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TO INTRODUCE THE ALTERNATIVE MATHEMATICAL MODELS FOR SOLVING THE CURRIER TRANSPORTATION PROBLEM IN THE MIDDLE - INCOME COUNTRY: A SMALL LOT DELIVERY

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A B S T R A C T
This study seeks to introduce the alternative mathematical models for addressing the courier transportation problem using personal vehicles. Initially, a review of relevant literature was conducted to inform the development of these models, particularly focusing on groups of courier deliveries characterized by special orders or small lot sizes, with an emphasis on minimizing costs associated with energy consumption. Subsequently, two mathematical models were formulated: one addressing the transportation problem based on distance with a fixed transport speed (TPD), and another that considers both distance and time (TPDT). These models were numerically analysed using the exact method facilitated by the Solver Add-in in Microsoft Excel 2021, incorporating secondary data sourced from Geographic Information System (GIS) data via Google Maps in Thailand, a middle-income country. The analysis revealed that the transportation model incorporating both distance and time proved to be a more effectiveness than the model based solely on distance with a fixed transport speed, particularly when evaluating the cost objective function. It was determined that focusing exclusively on transport distance is insufficient for minimizing costs in real-world courier delivery scenarios. Therefore, transport planners are encouraged to consider both distance and time for managing special orders or small lots, as this approach holds significant potential for cost savings in practical courier transport planning.

Keyword: Currier delivery, Traditional Transportation Problem, Transportation problem based on distance, Transportation problem based on distance and time, Geographic Information System, Energy consumption.

1. INTRODUCTION

In the realm of business, the manufacturing supply chain holds paramount significance. The manufacturing supply chain encompasses inbound logistics, which is defined as the process involving the procurement of raw materials into an organization. This process integrates activities related to transportation, warehousing, inventory management, and customer relationship management (Hu & Weisel, 2020; Minner, 2019). For instance, a shortage of raw materials can impede companies within the supply chain from converting inputs and delivering products to subsequent manufacturers. Thus, it can be asserted that effective management of manufacturing supply chain is crucial for overall business success.

Particularly, inbound transportation plays a critical role, as the movement of raw materials (Raw Material Transport) involves transporting inputs from various locations and sources in predetermined quantities. For example, expedited transport from raw material producers to manufacturing sites can enable organizations to minimize inventory holding costs while ensuring timely availability of raw materials for production processes (Misuko, 2015). It follows that if inbound transportation experiences disruptions or deficiencies, various logistics activities may be rendered ineffective. Therefore, research aimed at enhancing inbound transportation and the procurement of raw materials is essential for bolstering businesses within the manufacturing supply chain.

According to statistics from the Department of Industrial Works, as of the end of 2023, small industrial operators accounted for approximately 60% of all enterprises (Department of Industrial Works, 2023). Furthermore, small enterprises contribute over 15% to the Gross Domestic Product (GDP) and play a vital role in supplying fundamental raw materials for production, establishing connections with medium and large enterprises (Office of Small and Medium Enterprises Promotion,2023). Notably, transportation costs amount to as much as 1.2 trillion baht, representing 6.6% of the GDP, with over 80% of these costs attributed to road transport (Logistics Development Strategy Division, 2023). Consequently, promoting or supporting improvements in the transportation of goods or raw materials for small industrial operators is vital for fostering GDP growth.

Small industrial firms face pressures from all directions, as they typically operate with limited capital and smaller scales. This often necessitates reliance on third-party logistics providers for the transport of goods (Williams *et al.*, 2024; Latip *et al*., 2022). To meet the demands of their industrial customers, small enterprises frequently undertake inbound transportation activities themselves through the currier delivery, particularly when they have a small order or a special equipment demand of raw materials does not fill a transport vehicle. In such cases, small firms seek to ensure timely delivery of production inputs to their industrial business, but may inadvertently incur higher transportation costs due to constrained the currier delivery timelines (Aharoni, 2024; Kurniawan *et al.*, 2021; He *et al.*, 2018).

The operational focus of small industrial business is to achieve transportation cost savings while delivering materials to their manufacturing clients (Ni & Wang, 2021; Jothi Basu, 2015). For instance, they may coordinate the delivery of raw materials from various sources through the currier transport to subsequent manufacturing companies, ensuring compliance with required the small item and timelines while striving to minimize transportation costs. This aligns with the principles of transportation problems, which address the allocation of goods from origin points, such as factories and raw material sources, to destinations with minimal costs (Qiuping *et al.*, 2023; Zabiba *et al.*, 2023; Shivani Rani & Ebrahimnejad, 2022). Thus, applying these principles to the transportation of raw materials can significantly benefit small industrial operators.

