Analyzing Operation Plan of Ho Chi Minh City's Bus Rapid Transit System

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Abstract

Public transportation is vital for societal well-being, impacting economic, social, and environmental aspects. The Bus Rapid Transit (BRT) system, an urban traffic solution, requires effective strategies. To address the traffic problem in Ho Chi Minh city, BRT implementation has been proposed, specifically for the Vo Van Kiet - Mai Chi Tho boulevards as a pilot. However, there are scant assessments on how this system should be implemented effectively, especially by simulation approach, which could help to test different scenarios, saving huge money and time for real operation. In this study, we use discrete event simulation to explore different scenarios for implementing a BRT system in the case of Vo Van Kiet - Mai Chi Tho boulevards in Ho Chi Minh city. Simulation optimization via OpQuest in ARENA is used to suggest the best operation plan in terms of number of buses, speed and waiting time. In addition, Multiple Criteria Decision-Making (MCDM) approach is also employed to evaluate the solution priorties. This study offers a practical framework for decission makers to solve the urban mobility challenges.

Keywords
Bus rapid transit (BRT), Simulation, OptQuest, MCDM

1. Introduction
The Management Board of Urban Traffic Construction Investment and Construction of HCMC has approved policies, regulations and institutions to decide the first BRT route investment on Vo Van Kiet and Mai Chi Tho boulevards since 2015. The main reason is the heavy traffic congestion in this area, particularly during peak hours. The route connects two key areas in the city, the western and eastern parts, and serves as a major transportation corridor for commuters and goods. Additionally, the route was selected because it is relatively straight and has wide lanes, making it easier to construct dedicated bus lanes and stations. The construction of the BRT system on this route aimed to improve the efficiency and reliability of public transportation, reduce traffic congestion, and decrease the environmental impact of transportation in the city. Furthermore, several major public transportation systems in the city, including the future metro lines and existing bus routes, making it easier for commuters to transfer between modes of transportation. Overall, the selection of this route for the first BRT system in HCMC was a strategic decision to address the city's transportation challenges and improve mobility for its residents.

The objective of this study is to explore different scenarios of implementing the BRT line in Vo Van Kiet - Mai Chi Tho boulevards in Ho Chi Minh city and propose the most promising operation plan. This study offers a practical framework for decission makers to solve the urban mobility challenges.

2. Literature Review
The traffic management challenges usually involve many objectives, criteria and uncertainties. Thus, Multiple Criteria Decision-Making (MCDM) approach, multi-objective models and simulation are frequently found in the literature to address this problem. For instance, (Aramesh & Ghorbanian 2020) explore a multi-objective approach in traffic management, employing OptQuest optimization for Arena simulation to minimize wait times and air pollution at a T intersection with traffic lights. (Yang & Liu 2020) work also employs a multi-objective approach to optimize energy

consumption in vehicles, demonstrating the effectiveness of their algorithm. (Hassannayebi et al. 2021) tackle disturbance recovery for public transport systems, proposing an integrated model using variable neighborhood search to minimize passenger wait times during disruptions.

Research on Bus Rapid Transit (BRT) is crucial. (Hoonsiri et al. 2021) discuss strategies for optimizing BRT routes and (Dung & Ross, 2008) investigate public perception and environmental impacts of BRT systems. Additionally, (Kiani Mavi et al. 2018) evaluate BRT performance using a hybrid MCDM technique.

For institutional coordination in public transportation design, (Bouraima et al. 2023) employ MCDM methods, emphasizing the importance of governance principles. (Tus & Adali, n.d.) and (Ali Taş et al. n.d.) offer comparisons of MCDM methods in various contexts, suggesting effective strategies for decision-making.

Besides work pariculatly addressing the transportation problem, there are many other research demonstrating the usage of simulation and MCDM in other areas. One pivotal reference is (Aldurgam et al. 2019) study, which introduces a decision support tool utilizing discrete-event system simulation and optimization to enhance operational decision-making in an air conditioner manufacturing facility. This tool integrates simulation and mathematical programming, highlighting its real-world applicability. Methodological foundations are covered by (Sun, 2010), who explains Fuzzy AHP's application in performance evaluation. (Dogan et al. n.d.) propose an innovative integration of IVIF-AHP and TOPSIS for autonomous vehicle deployment, providing a robust approach to handle complexities and uncertainties.

