A Novel Real-Time Road Information Management Technique for Traffic Congestion Mitigation

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ABSTRACT

Road transport is an inevitable requirement to the human civilization where it provides considerable economic and social benefits to the society. However, poor management of traffic flow imposes challenges such as traffic congestion. Problems arise when there is too much traffic for the available physical road capacity to handle. This causes the road transport to be less efficient and it causes excessive effect on the environment. In this paper, a novel road information management technique for traffic congestion mitigation is presented. From the literature, main challenge has been identified in collecting real-time road data for traffic management. This paper describes a technique for collecting and managing the road data while focusing on traffic congestion mitigation. A mobile phone based road information management system has been designed and developed. The system comprises of three subsystems which work together in road data collection, processing and information dissemination. GPS technology integrated in the mobile phones has been used for vehicle location data tracking. Results show that the real-time road data can be processed and utilized as traffic status information for road users; so that they can skip congestion by choosing less congested roads, adjust traveling time as well as choose proper traveling mode.

Keywords: Traffic Congestion, Mobile Application, Road Information Management System.

1. INTRODUCTION

Intelligent Transportation System (ITS) is one of the technology-oriented traffic management solutions. ITS as a multi-technology framework, it integrates communication, processing and information technologies to give a road traffic management solution. The spreading of wireless technology such as V2I (Vehicle-to-Infrastructure) and V2V (Vehicle-to-Vehicle) communication brings new ways for ITS functions in collecting, processing and distribution of information [1]. Efficient methods for data collection, storage and provision are needed in order to get the most appropriate traffic information based on which intelligent decisions are to be taken by the system.

System design is a process which covers definition of the architecture, components, modules, interface and data for a system in order to satisfy the specified requirements. System development covers the products of the system design into a complete system and database(s). Most significant activities in development stage are acquiring and installing the necessary hardware and software that makes up the system environment, developing program code, creating database structure and testing the system [2]. In this paper design and development of a real-time road information management system to acquire road traffic information is presented. Road monitoring system based on GPS-enabled smart phones has been developed to exploit the extensive coverage provided by the cellular network. The high accuracy in position and velocity measurements provided by GPS devices, and the existing infrastructure of the communication network, are the main source of road information gathering.

Several techniques for congestion mitigation have been implemented but they face challenge on controlling the traffic based on the real-time road situation. Technologies such as traffic lights have not been able to solve traffic congestion problem [3]. They have no ability to control the traffic in relation to the real-time occurring situation. In Tanzanian context, the only implemented traffic management systems are traffic lights [4]. They operate under fixed time sequence in an automatic closed system where there are no travelers or other systems interaction. This causes difficulties if for some reasons the traffic scenario changes (e.g. an event like a strike or parade happens, or a car accident, or emergency cars rushing to a specific location) and the movement of the traffic are different from usual. The system keeps acting like in a normal situation and disregards the occurring changes.

Road traffic management requires real-time information dissemination to users so as they can have a pre informed travel. Real-time information enables road users to search for alternative traveling options. They can choose to travel or not, select appropriate destinations, timing of journeys, the transport mode, the route, or the transit line [5]. Appropriate management of disseminated information in relation to user’s traveling preferences leads to congestion reduction.

There are mainly two sampling techniques used for road traffic data gathering. These are: (i) Temporal sampling: Equipped vehicles report their information (position, velocity, etc.) at specific time intervals T, regardless of their positions. (ii) Spatial sampling: Equipped vehicles report their information (time, velocity, etc.) as they cross some spatially defined
sampling points [6]. The spatial sampling strategy is similar to the one used by inductive loop detectors, radio frequency identification (RFID) transponders or license plate readers, in which data are obtained at fixed locations. This research has adopted temporal traffic data sampling. Floating Car Data (FCD) method has been considered in road data collection. The study area for this research is Tanzania where there are no preinstalled road data collection systems. The FCD was considered as a suitable method since it does not require physical installation of electronic devices across the roads. It exploits existing infrastructure and requires minimal or zero additional infrastructure. Systems based on such designs are expected to have low deployment and maintenance costs [7, 8].

Design and development of Real-Time Road Information Management System (RIMS), was focusing on: - (i) Creation of information that can easily be disseminated to road users without any other modifications in the existing infrastructure (ii) Providing information that enables the road users to plan their trips appropriately in relation to the disseminated real-time road information (iii) Creating direct effect to the vehicle drivers who are the main controller of the vehicle. They have ability to slow/increase the speed, change vehicle direction as well as stopping the vehicle. By controlling the driver’s behavior indirectly even the traffic flow is automatically controlled [9].

