Traffic Modeling in Serang City Using the Extended Link Transmission Model

D.K.N. Rachim[1, a)], B.N. Pratiwi[2,b)], R. Syafrizal[3,c)], Toyibah[4,d)]

[1]*Department of Mathematics, UIN Sultan Maulana Hasanuddin, Banten, Indonesia*
[2]*Department of Physics, UIN Sultan Maulana Hasanuddin, Banten, Indonesia*
[3]*Department of Informatics, UIN Sultan Maulana Hasanuddin, Banten, Indonesia*
[4]*Department of Mathematics, UIN Sultan Maulana Hasanuddin, Banten, Indonesia*

[a)]*email: dimas.kukuh@uinbanten.ac.id*
[b)]*email: pratiwi@uinbanten.ac.id*
[c)]*email: reza.syafrizal@uinbanten.ac.id*
[d)]*email: tooyyy15@gmail.com*

Abstract

In many countries, traffic problem has increased time by time, it has been caused by the increasing amount of vehicle and the lacking of segment road. For the example, urban traffic problem such as traffic congestion has become a big problem for drivers. This research studied urban traffic modeling using the link transmission model (LTM). The method was proposed is mathematical modeling, including car and bus as the objects of research. The cars and buses data were collected directly by the observers at the intersection that has four links and that are connected each other. The simulation process was obtained for the each link at rush hour period. At the interval 6.30-7.30am the total time spend in the link A, B, C, and D were 45.93h, 28.58h, 37.25h, and 19.91h. At the interval 04.00-05.00pm the total time spend in the link A, B, C, and D were 27.38h, 28.58h, 37.25h, and 19.91h. Based on these results, we might to give an advice to control the duration of traffic lights that controlled traffic flow in the each link. The red traffic light duration of link A at 6.30-730am must be lower than the others so the vehicles at link A will send much better and the TTS will turn down.

Keywords: link transmission model, LTM model, traffic modeling

Introduction

The issue of traffic congestion has increased significantly for decades. The researchers have been trying to study and explore the solutions of these problems. For the examples, the intensity of traffic flow had been studied in Siberia [1], the 5G scenarios was implemented on traffic modelling [2], the complete street strategies in cycle-ways was applied to solve high delivery demand [3], the processing CCTV camera image feeds was used to detect the congestion levels in road traffic [4], traffic congestion made the growth of economy down [5], total time spent (TTS) of multi class vehicle was longer than the total time spent of original vehicle [6], the observed congestion is caused by two different factors [7], minimum demand and maximum difference method was used to solve transportation problem [8], and route determination for minimizing the total cost of vehicle [9].

From these examples, we have been motivated to study the traffic condition at the main intersection in Serang City, this intersection transfers the vehicles into business places in Serang city. The extended link transmission model (LTM) is used in this paper to study the dynamical traffic condition in Serang City. LTM model has been used in many different modeling system such as the LTM modeled the air traffic management [10], [11] used LTM to simulate traffic congestion, the shockwaves theory was derived from LTM model [12], the MPC controller applied in LTM model [13]. This paper gives another point of view about link transmission model that used in urban condition including the intersection lane.

Methods

Traffic modeling has been studying for decades, start from the conservation law of vehicle used by [14],[15], these results motivated many researchers to develop theories in traffic modeling. This research used mathematical modeling to study the dynamics of traffic flow and the total time spend of vehicles. The link transmission model (LTM) is the traffic model that used to determine the amount of vehicles flow from one link into another link. LTM have been developed in the several ways. In this study we used the LTM modified by [6] that included multi class of vehicles as described in Equation (1) and Equation (2) below.

$$S_i(k) = \min \left[\begin{array}{l} \left\{ \left(\begin{array}{l} N\left(x_{ci}^{O}, (k+1) - \dfrac{L_i}{v_{ci} \times T_s} \right) \mu_{ci} + \\ N\left(x_{ti}^{O}, (k+1) - \dfrac{L_i}{v_{ti} \times T_s} \right) \mu_{ti} + \end{array} \right) - \\ \left(N\left(x_{ci}^{L}, k \right) \mu_{ci} + N\left(x_{ti}^{L}, k \right) \mu_{ti} \right) \right\}, \\ \left\{ \begin{array}{l} \left(\mu_{ci} \times \rho_{\max,i} \left(\dfrac{v_{ci} \times w_{ci}}{v_{ci} + w_{ci}} \right) \times T_s \right) + \\ \left(\mu_{ti} \times \rho_{\max,i} \left(\dfrac{v_{ti} \times w_{ti}}{v_{ti} + w_{ti}} \right) \times T_s \right) \end{array} \right\} \end{array} \right]$$

