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Prediction of Travel Time Using Fuzzy Logic Paradigm

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ABSTRACT

Predicting travel time is an important aspect of human life. It helps to effectively manage and successfully make the most of time. So much time is usually spent on the road when travelling from one place to another, particularly in developing countries and in a mega city like Lagos for example, a little time wasted is a lot of money lost, hence the need to envisage the likely time to reach destinations.

This research work explores the robustness of fuzzy logic to predict travel time on all major routes out of the town where the Engineering faculty of Lagos State University is situated. This paper takes into consideration important factors that can lead to delay in travel time; period of day, weather, car density, and construction, as the fuzzy inputs and based on experience, fuzzy rules are generated to give an estimated time of arrival.

To prove the validity of this work, data were collected from frequent road users and co-efficient of determination was calculated for all three routes. The co-efficient of determination ranked above 90% for all three routes, two of which are discussed.

Keywords: travel time, fuzzy logic, fuzzification, inference, defuzzication, car density, weather, construction, time of day.

1 Introduction

Free flow travel speed is one of the factors that affect travel time. However, the journey speed along an arterial road depends not only on the arterial road geometry but also on the traffic flow characteristics and traffic signal coordination **[1].** Other main factors related to travel time prediction that have also been cited in previous studies include holiday and special incidents, signal delay, weather conditions, traffic operation (disturbed level) and congestion level (traffic flow) **[2,3,4]**.

Direct travel time measurement has only been carried out under regional travel time research projects, mainly in USA and Western Europe in a limited selection of corridors. With few exceptions, the availability of valid travel time databases is very limited. This lack of ground truth data has been a recurrent problem for practitioners in developing and validating their road management schemes **[5]**.

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In the past decades, researchers have been actively investigating how to estimate and predict travel time using numerous technologies and algorithms. Many algorithms performed with good accuracy in estimating travel time on freeways under incident and non-incident situations. However, the research of travel time estimation on main roads with signal intersections needs further work. Since vehicles may experience delays caused by intersection control, queue build up problems at intersection, lane drop at intersection, and bottleneck on the downstream link, it is more complicated to estimate the real time travel time on arterial streets than on freeway.

A travel time estimation procedure was developed which can be used for both peak, off-peak, and transition period traffic flow conditions. The methodology proposed is based on using fuzzy logic for the estimation of travel time from flow data obtained from history and experience. The model estimates speed and travel time as a function of time directly from flow measurements. This research incorporated several modifications to this theoretical model such that the model can be used for long analysis intervals and for varying traffic flow conditions. The proposed model is based on the effects of car density, weather, construction and time and day of the week. An estimated time of arrival for all the vehicles that travel during a particular time interval between two selected locations was calculated as output.

There are several methods available for the prediction of travel time, and they can be broadly classified into historic profile approaches, regression analysis, time series analysis, and Artificial Neural Network (ANN) and fuzzy logic models. This study involves the prediction of travel time using fuzzy logic.

Fuzzy Logic is a simple yet very powerful problem-solving technique with extensive applicability. It is currently used in the fields of business, systems control, electronics and traffic engineering. The technique can be used to generate solutions to problems based on "vague, ambiguous, qualitative, incomplete or imprecise information" **[6].** This concept was developed by Lotfi Zadeh in 1965. Fuzzy Logic helps to solve the problem generated by binary logic which classifies statements as either 'true' or 'false'. Fuzzy logic allows a statement to be partially true or partially false removing the crisp boundary that traditional binary logic creates. For example, for a statement 'I like my food hot', the question may arise as how hot is hot. Fuzzy logic defines a food temperature of 50^{o}c as partially hot and at the same time partially cold. In fuzzy logic, everything is a matter of degree. Fuzzy logic mimics human control logic and is based on natural language.

Fuzzy logic finds application in many areas e.g. predicting genetic traits, bus time-tables, antilock braking system, medical diagnoses, economics, agriculture, meteorology, aerospace, geology, computer software etc. One of the most popular applications of fuzzy logic is that of the Sendai Subway system in Sendai, Japan. Hence fuzzy logic is used to predict travel time on routes that leads to Epe, a town in Lagos State.

