, this algorithm can manage more complicated traffic problems in a large scale deployment of the RFID network. The main requirement for the deployment of ubiquitous RFID network is that every vehicle must carry a tag. This requirement involves decisions and policies adopted by higher authorities to ensure that every vehicle complies with the RFID scheme[8].

The RFID system can be enabled by the ubiquitous sensors, which are made as part of the input devices in the traffic management application. Extending the interface capabilities of the sensor is straightforward, by an active tag[9]. The tag is usually placed on the object to be identified or embedded in it.

The proposed tagged object can be a road tax sticker, driving license, a permit, plate number etc. Each tag has the detailed information of the vehicle such as type, weight, length, etc as in the centralized traffic management database. Instead of using AeroScout tag, another room of improvement is to use the RFID tag developed by Security Lab Inc. as shown in Table 5 which may improve the performance.

The system can randomize the reply time so that it can query multiple tags simultaneously hence minimizing contention between their responses. RFID reader is located strategically in order to collect all the data from the vehicles tagged with RFID tag passing ugh its reading range. The collected information is then sent to a centralized database of the traffic management system. The centralized database will process the collected data in order to generate a feedback signal to manage the intelligent timing for the sensor-based

Table 5: Specification of RFID tag for the proposed RFID based traffic management system

Features	Security lab Inc. Specification
Transponder type	Active
Reading range	Up to 80 m
Maximum object speed with guaranteed tag reading	Up to 180 km h^{-1}
Frequency	434.5 MHz, 433.3 MHz
Life time battery	1 year
Radio emitted power	Less than+0 dBm

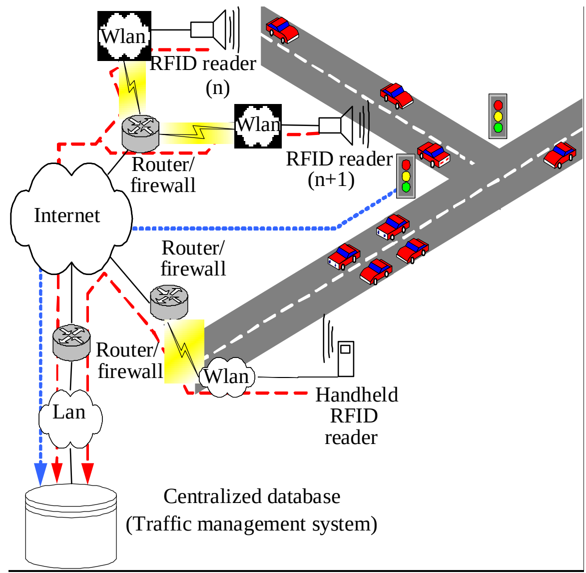


Fig. 6: Schematic design of the ubiquitous RFID network for traffic light management

traffic light[10], as shown in Fig. 6. The computed statistical data in the centralized database can be shared with other local authority databases through the secured structured network.

Traffic speed determination: The average speed measurement of vehicles using RFID devices was determined by a simulation technique. The simulation was based on actual data collected manually along the Malaysian North-South Highway (PLUS). The simulation was aimed at achieving the objectives listed below:

- To study the speed behavior of individual vehicles
- To study the speed behavior of vehicles in clusters.
- To evaluate the average speed behavior under extreme condition: very slow and very fast
- To determine an indicator that is characterized by extreme changes in average speed.

Individual vehicles: The system has the capability to determine the average speed of any individual vehicle along the road. Referring to Table 3, each row lists out the time periods collected for a vehicle every time it passes by an RFID reader. Based on the actual data of previous studies[2-6], vehicles move normally with a consistent average speed. In extreme cases, the vehicle may move in an inconsistent manner. Such situations are identified and isolated by the system and considered as special cases.

The simulation can be developed readily to consider various types of complexity, e.g., to set a threshold level for isolating the extreme cases. The simulation assumes that all vehicles move with a consistent speed and discards the data for extreme cases of inconsistent behavior, which is generally the norm.