→ Eq.(1). THE SENDING NUMBER OF VEHICLES

$$R_i(k) = \min \left[\begin{array}{l} \left\{ \left(\begin{array}{l} N\left(x_{ci}^{L}, (k+1) - \dfrac{L_i}{w_{ci} \times T_s} \right) \mu_{ci} + \\ N\left(x_{ti}^{L}, (k+1) - \dfrac{L_i}{w_{ti} \times T_s} \right) \mu_{ti} \end{array} \right) - \\ \left(\begin{array}{l} N\left(x_{ci}^{O}, k \right) \mu_{ci} + N\left(x_{ti}^{O}, k \right) \mu_{ti} - \\ \rho_{\max,i} \times L_i \end{array} \right) \right\}, \\ \left\{ \begin{array}{l} \left(\mu_{ci} \times \rho_{\max,i} \left(\dfrac{v_{ci} \times w_{ci}}{v_{ci} + w_{ci}} \right) \times T_s \right) + \\ \left(\mu_{ti} \times \rho_{\max,i} \left(\dfrac{v_{ti} \times w_{ti}}{v_{ti} + w_{ti}} \right) \times T_s \right) \end{array} \right\} \end{array} \right]$$

→ Eq.(2). THE RECEIVING NUMBER OF VEHICLES

The Equations (1) and (2) describe the number sending and the number receiving of vehicles. The number of sending vehicle is the maximum flow potentially leaving the end of segment and the receiving number of vehicle is the maximum flow able to enter the segment. From those formulas we have some of parameters such as $N\left(x_{ji}^{L},k\right)$ respect to the cumulative number of vehicles j at time k and link L, μ_{ji} represent the passenger vehicles j equivalent, L_i is the length of link i, T_s is the observation time, w_{ji} is the velocity vehicle j when the congestion occurred, v_{ji} is the velocity of vehicle j at free flow condition, and $\rho_{\max,i}$ represent to the maximum density at link j. LTM algorithm divided into three steps. The first step is the process of determining the number sending of vehicle and the number receiving of vehicle. The second step is determining the transition number of vehicle $G_{ij}\left(k\right)$, and the last step is updating the cumulative number of vehicle for each link at the next time step. To give more detail, we depict the procedure to do the LTM algorithm as shown in Figure 1.

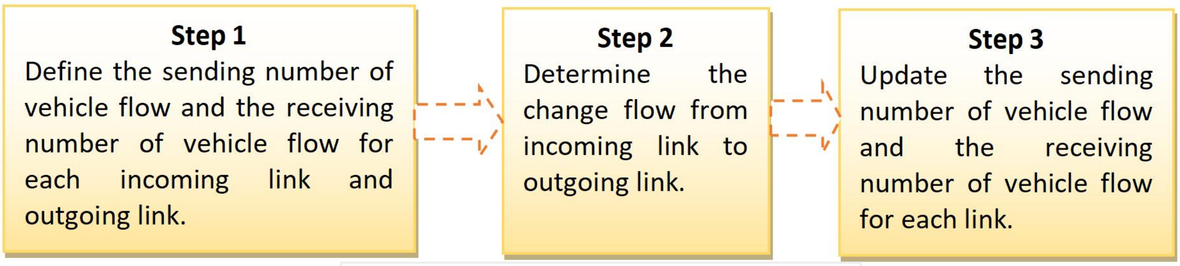

Figure 1. The Algorithm of LTM

Results and Discussion

In this section, the research results are presented using the real data and supported by empirical evidence. The data collected from the intersection as pictured in Figure 2.

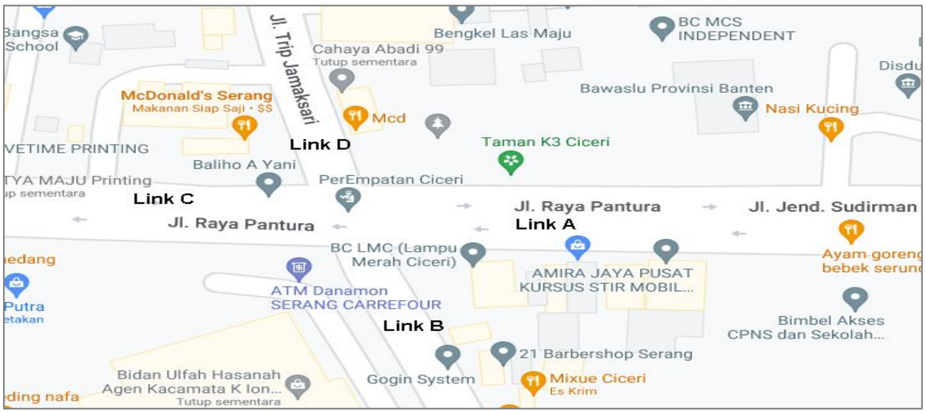

Figure 2. The Intersection in Serang City (Source: google maps)