3. Methods

There are currently 2 buses operating on Vo Van Kiet - Mai Chi Tho boulevards, namely bus D4 and bus 39. On the other hand, these 2 buses also serve other routes before entering and after leaving Vo Van Kiet - Mai Chi Tho boulevards. Thus, we suggest a simple and flexible solution that integrates the normal bus and the BRT concept. That is to say, bus D4 and bus 39 still operate as normal in other routes, but accelerate speed on a segregated lane when enterring the Vo Van Kiet - Mai Chi Tho boulevards.

In this study, we use discrete-event simulation with Arena to replicate the operation of bus D4 and 39 on Vo Van Kiet - Mai Chi Tho boulevards. Next, simulation optimization via OptQuest in Arena is carried out to suggest the optimum operation plan in terms of number of bus trips, speed, bus interval to minimize the passenger waiting time with minimum bus investment. Lastly, Fuzzy- Analytic Hierarchy Process (FAHP) is used to evaluate two options for improving public transportation performance and its attractiveness: adding more buses serving the route (the normal bus line) or increasing the speed of bus (the BRT line).

4. Simulation modelling

4.1. Inputs for Simulation

The data was collected over 15 days from 19 bus stops on an 18.8 km route (Mai Chi Tho - Vo Van Kiet) from 3 p.m. to 7 p.m. There are 2 buses operating on this route, namely bus D4 and bus 39 (figure 1). The data collection includes number of passenger boarding, alighting, delay times by comparing scheduled and actual arrival times, and distances between stations. At each bus stop, we counted the number of passengers arriving during the time between 2 bus arrivals and calculated the average passenger arrival rate. We assumed that the passenger interarrival time follows exponential distribution with mean interarrival time equal to the reciprocal of the average arrival rate. Bus map application and Google map were used to record the delay time of bus arrival and distances between stations.

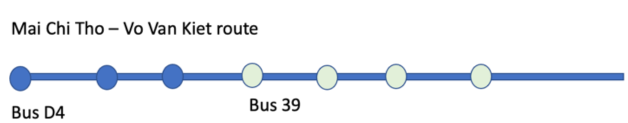
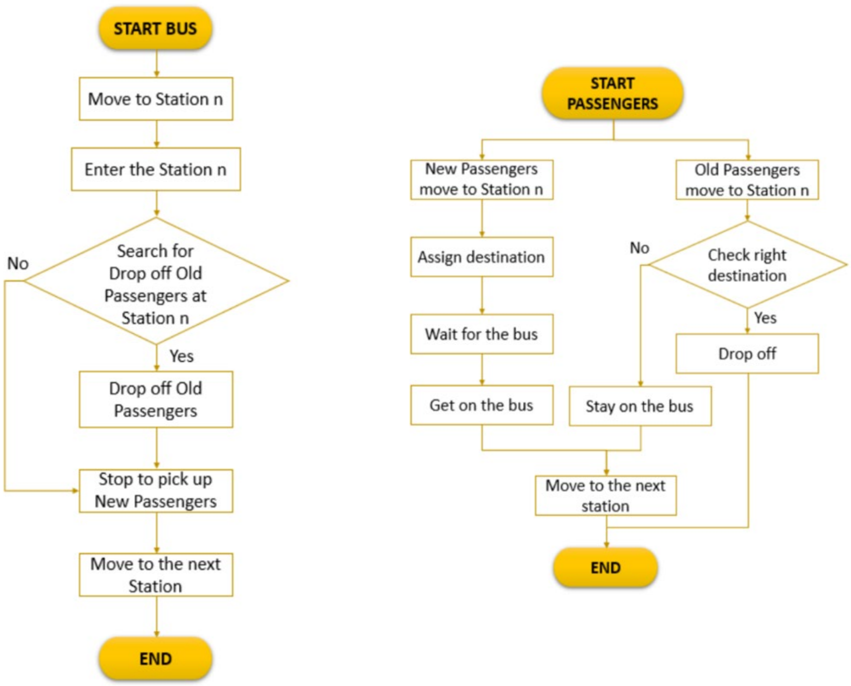


Figure 1. Bus D4 and Bus 39 operate on the Mai Chi Tho-Vo Van Kiet route

4.2. Conceptual model of current system

The Bus flowchart (Figure 2a) illustrates the sequential process of a bus moving from one stop to another, handling passenger drop-offs and pick-ups along the way. The flowchart captures the dynamic nature of the bus route as it progresses through each stop, accommodating the needs of existing and new passengers. The Passengers Flowchart (Figure 2b) presents two distinct paths that passengers can follow within a bus system. It outlines the steps for new passengers joining the system and old passengers already onboard, considering their respective actions at each station.