Traditionally, the transportation problem (TP) has been extensively utilized by planners to minimize transportation costs between supply and demand nodes. This objective function focuses on achieving the lowest overall transport cost by relying on historical fixed unit costs for each route (Qiuping *et al.*, 2023; Mardanya & Roy, 2023; Shivani Rani & Ebrahimnejad, 2022). However, road transportation conditions are subject to dynamic changes influenced by factors such as route distance and time, which affect travel speed. These variables ultimately determine fuel consumption, which in turn impacts the overall cost of road freight transportation. To date, there has been a lack of mathematical models addressing the transportation problem that incorporates cost calculations based on distance, time, and fuel consumption. It can be argued that developing such a model would contribute significantly to the literature, enhancing our understanding of the complex conditions necessary for addressing real-world currier transportation issues.

This research study aims to address two primary objectives related to the introduction of alternative mathematical models for solving the courier transportation problem using personal vehicles. First, it seeks to develop a novel mathematical model specifically designed to tackle the courier transportation issue with personal cars. Second, the study intends to evaluate the relative effectiveness of these alternative mathematical models in terms of energy consumption and its impact on transportation costs. The findings are expected to assist factory planners improving road freight transports and optimizing costs in the future.

2. LITERATURE REVIEW

The principles underlying the Transportation Problem (TP) are fundamentally aimed at optimizing the operational costs to achieve the lowest possible expenditure. This approach serves as a critical framework for planning prior to delegating the transportation tasks to the logistics units responsible for delivering goods or the production resources to the various destinations simultaneously, thereby fulfilling demand across multiple units. Recent research pertaining to Transportation Problem has yielded several notable contributions as follows.

Bai *et al.* (2023) investigated the incorporation of the additional data requirements into the transportation systems to enhance the problem-solving capabilities. Their findings indicate that the integration of current supplementary data significantly improves the transportation information system, leading to altered transportation cost estimates. Similarly, Oladimeji *et al.* (2023) conducted a comprehensive survey of the technological demands in transportation to make a better understanding in the user requirements. Their research concluded that the modern technologies play a pivotal role in enhancing the transportation operations from the user's perspective. This aligns with the work of Dekhtyaruk (2023), who explored the utilization of computational programming to address complex transportation challenges. This study posits that augmenting data within the transportation problem framework can enhance the optimization process.

Das *et al.* (2023) reported on travel scenarios involving multiple objectives, where the study incorporated both transportation costs and Euclidean distances into the mathematical framework of the Transportation Problem. Their research revealed that the inclusion of distance constraints leads to solutions that achieve minimum transportation costs while optimizing overall travel distance. In a parallel vein, Altschuler & Boix-Adsera (2023) along with del Barrio *et al.* (2023) examined polynomial-time algorithms designed to solve transportation optimization problems. They advanced a structural equation framework that considers both cost and polynomial time. Notably, this research remains in the developmental stage of creating structural models and has not yet been validated in real-world scenarios; however, preliminary simulations suggest improved cost outcomes.

Kaur *et al.* (2024) focused on addressing the transportation problems through the development of time-related algorithms, employing a two-tiered approach that integrates the polynomial equations as the mathematical conditions. Their findings demonstrate that this algorithmic development can also yield the optimal solutions. Similarly, Eckstein & Pammer (2024) explored the computational methods aimed at identifying the optimal solutions for the transportation issues, utilizing time-series data as a computational constraint, which proved effective in addressing time-sensitive problems.

Furthermore, Yang *et al.* (2024) examined the application of utility constraints to resolve the transportation cost issues by employing the game theory principles to elucidate the relational dynamics among multiple transportation service providers under a unified corporate umbrella. Their findings suggest that such principles can similarly facilitate optimal transportation solutions. Collectively, these studies suggest that enhancing the mathematical model of the Transportation Problem by incorporating additional constraint equations may significantly improve the optimization outcomes.

From a review of the relevant literature, it can be asserted that the nature of solving transportation problems primarily revolves around identifying optimal cost solutions. In pursuit of enhancing transportation efficiency, numerous researchers have made concerted efforts to introduce additional constraints into the transportation problem framework. These constraints aim to refine the solutions by considering factors such as time, distance, and the integration of other data inputs. The computational processing of these enhanced models is conducted through extensive programming and various algorithms, potentially yielding more accurate solutions that account for these supplementary conditions in real-world scenarios.

Despite the considerable body of research addressing transportation problems, including studies that incorporate constraints or employ computational processing systems, there remains a notable gap in the literature regarding the examination of conditions related to distance and time. Specifically, this gap pertains to the consideration of variable travel speeds across different routes, which significantly contributes to fuel consumption and thus impacts transportation costs. Especially, the important thing is to how to indicate the method for solving the complex problem in the real world, and this research will employ these conditions for designing the mathematic models in this research.

