

## The Effect of Road Roughness on Travel Time

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### ABSTRACT

Travel time can be decreased by increasing the speed. Speed has a relationship with road roughness. The goal of research was to achieve magnitude of influence of road roughness on travel time. Data were collected from forty different routes and each route had some locations of customers. OptimoRoute was used to sequence the locations. Travel time for each route was simulated by thirty different kinds of speed resulted from three categories: smooth, fair, and rough that range from 0.60 to 3.50 by Python program. The results showed that travel time on smooth road was more efficient around 27.23% than fair road, more efficient around 43.67% than rough road, and the travel time on fair road was more efficient around 29.18% than rough road. There was an opportunity to integrate several factors on travel time for next research: speed hump for preventing the accident, traffic congestion, road roughness, and narrow road.

### 1. Introduction

Operating speeds are mainly affected by five variables as follows: driver characteristics, vehicle characteristics, roadway characteristics, traffic conditions and environmental conditions. Driver characteristics such as age, occupation, sex, and experience such as trip length, trip purpose, and presence or absence of passengers. Vehicle characteristics such as engine size and power, type, age, weight, and maximum speed. Roadway characteristics such as geographic location, sight distance, lateral clearance, frequency of intersections, gradient length and magnitude, and type of surface have been shown to be important in speed analysis. Traffic volume and density, composition, access control, and passing maneuvers are the most important variables related to traffic. Time of day and climatic conditions are the major environmental factors and cannot be underestimated. Speed was significantly affected by pavement condition (Karan et al., 1976). The mean speeds decreased as IRI increased, this study was conducted on passenger cars and light trucks (Al-Masaeid et al., 1998). The road with roughness higher than 120 counts/km will cause driver discomfort and traveling speed decreased (King, 2014).

The road surface roughness measured by International Roughness Index (IRI) was indirectly proportional to the vehicle's recommended safe velocity (Nguyen et al., 2020). Road roughness would cause speed reduction, user discomfort and an increase in operating costs (Abeygunawardhan et al., 2020). All of the study mentioned above stated that speed has a relationship with road roughness.

The speed itself has a relationship with distance and time. According to Ling et al. (2018), average speed is the total distance traveled divided by elapsed time. The distance traveled is the total length of the path traveled between two positions. The elapsed time is the difference between the ending time and the beginning time.

$$\text{Average speed } s = \frac{\text{Total distance}}{\text{Elapsed time}} \quad (1)$$

In delivery time, Chandra, A. and Natalia, C. (2023) studied the effect of queue on delivery time. In this research, the roughness factor was not considered. When the roughness is used, then the speed and travel time may be affected.

From the formula (1), when one increases the speed, then time to travel will be decreasing, and on the contrary, when one decreases the speed, then time to travel will be increasing. The roughness for each road maybe different and will affect the time to travel. In this research, the authors will use simulation to get the magnitude of influence of road roughness (smooth, fair, rough) on travel time. From this result, one will also know that less travel time will be less fuel consumption too.

**2. Literature Review**

**2.1. Roughness road, speed and travel time**

Roughness is the result of surface deviations from a true planner surface with characteristic dimension that affect side quality. Smoothness is the lack of roughness. Road roughness is the irregularity on the road surface caused by distresses, construction defects, and which are perceived by road users due to its sensitivity to other pavement conditions and evaluation indicators. The roughness of road surface can be deteriorates due to deformation under traffic load influence and weather conditions (Beketov and Khalimova, 2023). The most common smoothness index is the IRI – International Roughness Index and reported in units of inches / mile or meters / kilometer. IRI is used to define a characteristic of the longitudinal profile of a traveled wheel truck and constitutes a standardized roughness measurement. International Roughness Index is a parameter used to determine the road surface's unevenness level. According to Wirnanda et al. (2018) there is a correlation between speed and road surface damage, the higher the level of road damage, the lower the vehicle speed. The lower the calculated IRI, the smoother pavement will ride and the higher IRI, the rougher pavement will ride (Missouri Department of Transportation, 2024). There are some categories of roughness – IRI scale:

**Table 1.** IRI Scale and description

IRI scale (in/mi)	IRI scale (m/km)	Description
<=60	<=0.9472	Very smooth
61-120	0.9630 - 1.8943	Smooth
121-170	1.9101 - 2.6837	Fair
171-220	2.6994 - 3.4730	Rough
>=220	>=3.4730	Very rough

Source: Missouri Dept of Transportation (2024)

According to Bin Yu and Qing Lu (2013), Geipot (1982), Morosiuk and Abaynayaka (1982), CRR (1982), Watanatada (1981), average vehicle speed decreases linearly with the increase of IRI (roughness index), but the decrease in speed was different from one to another.