At each of the downstream links, we placed the observers to observe the vehicles flowing into another link. As the second step of link transmission model, we intend to count the amount of vehicles that can flow from one link to another link. The flow of vehicles is updated by the transition number of vehicle $G_{ij}\left(k\right)$ adopted from [16] as shown in Equation (3).

$$G_{ij}(k)=\begin{cases} S_i(k) \text{ if } R_j(k)\geq S_i(k)+S_{i*}(k) \\ \text{mid}\left[S_i(k), R_j(k)-S_{i*}(k), \alpha_{ij}R_j(k)\right]\text{else}\end{cases} \tag{3}$$

The Equation (3) describe the number of vehicles may transfer from incoming link i to outgoing link j. The observation due at rush hour condition and the simulation is run by the data collected from the observation. The simulation is occurred in four steps for each link. The results below show the congestion and the total time spend that is occurred by the simulation process.

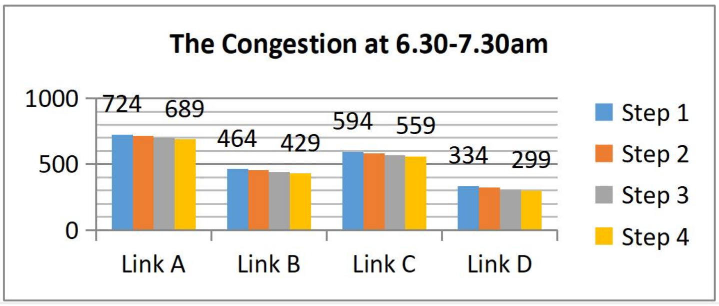

Figure 3. Total congestion of vehicles for each links at 6.30-7.30am

In Figure 3, we can see the congestion in the different steps and links. Link A has the highest congestion for each step with 706 vehicles in the average, Link C is the second, with 576 vehicles for the average, link B has 446 vehicles on the average, and link D has 316 vehicles on the average. This results appropriate with the real condition at Serang city where the link A, Jendral Sudirman street, is the major road transferred traffic flow into some of regions at Serang. In the other result, we can see the link D as the lowest. This condition relates with the fact that Trip Jamaksari Road is not a fundamental road in Serang City.

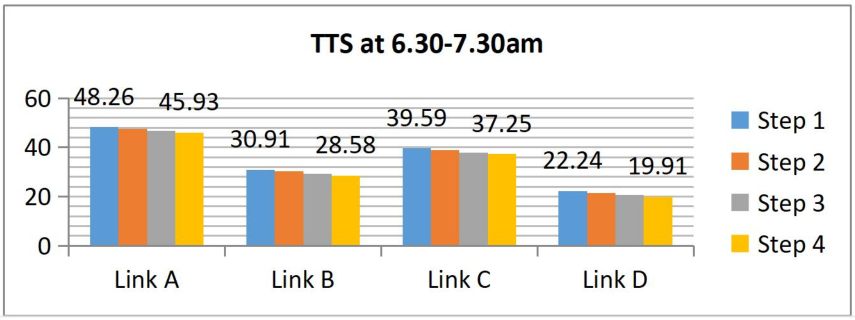

Figure 4. TTS of vehicles for each links at 6.30-7.30am

Figure 4 shows total time that vehicles spent in the road for each link. This result match with the result of congestion in Figure 1. Link A spent more time than others, 47.09 hours for the average and Link D is the smallest, 21.07 hour on the average. On this section, we compare the result at 06.30-07.30 am with the result at 04.00-05.00pm to get more accuracy about traffic flow at the intersection. The results are occurred for the congestion and TTS as described in Figure 5.

