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RESEARCH PAPER

A Novel Approach to Achieve Near-optimal Traffic Distribution by Distributed Decision Making

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ABSTRACT

The distribution of traffic in road network is called traffic assignment (TA). Finding an optional distribution of traffic in the road network is called traffic assignment problem (TAP). Advanced traveller information systems (ATIS) are designed to provide real time information enabling drivers to choose efficiently among routes and save travel time. If we provide travelers real time information, we may need rerouting and there may be a problem such as having congestion on the non-congested routes. Hence, by omitting the real time information provision we propose a TA method which will be able to allocate traffic based on the traveller's own perception of the road network. Travelers choose routes based on their own perception of road usages of the road network. This ensures distributed decision making and thus the traffic distribution becomes near optimal which enables travelers to reach their destinations within their expectations.

Key words: Advanced traveller information system, distributed decision making, Multi agent system, traffic assignment

Introduction

People frequently travel from origins to destinations. People travel from one place to another for numerous reasons. Trips are made for several reasons – going to office or work, shopping, education or training, dropping or picking up kids or companions, joining various events, going to restaurants or even for relaxing in parks or on beaches. These trips are often made by cars on roads. Thus traffic flow is created in the road networks. Road capacities are usually limited. When the traffic flow exceeds or approaches the capacity of a road, congestion occurs. Congestion increase travel time, on the other hand traveller wants to minimize their travel time. To reach the destination within a reasonable time, travelers strive to avoid congestions on their routes. There are usually a number of alternative routes between an origin and destination (OD) pair. Travelers take decisions about their routes so that they can reach destinations within their expected times. To travel from an origin to a destination i.e. between an OD pair, there may be numerous routes. Travelers usually choose their routes individualistically and may have some criteria. The criteria may include choosing the fastest route, choosing the inexpensive route or even choosing a scenic route. However, travelers often attempt to avoid congestion and reach the destinations within a reasonable time. A well-adjusted distribution of traffic can reduce the chance of congestion and also help travelers experience shorter travel times. For well-adjusted distribution, we have to gather knowledge about the road network and road capacities. Traffic assignment (TA) concerns itself with the selection of routes or paths between origins and destinations in a transportation network. The route selections of travelers between their OD pairs are the main objective of TA. TA results in a distribution of the travelers on the roads. A distribution of travelers for which everybody experiences minimal travel times and no traveller can minimize her travel time by unilaterally changing her route, is referred to as equilibrium or Wardrop's equilibrium (Wardrop & Whitehead, 1952). However, achieving an equilibrium is not a trivial task. Travel times that are fair on all travelers can be assured if the travelers sharing the same OD pair experience similar or equitable travel times.

Travelers usually have genuine expectations of how long the journey to their destinations would take if they regularly travel to the similar destination at a similar time of the day. The travel time experienced by a traveller can be considered as reasonable if the traveller reaches his/her destination within or close to the expected travel time.

Researchers have attempted to help travelers minimize their travel times by providing real time traffic information (Chmura & Pitz, 2006; Kitamura & Nakayama, 2007; Klügl & Bazzan, 2004; Selten et al., 2007), as well as by allowing communication with other travelers (Zhu et al., 2007). Both approaches are based on unrealistic assumptions as traffic information is incomplete given currently available technology and travelers cannot cooperate with all other parties involved. Therefore, we propose a technique for route choice which would not require to process real-time information. Moreover, in the proposed method, it would not be necessary for the travelers to communicate with the authority or other travelers. Travelers usually try to avoid congested roads to reach their destinations in a short time. If all travelers choose the non-congested routes based on current information, they eventually will face congestion. On the other hand, if most travelers choose the shortest route, they face the same problem. A balanced distribution of traffic can eliminate the chance of congestion and also help travelers experience shorter travel times. Travelers on the roads usually choose the routes to their destinations independently with the aim of minimizing their travel times.

The travelers are independent; they share limited information and try to minimize their travel times and thus, unwillingly, to form an equilibrium. Achieving the equilibrium is not a trivial task. Nonetheless, Challet and Zhang (1997) showed that their Minority Game (MG) model can achieve equilibrium among agents by self-organisation. The Minority Game is an easy model for the combined behavior of agents in a situation where agents compete for limited resource. The traditional MG is played by N (N is an odd number) number of agents who pick one of two substitutes to fall in the minority group (Challet & Zhang, 1997). The agents make independent decisions based on the history of winning alternatives. Agents do not communicate with each other for decision making and there is no central control over the agents. The authors showed that the agents self-organize over time. The scenario is very similar to a road traffic situation where travelers choose their routes independently and without communicating with each other most of the time.

