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Evaluation of a Proposed Road in a Campus Network based on Ideal Flow

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Abstract. A proposed road project inside a campus that will have to down trees from its mini forest have attracted different public opinion among the faculty and students. In this paper, we would like to justify our view objectively based on transportation engineering point of view. The Ideal Flow Network (IFN) method was used to do the analysis because its source code is publicly available for clarification. The network data is based on previous study of Ateneo Traffic Group report. Two scenarios were set: based scenario that represents the current road network, and two proposed scenario that represents the current road network with additional proposed road in two ways and one way respectively. Analysis of the results show that the total network travel time of the proposed scenario are increased by 4.69% and 2.32% respectively for two ways and one-way scenarios. The network speed will be slightly improved by 0.03% in when the proposed road project is added in two ways. Thus, we failed to justify that the proposed network has better network performance..

Keyword: ideal flow network, campus network, road evaluation

Abstrak. *Proyek pembangunan jalan di dalam kampus yang akan mengurangi jumlah pohon di hutan kampus telah memicu opini dari pihak fakultas dan mahasiswa. Pada karya ilmiah ini, kami mecoba untuk membuktikan satu pendapat berdasarkan sudut pandang teknik transportasi. Analisa akan dibangun ini menggunakan Metode Ideal Flow Network (IFN) yang dapat diakses secara terbuka. Data jaringan transportasi diambil dari studi sebelumnya tentang Ateneo Traffic Group Report. Ada dua skenario yang digunakan pada analisa ini: skenario jaringan jalan sekarang dan skenario jaringan jalan yang akan dibangun. Berdasakan penelitian ini, total network travel time dari jaringan jalan yang diusulkan bertambah sebanyak 4.69% untuk dua arah dan 2.32% untuk satu arah. Kecepatan travel juga mengalami peningkatan sebesar 0.03%. Berdasarkan data ini, kami tidak dapat menyatakan bahwa pembangunan jaringan jalan yang baru dapat meningkatkan performa jaringan*

Kata Kunci: *Jaringan Arus Ideal, jaringan kampus, penilaian jalan*

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1 Introduction

As the background of the study, when the department of public work and highway (DPHW) wanted to expand the major highway of Katipunan Avenue from 12 lanes to 16 lanes, 70 Ha campus of Ateneo de Manila University (ADMU) which located along the highway would like to anticipate the change outside the campus by building additional 4 lanes two ways road which will be called Library-JSEC. The planned road is already inside the university master plan and recent external donation to build such road have make natural trigger for the university administration the start the construction of the new road. However, such road construction is highly unpopular and has earned opposition from hundreds of faculty and staff [1]. This is because the construction of the additional road will affect part of the mini forest, a source of clean air for the campus and where the diverse plants and insects live. Some of its trees will have to be cut to give way to the new road.

The view of those who oppose are mainly based on environmental and subjective point of view. Thus, we would like to investigate from the traffic engineering point of view. This paper aims to give an objective evaluation of the resulting traffic flow when the road is actually added to the network. For this purpose, we created three scenarios:

1. Based Scenario is the current situation of the road network
2. Scenario A is the current situation and new two ways Library-JSEC road
3. Scenario B is the current situation and one way new road from Library to JSEC.

From scientific novelty, this study demonstrates that ideal flow network (IFN) can be used to evaluate objectively if the decision to cut down the trees in the mini forest in favor of the new road is a wise decision. The data used is the data reported by the Ateneo Traffic Group [2], and the source code of the tool for the analysis is open source and publicly available on GitHub. Hence, the results of the analysis can be verified objectively by others.

2 Literature Review

Most of the previous studies focus on methods for predicting network flow. More recent studies, however, show that it is becoming increasingly possible to detect and compute trajectories. This study takes advantage of this fact and proposes automatic mechanisms to compute actual (instead of simply predicted) flow on various areas of a network facility. The results of this study can be applied to any network (e.g., road networks, computer networks, etc.) in general, and subject to possibly additional constraints. Stated below are some significant literature reviews related to this project.