Another research by Golov,E.,et.al (2022) found that the roughness of road surface is one of the main indicators characterizing the convenience of driving on road and having a decisive influence on the speed of vehicles and the transportation function of the road as whole.

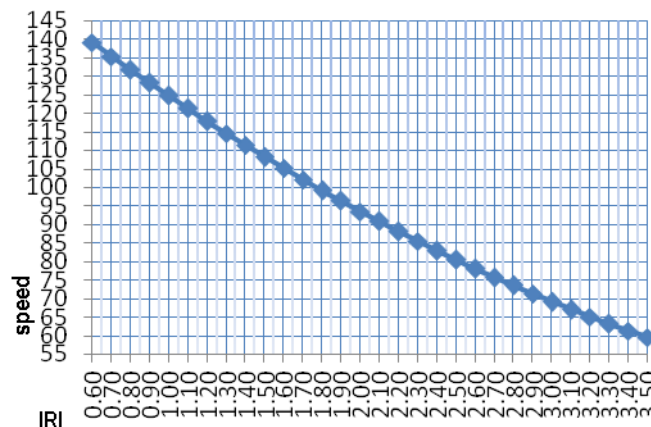
**Table 2.** Effect of Roughness on Passenger Car Speed

Country	Reference	Decrease in speed per increase in IRI (mph per in/mi [km/h per m/km])
Brazil	GEIPOT (1982)	0.0196 (2.00)
Caribbean	Morosiuk & Abaynayaka (1982)	0.00608 (0.62)
India	CRR (1982)	0.0252 (2.57)
Kenya	Watanatada (1981)	0.00627 (0.64)
USA - CA	Bin Yu & Qing Lu (2013)	0.0083 (0.84)

Another study of relationship between speed and IRI was done by Aden et al. (2023) and the formulae was:

$$y = -0.097x^2 - 41.4x + 162.65 \tag{2}$$

where x is IRI (m/km) and y is speed (km/hours). These formulae also strengthened the previous study which IRI increases then speed will be decreasing



**Figure 1.** Relationship between speed and IRI

Source: authors

The relationship between travel time and IRI was expressed as follow:

$$y = 0.062x^2 + 1.0686x - 1.0873 \tag{3}$$

where x is IRI (m/km) and y is travel time (hours/100km)

## 2.2. Optimoroute

In this research, OptimoRoute software was used to solve the traveling salesman problem in order to get the shortest distance for routes. OptimoRoute was regarded as one of the suitable software for solving vehicle routing problem and had following advantages: user friendly, the clarity with which solutions were easy to understand and interpreted, both graphically and analytically, through the use of colors and the sense of the streets, and the high amount of data from the different routes solved in previous research by Chandra and Natalia (2023). There were also some disadvantages: free-30 day-trial, if the destination points are very close to each other, the graphical interpretation becomes confusing (Masson et al., 2021). OptimoRoute is a routing optimization software, created in 2012 in the United States, used by multiple companies from different business sectors around the world. The program was at [www.optimoroute.com](http://www.optimoroute.com) (OptimoRoute, 2023).

## 2.3. Computational tools: Python

Python is an open source and cross platform programming language that has become increasingly popular for academicians. The reasons why authors used Python were Python is a multi-purpose and powerful programming language and can be used for simulation, calculation, web development, basic application without the need to know about or use the object oriented features. Python is easy to learn, in other words quick learning, has efficient high-level data structures and simple but very effective approach, can integrate the systems more effectively and work more quickly than other programming language (Halvorsen et al., 2020; van Rossum, 2018). In this research, authors used Python program to simulate and to get the shortest, average and the longest travel time.

## 3. Research Methodology

### 3.1. The Object of Research

The research conducted on routes which started from the main warehouse to location of customers. Location of customers were located in several areas: Jakarta, Bogor, Depok, Tangerang, Bekasi and the main warehouse, call depot, was located on Jatiuwung, Tangerang. One route consisted of several locations of customers and the route was not the same everyday because the customers did not order goods – baby and kids apparel every day. Goods are delivered by four-wheel trucks. The routes were recorded from January to May 2024 and covered the distance and locations, totally, there were forty different routes in this research.