There are usually various routes to arrive the destination. Some of the routes share the same links. Therefore, Challet and Zhang's traditional MG is not directly applicable optimize road traffic. To overcome this problem, Galib (2014) proposed Minority Game for Traffic Assignment (MGTA). In MGTA, for each link to the destination, each traveller has a set of predictors to anticipate the usage level of the links as a percentage of the link's capacity. A traveller also memorizes the usages of the links which she travelled previously which is called history of link usage. A predictor nearly maps a history of previous usage levels to a prediction of the present usage level (Galib, 2014). However, it has some limitation which is that MGTA is not always optimum. For this reason, we propose a method on the road network to help the travelers choose their routes and also distribute travelers optimally.

Methodology

People usually choose a common route which may create congestion. When people take independent decision for route choice, most of the time people usually choose a single route. If we can motivate travelers to choose their routes, we may be able to achieve a proper or near optimal distribution of traffic on the roads. A proper distribution of traffic may control congestion and also eliminate the chance of congestion on the road network.

Travelers may possess smart devices which can provide them route guidance towards their destinations. If these devices can be equipped with an algorithm which can ensure a distributed route decision, there may be a chance to obtain a fair distribution of traffic on the roads. Therefore we propose an algorithm which guides a traveller to the minimum cost (ratio of the free flow travel times and the capacities of the roads) path based on his/her own perception of the road network. Thus in this method, a traveller can take his/her independent route decision based on his/her own perception or the history of the road network.

When travelers on the road use smart devices which may have decision making software like a GPS system, these devices may guide the travelers in such a way so that optimal or near optimal traffic distribution can be achieved. We propose a novel algorithm that takes historical road usages into account and suggest routes to the travelers in such a way that each traveller has his/her own view of the road network and chooses the minimum cost path.

The road network

We considered a road network of Patuakhali Sadar from *LaunchGhat* to *Chourachta.* Fig. 1 shows the road network. There we can see that there are a number of alternatives routes from the source *Launch Ghat* to the destination *Chourachta*. We shall use this network to perform the survey and our proposed TA method.

Now, in Figure 1, we can see that the road network where Launch Ghat is the source and Chourachta is the destination. From the source to the destination there are many routes. There are some routes which have overlapping links meaning that the links are common between the routes. Even if different travelers make different route decisions, this may create congestion because of the common links.

The properties of each link or road are given in Table I. The link properties are the free flow travel time (FFTT) which is the time to travel through the link with the maximum permitted speed and the capacity of the road which is represented by vehicles per minute here.

We have shown the road network with its properties to our survey participants and requested them to choose roads so that they can go from Launch Ghat to Chourasta.