Traffic assignment deals with route selection and prediction between origin and destination pairs in a transportation network. Given the adjacency matrix of the graph representing the network, the traffic assignment methods require an Origin-Destination (OD) matrix as input.

The OD matrix specifies the possible origin-destination pairs to consider, and the number of agents that are expected to take each given OD pair. The main output of such methods is a flow matrix predicting the amount of flow in each edge of the network graph.. In much of transportation planning literature [3][4]. for classical examples), the OD matrix is used to represent flow from source nodes to sink nodes (as proposed by Voorhees in 1955). Mishalani et al.[5] evaluate various types of surveillance system to estimate OD flows. Wood et al [6] visualizes the structure and spatial organization of random trajectories into a form of traditional OD matrix using spatial tree map.

The collection of data to generate the OD matrix can be done in many ways. Teknomo & Gerilla in [6] use ordinal graph trajectory from a questionnaire survey to analyze pedestrian shopping behavior and flow pattern in a hypermarket. One part of this study is an extension and generalization of their work for any directed network graph. Saadat, Teknomo & Fernandez showed how real-time Euclidean trajectories can be computed from video images. They show that this is possible even with (partial or even full) occlusion of some agents on some frames [7].

The availability of the OD matrix information makes it possible to perform a variety of related analysis to traffic flow and network facilities. Teknomo and Fernandez in [8] measure graph complexity to analyze the effect of complexity on the evacuation process and pedestrian behavior under high-density situations within a facility. Teknomo and Fernandez in [9] used vary graph capacities of both vertices and edges to investigate the effects on pedestrian evacuation using the concept of Route Choice Self Organization (RCSO). They showed that the egress time gap between the shortest path configuration and RCSO configuration increases very quickly with respect to crowd size.

Transportation planning software is not new. There are many commercial transportation planning software available. Most notable software are TransCAD by Caliper, EMME by Inro, CUBE by CityLab and Vissim by PTV. Each of these commercial software cost about 10,000-25,000 USD per year. SUMO (Simulation of Urban Mobility) is free microscopic traffic simulation, which is also open source developed by the Institute of Transportation System in Germany. SUMO, however, is more of a simulator, not transportation planning software. It would fail to compute campus wide transportation network because the design is for the microscopic level. Again, the lack of OD data would also make this software not suitable for the context.

Recently, Ideal Flow Traffic assignment was developed by Teknomo [10]. He started to gain international attention [12]-[14]. Ideal Flow Traffic assignment is based on Ideal Flow Network (IFN) which is an open source Python module and library to compute network efficiency based on the theory of Ideal Flow proposed by Kardi Teknomo and his team. Ideal Flow is a new concept to analyze transportation and communication networks. Ideal Flow Network is based on the stochastic matrix that may be linked to the actual flow, trajectories or sensing devices. Unlike the existing software mentioned above, Ideal Flow network has better approach in dealing with lack of OD data. When the data is not available, the probabilistic nature of the model can be approached through network structure alone. When there is more data available, such as traffic flow or static OD, Ideal Flow Network would be closer to the reality. Ultimately, when dynamic data such as trajectory data based on GPS, mobile phone or probe car or floating car data or camera is available, Ideal Flow Network would be updated in real time. This kind of advantages are not available in the existing transportation planning software.

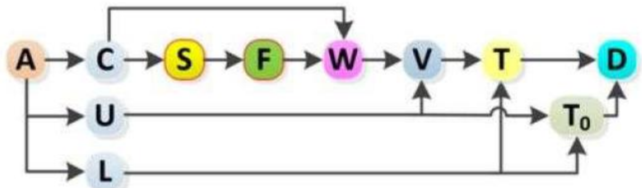
3 Methodology

Ideal flow model was initially developed through random walk agents on random network using uniform distribution in steady state condition [11]-[14]. Uniformly distributed flow over space and time is the most efficient utilization of a network. While the absolute flow of the random walk agents increases indefinitely into infinity, the relative flow aggregation of such random walk agents converges into simple integer numbers. The convergence values of the relative flow on each link on a simple strongly connected network is called the ideal flows. Based on uniform probability distribution, the ideal flow network has characteristics of equal outflow for each node and the network entropy is maximized.