## 3.2. Framework of Research

To find the travel time, distance and speed were needed. Total distance was measured from the start point – main warehouse to the end point – last customer's location and the principle of traveling salesman problem was applied which every location was passed only one (Hamiltonian cycle – Talbi, 2009) and the shortest distance was found. The software used was OptimoRoute. Speed was calculated by formulae (3) and based on IRI factor from 0.6 to 3.5 m/km. Travel time was calculated by formulae (1). There were thirty travel times for one distance, and there were many combinations of travel times, at the end, we had range of travel time data for one route and compared with travel time which generated from the software that IRI factor was excluded.

For simpler, one can refer to this research framework below:

- Step 1: To collect customer's locations and their coordinates – latitude and longitude in every route. These coordinates were obtained from the Google Maps. This route was origin and unsequenced.
- Step 2: To get the sequence and the shortest distance, then input or upload the coordinates into software OptimoRoute at [www.optimoroute.com](http://www.optimoroute.com) for every route
- Step 3: To generate speed from formulae (2) based on several IRI factors at table 1.
- Step 4: To calculate the travel time from formulae (1). Then we get the shortest, average and the longest travel time from the simulation by Python program
- Step 5: To compare the results with normal condition, then we will know the magnitude of influence of road roughness on travel time.

### 3.3. Assumptions of Research

In this research, there were some assumptions:

1. The travel time resulted from the formulae was not affected by congestions, accident time.
2. All drivers have the same capabilities in driving vehicle
3. The odd-even policy and other policies did not affect the route because shipping activities occurred at the time that was not affected by odd-even policy and the vehicle passed the route via toll road mostly

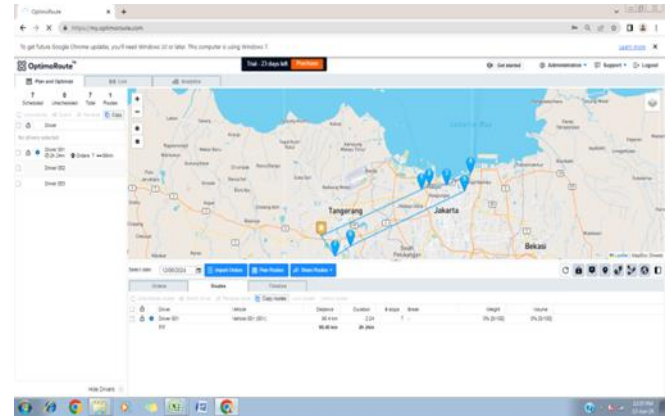
## 4. Results and Discussions

### 4.1. Data calculations

By using the OptimoRoute software and coordinates of customer location – latitude and longitude points, the sequence of locations for every route will be determined in order to get the shortest path or the shortest distance as shown at table 3.

**Table 3.** The sequence of locations resulted from optimoroute

Stop no	Order ID	Order Type	Location	Address
-		-	Depot	Jl. Raya Pajajaran, Banten
1	ORD003	Delivery	Karunia Permata Bunda	TAMAN PERMATA INDAH BLOK PF NO 1A
2	ORD004	Delivery	Gavin Samarinda	PT. KARUNIA CIPTA LOGISTICS
3	ORD005	Delivery	Handoko	NAGA LINTAS WAHID
4	ORD006	Delivery	Gavin kupang	SINDO EXPRESS
5	ORD007	Delivery	BCN / Marketplace	JALAN AGUNG JAYA 19, SUNTER
6	ORD002	Delivery	Mae bebe shop	RUKO ALAM SUTERA TOWN CENTER
7	ORD001	Delivery	Mustika baby shop	RUKO L'AGRICOLA BLOK C19
-		-	Depot	Jl. Raya Pajajaran Banten



**Figure 2.** Map for one route  
Source: OptimoRoute

After getting the shortest distance from OptimoRoute software, then the authors used the speed that had relation with IRI factor to get the travel time. There were forty routes that each route had thirty possibilities of travel times, see table 4. To simplify data processing, then Python software was used. In this software, the authors made program as shown in figure 3. This software also showed the map where the customer located clearly and equipped with the sequenced number which shown at figure 2.