(a) (b)

Figure 2. Bus flowchart and Passenger flowchart

4.3. Arena model

- **Passenger arrival at each station**

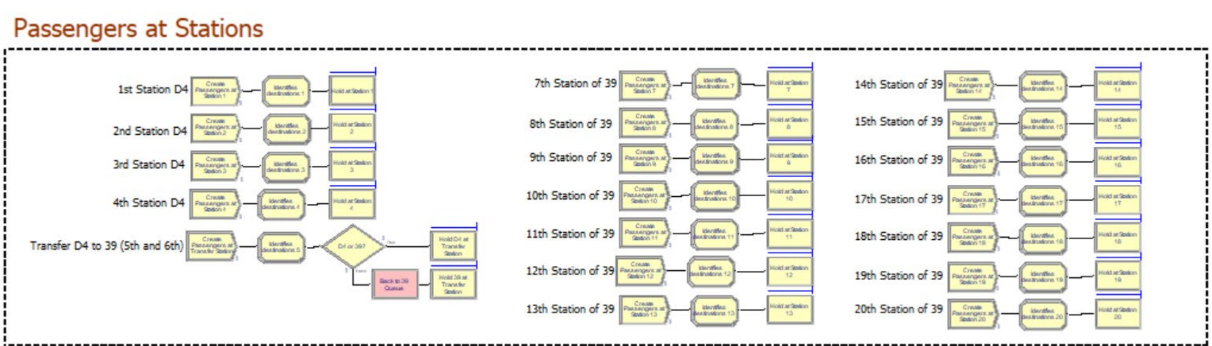


Figure 3. Passengers arrival at each station

Prior to the initiation of bus operations, the "Passenger" entities are generated at each station via a CREATE module. This involves an arrival rate of one entity per arrival, a parameter determined by EXPO(mean) expressions. Following entity creation, the ASSIGN module facilitates attribute allocation and entity illustration for the Passengers.

Concurrently, awaiting Passengers at Stations are systematically queued using a HOLD module, with the queue's continuity preserved until a Bus arrives for service. Notably, at the Transfer Station, Passengers are presented with the option to board either Bus D4 or Bus 39. All the flows are illustrated in figure 3.

Bus D4 & 39 route

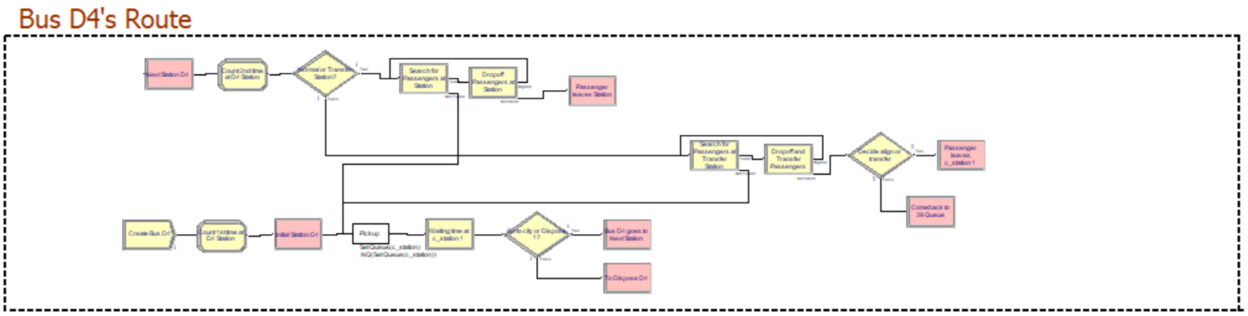


Figure 4. Bus D4's route in ARENA

Bus D4 makes its appearance along Mai Chi Tho every fifteen minutes through the CREATE module. Bus 39 is created at Transfer Station (station 5) to continue going on Vo Van Kiet Street. The logic of Bus 39's model is the same with Bus D4's, but it does not have the transfer station; therefore, the model just looping the normal station until it reaches the last station (figure 4 and figure 5).