Ideal flow matrix has two main characteristics, which is irreducible and premagic. Irreducible matrix has strongly connected network. Premagic matrix is a square nonnegative matrix where the sum of rows is the same as the sum of columns. Irreducible and premagic matrix conserve the flow. In each node, the sum of inflow is equal to the sum of outflow. Scaling operation an ideal flow matrix with a positive scalar produces equivalent ideal flow because ideal flow is a relative flow. Two ideal flow matrices are equivalent if each corresponding element of one matrix is a positive scalar multiple of the second matrix as shown in equation.

$$\boldsymbol{F} = k\,\boldsymbol{F} \quad K > 0 \tag{1}$$

Ideal flow is generalized for any probability distribution using Markov Chain. The probability distribution to enter a link can be computed based on the link capacity proportion. Ideal flow network is obtained from the stationary distribution of the simple irreducible stochastic matrix. Absolute ideal flow in the network can be obtained through the scaling property of ideal flow matrix. Bounding an ideal flow with an absolute capacity produces an absolute link flow. Travel time on each link in the network can be computed based on Greenshields cost function.



A: Adjacency matrix	W: Flow Capacity ratio matrix
C: Capacity matrix	V: Link speed matrix
U: Link maximum speed matrix	T: Travel time matrix
L: Link distance matrix	T_0: Minimum travel time matrix
S: Stochastic matrix	*D*: Delay matrix
F: Flow matrix	

Figure 1. Framework for ideal Flow model for Traffic Assignment in Matrix Form [14]

The framework for ideal flow model for traffic assignment using Greenshields cost function is shown in Figure 1. Given the network structure as an adjacency matrix **A**, we can configure link distance matrix **L**, link capacity matrix $\boldsymbol{C} = [c_{ij}]$and link maximum speed **U** using the same matrix structure. That means if we make all of these matrices into binary elements, they are equal matrices. In fact, all the matrices in the framework are using the same matrix structure.

Stochastic transition matrix $\boldsymbol{S} = [s_{ij}]$is formulated in (2) based on the general proportional capacity. Notation $e = 2.7172$ ...is the Euler number. The basic form of the general proportional capacity is power and exponential function resemblances the model of generalized cost [6]. While it is possible to set the value of α and β for each node, it is advisable to use single value of α and single value of β for the entire network.

$$s_{ij} = \frac{c_{ij}^{\propto} e^{\beta cij}}{\sum_{j=1}^{oi} c_{ij}^{\alpha} e^{\beta cij}} \quad (2)$$

When we set α=1 and β=0.00001 (small positive number), we would obtain the simplified version of the general proportional capacity which we called as the proportional capacity, as formulated in (3).

$$s_{ij} = \frac{c_{ij}}{\sum_{j=1}^{oi} c_{ij}} \quad (3)$$

Ideal flow matrix is computed based on Markov Chain by solving first the node probability distribution $\boldsymbol{\pi}=[\pi_i]$ of equation (4) in which **I** is the identity matrix and $\mathbf{j}^T=[1\ldots1]$. The proof of the convergence and uniqueness solution of irreducible stochastic matrix can be found in [7].

$$(\boldsymbol{S^T} - \boldsymbol{I})\boldsymbol{\pi} = \boldsymbol{0} \quad (4)$$

Subject to constraints:

$$j^T \boldsymbol{\pi} = \boldsymbol{1}$$
$$\boldsymbol{\pi} \geq \boldsymbol{0}$$

Ideal flow matrix $\mathbf{F}=[\boldsymbol{f_1^T}\cdots\boldsymbol{f_i^T}\cdots\boldsymbol{f_n^T}]^T$ is computed as equation (5). Since the stationary distribution $\boldsymbol{\pi}$ is unique, the ideal flow matrix, which each row vector is a scalar multiple of the stationary distribution and the row vector of the stochastic transition matrix, is also unique for each stochastic transition matrix.

