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Research Paper

Analysis and Evaluation of the Technical and Economic Application of RFID, GPS and GIS in Road Transportation

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Abstract

Today, with the growing population and increasing demand for the use of private cars, managing the demand without the use of smart electronic devices, will be complicated and somewhat impossible. One of the methods of demand management is the use of intelligent traffic control systems and pricing accordingly. In this research, in addition to investigating the use of intelligent radio frequency identification systems (RFID), geographic information systems (GIS), and global positioning systems (GPS) in road transportation, a model has been presented to obtain appropriate values. The toll rate and pricing based on the car's useful presence time in the high-traffic area are introduced using smart systems and the use of the Laspeyres index economic relation is presented as an innovation in this research. From the results of this research, we can mention the reduction of vehicle density in the region, improvement of vehicle control in the city, and encouraging people to use the public transportation system.

Keywords: road transportation; crowdedness Pricing; Radio Identification System (RFID); Global Positioning System (GPS); Geographic Information System (GIS); Demand Management

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1. Introduction

Today more than at any time in history, the term time is used in human's daily dialogue. This is due to the fact that it is now established in everyone's belief that the progress and development of countries have been due to the time-saving policies that their authorities or individuals had conducted. It is well known that in the past 400 hundred years, countries with more canals and inland waterways experienced dramatic progress in various aspects which is mainly due to cost efficiency in their transportation in addition to saving time and effort. However, regarding the present time, due to the progress in automobile engineering [Chandran, and Joshi, 2016, Ahmadian, 2017] and hence the highways and bridges [Li et al.2014], in addition to waterways [Charles, 1965], a new concern has emerged regarding transport and commutation. The problem that every community is facing in this regard is due to the population increase [Olstrup et al.2018]. An increase in the population is directly proportional to road traffic congestion which would result in harmful environmental pollution [ko, Myung, 2019], in addition to social [Oguchi et al.2011] and economic costs [Bin hu et al.2009].

The recent progress in intelligent systems has paved the way for enabling coordination in addition to controlling issues regarding traffic congestion. Now since the attitude of a driver is affected by various external players namely the physical conditions of the street and the weather conditions together with the traffic rules, a simulation in this context has been named the "intelligent drivers model" [Treiber et al.2000]. In the present study, an intelligent system has been proposed in the context of transport regarding controllers and coordinators that improve issues in the context of road congestion. The aim is to provide a model to reduce the economic and social marginal costs by encouraging people to use public transportation in order to experience an emergence of a new culture in public transport in the community.

In the current research, the aim is to explain the role of different actors in improving traffic congestion due to the use of intelligent systems. In this way, a pricing model has been proposed to reduce congestion, which is based on the cooperation of introduced intelligent systems. The radio frequency identification system provides a suitable platform for object identification, data collection, and object management. The Global Positioning Satellite System is also a positioning system that uses several satellites that, by implementing the triangulation method, determine the exact location of the person to whom the mobile receiver is connected. The GIS provides access to all information by storing geographic information. Therefore, any changes, modifications, and actions of other operators can be considered. Before proceeding, it is worth explaining the theory of electromagnetic waves. In 1846, Faraday discovered that light and radio waves were part of the electromagnetic energy spectrum, paving the way for Maxwell to present his theory of electromagnetic waves in 1864. However, it was not until 1896 that Marconi succeeded in sending and receiving radio waves in both directions. The Atlantic In 1944, equipped a combat aircraft with a radio identification system as large as a luggage bag to detect enemy planes. In 1948, Henry Stockman raised the idea of introducing a radio identification system in communication, which was termed "communication by radiant power". This led to further advancements in the use of radio waves, which implemented a one-way transmitter and receiver to control the origin of goods. In the 1980s, the radio identification system was used to control the movement of vehicles and the movement of company employees in Norway. A radio identification system was used within ID cards in 2003 before enabling identifying people by chip injections under the human skin 2005, see ref [24] and references therein. In 2006, the books of the Central Library of Munich (Germany) were equipped with the label of the radio identification system, and the "Smart Library" was exploited. Yang and Huang (2005) presented various methods for obtaining the amount of toll together with the position of the ring roads [Yang, huang, 2005]. Zhou Yang and Mark L.Franz (2018) analyzed Washington DC taxi demand using Gps and land-use data which showed a strong link between the demand for taxis, land-use patterns, and accessibility to other modes. They also found that the taxi mode of travel is likely to complement subway trips but compete with bus trips [Yang et al.2018]. Philip T. Blythe (2000) provided insight into the use of in-vehicle tags and transmitters to facilitate road travel. Vehicle data communication for electronic pricing systems and road usage, as well as pricing of trucks by the amount of load, moved have been modeled [Blythe, 2000]. In another research, Sadeghian et al. reviewed methods in transport mode detection based on GPS tracking data [Sadeghian et al.2021]. Also, Subramanya et al. evaluated E-Ticketing Technology in the Construction of Highway Projects [Subramanya et al.2022].

