P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol.27 No.1 January - March 2022
Page: [46-56]
Original research article

Analysis of Highway Network Performance on Truck Route Development for Eastern Thailand

Panatda Kasikitwiwat[1,*], Sarawut Jansuwan[2], Kitti Subprasom[3]

[1]*Department of Civil Engineering, Faculty of Engineering at Kamphaeng Saen, Kasetsart University, Nakhon Pathom 73140, Thailand*
[2]*Graduate School of Applied Statistics, National Institute of Development Administration, Bangkok 10240, Thailand*
[3]*Chonburi Highway District, Thailand Department of Highways, Chonburi 20000, Thailand*

Received 26 January 2021; Received in revised form 14 June 2021
Accepted 10 July 2021; Available online 28 March 2022

ABSTRACT

Traffic congestion occurs when the amount on the demand side (the number of vehicles on the roadway) is greater than the capability of highway networks to cope the traffic on the supply side. Solutions for traffic congestion can be implemented by adding capacity and/or managing traffic demand. Examples of improving the supply side are highway expansion or highway extension, while an example of demand management is truck route development for an area with high freight transportation use. This research has the objective of analyzing highway network performance when demand management, which is truck route development, was implemented for a network in Eastern Thailand. The method used for the analysis is solving the traffic assignment and the network capacity to compare volume to capacity (v/c) ratios and quantify capacity flexibility. Three truck routes were investigated: Case 1, a truck route for highway No. 331; Case 2, a truck route for the motorway; and Case 3, a truck route for both the motorway and highway No. 331. Performance comparisons among the three cases were based on volume to capacity (v/c) ratios for truck lanes and regular lanes. In addition, capacity flexibility was compared for the cases to determine if the networks could handle traffic demand. In all three cases, the v/c ratios for most truck lanes were a little higher, while the v/c ratios for the regular lanes were lower. Cases 2 and 3 had higher values for capacity flexibility. Case 3, with the highest total truck route distance, was recommended for accommodating demand uncertainty and promoting safety.

Keywords: Capacity flexibility; Network performance; Optimization model; Truck route; Traffic safety;

***Corresponding author:** fengpak@ku.ac.th
doi: 10.14456/scitechasia.2022.5

1. Introduction

The cargo handled by the Laem Chabang Port in 2018 and 2019 exceeded 85.8 and 89.2 million tons, respectively [1]. Consequently, the transportation network in eastern Thailand must accommodate the high volume of traffic, especially trucks and traffic becoming congested because the highway network capacity cannot accommodate the demand. Travel delays increase transportation costs and hurt the economy, society, and the whole environment. Solutions for traffic congestion can be implemented by adding capacity to the network or managing traffic demand. Examples of improving the supply side are highway expansion or highway extension. Examples of demand side management, which always require less budget than building the supply side, can be implementing a bus lane, or developing a truck route system for areas with high freight transportation use [2]. This research has the objective of analyzing highway network performance when truck route development, was implemented to alleviate the congestion level and promote safety. The highway network performance approaches used to analyze the improvement level of different cases of truck route development for this study were link v/c ratios and network capacity flexibility. Previously, Rakkrai and Kasikitwiwat [3-4] assessed the capacity flexibility of highway networks for Eastern Thailand to determine the ability of the network to cope with demand uncertainty. Evaluation of capacity flexibility provides the capability to handle changes in traffic demand. Factors of demand changes are special activities in the area and policy of area development which change according to the time and economic situation. Therefore, capacity flexibility can also be considered as a criterion for project evaluation to choose among projects to solve congestion of highway systems.

Capacity flexibility has been described as the characteristic of the interface between the transportation network capacity and traffic demand changes [5-7]. Capacity flexibility can be measured using two approaches. The first approach reflects flexibility with respect to changes in terms of demand volume only. The second approach determines the range of changes in demand volume and demand pattern. In this paper, the first approach is adopted for assessing reserve capacity for different cases of truck route development. The flexibility concept for transportation networks has been applied in many studies. Morlok and Chang [8] proposed measurement of the flexibility concept based on breakeven analysis of engineering economics. The assessment of capacity flexibility by Kasikitwiwat [5] measured and evaluated with a bi-level network capacity model to determine the ability of a transport system to accommodate changes in traffic demand. Rapeepat Chaipachittikul [9] developed a mathematical model to maximize the efficiency of a multimodal transport network. The flexibility of a multi-class network consisting of highways and railways was analyzed.