$$\mathbf{f}_i^T = \boldsymbol{\pi_i S_i^T} \textbf{ for } \mathbf{i} = \mathbf{1}..\boldsymbol{n} \quad (5)$$

Once the ideal flow $\mathbf{F}=[f_{ij}]$ is obtained, the flow/capacity ratio matrix $\mathbf{W}$ can be computed based on equation (6).

$$\mathbf{W} = [w_{ij}] = \frac{f_{ij}}{c_{ij}} \text{ if } c_{ij} \neq 0 \quad (6)$$

We need to set maximum allowable flow/capacity ratio ξ for the entire network. The value of ξ depends on the model to compute the travel time from flow/capacity ratio. In most practical cases, the value is in the range of $0.9 < \xi < 1.0$. Having the value of ξ set, we can find a scaling factor κ such that:

$$K = \frac{\xi}{max_{wij}} \quad (7)$$

To anchor the ideal flow matrix from relative flow into the absolute flow we can use the scaling property. The absolute flow matrix **F** is computed using equation (8). The new ideal flow matrix is the absolute link flow in the network with same unit as the capacity. If the capacity is in vehicle per hour, then the absolute link flow also in vehicle per hour.

$$f_{ij} = K w_{ij} c_{ij} \text{ If } c_{ij} \neq 0 \quad (8)$$

Having the final flow/capacity ratio matrix **W**=[wij] , link distance matrix **L**=[ℓij] and maximum speed on each link **U**=[μij], we can compute the speed on each link using Greenshields equation (9) and form it into link speed matrix **V**. Clearly, to make the link speed as a real number, the value of flow/capacity ratio cannot go beyond one.

$$\mathbf{V} = [\boldsymbol{v_{ij}}] = \left[\frac{\mu_1}{2}\left(1 + \sqrt{1 - w_{ij}}\right)\right] \quad (9)$$

Setting travel time as the ratio of travel distance and traffic speed, we have equation (10). If the link speed is in km/hour and link distance is in km, then the travel time is in hour. Putting the link travel time into matrix form, we have travel time matrix **T**.

$$\mathbf{T} = [\boldsymbol{t_{ij}}] = \left[\frac{2\ell i}{\mu_1\ (1 + \sqrt{1 - w_{ij})}}\right] \quad (10)$$

The value of minimum travel time happens at free flow condition is computed as equation (11). Putting the minimum travel time into matrix form, we have minimum travel time matrix $\mathbf{T}_0$.

$$\mathbf{T}_o = [t_{ij}^o] = \frac{\boldsymbol{\ell_{ij}}}{\boldsymbol{\mu_{ij}}} \quad (11)$$

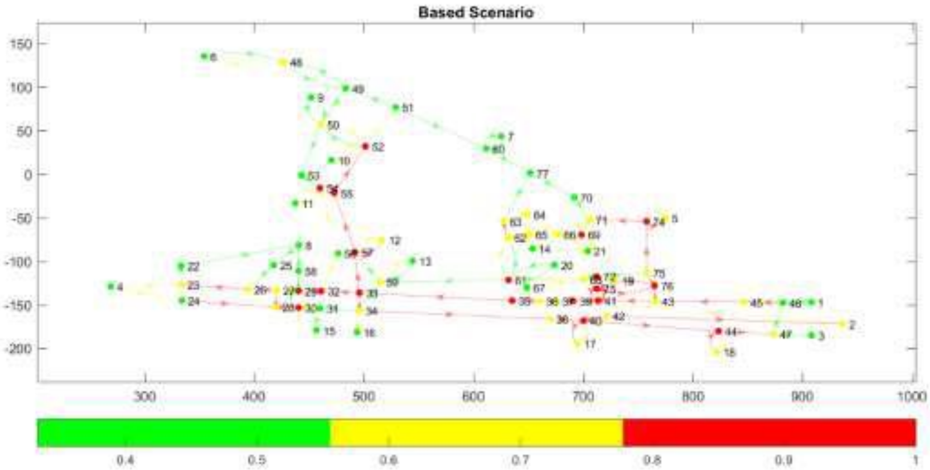
Delay is the difference between the actual travel time (due to traffic flow) and the minimum travel time. Putting the delay of each link into matrix form, we have delay matrix **D**