Every route was simulated by Python program. This program checked for every possible combination of speed, and the shortest, the average, and the longest time were showed in Table 5. Every route had only one shortest time and one longest time.

### 4.2. Data Analysis

From Table 5, it can be interpreted that one route would be in the range between the shortest and the longest time to finish its shipment. It means that when one drives and passes the smoothest road during his trip, then he will finish with the shortest time. On the contrary, when he drives and passes the roughest road, then he will finish with the longest time. The smoothest road means the smallest IRI index and the roughest road means the largest IRI index. After that, the comparison of travel time was made based on the roughness of road – Table 1 and equation number 2: smooth, fair and rough that in the *smooth category*, the speed ranges from 97 to 130 KM per hour; *fair category*, the speed ranges from 75 to 96 KM per hour, and *the rough category*, the speed ranges from 60 to 74 KM per hour. The comparison is at table 6.

**Table 4.** Possibilities of travel time based on IRI factor-speed for every route generated by Python software

Route	Distance 1	Speed - IRI factor	Travel time1	Distance 2	Speed - IRI factor.2	Travel time2	Distance 3	Speed - IRI factor.3	Travel time3	Travel time6	Distance 7	Speed - IRI factor.7	Travel time7	Distance 8	Speed - IRI factor.8	Travel time8	Distance 9	Speed - IRI factor.9	Travel time9		
0	1.0	16.8	139.04	0.120829	17.9	139.04	0.128740	0.8	139.04	0.005754	...	0.0	0.0	139.04	0.0	0.0	139.04	0.0	0.0	139.04	0.0
1	1.0	16.8	135.34	0.124132	17.9	135.34	0.132259	0.8	135.34	0.005911	...	0.0	0.0	135.34	0.0	0.0	135.34	0.0	0.0	135.34	0.0
2	1.0	16.8	131.71	0.127553	17.9	131.71	0.135905	0.8	131.71	0.006074	...	0.0	0.0	131.71	0.0	0.0	131.71	0.0	0.0	131.71	0.0
3	1.0	16.8	128.15	0.131096	17.9	128.15	0.139680	0.8	128.15	0.006243	...	0.0	0.0	128.15	0.0	0.0	128.15	0.0	0.0	128.15	0.0
4	1.0	16.8	124.66	0.134767	17.9	124.66	0.143591	0.8	124.66	0.006417	...	0.0	0.0	124.66	0.0	0.0	124.66	0.0	0.0	124.66	0.0
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	
1195	40.0	17.1	67.08	0.254919	6.6	67.08	0.098390	34.2	67.08	0.509839	...	0.0	0.0	67.08	0.0	0.0	67.08	0.0	0.0	67.08	0.0
1196	40.0	17.1	65.09	0.262713	6.6	65.09	0.101398	34.2	65.09	0.525426	...	0.0	0.0	65.09	0.0	0.0	65.09	0.0	0.0	65.09	0.0
1197	40.0	17.1	63.16	0.270741	6.6	63.16	0.104497	34.2	63.16	0.541482	...	0.0	0.0	63.16	0.0	0.0	63.16	0.0	0.0	63.16	0.0
1198	40.0	17.1	61.31	0.278910	6.6	61.31	0.107650	34.2	61.31	0.557821	...	0.0	0.0	61.31	0.0	0.0	61.31	0.0	0.0	61.31	0.0
1199	40.0	17.1	59.52	0.287298	6.6	59.52	0.110887	34.2	59.52	0.574597	...	0.0	0.0	59.52	0.0	0.0	59.52	0.0	0.0	59.52	0.0

1200 rows x 28 columns

When comparing smooth to fair road, one will drive faster and save the time around 27.23%; on the contrary, when comparing rough to fair road, one will drive longer and waste the time around 29.18%. The largest gap in time happened when one compared driving between on the smooth road and on the rough road, the gap was 43.67%, it means driving on the smooth road will be more efficient around 43.67% in time than driving on the rough road. Not only efficient in time but also in fuel consumption (Marks, 2009).