The results from the study of the Eastern Economic Corridor area detected traffic problem areas [10] as shown in Fig 1. Information of level of service from A to F reflects the different level of traffic congestion. High value of v/c ratios represent the level of traffic volume. Level of service F means that traffic demand is greater than the roadway capacity.

Fig. 1. Level of service for highway at EEC area.

Congestion was identified in the following areas:

- Motorway No.7 and Highway No. 34 (near the Amata Nakorn Industrial estate)
- TFD Estate area near the exit ramp of Motorway and Highway No. 314
- Traffic jam in the road heading to Laem Chabang Port

The high volume of trucks in this area caused traffic delays for both freight and passengers. Therefore, a truck lane or truck route should be introduced to the area. In this paper, three different truck route scenarios are proposed and analyzed to determine the most appropriate one for implementation. The analysis provides link v/c ratios for a truck lane and regular lanes and a comparison of capacity flexibility for different cases to check the ability of the network to handle increased traffic demand.

2. Materials and Methods

2.1 Truck route solution for traffic problem

Generally, traffic becomes congested because the network capacity cannot accommodate changes in traffic demand. Travel delays increase transportation costs and hurt the economy, society, and the whole environment. Causes of traffic congestion are shown in Fig. 2 and various solutions have been suggested for different periods. Short-term measures include traffic signal optimization at intersections and/or U-turn improvements. Intermediate measures cover a Smart Traffic Information System, reversing lanes, truck lanes, and truck rest areas. Long-term measures include highway improvement projects such as a motorway network or rail network developments. Solutions for traffic congestion can be implemented by adding capacity to the network (improving supply side) and/or managing traffic demand. Examples of improving the supply side are highway expansion or highway extension. For eastern Thailand, various development plans have been proposed for traffic improvement such as Logistics Master Plan for Eastern Thailand and Department of Highways strategic plans that support the development of EEC. One of the development plans that correspond to EEC development is a highway development plan to support transportation in eastern Thailand for industrial estate and Laem Chabang/Maptaphut ports [11]. Important highway projects are the Dawei-Phunomron-Lam-chabang Economic Corridor Development project, the Highway Expansion project for Highway No.317 Chanthaburi-Srakaew, and the Motorway project in the Eastern Region. Once these projects are implemented, there will be more motorway routes for freight transportation. The network shown in Fig. 3 represents the different highway projects that will be implemented for different periods. Safety issues should be a concern. Therefore, demand management corresponding to both efficiency and safety issues should be implemented. An example of demand management is truck route system development.

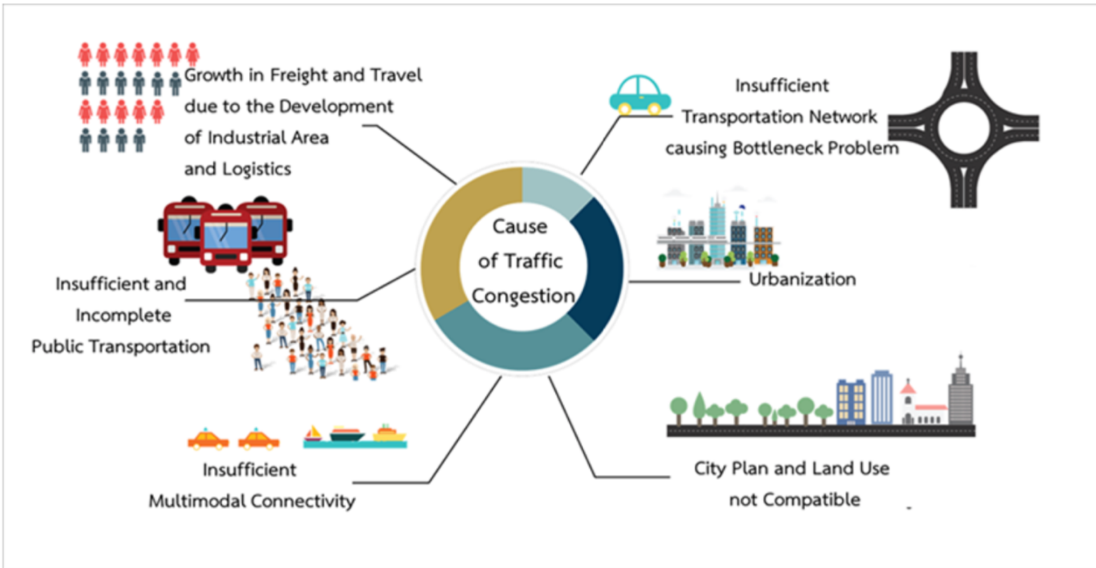

Fig. 2. Causes of traffic congestion.