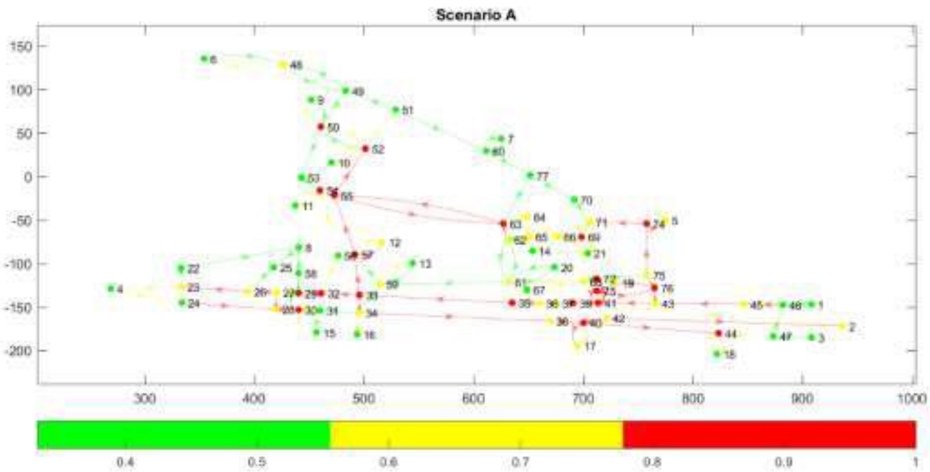
$$\mathbf{T} = [\delta_{ij}] = \left[\frac{2\ell i}{\mu_1\ (1 + \sqrt{1 - w_{ij})}} - \frac{\boldsymbol{\ell_i}}{\boldsymbol{\mu_i}}\right] \quad (12)$$

4 Result and Discussions

The road network data including the capacity was taken from the winning scenario of the previous study of Ateneo Traffic Group (Franco et al, 2012) and slightly modified to be updated with the current network structure (such as removal of the U-turn sections that has been replaced with traffic signal). We set up three scenarios: the based scenario represents the current road network, while the two proposed scenarios denoted as scenario A and B represents the current road network with additional proposed road in two ways or one way, respectively. In the proposed scenario A, an additional two-way road with 12 meter width capacity and 278 meter length from node number 55 to 63 and vice versa was added into the current network. The maximum speed is assumed to be the same as the campus regulation of 40 km/hour. In the proposed scenario B, an additional one-way road with 6 meter width capacity and 278 meter length from node number 55 to 63 was added into the current network. The maximum speed is assumed to be the same as the regulation of 40 km/hour..

Both scenarios went through the preparation for the analysis with a change that the first 21 centroids are connected to the cloud node. The centroid represents the major attraction such as parking lots of the nearby central buildings such as the Grade School, High School and College as well as connectors to the external place outside the study area. All centroids are considered as both sink and source and have two-way dummy links to the cloud, except for nodes 1 and 16 are source only centroid while node 3 and 15 are sink only centroids. One dummy link connect the cloud node to the source centroid and the sink centroid to the cloud node. These cloud node and dummy links are useful only to assist the computation to guarantee the strongly connected network as the requirement of the ideal flow network modeling. For the actual analysis, however, the flows on the dummy links and the cloud node that help to computation are excluded. For the analysis, we set the maximum allowable flow/capacity parameter is set to be ξ=0.95..