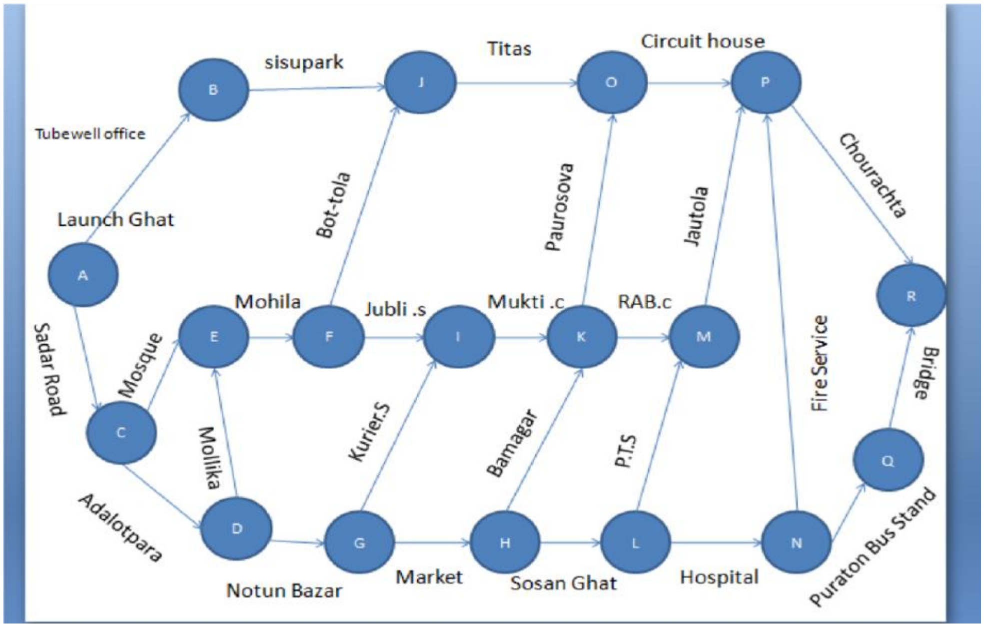

Figure 1. Road network for the experiment

Table 1. Properties of links of the road network

Link ID	Link	FFTT (minutes) for each path (τl,0)	Capacity(Cl)(cars/min)	Physical Location
1	A-B	1.5	5	Launchghat-tubewell officeroad
2	A-C	1.5	3	Sadar road
3	B-J	2.5	3	Sisupark road
4	C-D	1.0	5	Adalotpara road
5	C-E	1.5	6	Mosque road
6	D-E	1	3	Mollika road
7	D-G	2.0	2	Notun bazar road
8	E-F	0.5	3	Mohila college road
….	…….	……………….	………..	…………….
19	L-N	2.5	4	Hospital road
20	N-P	3	4	Fire service road
21	N-Q	3	4	Puraton bus stand road
22	M-P	3	2	Jhautola road
23	J-O	3	3	Titas road
24	O-P	1.5	4	Circuit house road
25	P-R	5	3	Chourasta
26	Q-R	1	5	Bridge road

Table 2. Information of survey participants

Travelers	Familiarity	Time of the day			Profession	Age Range (years)				Gender		Cause
	0-10	8am-10 am	10am-4pm	4pm-7pm		18-25	26-32	33-40	40+	Male	Female	
1												
2												
3												

Survey format

In our survey, we use the format shown in Table II where there are different fields such as profession, age group and gender. We kept these three categories as difference age group people tend to decide routes in different ways for different purposes. This same reason goes for different professions and gender.

The time of day is another field which we kept in our survey. The reason behind this is, the decision may differ based on the time of day due to office hours or school hours or even lunch hours. Therefore, it is important that we consider the time of the day when we ask our survey participants to fill out the form.

Table 3. Travelers' route choice survey

Links	Travelers														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
A-B															
A-C															
B-J															
C-D															
….	….	….	….	….	….	….	….	….	….	….	….	….	….	….	….
O-P															
P-R															
Q-R															

After route decision the travelers have different travel times. The participants' road familiarities may be different from each other. For this reason, we kept the familiarity field in our survey. We also ask them to choose routes repeatedly in our survey. When we took survey, we showed the road map to the traveller and said to choose their routes from source to destination. After that, we indicate their route in our survey by tic symbol. Travelers choose their route for repetitive trip. Sometimes they choose similar route and sometimes different routes.

Distributed decision making using own perceived road usages

Every traveller has his/her own network view of the road and they choose their shortest path based on their perceived road usages. For repetitive travel, every time they can update their perceived road usages. This is obvious that when the number of traveller increases, the amount of travel time will also increase. We do this experiment to see in which point, we find a drastic change of travel time. For that reason we took 5 travelers and run our experiment and obtain the travel times for three different initial values. Then we took 7 travelers and run our experiment for three different initial values and repeat the experiment for 12, 15, 20 and so on.

We perform experiments for different number of travelers. We have found that when we have 9 or 10 travelers in the road network, the average travel times of the travelers increases towards one and a half times of the average route free flow travel times. As one and a half times of the free flow travel times has been considered in previous studies (Everitt, 1998), we considered the traffic load of 10 travelers in our road network as the critical load. Therefore, we show the result of the survey and our experiment of 10 travelers traveling in the road network. The travel time of the travelers can be different because they take different routes both in survey and experiment. These two calculations can show the fairness of our proposed algorithm by calculating the standard deviation, σ, of the travel times of the travelers as the standard deviation shows the dispersion from the average of the travel times of the travelers. We shall show the fairness of our algorithm for different number of travelers from 5 to 15. However, the standard deviation of different number of travelers has to be understood in terms coefficient of variance, Cv, because as the scale will be changed for different number of travelers.

The standard deviation, σ, has to be understood in the context of the mean value with the scale. Cv is independent of unit and a normalized measure of dispersion of the data set.

The Cv of a data set can be calculated by equation 1.

$$Cv = \frac{\sigma}{\mu} \text{ -------------- (1) (Everitt, 1998)}$$

Where, μ = mean of the data set and
σ = standard deviation of the data set

A distribution with $Cv < 1$ indicates that the distribution has low variance while a distribution with $Cv > 1$ indicates the distribution has high variance. The smaller the value of Cv, the less variation is present in the data set.