Fig. 3. Highway network development plans for EEC area.

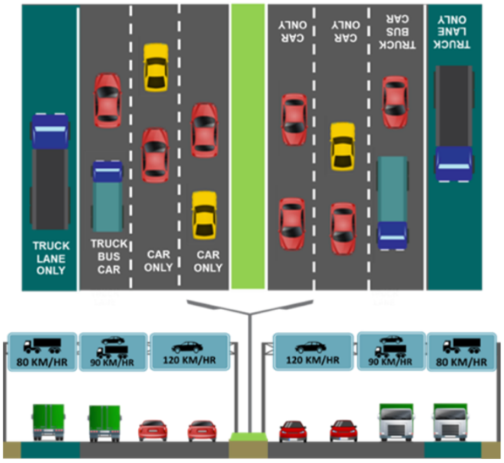

Fig. 4. Example of guide signage for truck route (Motorway).

In this study, it was recommended that a truck route have at least 4 lanes per direction to separate low-speed trucks from the passenger vehicle lanes. Examples of signage for a truck route on a motorway is shown in Fig. 4. Speed limits and the number of lanes for each category can be varied by legislation and the criteria of the highway.

2.2 Truck route scenarios

The network for the DOH plan (2022-2036) involves considering three development routes that must be analyzed to identify the most appropriate case to implement.

- Route1: Motorway No.7 from Srinakarin-Bangprakong to Nongkham-Pattaya (distance about

120 km), an extra 32 km (Pataya-Maptaphut) to be added later.

- Route2: Motorway (Chonburi-Nakornrachaseema, Eastern outer ring road – Srakaew (Arunyaprated border)
- Route 3: Highway No.331 from Nernmoak-Plaengyao to HuayYai-Punsadednok (distance about 100 km).

The truck route development project was analyzed for these 3 cases (Figs. 5-7).

Case 1: Truck route for Highway No. 331.

Case 2: Truck route for motorway (DOH plan).

Case 3: Truck route for both motorway (DOH plan) and Highway No. 331.

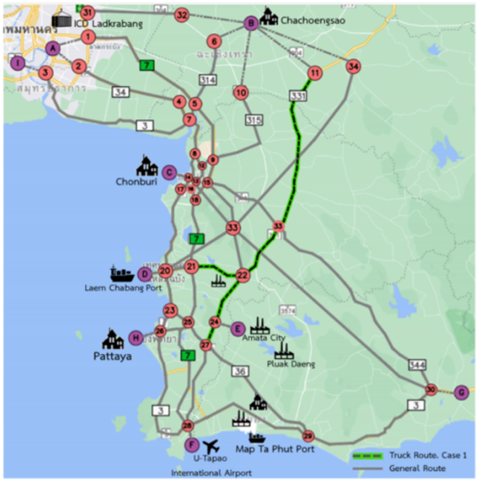

Fig. 5. Truck Route for Case 1.

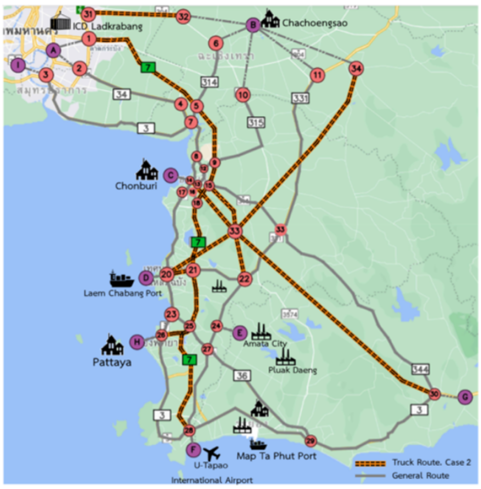

Fig. 6. Truck Route for Case 2.