1.1 Road Information Management Technologies

Communications networks are among the fundamental structural elements that make up an intelligent transportation infrastructure, because they serve as the paths ITS services use to access and share information. These networks link disparate ITS applications to each other and to centralized management centres, allowing for the key functions of data gathering, synthesis, delivery, and broadcast to occur in real-time [10]. Moreover, individual applications may utilize several communications modes, and impose different performance requirements on the network in terms of bandwidth, latency, and quality of service (QoS). As a result, specific wireless communication architectures and methods are being developed for particular ITS applications within the vehicular transportation community.

Advanced Traveller Information System (ATIS) is an area of ITS applications. Recent advances in electronics and micro-computing have led to the feasibility of functionally powerful, computer-based advanced traveller information systems as part of the automotive environment. Although these systems range in functionality, they all have the goal of acquiring, analysing, communicating, and presenting information to assist travellers in moving from a starting location to a desired destination [11]. ATIS implementation cost is related to the technology used, for the case of developing countries like Tanzania, a cost effective technology is preferred. Floating car technology often utilizes Global Positioning System (GPS) to determine position and velocity information on the road surface. It is a less expensive and more accurate technology, currently the GPS is becoming dominant technology deployed for locating and tracking vehicles for road status information [12]. GPS equipped vehicle can transmit location and travel time data to a traffic management center at frequent time intervals. This type of system requires significantly more components in each vehicle, but has the advantage of little or no roadside infrastructure is required [13].

1.2 Information Management Systems Design

Design is central to engineering among other fields, and clearly important to the information systems discipline [14]. In design and development the systematic use of scientific knowledge is directed toward the production of useful materials, devices, systems, or methods, including prototypes and processes [15]. Generally information system design requires effective collection, analysis and utilization of the system requirements [16, 17]. Accurately identified requirements result from effective communication and collaboration among all members of the project team, and provide the best chance of creating a system that fully satisfies the needs on the customers [18]. In this paper the main requirement was creation of cost effective system for mitigating road traffic congestion. To cut the cost down, the research has taken an advantage of availability of mobile phones carried by road users all the time when they travel across the roads [19]. The mobile phones were used as road data collection probes which sends road data to the centralised server.

2. METHODOLOGY

2.1 System Design

To design RIMS the system architecture was constructed to give the general structure of the system. The architecture considers real-time road traffic data collection, processing, and dissemination. GPS enabled mobile phones have ability to be used as moving sensors which collects road information [13]. Mobile phones are also used for information dissemination, in addition to other techniques such as radio, television, and the Internet. As shown in Figure 1, main components of the constructed architecture are:-

(i) **Data collection**: This part uses the GPS enabled mobile phones as road traffic probes providing real-time data of vehicles moving on the road. The collected data includes vehicle location, speed, and time. The phones communicate with GPS satellites for acquiring location data. To send the collected data to the next stage, the phones use cell towers with GPRS technology.
(ii) **Data processing and storage:** This is the second part of the architecture; it converts the collected road data to the traffic status information suitable for road traffic management. The information is then stored in the database as well as posted to the next part of the architecture through the Internet.

(iii) **Information dissemination:** This is the last part of the architecture, where information users access real-time traffic information by sending a request to the system.

2.2 **Approach**

Object oriented analysis and design technical approach was used for RIMS design. For the end product (i.e. RIMS) to function properly testing was done at each stage of components development. Testing was conducted thoroughly within specification, design and source code writing. In general every development activity that produces a work product was “shadowed” by test activity. Unified Modeling Language (UML) was implemented for object oriented design methods to unify all notations of the system design. The UML is a tool for specifying and visualizing software systems. It includes standardized diagrams to define, illustrate and visually map or model a software system's design and structure [20]. The diagrams provide for different static and dynamic model that may be produced to document a system design [21]. UML diagrams include the use case diagram, class diagram, sequence diagram, state chart diagram, activity diagram, component diagram, and deployment diagram.

Open source software was considered in system development. This is due to their easy accessibility; they were just downloaded from the internet. Open source software has freedom of use for the source code [22]. The software gets modified in relation to the developers’ requirements. For RIMS development, Android platform was programmed to create mobile application module. Web interface was created using PHP, JavaScript and HTML. Apache web server was used for the script processing and delivering web pages to clients. Road traffic data were stored and managed in MySQL RDBMS.

3. **RESEARCH FINDINGS**

3.1 **System Context Diagram**

A context diagram as part of system functional modeling is presented in Figure 2. It allows production of high-level model of the system. The diagram does not give details of its interior structure or functions, it is surrounded by elements in its environment with which it interacts [21]. For RIMS elements, a mobile phone application is used for road data collection. The collected data is then processed in a server, where it is refined for storage within a database. To access the road information, web application provides interfaces where road users can access specific road information. The provided information enables road users to make appropriate traveling decisions. To allow system utilization flexibility, web interface responsive design was considered. The design allows information access on both desktop computers as well as mobile devices (such as tablets and mobile phones).