2.1 Currier delivery

Courier delivery is defined as a specialized mode of transportation used for the distribution of particular packages from one supply location to another (Chen & Hu, 2024; Orenstein & Raviv, 2022). This transport method is typically employed for the urgent delivery of critical components, specialized equipment, and unique tools from their point of origin to designated demand locations (Novitasari & Anwar, 2022; Praet & Martens, 2020). Consequently, this type of delivery often involves the use of personal vehicles to collect items before delivering them directly to clients, given the urgent need for these items in operational facilities to support ongoing business activities. Therefore, it can be inferred that the efficiency of the manufacturing supply chain may be compromised if courier services fail to deliver essential parts to their intended locations.

The courier transport utilized for delivering special orders typically involves the use of small trucks or personal vehicles (Liang *et al.*, 2024; Peng *et al.*, 2024). Personal cars are often designated for quick deliveries, as these vehicles can accommodate manufacturing equipment—such as pickups, cars, and vans—that consume less fuel compared to larger vehicles like trucks and lorries (Sikora, 2024; Silva *et al.*, 2024). For instance, when a factory requires a specialized water pump to replace outdated equipment, supply planners generally recognize that using a truck may not be energy-efficient for such deliveries. Furthermore, transporting this industrial item via motorbike is not feasible due to the risk of potential damage, making personal cars the preferred choice for fulfilling order.

An essential characteristic of courier delivery is the pressure of time (Novitasari & Anwar, 2022; Rajendran, 2021). The duration of transportation in courier services is a crucial factor, as customers expect swift delivery while prioritizing their anticipated demand (Auad *et al.*, 2023; Marcysiak, 2021; Ejdys & Gulc, 2020). In instances of special orders, factories often inquire about delivery timelines, as delays in transportation can lead to productivity issues, preventing them from generating and selling products in a timely manner. Thus, it can be argued that transport time is a critical aspect of courier services, as it is vital for maintaining subsequent customer business operations.

In conclusion, courier transport is identified as a specialized form of distribution. Within the manufacturing supply chain, its attributes are particularly pertinent for addressing urgent situations, such as special orders, immediate needs, and unique demands. Furthermore, the use of reliable and safe transportation vehicles, such as personal cars, is essential for minimizing energy costs. Clients also expect timely delivery, which underscores the importance of transport time. Therefore, it can be asserted that considerations for small-scale transportation should not solely focus on transport distance; rather, transport time and energy consumption associated with the chosen vehicles must also be taken into account by organizational planners when addressing transportation challenges prior to scheduling courier deliveries.

2.2. Traditional Transportation Problem

The transportation problem is conventionally characterized as an issue involving the allocation of resources from initial sources—such as factories, raw material providers, or warehouses—to various destination points. Its primary objective is to minimize costs (formulating a minimization problem) or to identify the lowest possible expense (Mardanya &

Roy, 2023; Qiuping *et al.*, 2023; Shivani Rani & Ebrahimnejad, 2022). Typically, the transportation unit costs are determined based on historical transportation expenses. Consequently, the mathematical framework of the traditional transportation problem (TTP) can be generally represented as follows.

Indexes

i, j That is, the supplier of the raw materials located at the initial point i and the customer, who responses the manufacturing entity, located at the terminal point j

Parameters

a_i The quantity of raw materials available from the supplier at the initial point.

b_j The quantity of raw materials that the supplier must deliver to the manufacturing customer located at the terminal point j.

C_{ij} The transportation cost of delivering one unit of raw material from supplier i to the manufacturing entity at terminal point j.

TC_{ij} The transportation cost of delivering whole unit of raw material from supplier i to the manufacturing entity at terminal point j.

X_{ij} The quantity of raw materials transported from supplier i to the manufacturing entity at terminal point j.

$TTPf(x)$ The total transportation cost per a delivery planning cycle following the concept of Traditional Transportation Problem.

TTP is traditionally predicated on the volume of transportation involved. This scenario is typically observed in the large-scale transfer of materials from major supplier facilities to significant consumption sites. The objective of TTP is to reduce transportation costs, which are contingent upon both the unit transport price and the quantity transferred. The mathematical model can be expressed as follows.

1) Objective function

$$TTP\ f(x) = \sum_{i=1}^{m} . \sum_{j=1}^{n} \left(C_{ij}X_{ij}\right) \qquad (1)$$

2) Constraints

2.1) Amount of materials in each road transport route has not a more quantity than the material volume at the supply location i. $\sum_{j=1}^{n} \left(X_{ij}\right) = \left(a_i\right) \quad (i = 1, 2, 3, \ldots . m)$ (2)

2.2) Amount of materials in each road transport route has not a more quantity than the material volume at the demand location j. $\sum_{i=1}^{m} \left(X_{ij}\right) = \left(b_j\right) \quad (j = 1, 2, 3, \ldots . n)$ (3)

2.3) Amount of materials in each road transport route has a more value than zero, or it is equal to zero.

$$X_{ij} \geq 0 \qquad (4)$$

Decision variables

$X_{ij} > 0$ The materials are transferred from the material location i to the usage point j.