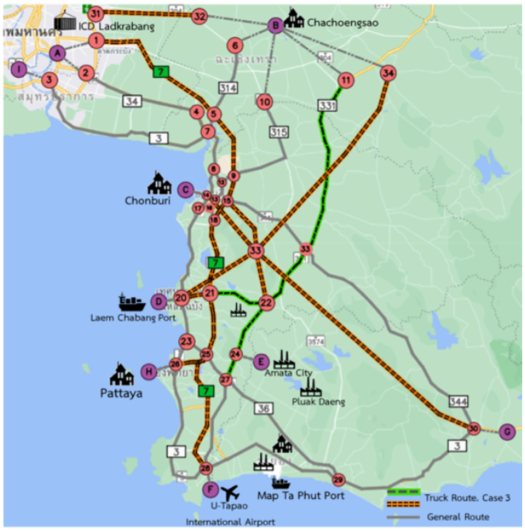

Fig. 7. Truck Route for Case 3.

2.3 Network capacity model

Traffic assignment based on a user equilibrium model was performed to quantify the traffic congestion levels of highway links in the network using volume to capacity ratios of roadways (link v/c ratios). Performance evaluation of highway network capacity and capacity flexibility used a bi-level network capacity model [5, 12-13]. The bi-level model included the upper-level problem, which determines the maximum capacity with the O-D demand multiplier, μ, and the lower-level problem, which is formulated as the user equilibrium for traffic assignment model [14].

Upper-Level Problem

$$Max \quad \mu \tag{2.1}$$

Constraints

$$v_a(\mu \mathbf{q}) \leq C_a, \quad \forall\, a \in A \tag{2.2}$$

Lower-Level Problem

$$MinZ = \sum_a \int_0^{v_a} t_a(x)\, dx \tag{2.3}$$

Constraints

$$\sum_{r\in R_{ij}} f_r^{ij} = \mu q_{ij}, \quad \forall\, i \in I, \forall j \in J, \qquad (2.4)$$

$$v_a = \sum_{i\in I}\sum_{j\in J}\sum_{r\in R_{ij}} f_r^{ij}\,\delta_{ra}^{ij}, \quad \forall\, a \in A, \qquad (2.5)$$

where all notions are described as follows:

- A set of links in the network,
- I set of all origin nodes,
- J set of all destination nodes,
- R set of routes in the network,
- R_{ij} set of routes between origin and destination,
- Z objective function,
- C_a capacity on link *a*,
- v_a flow on link *a*,
- t_a travel time on link *a*,
- q_{ij} O–D demand from origin *i* to destination *j*,
- f_r^{ij} flow on route r between O–D pair *ij*,
- δ_{ra}^{ij} 1 if link a is on route r from origin *i* to destination *j*.

The link travel time function used is the standard Bureau of Public Road (BPR) function as follows (see [15]):

$$t_a(v_a) = t_a^0\left[1 + 0.15\left(\frac{v_a}{C_a}\right)^4\right],$$

where t_a^0 is free-flow travel time.

2.4 Measurement method

The process for analyzing the congestion level for the highway links and capacity flexibility of the network is shown in Fig.8. The percentage of trucks choosing the truck lane can be varied. Empty trucks tend to use regular lane more than the truck lane. The decreased number of backhauls in the future would increase the percentage of trucks choosing the truck lane and affect the results of v/c ratios. Currently, the number of backhauls in Thailand is still high. For traffic assignment, this study assumed that 60 percent of trucks would select the truck-only lane because some empty trucks do not choose the truck-only lane. Therefore, the other 40 percent of trucks and other vehicles were loaded in the other three lanes. Outputs were link v/c ratios and were obtained from traffic assignment representing congestion levels. The results of capacity flexibility for different cases provided the reserve capacity or the ability to accommodate increased demand. In this study, Microsoft Excel (Analytic Solver Version 2018) was used as the analytical tool for solving traffic assignment and network capacity. GNG nonlinear, which was selected as a solving algorithm, can find a locally optimal solution to a reasonably well-scaled, non-convex model, so it cannot guarantee the exact solution. For the bi-level problem, the procedure started with determining an appropriate incremental amount μ of the upper-level problem. Then, an equilibrium traffic assignment was solved to obtain v_a. These equilibrium link flows were transmitted to the upper-level problem to determine the maximum μ.