Currently, the aim is to provide a method that, in addition to considering the opinion of experts in transportation matters, uses the influential factors in crowded areas to measure the importance of each factor. The amount of casualties is obtained by going through a correlation theory based on previous studies and using the Laspeyres index method [Laspeyres, 1890] according to the distance traveled and the duration of being in the area. In past studies, instead of other control tools, to predict traffic jams and receive tolls, traditional and annual methods were used. Therefore, it is problematic to update the system according to the passed variables. Collecting tolls traditionally and semi-electronically in different ways, including field observations and traffic counting, which is a very costly and time-consuming solution, and the more important problem is that there is no focus on the presence of vehicles in the crowded area. In this research, the tolls received from passing vehicles are more accurately compared to the traditional methods in shorter periods by using modern equipment and calculating the number of tolls and it is received as a variable for different periods of the year.

2. Materials and Methods

The first step in determining a suitable system for pricing is determining the effective factors in the region, which should be identified and evaluated by experts and researchers. In this study, based on the summary of similar records and expert opinions, the following factors are included in the proposed model. Additionally, considering the characteristics of the target area, the basic information of the desired range is extracted from organizations and statistical websites and incorporated into the proposed model. This model uses a non-linear programming pricing model [Blythe, 2000] instead of using the usual two-level model [Bazaraa et al.2010] to determine the amount of charges. bilevel (two-level) linear programming (blp) is an optimization problem in which the decision changes in the optimal set become a second-level optimization problem and has continuous changes and linear objective functions. In general, it can be said that in one-level planning, there is a decision maker and he decides on all the variables and all the resources are at his disposal. For this reason, this type of planning is called centralized planning. But, two-level planning is a useful tool for modeling decentralized decision-making. This model reduces the problems of finding the amount of complications [Verhoef, 2000 and, Hern and Ramana, 1998].

The methodology is as follows:

after selecting the influential factors based on the specified range and considering the pricing model and expert opinions, the weight of each factor is determined. Finally, using a hierarchical method, the importance percentage of each mentioned factor is obtained.

3. Case Study

A case study was conducted in District 11 of Tehran Municipality, the capital city of Iran. The study area covers the southern part of Valiasr Street, from Rah Ahan Square to Theatre Shahr Intersection. The reason for selecting this area is its high traffic flow as it is one of the busiest areas in Tehran. All traffic control plans and transportation modes, including high-speed bus lines and subway lines, are implemented in this area, making it a significant area in the city. The study area is depicted in Figure 1.