Predicting travel time has been exploited in time past using several methods. Traffic data can be obtained historically, from loop detectors, registration plate matching technique, which recognizes plate number between check points and then measure the time taken; Automatic vehicle identification (AVI) transponders are located inside a vehicle and are used in electronic toll collection applications. A practical case of signpost-based system in Sydney is ANTTS (Automatic Network Travel Time System) **[7].** Other method includes: inductance loops, weigh-in-motion stations, or aerial video to estimate or calculate travel time. However, this research is not as considered about method of accumulating traffic data than the technique of predicting the travel time. Many research studies have used ANN techniques to estimate and predict travel-time that includes Advanced Neural Network and Mix-structure Neural Network **[8, 9]**.

In Anderson and Bell's study, they used traffic data from registration plate survey, traffic detectors and simulation software, VISSIM, to develop Neural Network estimation techniques and a queuing model for travel-time prediction in urban road networks. However, this research used fuzzy logic to estimate historical traffic data and to predict travel time on the roads specified.

2 Methodology

Fuzzy logic inference system was used in this project for predicting travel time. Fuzzy logic, the ultimate subject of this text, was developed to accommodate sentences containing vague predicates (as well as other vague parts of speech). One of the defining characteristics of fuzzy logic is that it admits truth-values other than true and false; in fact it admits infinitely many truth-values. Fuzzy logic does not assume the Principle of Bivalence **[10].**

Fuzzy logic interference systems are of two types namely: Mamdani and Sugeno. Mamdani inference style is used in this paper as it is more intuitive, has widespread acceptance and better suited to human input. Fuzzy inference system is divided into: Fuzzification, inference which includes aggregation and implication and then defuzzification.

Fuzzification is the process of determining the degree to which each input belongs to each of the appropriate fuzzy sets through membership functions. It converts a crisp numerical value from the universe of discourse of the input variable into a linguistic variable and corresponding level of belief. Inference implies the generation of rules and assigning weight to each rule using fuzzy operators.

Aggregation serves as the input to the defuzzication process. It involves making into fuzzy set, the output of each rule. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. Each rule gives an output which is aggregated; the output of the aggregation process is one fuzzy set for each output variable.

The process of converting these fuzzy sets back to a crisp value is known as defuzzification. Matlab fuzzy logic toolbox is used to design the prediction mechanism.

2.1 Input Space

The input variables to be considered are the factors that affect travel time which are time of the day, weather, car density and construction, while time of arrival is the output variable. The variables are then categorized into domains known as fuzzy sets. Table 1 shows the fuzzy sets defined in this system.

Table 1. Fuzzy sets used in predicting time travel.

Time	Weather	Car Density	Construction
Off peak	Clear	Low	None
Semi peak	Light rain	Medium	Minor
Peak	Heavy rain	High	Major

Input membership functions are then selected to accurately define the fuzzy sets. Membership functions are curves that determine the degree to which each i0nput belongs to a fuzzy set. Various membership functions were used in this research as provided by fuzzy logic Toolbox. E.g. triangular membership function (trimf), z-membership function (zmf) and s-membership function (smf). Others include guassmf, guass2mf, trapmf, dsigmf, sigmf, psigmf, gbellmf, pimf. The synopsis of the input membership functions used is shown below.