The CPU times depend on the starting point and the incremental amount μ. For the network in this study, with 100 iterations, the CPU times were about 60 -80 seconds.

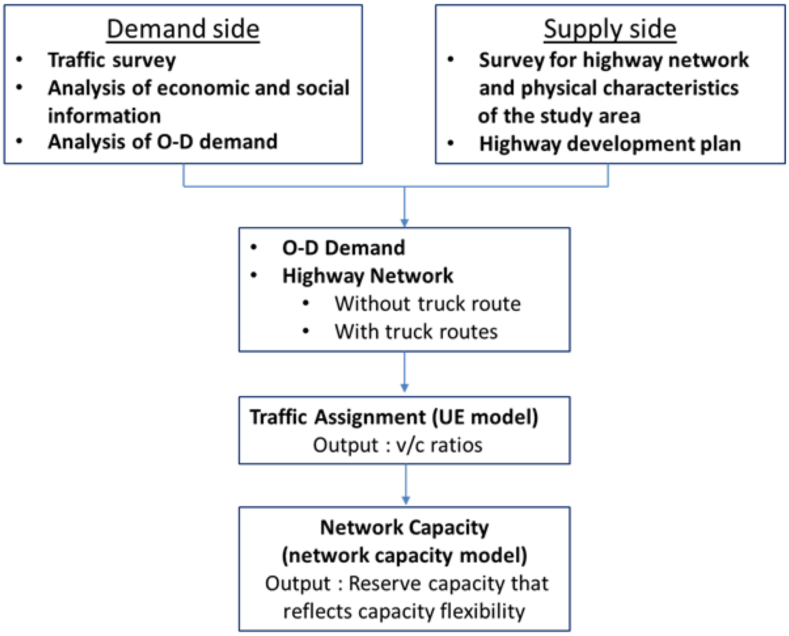

Fig. 8. Process of network performance analysis.

3. Results

The analysis provided performance comparisons for the three different cases with link v/c ratios for the truck-only lane and the regular lanes. A comparison of capacity flexibility for the different network cases was also provided to investigate the ability of the network to handle increased traffic loads.

3.1 Volume to capacity ratios of roadways

The results are shown in Fig. 9 to Fig. 11 with the v/c ratio of truck lanes and regular lanes. Higher values of v/c ratio reflect higher levels of congestion. The information shown in the three figures include v/c ratios for the situation in which there is no truck route development and v/c ratios for the situation in which there is truck route development. With truck route development, the comparison between v/c ratio of truck lane and v/c ratio of passenger lanes is demonstrated. The values in the area represent the v/c ratio of the roadways for the situation without a truck route. With truck route development, the values are shown using lines for passenger lanes and bars for truck lanes. V/C ratios of some truck lanes are a little higher than the case without truck route development.

The results for Case 1, with the shortest distance of truck route, are shown in Fig. 9. The v/c ratio of truck lanes and regular lanes are not significantly different. There were not many links that were more congested in the truck lane. The v/c ratios of some truck lane were almost the same as for without truck route development.

For Case 2, with truck route development on the motorway route, the v/c ratio results for truck lanes and regular lanes are shown in Fig. 10. In many links, the v/c ratios of truck lane were a little higher than without truck route development, while the regular lanes had lower v/c ratios.

For Case 3, with truck route development on highway No. 331 and the motorway, the results of v/c ratios of truck lanes and regular lanes are shown in Fig. 11.

In many links, v/c ratios of truck lanes were a little higher than regular lanes. For the links with low truck usage, the v/c ratios for the truck lane only were not higher than the v/c ratios for regular lanes. Because there are more truck-lane links for Case 2 and Case 3 (longer distance of truck routes), the differences of v/c ratios of truck lanes and regular lanes are seen more for Case 2 and Case 3 than Case 1. Therefore, longer distances of truck lanes could lower the v/c ratios for regular lanes.