$X_{ij} = 0$ The materials are not transferred from the material location i to the usage point j

2.3 Problem formulation

The statement of the currier transportation problem is usually found in the small material transfer from the small supplier sites to the various usage plants. For example, the currier materials transfer services or special orders are always a piece or a small lot with the urgent need, so this situation requires a rapid delivery coupled with concentrating on the distance and charge price. Besides this, when there have the special material orders from the usage plants, the supply locations need to delivery their materials to their client location even if there are not full truck loads. Following this, it might be stated that the supply locations require transferring the intermediate material along every road freight transport routes upon demands in each planning cycle, so the road transport cost might not depended on volume but it depends on order.

As reviewed from a number of former literatures, two important variables involving the currier transportation problem were the transport distance and transport time respectively, and this transportation highly concentrate on lowering the energy consumption driven by transport vehicle. Following this, this study decisively made an intention to firstly develop the mathematical model of the transportation problem based on distance by ideally fixing the transport speed (TPD), and then additionally formulate the mathematical model of the transportation problem based on distance and time (TPDT). Especially, their objective functions were transformed into the term of energy consumption. Furthermore, both alternative mathematical models for solving the currier transportation problem transport with using the personal cars were developed and introduced as follows.

2.3.1 Transportation problem based on distance: TPD

The mathematical model of the transportation problem based on distance (TPD) assumes a constant transport speed. This model operates under the premise that the transport planner allocates resources for courier deliveries, using identical personal vehicles that travel at the same speed across all routes. At this stage, all transport vehicles consume fuel at a uniform rate, resulting in energy consumption on each transport route being proportional to the distance from each supply point to each destination. Thus, the objective of TPD is to minimize the total transportation cost for all items across each courier delivery. The mathematical representation of this model is as follows.

Additional parameters

d_{ij} The transportation distance of delivering of raw material from supplier i to the manufacturing entity at terminal point j.

e The fixing energy consumption rate of delivering of raw material from supplier in unit of liter per kilometer.

Y_{ij} The route of raw materials transported from supplier i to the manufacturing entity at terminal point j.

$TPDf(y)$ The total transportation cost per a delivery planning in term of energy consumption following the transportation problem based on distance (TPD)

The target of TPD is to minimize the transportation cost based on the transport distance idyllically stabilizing the transport speed which subsequently produces the similar velocity resulting to the identical energy consumption rate. Moreover, the mathematical model can be illustrated as follows.

1) Objective function

$$TPD\ f(y) = e \sum_{i=1}^{m} \ . \sum_{j=1}^{n} \left(d_{ij} Y_{ij}\right) \tag{5}$$

2) Constraints

2.1) Transportation cost in each route is calculated by the normal distance multiplying with the fixing energy consumption rate.

$$TC_{ij} = \left(d_{ij}\right)(e) \tag{6}$$

2.2) Amount of transport routes is selectively transferred a special order arriving to each usage location j, is equal to or less than suppliers. $\sum_{i=1}^{m} \quad (Y_{ij}) \leq m \qquad (j = 1, 2, 3, \dots . n)$ (7)

2.3) Amount of transport routes is selectively transferred a special order leaving from each supplier i, is equal to or less than clients.

$$\sum_{j=1}^{n} \quad (Y_{ij}) \leq n \qquad (i = 1, 2, 3, \dots . m) \qquad (8)$$

2.4) The selective route for each road transport order has a more value than zero, or it is equal to zero.

$$Y_{ij} \in \{0,1\} \qquad (9)$$

Decision variables

Y_{ij}= 1 The special order is transferred from the material location i to the usage point j.

Y_{ij}= 0 The special order is not transferred from the material location i to the usage point j.

2.3.2 Transportation problem based on distance and time: TPDT

This mathematical model aims to describe a specific problematic scenario involving the allocation of special orders or small lots through a road courier service, transporting goods from the supply point to the usage point. The primary objective of this investigation is to minimize potential costs, which aligns closely with the concept of Time-Dependent Pricing (TPD). However, Time-Dependent Transport (TPDT) differs by emphasizing transport distance and time, which can lead to varying velocities on different routes. Consequently, these differing velocities result in distinct transportation costs, as energy consumption per kilometer is influenced by both transport speed and distance. This relationship can be articulated mathematically in the context of TPDT as follows.

Additional parameters

e_{ij} The diverse energy consumption rate of delivering of raw material from supplier in unit of liter per kilometer, which is depended on each different transport speed on each route.

t_{ij} Time of transferring material from supplier i to client j on each route.

v_{ij} The velocity of transferring material from supplier i to client j on each route.