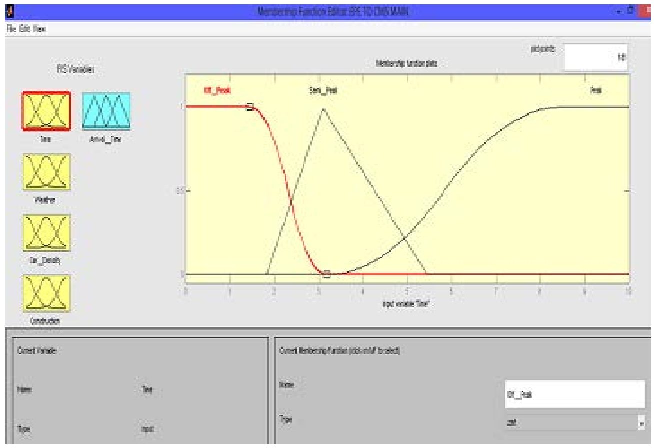

Figure 1. Input membership function

2.2 Output Space

The membership function description of the output space i.e.arrival time is considered in this section. All linguistic terms are described using the triangular membership function curves. A total of 81 rules were exhaustively used for this road. These rules combined all possible condtions that could ever happen using all the input variables.

2.3 Rule Construction

The rules are described using the "If (precedent), then (antecedent)" format. Examples of situations that could result are TIME: off peak, WEATHER: clear weather, CAR DENSITY: low car density and CONSTRUCTION: no construction, TIME: semi peak, WEATHER: heavy rain, CAR DENSITY: high car density, CONSTRUCTION: minor construction, to mention a few.

3 Result Analysis

As earlier mentioned, the three roads considered were CMS-Epe road, Ketu- Epe road and Ijebu-Ode-Epe road. A collection of data was carried out before the commencement of simulation. These data were collected through examination of the roads, interview of drivers that regularly ply these roads, visits to Lagos State Drivers Institute (Epe Branch) and also the internet. To predict the time of arrival, the rule view is used and three different situations are considered for each road.

3.1 Siuation Comparism for the three roads

Situation 1:this situation occurs when the rules says it is peak period, clear weather, low car density and no construction on the road. This situation is entered as [0 0 0 0] in the rule view of matlab fuzzy logic toolbox and the output which is the estimated time of arrival is 99.5 minutes.

Situation 2: It happens when the rule says it is peak period, there is heavy rain, high car density and a major construction. This situation represents worst conditions and is entered as [10 10 10 10] in the rule view. The output shows 203 minutes or 3 hours 23 minutes.

Situation 3: when the rule says the it is off-peak, there is heavy rain, low car density and a major construction. The output shows that it will take 127 minutes or 2hours 7 minutes.this is inputted as [0 10 0 10]. The figure below shows the result of the rule view.0

The estimated time of arrival for the other two roads are shown in Table 2.

Table 2. Arrival Time for the 3 situations

Situation	Epe-CMS (mins)	Epe-Ketu (mins)	Epe-Ijebu-Ode (mins)
[0 0 0 0]	99.5	99.5	46.4
[0 10 0 10]	127	142	92.3
[10 10 10 10]	203	203	100

3.2 Relationship Between the Input Variables

The relationship between the inputs variables such as the 'Time_and_Day', 'Weather', 'Car Density' ,and 'Construction' and 'Arrival_time' can be shown using the surface viewer of the matlab® fuzzy logic toolbox.

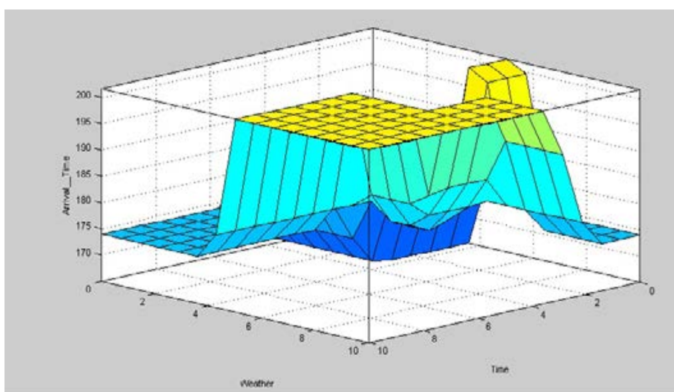

Figure 2. Weather against Time

Figure 2. shows the relationship between weather and time and how it affects the arrival time for the CMS_EPE route. Weather takes into consideration that although there may be a forecast of rainfall, the effect of light rain on the time of arrival, clearly differs from when the rainfall is heavy. Variations also occur during transitions from off-peak periods through semi-peak to peak periods. Analysing the individual effects of the inputs on the time of arrival would be considered simple to do but in a real life scenario that doesn't apply, but from the three-dimensional graph above, it is evident that at the peak of the day and at worst weather conditions the time of arrival is greatly affected i.e time of arrival is very late. There is a gradual and then steep rise in the curve of the weather as the weather grows worse but the effect is dependent on the period of the day. For example, the arrival time will be slightly affected when the rainfall is heavy in an off-peak period.