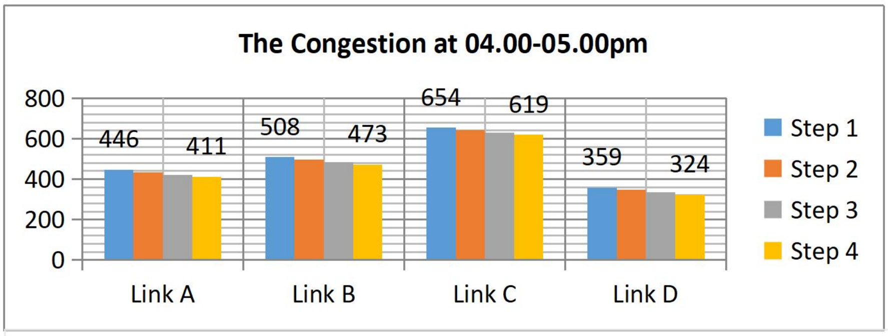

Figure 5. Total congestion of vehicles for each links at 04.00-05.00pm

In Figure 5, we get the different result from Figure 3. Link C has the highest congestion for each step with 636 vehicles on the average, Link B is the second, with 490 vehicles on the average, link A has 428 vehicles on the average, and link D has 341 vehicles on the average. These results show another condition that occurred at 04.00-05.00pm. Link C as the opposite route of link A send back the vehicles into Link A at 04.00-05.00pm. Both Link B and link D has improved the congestion, These condition are influenced by the amount of vehicles from Link C that have chosen alternative routes, Link B and Link D, to send into Link A.

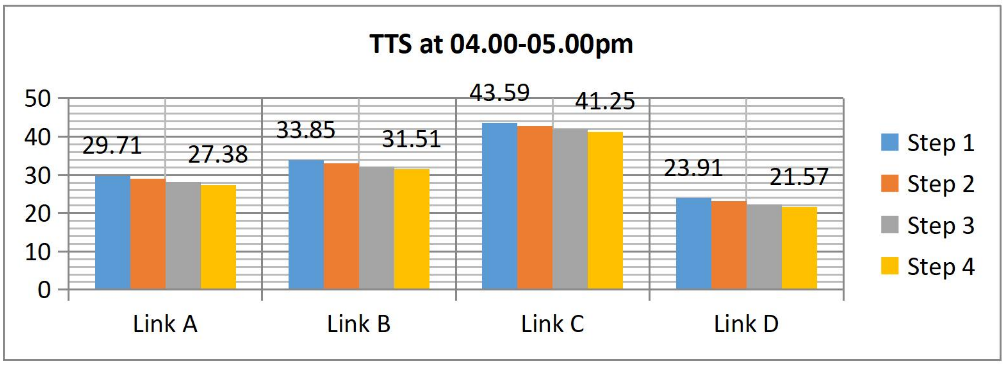

Figure 6. TTS of vehicles for each links at 04.00-05.00pm

The result in Figure 6 matches with the result of the TTS in Figure 4. Link C has the highest TTS, 42.42 hours for the average and Link D is the smallest, 22.07 hour on the average. At 04.00-05.00pm , The TTS of Link A had been decreased as the impact of the congestion on there. In Table 1, we can see the numbers of parameters that we used in this research.

Table 1. Parameter of Model

Parameter	Description	Interval
vi_j	Velocity of vehicle *j* in the link *i*	$45 < vi\_j < 80$
ρ_{max}, i	Traffic density in link *i*	$)0 < \rho_{max}, i < 230$
L_i	*The length of link i*	$0.5 < L_i < 2$

Conclusion

In this section, the results is summarized to get more specific information about the dynamics of traffic condition. The Modified Link Transmission is used to study dynamical condition at the intersection at different time. As the result, we get the information that the traffic condition at Ciceri intersection has different total time spent of vehicle in each segments of intersection. As the impact, we give the recommendation to the policy makers in Serang City to control the time of traffic light appropriate with the traffic condition in each links. For the example, at 6.30-7.30am, the time of green light in link A must be changed longer than the others, in order to transfer more vehicles in link A to another link. In the other hand, at 04.00-05.00pm, the time of green light in the link C must be matched, so the traffic from link C to the other links can flow more fluently. The discussion in this paper is limited on one intersection, the further research may elaborate with add or connect multiple intersection to get more complicated and specified results.

References

[1] S. Dorokhin, D. Likhachev, A. Artemov, A. Sevostyanov, A. Kulikov, and A. Novikov, “The Dynamic Traffic Modelling System BT - International Scientific Siberian Transport Forum TransSiberia - 2021,” A. Manakov and A. Edigarian, Eds., Cham: Springer International Publishing, pp. 1586–1594, 2022.