Y_{ij} The route of raw materials transported from supplier i to the manufacturing entity at terminal point j.

$TPDTf(y)$ This refers to the total transportation cost per a delivery planning in term of energy consumption following the transportation problem based on distance and time.

The target of TPDT is to minimize the transportation cost based on the dissimilar transport distance and time which subsequently produces the different velocity resulting to the diverse energy consumption rate. Moreover, the mathematical model can be illustrated as follows.

1) Objective function $TPDT\ f(y) = \sum_{i=1}^{m} \quad . \sum_{j=1}^{n} \quad (e_{ij} d_{ij} Y_{ij})$ (10)

2) Constraints

2.1) Transportation cost in each route is calculated by the normal distance multiplying with the fixing energy consumption rate.

$$TC_{ij} = (d_{ij})(e_{ij}) \qquad (11)$$

Where e_{ij} is depended on v_{ij} , and v_{ij} is calculated from $(d_{ij})/(t_{ij})$.

2.2) Amount of transport routes is selectively transferred a special order arriving to each usage location j, is equal to or less than suppliers. $\sum_{i=1}^{m} \quad (Y_{ij}) \leq m \qquad (j = 1, 2, 3, \dots . n)$ (12)

2.3) Amount of transport routes is selectively transferred a special order leaving from each supplier i, is equal to or less than clients

$$\sum_{j=1}^{n} (Y_{ij}) \leq n \qquad (i = 1, 2, 3, \ldots. m) \tag{13}$$

2.4) The selective route for each road transport order has a more value than zero, or it is equal to zero.

$$Y_{ij} \in \{0,1\} \tag{14}$$

Decision variables

Y_{ij}= 1 The special order is transferred from the material location i to the usage point j.

Y_{ij}= 0 The special order is not transferred from the material location i to the usage point j.

2.4 Geographic Information Systems: GIS

Geographic Information Systems (GIS) are defined as specialized systems designed for the capture, storage, and geographical visualization of data, aimed at enhancing the management of information in relation to geographic contexts (Sadeghvaziri *et al.*, 2024; Spriggs *et al.*, 2024; Alamri et al, 2023). Initially, GIS tools assist users in gaining a more comprehensive understanding of location data from various perspectives (Boroomand & Mohammadpour, 2024; Alamri et al, 2023). Examples of such tools include Google Earth, Google Maps, and CityMapper, which serve to manage geographic data while analysing physical information to inform transportation decisions. Consequently, it might be stated that the utilization of GIS may enable managers to enhance their operational effectiveness.

Geographic Information Systems (GIS) facilitate users in gaining a deeper understanding of geographical relationships and patterns. Typically, GIS applications offer a diverse array of analytical tools for assessing current conditions (Aati *et al.*, 2024; Arango *et al.*, 2024; Boroomand & Mohammadpour, 2024). For example, Google Earth enables drivers to familiarize themselves with the features of unfamiliar transportation routes prior to embarking on a journey, thereby mitigating the risk of unforeseen events such as incidents, accidents, and traffic congestion. Consequently, it might be argued that the implementation of GIS enhances the safety and efficiency of operators in their tasks.

The Google Maps application is extensively utilized for navigation in transportation. This platform leverages Geographic Information Systems (GIS) to calculate distance and travel time between two locations using real-time data. It determines routes based on the movements of actual travellers who activate their Global Positioning System (GPS) signals, integrating this information with geographical data to identify the shortest pathways along road networks (Ganiyev *et al.*, 2023; McQuire, 2019). Furthermore, the application can estimate travel time by dynamically processing the GPS signals of its users (Ganiyev *et al.*, 2023; Mehta *et al.*, 2019). Thus, it might be referred that the Google Maps application enhances the accuracy of transportation planning for operators.

Based on the information presented, Geographic Information Systems (GIS) are recognized as a geographical analytical framework that offers numerous advantages for business operations. Firstly, GIS can accommodate more intricate workflows. Additionally, it can aid personnel in executing tasks more safely. Currently, applications such as Google Maps provide precise assessments of distance and time. Consequently, the data derived from GIS within the Google Maps application was extensively utilized in this research.

2.5 Conceptual framework

The literature review indicates that the transportation problem is typically utilized to minimize costs within the objective function. Traditionally, the quantities of materials transferred between supply and demand points are treated as decision variables, alongside the transportation cost per unit for multiple items. However, when dealing with special orders or small lot sizes—central to this research—the selection of transportation routes and distances becomes significantly more critical. Additionally, the delivery of special orders is commonly referred to as courier service, which is typically employed for transporting specialized tools, urgent equipment, and other time-sensitive items.