Algorithm of the proposed method

The proposed method provides different network views to different travelers, so that it mirrors the human perception. Therefore, at first we assume some traffic load in the road network. This traffic loads are different for each traveller. Thus each traveller has his/her own perceived network view in this way. Now, each traveller choose his/her route towards the destination using Dijkstra's shortest path algorithm (Khanom et al., 2015). This allocates traffic to different links of the road network. Therefore, we can expect a near optimal traffic distribution by this distributed decision making. The weights of the links are updated after the traveller reaches his/her destination.

The algorithm steps are given below:

1. For each traveller
2. Load the own perceived road network
3. Use Dijkstra's algorithm to find the minimum cost path
4. Update the traffic flow after reaching the destination

Travel time calculation

When the traveller reaches his/her destination his/her experienced travel time can be calculated by adding the travel times required to travel the links he/she chose while traveling. The link travel time, τ_l for link l is given by

$$\tau_l = \tau_{l,0} + \tau_{l,0}(\frac{x_l}{C_l}) \text{ ------------ (2)} \qquad \text{(Galib, 2014)}$$

Where, $\tau_{l,0}$ is the free flow travel time of link *l*

C_l is the capacity of link *l*

x_l is the expected traffic flow on link *l*

Thus, the experienced travel time of traveller n is τ_n, can be calculated by

$$\tau_n = \sum l \in R_n \tau_l \text{------------------ (3)}$$

Where, R_n is the route chosen by traveller *n*.

Results

The survey result is evaluated in this section. We show some facts that are evaluated during our survey and experiment on road network.

It was mentioned earlier that the average travel times of the travelers are different when number of travelers is changed. For increased number of travelers, we found that the average travel times also increase. As the scale of the travel times changes, we calculated the coefficient of variance, Cv to observe the fairness of the proposed method.

Table 4 shows that the standard deviations and co-efficient of variance for different scenarios are different. In Scenario 1, we take 5 travelers average time of our experiment. Then calculate mean, standard deviation and co-efficient of variance. After that, similarly in Scenario 2, Scenario 3, Scenario 4, Scenario 5, we calculate mean, standard deviation and co-efficient of variance of 7 travelers, 10 travelers, 12 travelers and 15 travelers. In this table, we see Scenario 1 and Scenario 2's mean values are similar. However, in Scenario 3, there is high difference of mean value from Scenario 2. We can say that there is a sharp change in travel time after Scenario 2.

Table 4. Results of travelers' route choice survey

Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Average travel times				
For 5 travelers	For 7 travelers	For 10 travelers	For 12 travelers	For 15 travelers
24.2 23.83667 23.83667 23.83667 25.54	25.58667 25.58667 25.58667 26.47333 27.66333 27 26.91667	30.66667 30.82333 30.82333 30.5 31.92 30.66667 30.5 30.99 30.5 30.5	31.83 30.18333 30.3 30.18333 30.87667 29.81 30.3 30.3 30.25667 30.3 30.96667 29.81	34.06333 34.06333 33.63333 34.06333 33.01667 34.12667 34.06333 34.06333 34.06333 34.46 32.76667 33.02667 33.16 32.89667 34.06333
Mean (µ) 24.25	Mean (µ) 26.4019	Mean (µ) 30.419	Mean (µ) 30.42639	Mean (µ) 33.702
Std (σ) 0.738094	Std (σ) 0.837938	Std (σ) 0.432812	Std (σ) 0.558854	Std (σ) 0.561661
Cv 0.030437	Cv 0.031738	Cv 0.014057	Cv 0.018367	Cv 0.016666

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People usually know which road is less probable to be congested. Therefore, when they fill up their survey form, they use this knowledge. Thus the route choices we obtain from them are based their own perception. In out proposed method, we also impersonate this natural human behaviour through weighting the links by dividing the link free flow travel time with the difference between the link capacity and the expected traffic flow on the link. Thus the weight, w_l, is calculated by

$$w_l = \frac{\tau_{l,0}}{C_l - x_l}$$

Where, w_l is the weight for link l

$\tau_{l,0}$ is the free flow travel time of link l

C_l is the capacity of link l

x_l is the expected traffic flow on link l

With the weights for the links, travelers choose the minimum cost path using Dijkstra's shortest path algorithm. As this weight consist of FFTT and capacity, this algorithm thus choose a minimum cost path based on the human perception.