This research has a limitation because it only considered a single factor – road roughness on travel time, of course, practically the travel time affected by several factors, then the travel time needs to be explored further to get a closer look for researchers and drivers, such as the impacts of multiple factors on travel time: the combination of speed hump or speed bump , road roughness, traffic congestion, and narrow road whether its combination can prolong the travel time or can yield a steady travel time. Table can be depicted by box plot in Figure 4.

```
df = pd.read_excel("Routes_update.xlsx", sheet_name="Distance", index_col=0)
df = df.loc[:, ~df.columns.str.contains('Speed', case=False)]
df = df.loc[:, ~df.columns.str.contains('Travel', case=False)]
df.fillna(0, inplace=True)

speed_data = [
    139.04, 135.34, 131.71, 128.15, 124.66, 121.24, 117.88, 114.59, 111.37,
    108.22, 105.14, 102.12, 99.18, 96.30, 93.48, 90.75, 88.07, 85.47, 82.93,
    80.46, 78.06, 75.73, 73.46, 71.27, 69.14, 67.08, 65.09, 63.16, 61.31, 59.52
]

expanded_data = []

for i in range(9):
    if i == 0:
        for idx, row in df.iterrows():
            route = row.name
            # print(route)
            distance = row[f'Distance {i+1}']
            # print(distance)
            for speed in speed_data:
                expanded_data.append([route, distance, speed, distance/speed])
            # print(expanded_data)
        df_n = pd.DataFrame(expanded_data, columns=["Route", "Distance 1", "Speed - IRI factor", "Travel time"])
        expanded_data = []
    else:
        for idx, row in df.iterrows():
            distance = row[f'Distance {i+1}']
            # print(f'{i+1} {distance}')
            for speed in speed_data:
                expanded_data.append([distance, speed, distance/speed])
        df_n = pd.concat([df_n, pd.DataFrame(expanded_data, columns=[f"Distance {i+1}", f"Speed - IRI factor.{i+1}", f"Travel time{i+1}"])], axis=1)
        expanded_data = []

df = df_n.copy()
df["Total"] = df.loc[:, df.columns.str.contains('Travel', case=False)].sum(axis=1)
df.head(40)
```

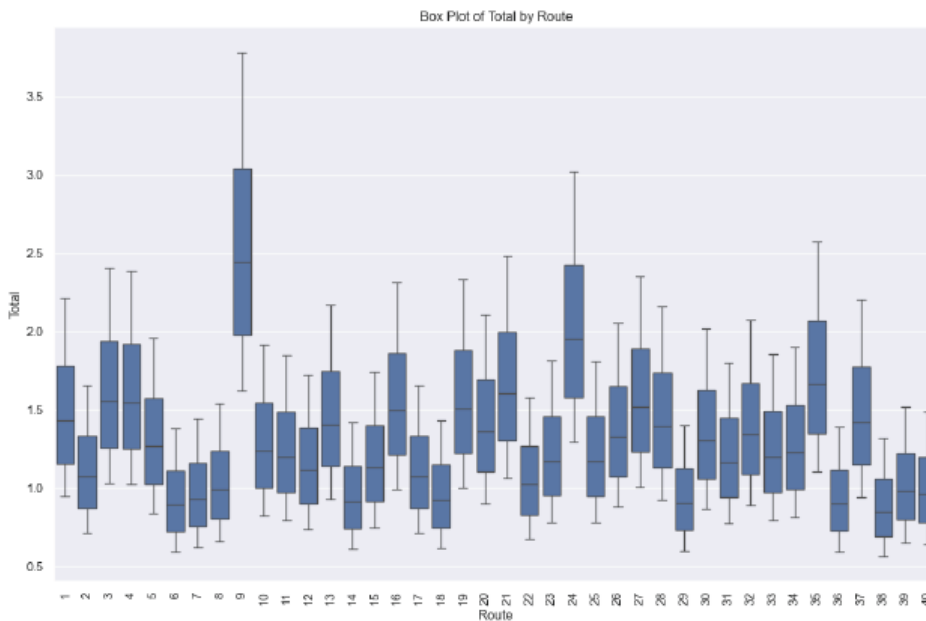
Figure 3. Program at Python  
Source: Python program by authors