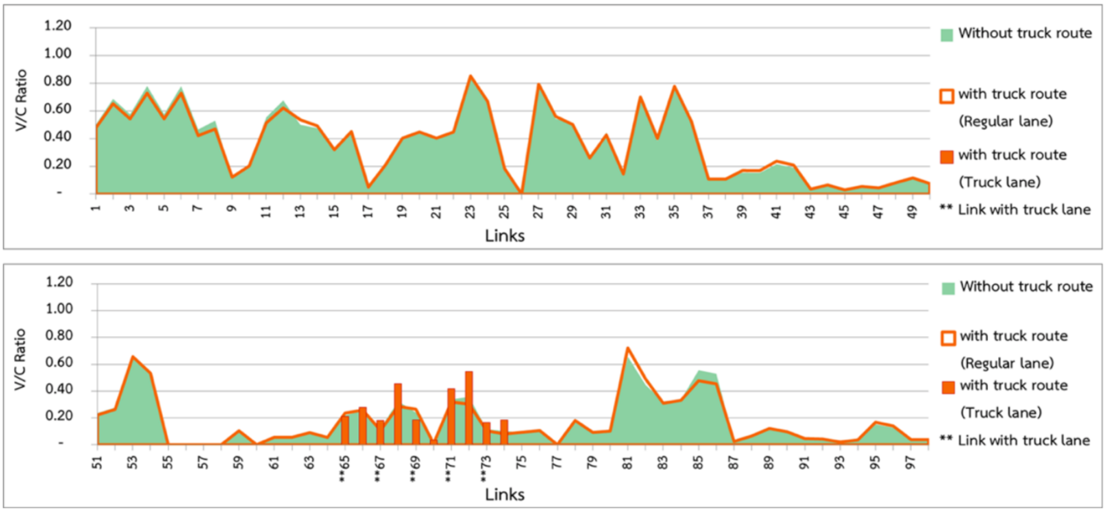

Fig. 9. V/C ratio comparison for case 1.

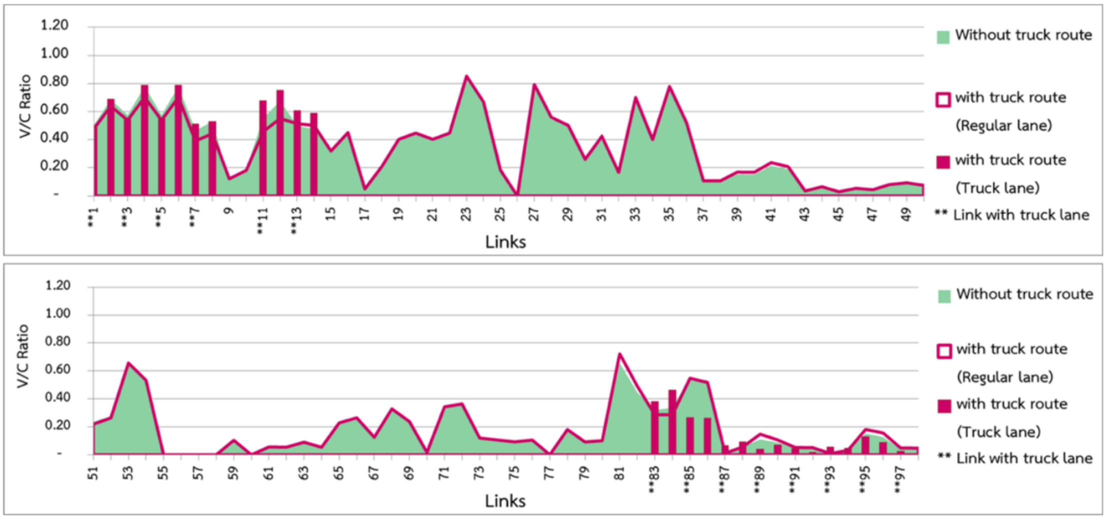

Fig. 10. V/C ratio comparison for case 2.