[2] J. Navarro-Ortiz, P. Romero-Diaz, S. Sendra, P. Ameigeiras, J. J. Ramos-Munoz, and J. M. Lopez-Soler, “A Survey on 5G Usage Scenarios and Traffic Models,” *IEEE Commun. Surv. Tutorials*, Vol. 22, No. 2, pp. 905–929, 2020, doi: 10.1109/COMST.2020.2971781.

[3] M. Alexandro, M. Gloria, and C. Fernando, “Complete Street strategies in cycleways applied in district with high delivery demand to reduce travel costs,” in *2022 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI)*, pp. 1–6, 2022. doi: 10.1109/CONIITI57704.2022.9953729.

[4] V. Jain, A. Sharma, and L. Subramanian, “Road traffic congestion in the developing world,” in *Proceedings of the 2nd ACM Symposium on Computing for Development*, in ACM DEV ’12. New York, NY, USA: Association for Computing Machinery, 2012, doi: 10.1145/2160601.2160616.

[5] M. Sweet, “Does Traffic Congestion Slow the Economy?,” *J. Plan. Lit.*, Vol. 26, No. 4, pp. 391–404, 2011, doi: 10.1177/0885412211409754.

[6] D. K. N. Rachim, Salmah, and I. Solekhudin, “Link transmission model involving multi class vehicle,” *Proc. 2017 5th Int. Conf. Instrumentation, Control. Autom. ICA 2017*, pp. 158–162, 2017, doi: 10.1109/ICA.2017.8068432.

[7] A.H. F. Chow, A. Santacreu, I. Tsapakis, G. Tanasaranond, and T. Cheng, “Empirical assessment of urban traffic congestion,” *J. Adv. Transp.*, Vol. 48, No. 8, pp. 1000–1016, 2014, doi: https://doi.org/10.1002/atr.1241.

[8] F. Muhtarulloh, E. W. Mardiah, and A. F. Huda, “Penyelesaian Masalah Transportasi dengan Degenerasi dan Siklus Berulang Menggunakan Minimum Demand Method dan Maximum Difference Extreme Difference Method,” *KUBIK: Jurnal Publikasi Ilmiah Matematika, Vol.* 8, No. 1, pp. 35-43, 2023, https://doi.org/10.15575/kubik.v8i1.

[9] M. Rohmah, E. R. Wulan, and F. Ilahi, “Penentuan Rute Transportasi untuk Meminimalkan Biaya Menggunakan Metode Nearest Neighbor dan Nearest Insert (Studi Kasus dalam Pendistribusian Sandal di Tasikmalaya),” *KUBIK: Jurnal Publikasi Ilmiah Matematika*, Vol. 4, No. 2, pp. 187–194, 2019.

[10] Y. Cao and D. Sun, “Link Transmission Model for Air Traffic Flow Management,” *J. Guid. Control. Dyn.*, Vol. 34, No. 5, pp. 1342–1351, 2011, doi: 10.2514/1.51495.

[11] G. Gentile, “Using the General Link Transmission Model in a Dynamic Traffic Assignment to Simulate Congestion on Urban Networks,” *Transp. Res. Procedia*, Vol. 5, pp. 66–81, 2015, doi:

https://doi.org/10.1016/j.trpro.2015.01.011.
[12] M. C. J. Bliemer, and M. P. H. Raadsen, "Continuous-time general link transmission model with simplified fanning, Part I: Theory and link model formulation," *Transp. Res. Part B Methodol.*, Vol. 126, pp. 442–470, 2019, doi: 10.1016/j.trb.2018.01.001.
[13] G. S. van de Weg, M. Keyvan-Ekbatani, A. Hegyi, and S. P. Hoogendoorn, "Linear MPC-Based Urban Traffic Control Using the Link Transmission Model," *IEEE Trans. Intell. Transp. Syst.*, Vol. 21, No. 10, pp. 4133–4148, 2020, doi: 10.1109/TITS.2019.2938795.
[14] G. B. Whitham, "On kinematic waves II. A theory of traffic flow on long crowded roads," *Proc. R. Soc. London. Ser. A. Math. Phys. Sci.*, Vol. 229, No. 1178, pp. 317–345, 1955, doi: 10.1098/rspa.1955.0089.
[15] P. I. Richards, "Shock waves on the highway," *Oper. Res.*, Vol. 4, No. 1, pp. 42–51, 1956.
[16] I. Yperman, "The link transmission model for dynamic network loading," *Kathol. Univ. Leuven*, Vol. 481, p. 482, 2007.