Speed behavior of clustered vehicles: The simulation system is able to determine the average behavior of all vehicles on the road. It accumulates the data into a database. The average speed can then be used to control the batch size, separated by appropriate gaps in time and space. This can be simulated as a mark-to-space ratio. An intelligent mark-to-space ratio, based on efficient traffic flow estimation is used to time the signals for the Red and Green (R-G) lights in and adaptive manner that can create a green wave for the traffic to move with safe and efficient speeds. This simulation and the database can form a coherent solution, "Advanced Traveler Information System"

The system has the ability to adjust itself even with the possibility of the presence of some extreme cases. As mentioned in the previous section, extreme cases, which may perturb the reliability of the estimation, are usually discarded. However, proper decisions can still be made by the Advanced Traveler Information System (ATIS). Electronic signs would indicate recommended speeds to the drivers. Hence a driver, who violates the recommendations and fails to follow the instruction, would not stay in a batch cluster of a green wave.

Extreme average speeds: The simulation indicates that some extreme cases may occasionally cause errors in the database that can cause disturbance in the data accumulation process. It may also interrupt the overall system learning, such as a cluster of inconsistently moving motor-cycles. This problem can be solved by a standardized threshold for speed level in order to filter out such irregularities. The extreme cases can either be extremely fast or extremely slow, e.g. above 200 km.h^{-1} or below 20 km.h^{-1}, which can be excluded from the threshold level as shown in Fig. 7.