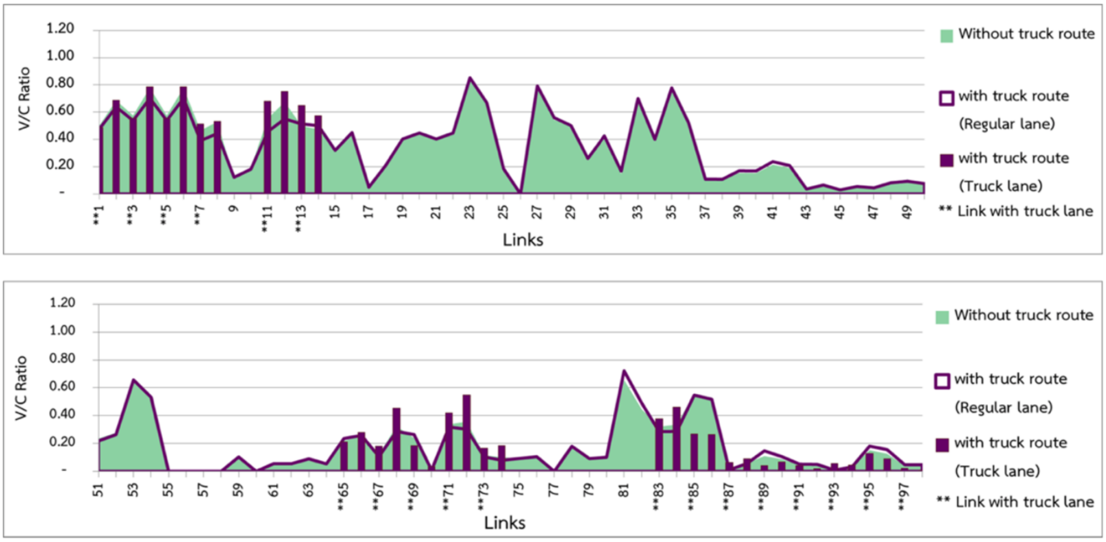

Fig. 11. V/C ratio comparison for case 3.

3.2 Capacity flexibility results

Capacity flexibility for highway networks can be achieved with various development plans such as building new roadways, expanding existing highways by adding more lanes to the roadways, or shifting the traffic to other modes of transport such as railways.

The results of capacity flexibility, which reflect the ability to handle increased demand for the highway projects and different truck route development cases, are shown in Fig. 12. Capacity flexibility is increased when the projects are implemented. For the first period (2018 – 2021), the ability to handle the demand is not increased significantly because the number of the projects completed are limited. O-D demand multipliers are 1.03 and 1.04 for the case without truck route and the case with the short distance truck route, respectively. For the period that the most DOH plans were implemented (years 2022-2036), O-D demand multipliers are 1.26. 1.25, 1.33, and 1.33 for the case without truck route, truck route Case 1, truck route Case 2 and truck route Case 3, respectively. The results showed that the difference between capacities for the case without a truck route and Case 1 with a truck route were not significantly different. However, applying a truck route for Case 1, which is applied for Highway No. 331 only, decreases capacity flexibility.

Capacity flexibility was higher for Case 2 and Case 3 while Case 2 had the highest capacity flexibility. From a safety point of view, Case 3 having the longest distance of truck route would be safest for other vehicles.

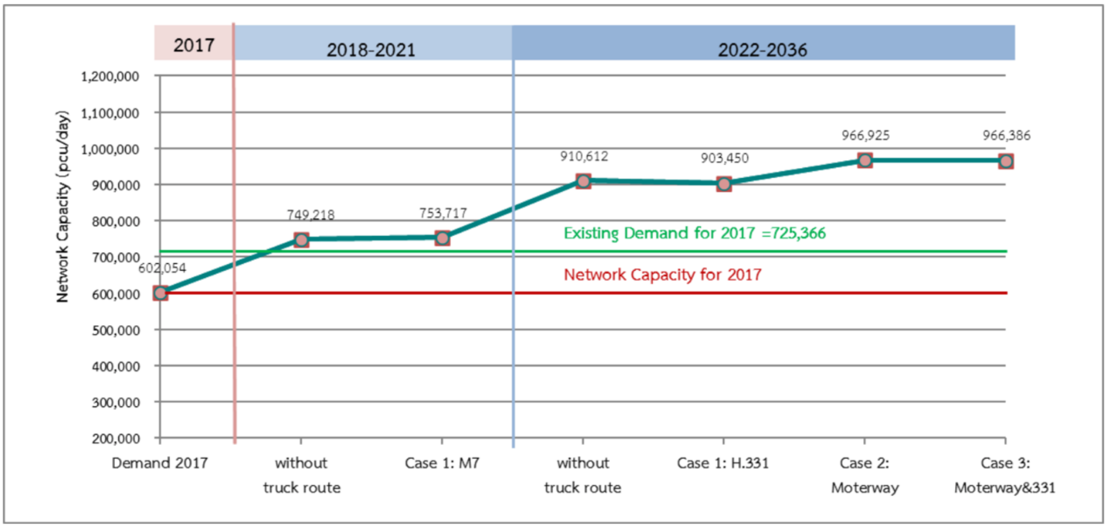

Fig. 12. Capacity flexibility comparison for truck route development.