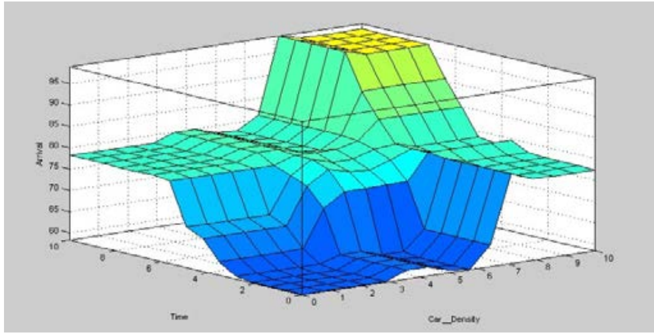

Figure 3. Weather against Time

Figure 3. shows the effects of 'time' and 'Car-density' on the EPE-IJEBU route. Obviously, when observing the action of time on arrival, it is seen that the time of arrival increases, and the same goes with the effect of car_density alone. Bank holidays and festive periods were taken into consideration in the determination of the effect of car density on the time of arrival. The fuzzified effect of both inputs can also be observed from the three-dimensional graph above. The time of arrival increses as both inputs increases.

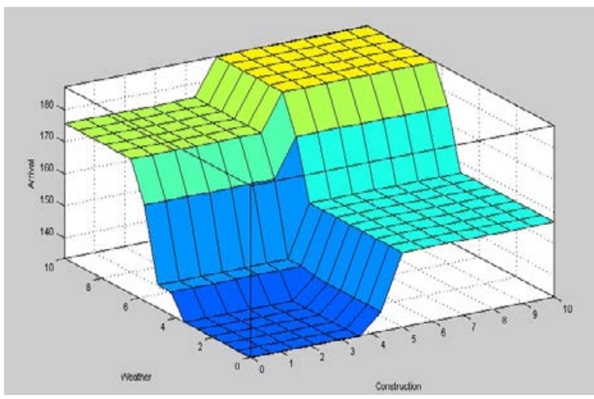

Figure 4. Weather against Construction

Weather against construction is considered for EPE-KETU route. Construction and weather are major impediments on lagos routes and a sharp increase is seen on the time of arrival as light rain graduates into heavy rain and as construction moves from minor to major. The effect of major construction is definite as that speaks of the flat bed observed from the point of 5-10 on the y-axis. The arrival time is very late as both inputs reach their peak conditions. With the absolute absence of construction and on a clear weather day, the arrival time is observed to be reasonably early.

3.3 Confirmation of Result Obtained using the Discussed Approach

The results of the prediction is compared with data collected from frequent road user via questionnaires. Questionnaires were issued to commercial cab/bus driver to know their time of arrival on specific situations.

Table 3. Predicted Time of Arrival vs. Collected Time of Arrival for Epe- Ketu

Time	Weather	Car Density	Construction	Predicted Time of arrival (mins)	Collected time of Arrival (mins)
off peak	clear weather	low car density	no construction.	99	100
off peak	heavy rain	low car density	no construction	142	148
semi-peak	clear weather	medium car density	no construction	133	142
semi peak	light rain	medium car density	major construction	157	143
Peak	heavy rain	low car density	major construction	174	178
semi-peak	heavy rain	medium car density	major construction	187	190
Peak	light rain	low car density	major construction	165	164
off-peak	light rain	low car density	minor construction	127	125
Peak	Clear	low car density	major construction	156	159
Peak	heavy rain	high car density	major construction	203	208

The co-efficient of determination calculated for the data for Ketu-Epe road is 0.9812. This demonstrates that the linear equation $1.0592x - 7.2950$ predicts 98% of the variance in the collected time of arrival.