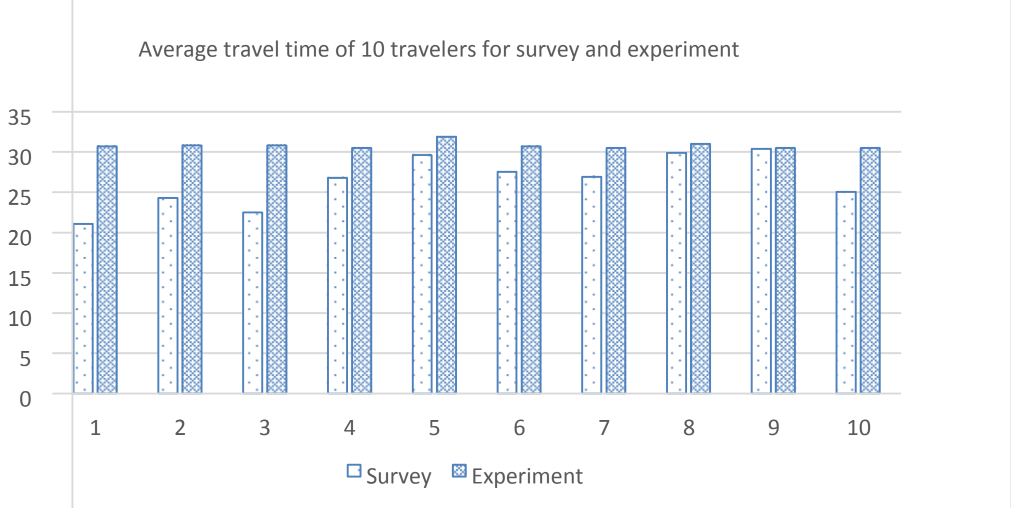

Figure 2. Average travel time of 10 travellers for survey and experiment

To observe the effect of different initial load, we have performed our experiments three times and then we took the average travel times of these three different experiments for each traveller. If we increase travelers in the road more than the critical load, the average travel times also increase. In this situation, it is not possible to distribute travelers in a way such that they experience shorter travel times because every road becomes congested.

In figure 2, we compared the average travel times for the survey and experiments. Here we see the travel time difference between survey and experiment. For some travelers we can observe that there are about ten minute's difference in travel times between the survey and the experiment. This may be due to the effect of initial weight. However, for most of the travelers, the average travel times in both the survey and experiments are similar. This indicates that the proposed method of having different network views for different travelers has close relationship with usual human perception.

Discussion

We surveyed on 50 people who are familiar with our road network. They choose different routes based on their criteria. We took different numbers varying from 5 to 15 travelers to observe their travel times. Also, we have performed experiments for different numbers of travelers where numbers varied from 5 to 15. This varying of numbers was specifically done to observe the change in travel times due to the change in number of travelers. We found that for 9 and 10 travelers, their average travel times become one and a half times the route free flow travel times. Therefore, we decided to show the results of 10 travelers where we took 10 as the critical load for our road network.

We also compared the experienced travel times of the travelers for the experiment with the survey. This was done with the purpose of noticing if there is any relationship with the results of the experiment and the real life i.e. the survey. There we found that most of the travelers experience similar travel times. This indicates that the proposed method of providing different network views to the travelers is humanlike and simple.

Conclusion

In this paper, we propose a novel algorithm that takes historical road usages into account and suggest routes to the travelers in such a way that each traveller has his/her own view of the road network and chooses the minimum cost path. For repetitive travel, every time they can update their perceived road usages.

We consider Patuakhali sadar road network and we performed a survey over 50 travelers. We show the results of the survey and our experiments of 10 travelers traveling in the road network. The travel times of the travelers can be different because they take different routes both in survey and experiment. These two calculations show the fairness of our proposed algorithm. Therefore, we calculate the standard deviation of the travel time of the travelers because standard deviation shows the dispersion from the average of the travel times of the travelers. We show the fairness of our algorithm for different number of travelers from 5 to 15 using co-efficient of variance.

Results illustrate that the travelers in the experiments experience similar travel times as the travelers experience in the survey. This indicates that our proposed method of applying distributed decision making by providing the travelers their own perceived network view is very similar to human's natural instinct. Moreover, the coefficient of variances of the average travel times for different number of travelers having smaller values indicate that our proposed method ensures almost fair travel times for the travelers.

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