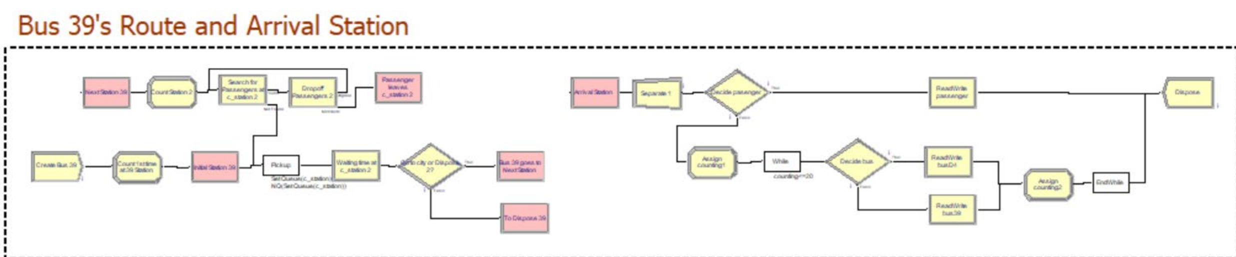


Figure 5. Bus 39's route in ARENA

Model validation

T-test is performed to test the hypothesis that the average waiting time of passengers from simulation (table 1) is not significantly different with the real system.

$$H_0: E(Y) = 9 \; minutes$$

$$H_1: E(Y) \neq 9 \; minutes$$

$$\alpha = 0.05, sample\ size\ n = 7$$
$$\rightarrow t_{(0.025,6)} = 2.45\ (t - table)$$

Table 1. Passenger waiting time from simulation

Replication		Average Passengers Waiting time after running model (Y – Unit: Minutes)
1		9.7184
2		10.0355
3		9.5134
4		9.9971
5		9.8711
6		10.323

7		9.9118

$$\rightarrow \bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i = 9.910 \rightarrow S = \frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n-1} = 0.0649$$

$$\rightarrow |t_0| = \left|\frac{\bar{Y} - \mu_0}{S/\sqrt{n}}\right| = 2.3531 \ < t_{(0.025,6)} = 2.45$$

$$\rightarrow \boldsymbol{H_0\ is\ not\ reject \rightarrow the\ model\ is\ valid}$$

4.4. Simulation optimization via OptQuest

Objective functions:
$\boldsymbol{Objective}$ **1**: $Minimize\ WT\ passenger$
$\boldsymbol{Objective}$ **2**: $Minimize\ number\ of\ bus$

Subject to:
Constraint 1: The speed of buses (both Bus D4 and Bus 39) should be less than or equal to 50 km/h and higher than or equal to 15 km/h.
$15 \leq speed \leq 50$
Constraint 2: The number of buses (both Bus D4 and Bus 39) should be higher than or equal to 1 unit.
$MaxBusD4 \geq 1$
$MaxBus39 \geq 1$
Constraint 3: The time between two buses should be higher than or equal to 15 minues and less than or equal to 20 minutes.
$15 \leq Bus\ D4\ InterArrivalsTime \leq 20$
$15 \leq Bus\ 39\ InterArrivalsTime \leq 20$

After running the OptQuest, Average Passenger Waiting Time is minimized to 2.31 minutes with the bus speed of 50 km/h, usage of 27 buses D4 and 30 bus 39 and bus interval of 15 minutes. It is noted that the average normal bus speed is less than 30 km/h, but a BRT can afford the speed of 50 km/h.

4.5. Increasing number of passengers scenario

We use simulation to test the scenario when the number of passengers doubly increases due to the attractiveness of the BRT line. The proposed operation plan of 27 buses D4 and 30 bus 39, speed of 50 km/h and bus interval of 15 minutes is still able to keep the average passenger waiting time less than 3 minutes.