Coefficient of determination, or R^2 (pronounced r-square) was calculated for this data. This statistic indicates how closely values we obtained from fitting a model match the dependent variable the model is intended to predict. Statisticians often define R^2 using the residual variance from a fitted model:

$$R^2 = 1 - \frac{\text{SSresid}}{\text{SStotal}}$$

SSresid is the sum of the squared residuals from the regression.

SStotal is the sum of the squared differences from the mean of the dependent variable (*total sum of squares*).

The co-efficient of determination for the data for Epe-Cms reads 0.9467. This demonstrates that the linear equation $1.0133x - 0.6445$ predicts 96% of the variance in the collected time of arrival.

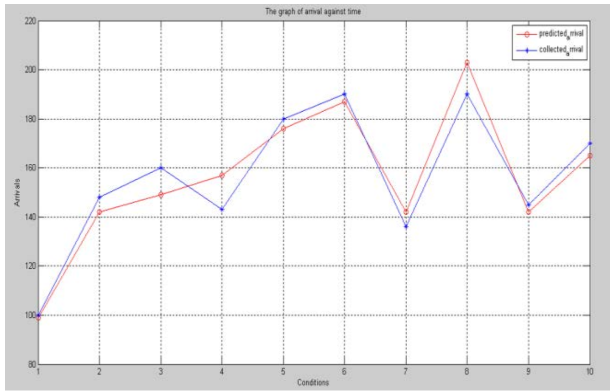

Figure 5. Graph showing relationship between predicted arrival and collected arrival for Epe-Ketu

Table 4. Predicted Time of Arrival vs. Collected Time of Arrival for Epe- Ijebu-Ode

Time	Weather	Car Density	Construction	Predicted Time of arrival (mins)	Collected tie of Arrival (mins)
off peak	clear weather	low car density	no construction	99	96
off peak	heavy rain	medium car density	no construction	127	130
semi-peak	clear weather	medium car density	no construction	165	167
semi-peak	light rain	medium car density	major construction	182	190
Peak	heavy rain	low car density	major construction	202	205
semi-peak	heavy rain	medium car density	major construction	202	200
Peak	light rain	low car density	major construction	165	170
off-peak	light rain	low car density	minor construction	152	145
Peak	Clear	low car density	major construction	174	185
Peak	heavy rain	high car density	major construction	203	209

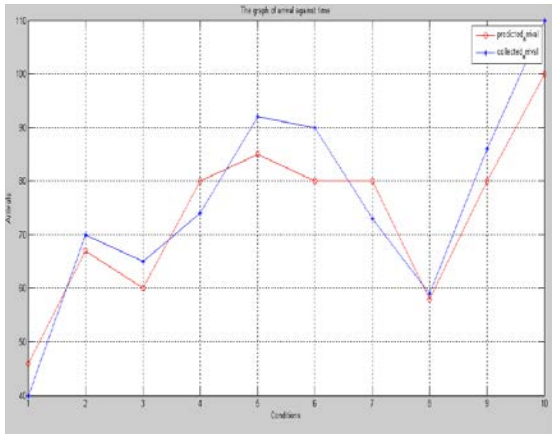

Figure 6. Graph showing relationship between predicted arrival and collected arrival for Epe-Ijebu-Ode

The co-efficient of determination for the data collected for Epe-Ijebu-Ode road reads 0.9114. This demonstrates that the linear equation $1.1912x - 11.7688$ predicts 91% of the variance in the collected time of arrival.

4 Conclusion

It can be concluded that the fuzzy logic paradigm approach to travel time prediction is very robust and even with not very precise input variables, we are still able to obtain near accurate output as seen from the coefficient of determination of the results obtained. Further work can be done to extend this model to other major roads and include more input variables for greater accuracy and resilience in computation.

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