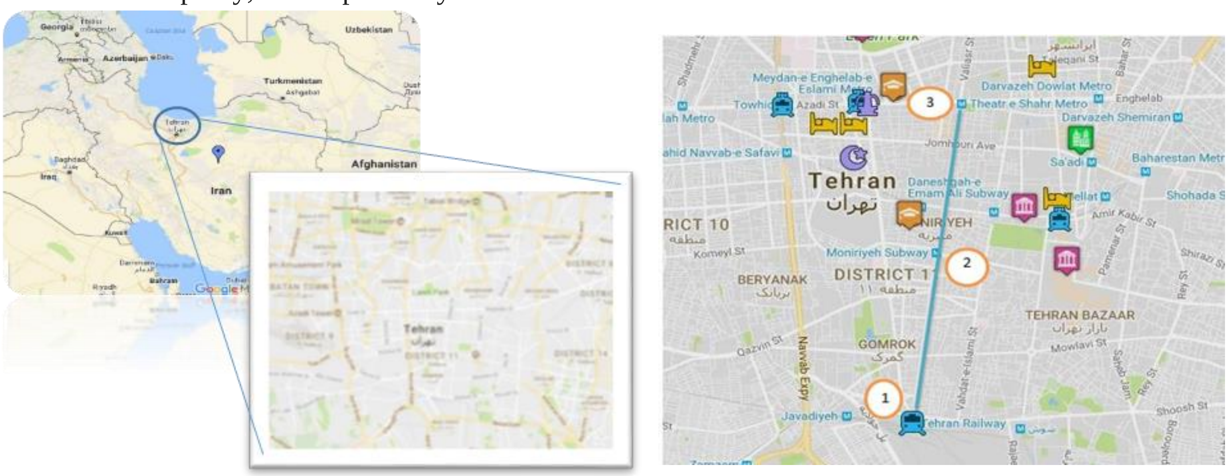

Figure 1. Scope and zoning

In this research, the study area is divided into three zones based on land use. Each land use category contributes to the traffic factors within the specified area, and pricing can be determined accordingly. The mentioned area encompasses all land uses except industrial. The area is divided into the following three zones:

Zone 1: Between the origin (Rah Ahan Square) and the destination (Muniriyeh Square), predominantly residential land use.

Zone 2: Between Moniriyeh Square to the intersection of Jomhuri Street. The dominant land use in this zone is commercial.

Zone 3: From the Jomhuri intersection to the Theatre Shahr intersection, including the intersection of Enqelab Street and Valiasr Street. The dominant land use in this zone is commercial and administrative.

After the zoning based on land use, the distance of each zone is determined using local surveys and Google Maps. Also, the distance traveled by each vehicle can be measured using smart electronic devices to assess the duration of presence and congestion in the designated area. Finally, after determining the distance of each zone, it is necessary to calculate the duration of vehicle presence in each zone. This information can be obtained from the intelligent systems introduced in this study. Moreover, the level of useful presence time in each zone will be determined according to expert opinions and incorporated into the pricing model.

The travel time is calculated based on the design speed limit of the studied area and the length of the route without considering the stop times. Information regarding travel attractions, car ownership, and population in the studied area was obtained through the Tehran Atlas and consulting the relevant municipality. It should be noted that the accessible information on the mentioned website has a one-year delay. The data used in this study corresponds to the years 1393-1394. The information is presented in Tables 1 to 4. By using the acquired information and the weight coefficient of each factor, it is possible to prioritize the factors related to congestion in different regions.

Table 1. Regional Population Specifications

Population (people)	area
110032	First area
75365	Second area
110781	Third area
296178	Total

Table 2. Travel Attraction Level of the Studied Regions

Travel attraction	area
1200	First area
1000	Second area
1700	Third area
3900	Total

Table 3. Ownership and number of vehicles by Region

Car (number)	area
38511	First area
18841	Second area
44312	Third area
101664	Total

Table 4. The travel time between Regions at 40 km/h

Travel time (s)	area
425	First area
276	Second area
423	Third area
1125	Total

The factors directly affecting traffic congestion in the designated area, according to transportation experts and previous studies, can be classified as follows:

- Travel attraction level by region
- Number of vehicles in each region based on resident households in the area
- Population of each region
- Travel time between each region

Note: Volume-to-capacity ratio (if less than zero, the area is not congested and is not included in the calculations)

Based on the defined factors and the obtained coefficients for each factor, a simple linear mathematical relationship between the factors can be derived using the hierarchical method. The relationships for each index are as follows:

A) Burden indicator for each area

$$Pz = \sum_{1}^{n} \alpha_{S_i} * S_i \tag{1}$$

Using Eq. (1), the values of each factor specified in Table 2 are multiplied by the assigned importance coefficients, resulting in the congestion index for each region.