Regarding statement of problem in this research , the currier transport problem has highly interested in the transport distance and transport time. Afterward, this study decisively made an intention to initially develop the mathematical model of the transportation problem based on distance by ideally fixing the transport speed (TPD), and then subsequently formulate the mathematical model of the transportation problem based on distance and time (TPDT), this was to introduce the alternative mathematical models for solving the currier transportation problem using the personal cars which was the original research purpose. In actually, the TPD was an initial mathematical model while TPDT was extensively enhanced stepping forwardly from TPD. Thus, this research had expected that applying TPDT after implementing TPD might facilitate the currier transport planners obtaining a more energy saving or a lesser minimize transport cost, and the theoretical model can be illustrated in **Figure 1**.

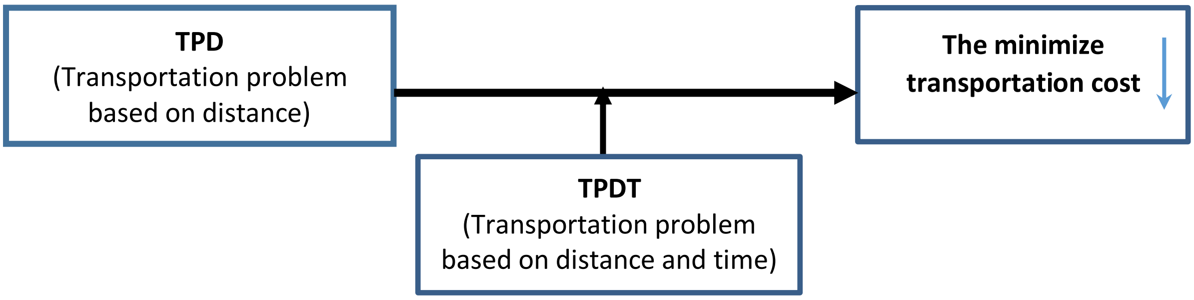

Figure.1 The theoretical model. Source: the Authors

3. RESEARCH METHOD

3.1 Initial population

The solution is to solve the minimize transport cost following the transportation problem by comparing TPD and TPDT. Practically, the definite distances by the actual measurement between a number of supply locations and an assortment of usage plants are difficultly collected and extremely charged (Linganathan & Singamsetty, 2024). Presently, it has Geographic Information System (GIS) from Google Map application, which is a freeware geographical application navigating the accurate distance and the precise time between two locations, is wildly used because its algorithm processes the actual traffic conditions by employing the Global Positioning System or GPS signal from a number of users before displaying the results (Ganiyev *et al.*, 2023; McQuire, 2019; Mehta *et al.*, 2019). Consequently, it might be stated that those analysis through a number of geographical points might present the truthful distance and the exact time after processing the present situation on the road freight transportation.

Following this, the location data in Thailand will be randomly drawn from the Google Map application. Initially, the district data in Thailand had been drawn from the report of Administrative data (Department of Provincial Administration, 2024). Besides this, the investigative locations in this research will not detailed in the specific name or the definite organization, but there will only show in general term of province or district. Moreover, the number of the transport routes in this test was indicatively needed to have a more transport route than thirty paths according to the rule of thumb for the numerical testing (Black & Babin, 2019), so the transport distance d_{ij} and the transport time t_{ij} between the supply location and the usage plant will be illustrated in this stage.

3.2 Energy consumption

As seen in the introductive mathematical models of the currier transportation problem, the energy consumption is the important parameter for mirroring the transportation in a special order or a small lot size. Normally, these transports are the road freight courier services, and usually employ the small truck or the personal car for making the delivery activity (Liang *et al.*, 2024; Peng *et al.*, 2024; Silva *et al.*, 2024). Recently, Yang *et al.* (2018) had reported on the relationship between the energy consumption and the personal cars speed in the urban region, and the energy consumption data from a number of personal cars was formulated to be the mathematic model as $0.003968v^2 - 0.5826v + 25.66$ with R^2 0.84 which this fuel consumption is in unit of liter per a hundred kilometer. Accordingly, these details were employed to be the initial guidelines for calculating the transport energy consumption in this research.

Regarding the concept of TPD is conceptually situated by ideally fixing an average velocity which creates the identical fuel consumption per kilometer on every road freight transport, and Office of the Council of State (2022) had regulated the traffic speed control the personal car outside the metropolis in Thailand average at $v = 100$ kilometers per hour which normally has rate of energy consumption e at 0.0708 liter per kilometer when is based on the energy formula of Yang *et al.* (2018). Subsequently, this energy consumption will be used when consider the transport cost following the concept of TPD.

On the other hand, the concept of TPDT, it was to introduce the alternative concept of the distance and time on each road transport route which might lead to have the dissimilar velocity, and this consequence might create the diverse energy consumption rate on each road line before totally collecting the whole energy expense. As a result, this concept stands on the conception of the changeable energy consumption upon the unstable speed e_{ij} based on the energy formula (Yang *et al.*, 2018), and this energy consumption will be used when consider the transport cost following the model of TPDT.