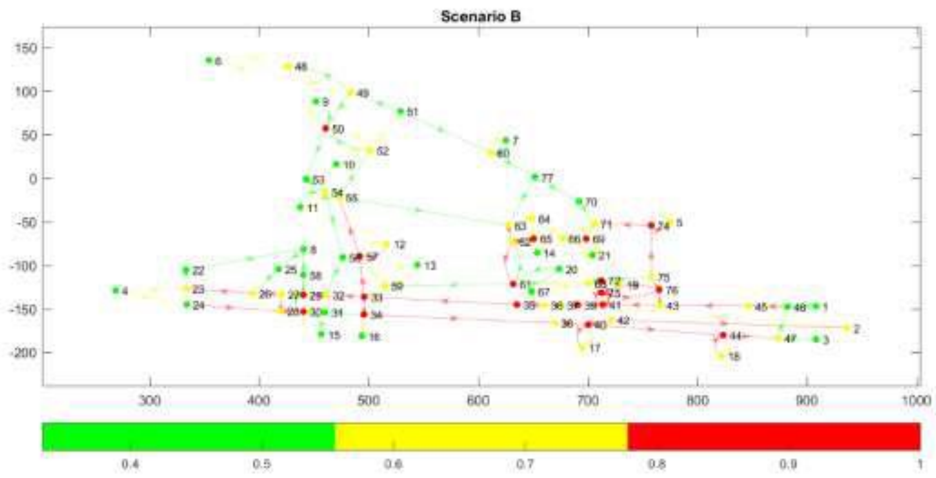


Figure 2 Comparison of congestion result of the three scenarios.

Figure 2 shows the normalized traffic congestion (i.e. flow/capacity ratio) color coded into three categories. Red color would be heavier congestion links. The based scenario flow/capacity results is remarkably reflecting the current congestion situation. Building one way road as Scenario B would not make this new road to be heavily used. Building the new road into two ways (as in Scenario A), however, would give better accessibility and therefore the new road would be predicted as congested as well. Visually, we can also see that the additional road does not actually shift any existing congestion in the current scenario.

The network performance for the three scenarios are shown in Table 1. The current total length of road network under consideration is 11.68 km (including the road network outside of the campus within the study area). The new road would increase the road length by 4.8% in Scenario A and 2.4% in Scenario B. In the overall network performance, the total travel time would increase by about 4.69% in Scenario A from 18.20 minutes into 19.05 minutes when the proposed two way road were added. In Scenario B, the increasingof network travel time would be about 2.32% from 18.20 minutes to 18.62 minutes when the proposed one way road were added. Interestingly, the average network speed will be slightly improved by 0.03% from 38.45 to 38.47 km/hour in Scenario A and by 0.01% to 38.46 km/hour in Scenario B. The median network delay per unit length of the road will improve in Scenario B by 0.82% due to the proposed project.

The analysis results show that in term of travel time, the based scenario (which is the current condition) is actually better than the proposed new road project. The slight improvement in term of the speed and delay would be insignificant compared with the cost of road construction as well as the intangible environmental cost and resentment of the faculty and staffs.

Table 1. Network performances for the scenarios**.**

Scenario Name	Based Scenario	Scenario A		Scenario B	
Description	Current Road Network	Current Road Network plus Library to JSEC 2 Ways		Current Road Network plus Library to JSEC One Way	
Total road length in km	11.68	12.24	4.76%	11.96	2.38%
Total network travel time in sec	1,091.92	1,143.14	4.69%	1,117.23	2.32%
Median network travel time in sec	9.19	9.19	0.06%	9.19	0.06%
Total network delay in sec	35.32	36.50	3.33%	35.61	0.82%
Median network delay in sec	0.11	0.11	0.57%	0.11	-0.82%
Median travel time/km in sec/km	90.96	91.01	0.06%	91.01	0.06%
Median delay/km in sec/km	1.08	1.08	0.57%	1.07	-0.82%
Avg speed in kph	38.45	38.47	0.03%	38.46	0.01%
Median speed in kph	39.48	39.49	0.04%	39.48	0.00%

5 Conclusion

While the justification of 0.03% improvement in network average speed from 38.45 to 38.47 km/hour may be used the university administration to push through with the unpopular scenario of cutting some of the trees from the mini forest inside the university in favor of adding a road, the ideal flow analysis shows that such proposed project would actually increase the total travel time by approximately one minute. Thus, we failed to justify that the proposed scenario has better network performances

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