The Variables are defined as follows:

S_1: Travel attraction level by region

S_2: Number of vehicles in each region based on resident households in the area

S_3: population of each region

S_4: Travel time between each region

α_{si}: Coefficients and weights of the influencing factors in the pricing model

S_i: Percentage of the importance of extracted factors

B) The amount of basic toll

The amount of toll in crowded areas should be determined according to studies and the needs of the area. In this study, since the magnitude of the toll for each area is not specified, the base price is selected based on the most cost-effective mode of transport on the studied route.

C) Reference Price Index Ratio

According to equation (1) and considering the volume-to-capacity ratio, the region with a value closer to one has a higher congestion level and volume. To determine this congestion level, the reference price index ratio is calculated by dividing the price index of the origin region by the price index of the destination region. It should be noted that the region with a lower price index is considered as the origin in the equation.

$$k_{od} = \frac{k_{po}}{k_{pd}} \quad (2)$$

Where the variables are described as follows:

k_{po}: Price index of the origin or base area (minimum value)

k_{pd}: Price index of the destination area

Finally, the maximum obtained value close to one is considered as the reference price index.

D) The price index of each area

Using equation 2, known as the Laspeyres equation, after determining the reference price index for the base area, to obtain the price index of each other area, first calculate the ratio of their indices similar to equation (3). Divide the obtained value by the reference price index ratio and multiply it by the assumed base price between the areas. The entry price between those two areas is calculated.

$$\beta_{od} = \frac{k_{od}}{k_{ods}} \times \beta \quad (3)$$

In this equation, the variables are described as follows:

k_{od}: The price index of each area based on equation (2)

k_{ods}: Base price index

β: Assumed base price

Now, if there is a route passing through different areas, the sum of the price indices of each area is calculated according to equation (4).

$$\beta_{od} = \sum_{i=1}^{n} \beta_{odi} \quad (4)$$

Despite the radio identification system, the global positioning system, and the geographic information system that record the distance and entry time into the area, it is sufficient to calculate the congestion price based on equation 5 for the busiest route in terms of distance between the origin and the congested area and the price per traversal is obtained based on the congestion area.

$$\beta_{odu} = \frac{\beta_{od}}{x(m)} \quad (5)$$

4. Results

After determining the assigned weight coefficients and their importance using the hierarchical method, the importance degree of each factor will be obtained as described in Table 5.

Table 5. The coefficients of the factors and the defined weights based on their importance in the relevant area

	Car ownership	Trip time	Population	Travel attraction
coefficients of the factors	25%	15%	25%	35%
The degree of importance	2	3	2	1

Table 6. Price Index of Regions

area	Price Index
First area	37622
Second area	23944
Third area	39411

4.1. The Basis of the Congestion of Each Area

Using Eq. (1), the values for each of the factors introduced by the tables multiplied by the assigned importance coefficient the price index of each area is determined.

It should be noted that a region with a lower price index is selected as the origin. By using the obtained information, the price index for each area is calculated according to Table 6.

These numbers indicate the level of traffic and congestion in each area based on the factors influencing the research in that region. Accordingly, entering a busier area will require paying higher fees.

According to equation (1) and considering the volume-to-capacity ratio of each area, the area with a value closer to one for the price indices between the two areas is considered the more congested area. To determine the level of congestion, the price index of the origin area is divided by the price index of the destination area in each region, and the ratio of the reference price index for the most congested and critical path is determined. It should be noted that the area with a lower price index should be considered as the origin in the equation.

Finally, the highest obtained value close to one is considered as the reference price index.

Table 7. The price indices between the areas

Price index	Area
0.64	1st and 2nd area
0.61	2nd and 3rd area
0.95	1st and 3rd areas

As observed, the first and third areas have the highest values, which can be considered as congested areas for pricing purposes. Thus, Area 1 is the numerator and Area 3 is the denominator, and the reference price index is obtained for the two congested areas.

To price the plan as the baseline cost of the proposed pattern, the cost of using a taxi as the most expensive and congested mode of transportation for the most congested path is considered, with a base fare of 10,000 Tomans as the revenue from the path, and the baseline cost (β) is taken into account.