5. Multi-Criteria Decission Making

5.1. Inputs for the MCDM

- **Proposed alternatives**

Two alternatives for for improving public transportation performance and its attractiveness are selected from the literature:

- *Adding more buses serving the route (the normal bus line):* A case study from (Tengecha, N. A., & Mwendapole, M. J., 2021) shows that while adding more buses to reduce waiting times is costly it yields benefits like curbing air pollution, congestion, and accidents. The city's air quality impact costs, resulting from private car use, outweigh adding 35 buses and compensating for school closures.
- *Increasing the speed of bus (the BRT line):* (Nesmachnow et al., 2019) proposed an efficient solution for faster Bus Rapid Transit (BRT) by using segregated lanes to avoid congestion. While this reduces waiting times and traffic jams, safety concerns arise for standing passengers due to higher speeds.

Proposed Criteria

Four criteria for public transpotation are adopted from the literature for this study:

- *Transportation Cost:* Evaluating expenses like fuel, maintenance, and labour; Optimizing routes and using eco-friendly tech lowers costs and benefits passengers and the environment.

- *Environmental Friendliness:* Measuring CO2 reduction and global impact; Using eco-materials, renewable energy, and recycling improves sustainability.
- *Ridership Satisfaction:* Gauging passenger contentment with comfort, reliability, and service quality; Positive experiences are vital for assessing system effectiveness.
- *Fuel Efficiency:* Maximizing travel per fuel unit through technology and lightweight materials, reducing costs and emissions for economic and eco-friendly gains.

The scale in table 2 is used for determining preferred score among criteria and also among alternatives under each criterion.

Table 2. Evaluation scale for pairwise comparison

Judgement	Value	Reciprocal
Equal importance	1	1
Moderate importance	3	1/3
Strong importance	5	1/5
Very strong importance	7	1/7
Extreme importance	9	1/9

The survey uses pairwise comparisons to collect preferred scores. Questions compare criteria using a scale. The most important criterion is determined, and alternatives are chosen through pairwise comparison within each criterion.

5.2. Pairwise Comparison matrix of criteria

Creating a criteria comparison matrix aids structured decision-making, aligning choices with desired outcomes and Core Values. To ensure fairness, criteria should be defined before alternatives. Key criteria for evaluation are:

- Transportation cost
- Environmental friendliness
- Ridership satisfaction
- Fuel efficiency

After collecting all the data from the survey, we form a criteria matrix with the score of the survey. The matrix ranks criteria, aiding decision-making by highlighting relative importance. Applying Fuzzy AHP procedure (Sun, 2010), we come up with the priorities of criteria (table 3). This table is later used for calculating the consistency check at table 4.

Table 3. Priorities calculation of criteria pairwise matrix

	Transportation cost	**Environmental friendliness**	**Ridership satisfaction**	**Fuel efficiency**	**Priorities**
Transportation cost	0.22	0.18	0.41	0.21	0.26
Environmental friendliness	0.64	0.56	0.41	0.5	0.53
Ridership satisfaction	0.07	0.18	0.14	0.21	0.15
Fuel efficiency	0.07	0.08	0.04	0.08	0.07
SUM	**1**	**1**	**1**	**1**	

Additionally, in real-world situations, a comparison matrix that satisfies the consistency check requirement can be identified as a consistent matrix. The most frequent way to determine if a comparison matrix is consistent or not is to use the consistency ratio. To guarantee the accuracy of the comparison weights, including the consistency ratio CR and consistency index CI, as well as the consistency of the subjective impression.

$$CI = \frac{\lambda max - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Where the value of RI takes from the Consistency indices for a randomly generated matrix (figure 6):

n	1	2	3	4	5	6	7	8	9	10
Random Index	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Figure 6. Random Index

If the consistency ratio (CR) is less than or equal to 0.10, it is satisfactory. If the consistency ratio is more than 0.10, or 10%, the judgments must be revised to identify and address the source of the inconsistency. With the result from table 3, we conduct the $\lambda max, CI, RI\ and\ CR$ to ensure that the criteria matrix is acceptable as table 4 below.

Table 4. CR calculation of criteria matrix

λ max	4.19
CI	0.06
RI	0.9
CR	0.07 (<0.1)

5.3. Pairwise Comparison matrix of alternatives

This study examines two key scenarios: Bus adjustment to the BRT line and BRT bus acceleration. The survey between alternatives and criteria is also conducted to collect the score of them. We then analyze scores to compare each alternative pairwise. A fuzzy matrix of alternatives is formed for each criteria of Environmental friendliness, Transportation cost, Ridership satisfaction and Fuel efficiency.