3.3 Data analysis

The data analysis was based on the numerical test. The collective data were analyzed to compare the effectiveness of the concept TPD and TPDT. These values were to explore the evidence of alternatively planning in order to make a lower minimize transport cost level for transferring a special order or small which are in the context of currier service context. The data investigation in this research had been analyzed through the exact method by Solver Add-in in Microsoft Excel 2021 for numerically testing the mathematical models which were TPD and TPDT following procedures in **Figure 2** and **Figure 3** respectively.

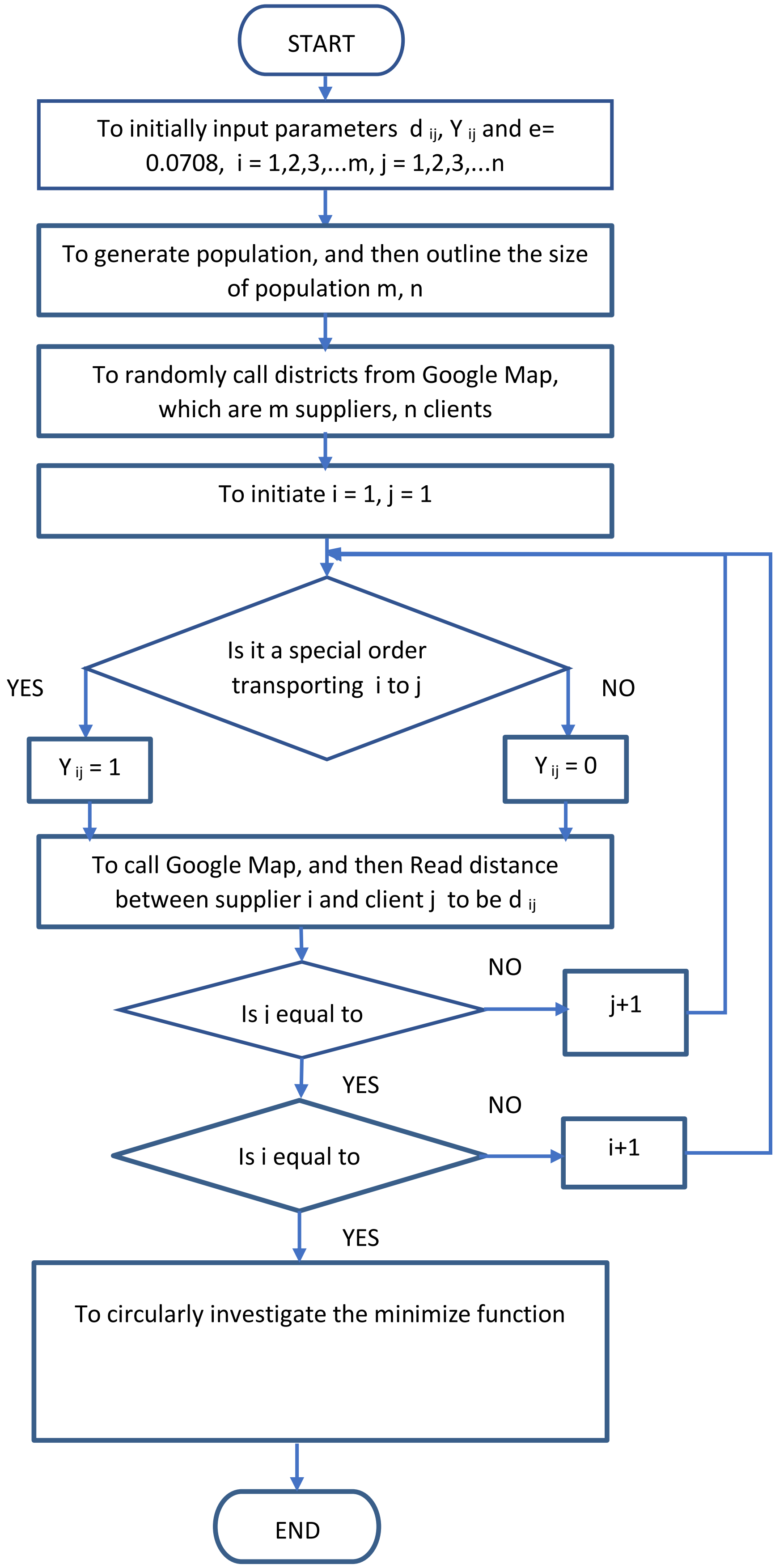

Figure 2. Flow chart of transportation problem based on distance. Source: The Authors