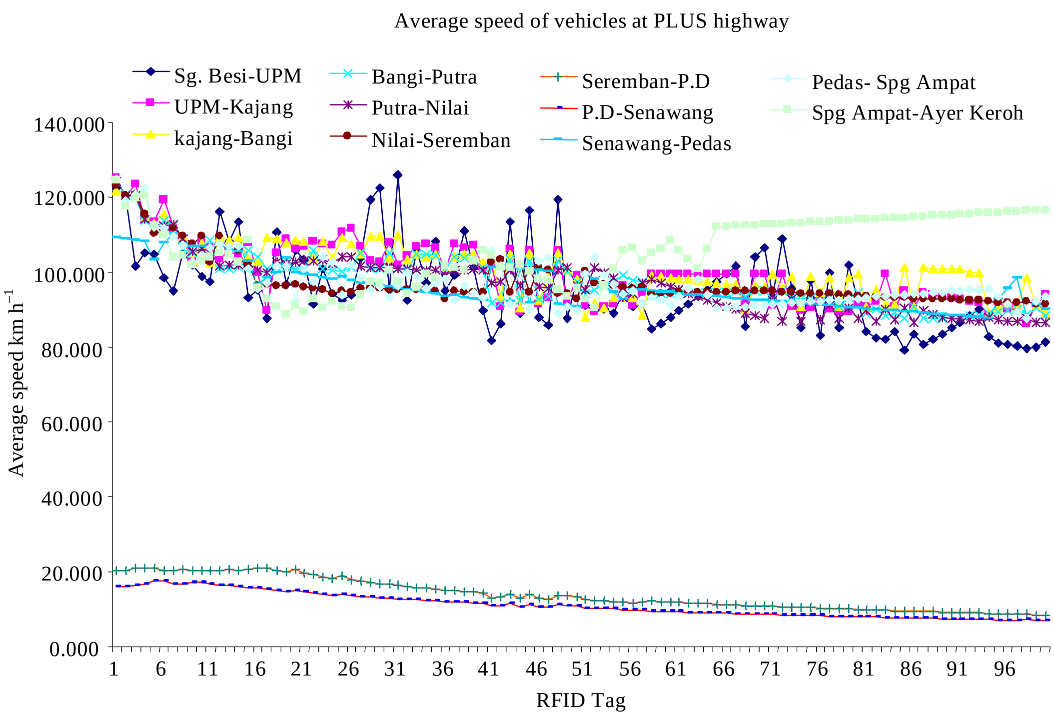


Fig. 7: Simulation of an average speed at particular location

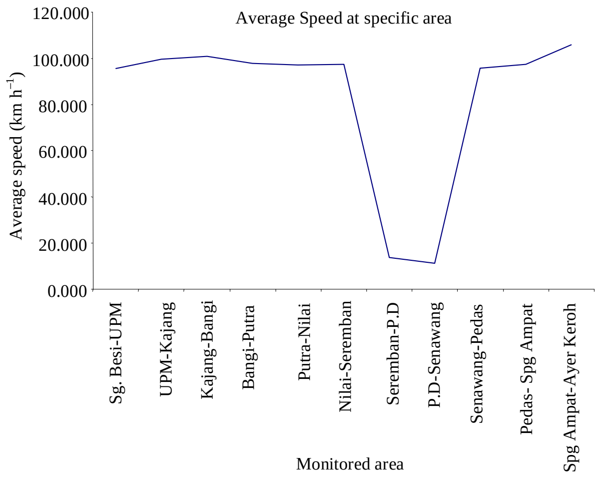


Fig. 8: Simulation of an average speed shows a heavy traffic jam

Average speed Indicator of extreme changes: The system can also indicate sudden changes in the average speeds. This simulation was verified by the actual data, which was recorded at 11:00a.m on November 25, 2006, between km 244 and km 256 of PLUS Highway as shown in Fig 8. It turned out that the situation was created by construction work involving road widening between Seremban and Senawang. The indicator can also provide real time information about the occurrence of accidents or other traffic flow interruptions. This facility is meant to alert appropriate authorities that sudden traffic congestion has occurred.

The indicator therefore becomes one of the main inputs to the algorithm. Although the algorithm is based on the number of vehicles in a queue, the collected data include information about the number of cars, individual vehicles, clusters, as well as the average speed indicator, which are all interrelated. Hence vital information can be provided to the driver, the traffic officer, the traffic planner and other related parties, and consequently better solutions can be arrived at for smoother road environment.

DISCUSSION

The proposed concept can form the basis for appropriate solutions to tackle a variety of road related problems. The implementation however requires that a number of decision making authorities to coordinate their effort to create a comprehensive solution.

The system can for example be readily employed to create an electronically controlled green wave flow, and a tidal traffic management system.

Other strategic applications involve traffic prioritization and intelligent dynamic time scheduling, as may be needed by emergency vehicles such as ambulance, police patrol and fire engine, etc. Such vehicles will have to be tagged with special RFID tags. The proposed system may even be integrated with GPS under certain conditions in the future to guide vehicles to their destinations efficiently.

The great challenge would be to design a system with a sophisticated electronic traffic management that is capable of understanding and identifying traffic movement and routine destinations for a whole city. Understanding the routine traffic pattern can provide accurate information to the traffic planner or urban designer to develop a traffic jam free city.

CONCLUSION

The RFID technology may lead to a revolution in traffic management, when it is properly deployed as an intelligent system with suitable algorithm. One of its main features is the ability to communicate operation commands from head-quarters or any other subsidiary command station to any location in the system via existing infrastructure such as GSM or Internet. This system can enhance the transportation system of the country, by efficient management.

The dynamic management scheme operates in real time and emulates the judgment of a traffic policeman on duty. The efficiency of the system may save many man-hours usually lost in traffic problems. Accidents may also be prevented and lives can be saved as well as property. Priority emergency tags can be deployed on ambulance, fire, police and other emergency vehicles.

The system saves valuable details in the records of the database, which can provides ample and valuable information to planners and investigators. However, the integration of the databases among the local authorities is a challenge that requires decisions at national level. Data sharing and secure hierarchical access to various levels of databases and protocols must be designed to integrate new information with existing systems. The issues of integration and collaboration may be a subject for future work.

The legal issues and privacy laws relating to the monitoring of drivers all the time may cause a major public concern. Such study would need to address subjects relating to civil rights and personal freedom issues as well as social acceptance.

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