![Fig 2: RIMS Context Diagram](image-url)
Table 1: Components of the Context Diagram

<table>
<thead>
<tr>
<th>SN.</th>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GPS-enabled Mobile Application</td>
<td>Mobile phone application for road data collection: it collects vehicle location (Latitude and Longitude), speed and direction of travel.</td>
</tr>
<tr>
<td>2</td>
<td>RIMS</td>
<td>Web server and database: It analyses the collected data for detecting level of congestion, as well as updating the real-time road information in the database.</td>
</tr>
<tr>
<td>3</td>
<td>Web application</td>
<td>Web interface: used by road users for sending request and retrieving the real-time road information.</td>
</tr>
</tbody>
</table>

3.2 Sequence Diagram

Sequence diagram for RIMS is shown in Figure 3. The system administrator should first register the road data tracking devices (mobile phones) to the system. Only registered phones are able to send road information to the server. At any given time the system administrator can manage the system by creating, updating or deleting system information. Registered vehicle drivers carrying GPS enabled smart phones in their car are able to start the installed vehicle tracking application in their mobile phones at the beginning of their trips. The tracking application sends road information to the server as a background service. The driver can view the status of road data uploading to the server. Sent information includes GPS coordinates, direction of travel and vehicle speed. When not traveling, the drivers stop the tracking application. Only drivers’ phones are allowed to send road data, it is assumed that one mobile phone is fixed in each vehicle, so as vehicles are then utilized as road data collection probes. Due to the reason that one car is tracked per time. This will not bring confusion on counting number of vehicles existing on a specific road segment. Number of vehicles is equivalent to number of tracking mobile phones. All road users are able to request and access the road information from the system.

Fig 3: Sequence Diagram for RIMS

The sequence diagram captures varieties of interaction and instantaneous states within a model as it executes over time. It tracks how the system will act in a real world environment, and observes the effects of an operation or event, including its results. This is done before system development so as to save time of troubleshooting the system behavior during the system implementation phase.

3.3 Test Cases Design

RIMS design and development process followed the W-Shaped model. The model requires testing process to be done in parallel to the design and development process. During the design and development phase of RIMS, Typical and exceptional workflows from the use case were tested as indicated in Table 2 and Table 3. This was done from the point of view of the various actors who directly interact with the system and from the point of view of the various stakeholders who indirectly interact with the system.

Table 2: Test for Typical Work Flow

<table>
<thead>
<tr>
<th>No.</th>
<th>Test Step</th>
<th>Expected Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Start car tracking mobile application</td>
<td>Display status of tracking</td>
</tr>
<tr>
<td>2</td>
<td>Open web interface URL</td>
<td>Display home page</td>
</tr>
<tr>
<td>3</td>
<td>Request road information (Enter specific road name)</td>
<td>Display road traffic condition information</td>
</tr>
<tr>
<td>4</td>
<td>Stop car tracking mobile application</td>
<td>Close status of tracking window</td>
</tr>
</tbody>
</table>
Table 3: Test for Exceptional Work Flow

<table>
<thead>
<tr>
<th>No.</th>
<th>Test Step</th>
<th>Expected Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enter invalid data for starting car tracking mobile application</td>
<td>Error message, no status of tracking is displayed</td>
</tr>
<tr>
<td>2</td>
<td>Request invalid road information (Enter invalid road name)</td>
<td>Error message, display page for sending request</td>
</tr>
<tr>
<td>3</td>
<td>Enter wrong stop request</td>
<td>Continue to display status of tracking</td>
</tr>
</tbody>
</table>

The goal of software industry is to develop software system that satisfies the needs of users and clients. The right implementation of the expected functionality of the system is an important amount of this satisfaction. Thus, it is vital to test the system in order to verify that it commits its functional requirements. This test phase is usually called system testing [23]. In current practice, use cases are associated with the front end of the software development lifecycle and test cases are typically associated with the latter part of the lifecycle. By leveraging use cases to generate test cases, however, testing teams started much earlier in the lifecycle, that allowed them to identify and repair defects that would be very costly to fix later, ship on time, and ensure that the system will work reliably [24].

3.4 System Development

3.4.1 Mobile Application

Mobile Application based on android platform was developed as a road data tracking and collection module for RIMS. Figure 4 gives an algorithm used to implement the mobile application. Source code created for the application is based on the steps and procedures provided in the flow chart. This enabled the module to function in relation to the RIMS requirements.