In equation (3), the ratio of the price index of the desired path is calculated according to equation (2), and the result is divided by the ratio of the price index of the most congested path (Area 1 and 3), and the obtained number is multiplied by the revenue base cost. The resulting revenue is calculated and presented in Table 8.

Table 8. Tolls from the busy model introduced

Route tolls β_{odu} (Toman)	Baseline toll B (Toman)	The ratio of price indexes β_{od}	Base price index ratio (K_{ods})	Passing areas	Route number
10000	10000	0.95	0.95	1-3	1
6667		0.633		1-2	2
6364		0.604		2-3	3

As observed, higher revenues are collected for entering areas with higher travel attractions. Furthermore, the distances of the paths using private vehicles and satellite imagery are shown in Table 8. The highest cost obtained from the revenues, as shown in Table 7, is calculated based on the distance of the path, and the prices are listed according to the distance in the table. The other paths are calculated based on their respective distances and the price based on the distance of the most congested path.

Table 9. Routes Distance

Distance (m)	Area
4926	1st to 2nd areas
3170	2nd and 3rd areas
8096	1st and 3rd areas

Table 10. Prices in terms of the route length

Cost of mileage (Toman)	area
0.75	First area
0.48	second area
1.24	Third area

According to equation (4), first, the revenue collected from the most congested path, i.e., Path 1 to 3 (βodu), is divided by the distance between these two areas according to Table 9. It is considered as the baseline price based on the traveled distance, and the remaining areas are calculated relative to the specified revenue base cost and listed in Table 10.

The obtained fees for each area are calculated based on the travel time between the origin and destination of that area without considering the additional delay time on the route, which is provided in Table 13. For each additional presence, including the distance traveled and the additional time spent in the area, higher fees are charged relative to the specified amounts.

5. Discussion and Conclusion

In this study, the formula for determining price indices and prices based on distance and presence time in the desired area was determined using the economic price indices of Laspeyres and the variables and constraints of previous pricing models. Intelligent devices were introduced in this research, which can record the duration of a vehicle's presence in the area and the distance traveled on the route. Based on the basic information of that area, they calculate the pricing based on the congestion level of the area. In fact, to calculate how much this vehicle contributes to the congestion of the area, radio identification systems, along with code readers, register the entry and exit of the vehicle at the entry and exit points of each area. The required time for passing through the areas, including travel time based on the planned speed on the route and time wasted due to vehicle stops on the route, traffic lights, tolls on the route, etc., are included in the allowable route times. Times exceeding the defined times are considered as receiving additional fees compared to the defined fees. If a vehicle has a longer presence time in the area, calculated without stopping time plus authorized stops such as traffic lights and speed breakers, it will incur higher fees.

For comparison and based on the obtained distances and prices in Tables 9 and 10 for a trip from the first area to the third area, as well as the cost of public transportation according to Table 11 and equation (6), the cost of the trip with private vehicles to different transportation modes will be determined.

$$A = \frac{P * X}{G} \quad (6)$$

P = determined cost according to third region scrolling based on table 10 (1.24)
X = the third region scrolling (8096 meters)
G = transportation cost at the third region according to Table 11.

Table 11. Travel costs

The proportion of travel expenses by personal means to public transport	Passenger Passage Traffic Vehicle in the Third Occupied Area (Toman) (G)	The Device
20	500	BRT
14	700	SUBWAY
4	2500	TAXI

Based on the updated costs (table 11), considering the route distance, traveling by private vehicle is respectively 20, 14, and 4 times more expensive rather than the BRT, Subway, and Taxi transportation modes.

A result of this research is decreasing the region's crowded by up to 50%, the crowding of the region is due to stopped cars for long times. Made studies of the region indicate that most trips were done by private vehicle for commercial purposes and it can be done by other transportation modes.

By the implementation of this study, reducing congestion, improving vehicle control within the city limits, encouraging people to use public transportation system instead of private vehicles, decreasing air pollution, updating the urban traffic control, increasing the government income, more efficiency and less fuel consumption, controlling the passing cars about insurance coverage and technical examination and the implement of low emission zone (Green Zone based on vehicles pollution) will be obtained.

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