4. Conclusion

The solutions to decrease the traffic congestion and to support freight transportation in the EEC area can be many alternatives such as applying the smart management system to decrease the service time or the time that trucks must spend in the port or providing Logistics Park and/or truck rest area nearby Laem-chabang Port.

This research proposed concepts for the analysis of truck route development. Congestion levels and capacity flexibility were used as performance indices for highway network performance. Three truck routes were proposed and analyzed to determine the most appropriate case to implement.

The analysis provided a performance comparison among the three different cases based on link v/c ratios for truck lanes and regular vehicle lanes. In all three cases, the results showed that the v/c ratios for most truck lanes were a little higher, while the v/c ratios for passenger lanes were lower.

Capacity flexibility for the different cases was measured to investigate the ability of the network to handle traffic demand. Case 2 and Case 3 had higher values of capacity flexibility. Case 3, with the longest distance of truck route would best accommodate demand uncertainty and promote safety.

Acknowledgements

The research was funded by the Department of Highways (Thailand) and this study was supported by the Faculty of Engineering at Kamphaeng Saen, Kasetsart University, Thailand.

References

[1] Port.co.th, Statistics of Thailand Laem Chabang Port [internet]. [cited 2020 June 22]. Available from: http://www.port.co.th/cs/internet/internet/annual statistics.html

[2] Department of Highways. Capacity Reliability and Capacity Flexibility Assessment of Highway Networks for the Eastern Thailand. Executive Summary Report by Kasetsart University; 2018.

[3] Rakkrai, W. and Kasikitwiwat, P. Capacity Flexibility Analysis of the Highway Network for the Eastern Thailand. Proceedings of the 22nd International Conference of Hong Kong Society for Transportation Studies. Kowloon, Hong Kong. 2017; 507 -14.

[4] Rakkrai, W. and Kasikitwiwat, P. Capacity Flexibility Assessment of the Highway

Network for the Eastern Economic Corridor Area. Engineering Journal Kasetsart University 2018: 033-44.

[5] Kasikitwiwat, P. Capacity Reliability and Capacity Flexibility of a Transportation network, [Ph. D. Dissertation]. Utah: Utah State University; 2005.

[6] Chen, A. and Kasikitwiwat, P. Modeling capacity flexibility of transportation networks, Journal of Transportation Research, Part A 2011; 45:105-117.

[7] Chen, A. Kasikitwiwat, P. and Yang, C. Alternate capacity reliability measures for transportation networks. Journal of Advanced Transportation 2013; 47(1):79-104.

[8] Morlok, E.K., Chang, D.J. Measuring capacity flexibility of a transportation system. Journal of Transportation Research, Part A 2004; 33(6): 405-20.

[9] Chaipachittikul, R. and Jansuwan, S. Measuring Capacity Flexibility of Freight Transportation Network between Ladkrabang Inland Container Depot (LICD) and Laem Chabang Port (LCB). Proceedings of Operations Research Network of Thailand, Bangkok. 2016; 240-8.

[10] Department of Highways, Capacity Reliability and Capacity Flexibility Assessment of Highway Networks for the Eastern Thailand, Bangkok. Final Report by Kasetsart University, 2018.

[11] Planning Division, Department of Highways, Planning of Highway Development Projects for the Eastern Economic Corridor, Bangkok, 2017.

[12] Kasikitwiwat, P. and Chen, A. Analysis of Transportation Network Capacity related to Different System Capacity Concepts. Journal of Eastern Asia Society for Transportation Studies 2005; 6:1439-54.

[13] Wong SC, and Yang H. Reserve capacity of a signal-controlled road network. Journal of Transportation Research Part B, 1997; 31 (5):397-402.

[14] Sheffi, Y. Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods. New Jersey: Prentice Hall; 1985.

[15] US Department of Commerce. Traffic Assignment Manual. Washington D C.: Bureau of Public Road; 1964.