GPS receiver which is integrated within mobile phones was programmed as the source of location details. The details needed by RIMS include latitude, longitude, speed and time. Main class Pos_Provider was created purposely to handle location management issues. It is responsible for updating the location data in relation to the location of the mobile phone. Android provides access to the location details that can facilitate performance of the mobile application through, Location Manager, Location Listener and Location Provider classes [25].Whereby Location Manager class provides access to the system location services, Location Listener class is used for receiving notifications from the Location Manager when the location has changed, and Location Provider class provides periodic reports on the geographical location of the device. The collected location data are then processed in the format that can be easily understood. The processed information is then stored to the database saver. The resulted mobile application had ability to collect road information and sent them to MySQL database.

3.4.2 Data Processing and Storage

Collected road data from the mobile phones are stored in the database. Mobile phones registration to the database is considered at the beginning of the process to uniquely identify the phones as sensing probes. The server upon receipt of the request from road users or other systems concerning traffic situation on a specific road segment, the stored data are processed to give the
detected traffic condition to the requesting part. Figure 5 shows database schema for road data processing and storage. The database comprises of seven tables which works together in processing road data, and hence detection of traffic condition.

![Database Schema](image1.png)

Fig 5: RIMS Database Schema

### 3.4.3 Web Application

A connected road segment is a segment between two adjacent road intersections with enough vehicular traffic to ensure roads network connectivity [26]. The web application provides the status of traffic condition on a specific road segment. Existing physical road intersections forms the digital road segments by considering the junctions as entry and exit points. Figure 6 shows an algorithm for traffic information dissemination module.

![Algorithm](image2.png)

Fig 6: An Algorithm for Traffic Information Dissemination Module

The module allows selection for the name of the city and junctions of the road segment which its traffic status is needed. Based on the selected segment, the system calculates average speed and vehicle density of the past 20 seconds recorded data for that segment. The calculated values are then compared to the standard preset values to detect traffic conditions. The detected traffic conditions are then displayed as feedback message indicating whether there is traffic jam or not. The message can be one of these: (i) Traffic jam (ii) Slow motion or (iii) Free flow.

Derivation of the feedback messages are based on Kerner’s three phase traffic theory. The model FOTO (Forecasting of Traffic Objects) identifies traffic phases and performs tracking patterns of the traffic phase “synchronized flow”. The model ASDA (Automatic Tracking of Moving Traffic Jams) performs automatic tracking propagation of moving traffic jams. FOTO and ASDA models performs without any validation of model parameters in different environmental and traffic conditions [27]. As inputs, ASDA/FOTO model needs traffic volumes and speeds; the output is the current situation of traffic objects over the detected section.
Measured components for detecting traffic condition are velocity $v$, density $\rho$ and flow rate $q$ of vehicles [28]. They are related as shown in equation 1.

$$q = \rho v$$

(1)

The ASDA/ FOTO model analyses average speeds and flow rates. Traffic phases are identified based on the following rules:

(i) Synchronized/Slow Motion is detected, when $v \leq v_{fam}$

(ii) Wide moving jam/Traffic Jam is detected, when $v_{fam} < v \leq v_{2fm}$ and $q > q_{fam}$

(iii) Free flow is detected, when $v > v_{2fm}$

Whereby $v$ and $q$ are average speed and flow rate measured at each time step. The speeds $v_{fam}$, $v_{2fm}$ and the flow rate $q_{fam}$ are model parameters.

The results indicated that three modules of RIMS when integrated together, they enable traffic management according to the real-time situation occurring on the road. Furthermore, the proposed RIMS architecture is expected to improve the quality of traffic management procedures and hence reduce traffic congestion problem which is currently affecting the countries’ economy.

4. CONCLUSION AND FUTURE WORKS

An informed road user can avoid problem areas and not only make their trip better, but for the case of drivers it helps lessen overall road traffic congestion. Despite the challenges brought by traffic jams, most of the available systems for road information management require construction of physical infrastructures across the roads, expensive hardware and software setups. In this paper a cost effective system design and development has been considered. The design is targeting a developing country Tanzania, where there is a rapid growth of mobile phone utilization, the same way it is happening to other developing countries. Mobile phones are diffusing rapidly, but research conceptualizations have been lagging behind practice, particularly those that link mobile phones to livelihoods [8]. To fill the gap of proper utilization of mobile phones to solve problems of the poor, where traffic congestion is among the problems, this paper has explained in details the system design and development procedures that can be followed to implement a real-time road information management technique with the main focus on traffic congestion mitigation. We have indicated that road information is collected using mobile phones which are all the time available on the roads. Object oriented design and development has also been considered, in order to widen the selection of various open source software. For future work the developed system should be tested and implemented to measure its performance in a realistic situation. Also further work should consider integrating the processed real-time road information to the traffic light control systems. This will enable the traffic light systems to control traffic flow in relation to the real-time situation of the road.

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