After a comprehensive evaluation, we transfer all the scores into fuzzy numbers and apply formula to have the mean and weight of all elements. To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \cdots \otimes \tilde{a}_{ij} \otimes \cdots \otimes \tilde{a}_{in}\right)^{1/n}$$

$$\widetilde{w}_i = \tilde{r}_i \otimes [\tilde{r}_i \oplus \cdots \oplus \tilde{r}_i \oplus \cdots \oplus \tilde{r}_i]^{-1}$$

$$where \begin{cases} \tilde{a}_{ij} is\ fuzzy\ comparison\ value\ of\ dimension\ i\ to\ criterion\ j \\ \tilde{r}_i\ is\ a\ geometric\ mean\ of\ fuzzy\ comparison\ value\ of\ criterion\ i \\ to\ each\ criterion \\ \widetilde{w}_i\ is\ the\ fuzzy\ weight\ of\ the\ ith\ criterion \end{cases}$$

The final fuzzy weight value of each alternative:

$$\widetilde{R}_i = \begin{bmatrix} \widetilde{w}_{11} & \widetilde{w}_{21} & \cdots & \widetilde{w}_{m1} \\ \widetilde{w}_{12} & \widetilde{w}_{22} & \cdots & \widetilde{w}_{m2} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{w}_{1n} & \widetilde{w}_{23} & \cdots & \widetilde{w}_{mm} \end{bmatrix} = \begin{bmatrix} \widetilde{w}_1 \\ \widetilde{w}_2 \\ \vdots \\ \widetilde{w}_n \end{bmatrix}$$

$$\text{where } i = 1,2,\ldots,n$$
$$j = 1,2,\ldots,m$$

The best non-fuzzy performance (BNP) value:

$$BNP_{\tilde{R}_i} = \left(\frac{l_i + m_i + u_i}{3}\right)$$

The comparison result for these two scenarios is summarized in table 5 below.

Table 5. MCDM Output

Alternatives	r_{ij}			**BNP**	**Rank**
Adding more buses serving the route	0,036	0,398	5,015	1,816	2
Increasing the speed of bus	0,062	0,602	5,832	2,165	1

With the higher BNP, option of accelerating the BRT buses is preferred over the option of adding buses to the normal line. Accelerating BRT buses can reduce waiting times and emissions, boosting the attractiveness of public transport and aligning with eco-friendly goal.

6. Conclusion

This study successfully developed a BRT optimization model using OptQuest for Arena software. It aims to minimize passenger waiting time and vehicle energy consumption through real-world simulations of Bus 39 and Bus D4 in Vo Van Kiet - Mai Chi Tho boulevards. MCDM method is also employed to reaffirm the need of implementing the BRT line over other options. This approach can be applied for other similar contexts, promoting urban mobility and accessibility with prudent implementation management amid potential infrastructure challenges.

Future research could expand analyses to diverse routes and conditions while integrating real-time bus data to enhance decision-making precision.

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Biography

Tran Huynh Diem Phuong A senior-student majoring in Logistics and Supply Chain Management in the School of Industrial Engineering and Management at Vietnam National University of Ho Chi Minh City - International University. She adds a new viewpoint to supply chain dynamics with her keen interest in operational data analysis, distribution planning, and process optimization.

Her curiosity goes beyond her degree, and she periodically explores the world of Marketing to deepen her grasp of how businesses function as a whole. Her commitment to learning and desire to make significant contributions to both logistics and the larger business community is shown by her diverse approach.

Phan Thi Ngoc Anh A senior at Vietnam National University of Ho Chi Minh City - International University is majoring in Logistics and Supply Chain Management in the School of Industrial Engineering and Management. She hopes to master the challenges of global logistics because of her intense interest in international trade and transportation.

Apart from her academic pursuits, she is attracted to the ever-evolving electricity business sector. Her entrepreneurial drive is evident as she sets her sights on launching her own venture before turning 20. This progressive mindset highlights her resolute determination and preparedness to make innovative contributions not only within the realm of logistics but also in broader horizons.

Dr. Pham Huynh Tram got her Doctorate in Innovation in Manufacturing and Technology from Nanyang Technological University - Singapore. She has been lecturing in Department of Industrial and Systems Engineering of International University- Vietnam National university HCMC since 2012. Her research interest is in operations research, simulation and lean manufacturing

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