Table 5. The shortest, average and longest time in hours for every route

Route	Shortest time	Average time	Longest time	Route	Shortest time	Average time	Longest time
1	0.945771	1.481751	2.209341	21	1.063723	1.666547	2.484879
2	0.709148	1.111031	1.656586	22	0.675345	1.058071	1.577621
3	1.029200	1.612460	2.404234	23	0.775676	1.215261	1.811996
4	1.022008	1.601192	2.387433	24	1.291679	2.023688	3.017389
5	0.837888	1.312730	1.957325	25	0.774597	1.213571	1.809476
6	0.591197	0.926235	1.381048	26	0.878884	1.376958	2.053091
7	0.617089	0.966800	1.441532	27	1.006185	1.576402	2.350470
8	0.657724	1.030465	1.536458	28	0.924914	1.449073	2.160618
9	1.618239	2.535315	3.780242	29	0.599108	0.938630	1.399530
10	0.820268	1.285123	1.916163	30	0.864140	1.353858	2.018649
11	0.792578	1.241741	1.851478	31	0.770282	1.206810	1.799395
12	0.736479	1.153850	1.720430	32	0.888593	1.392169	2.075773
13	0.929948	1.456961	2.172379	33	0.792937	1.242304	1.852319
14	0.607020	0.951025	1.418011	34	0.812716	1.273291	1.898522
15	0.746188	1.169062	1.743112	35	1.101841	1.726268	2.573925
16	0.991082	1.552739	2.315188	36	0.594074	0.930742	1.387769
17	0.709148	1.111031	1.656586	37	0.942175	1.476117	2.200941
18	0.612054	0.958912	1.429772	38	0.563147	0.882289	1.315524
19	0.999712	1.566261	2.335349	39	0.650173	1.018633	1.518817
20	0.901180	1.411889	2.105175	40	0.637227	0.998351	1.488575

**Table 6.** Comparison of average travel time for smooth, fair and rough condition of road on forty different routes

Route	Travel time (hour) simulation based on:			Route	Travel time (hour) simulation based on:		
	Smooth road	Fair road	Rough road		Smooth road	Fair road	Rough road
1	1.1234	1.5438	1.9942	21	1.2635	1.7363	2.2430
2	0.8424	1.1575	1.4953	22	0.8022	1.1024	1.4240
3	1.2225	1.6799	2.1702	23	0.9214	1.2661	1.6356
4	1.2140	1.6682	2.1550	24	1.5343	2.1084	2.7236
5	0.9953	1.3677	1.7668	25	0.9201	1.2644	1.6333
6	0.7023	0.9650	1.2466	26	1.0440	1.4346	1.8532
7	0.7330	1.0073	1.3012	27	1.1952	1.6424	2.1216
8	0.7813	1.0736	1.3869	28	1.0987	1.5097	1.9503
9	1.9222	2.6414	3.4122	29	0.7117	0.9779	1.2633
10	0.9744	1.3389	1.7296	30	1.0265	1.4105	1.8221
11	0.9415	1.2937	1.6712	31	1.1841	1.6271	2.1019
12	0.8748	1.2021	1.5529	32	0.7864	1.0806	1.3960
13	1.1046	1.5179	1.9609	33	0.9419	1.2943	1.6720
14	0.7211	0.9908	1.2800	34	0.9654	1.3266	1.7137
15	0.8864	1.2180	1.5734	35	1.3088	1.7985	2.3233
16	1.1773	1.6177	2.0898	36	0.7057	0.9697	1.2527
17	0.8424	1.1575	1.4953	37	1.1192	1.5379	1.9867
18	0.7270	0.9990	1.2906	38	0.6689	0.9192	1.1874
19	1.1875	1.6318	2.1080	39	0.7723	1.0613	1.3709
20	1.0705	1.4710	1.9002	40	0.7569	1.0401	1.3436



**Figure 4.** Box plot in travel time for every route

Source: authors

### 5. Conclusion

Travel time can be decreased by several methods and one of these methods is to increase the speed. Speed is affected by road roughness. In this research, travel time was simulated by various speed based on three categories of IRI (smooth, fair, rough). The simulation of travel time was conducted by Python program on forty different routes which each route has thirty different speeds.

The results indicated that the travel time with smooth road had 27.23% more efficient than fair road and 43.67% more efficient than rough road, and the fair road had 29.18% more efficient than rough road. The limitation of this research was only considering one factor – road roughness in obtaining the travel time, then, there was opportunity research that focus on these unexplored factors and one should integrate the factors: speed hump or speed bump or zebra cross in certain areas for preventing the accident or human consideration, traffic congestion in rush hour / business hour, road roughness, and narrow road.

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