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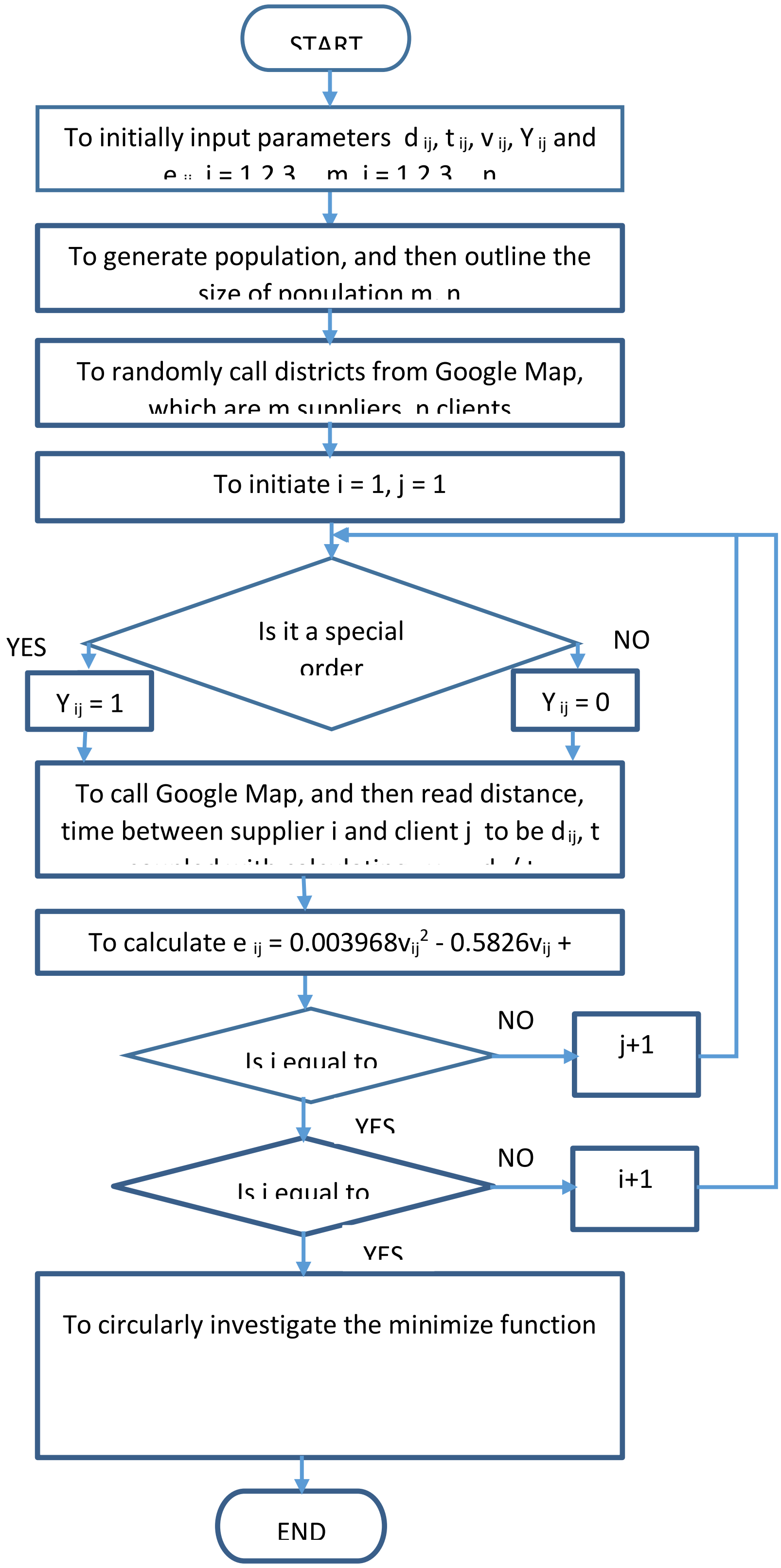

Figure 3. Flow chart of transportation problem based on distance and time. Source: The Authors

4. RESULTS

4.1 Initial population

This present study had randomly selected the number of supply points (m) and the number of usage points (n) from the Administrative data in Thailand (Department of Provincial Administration, 2024). Besides, the number of supply points (m) and the number of usage points (n) were 10 and 12 respectively, and all location names were differentiated which can be presented as **Table 1**.

Table 1. The random locations of suppliers and clients. Source: the Authors

No.	Origin (Supply Location)	No.	Destination (Usage Location)
1	Chiang Mai	1	Prachin Buri
2	Nakhon Nayok	2	Ang Thong
3	Chanthaburi	3	Chumphon
4	Narathiwat	4	Chiang Rai
5	Roi Et	5	Pathum Thani
6	Sa Keaw	6	Mukdahan
7	Phra Nakhon Si Ayutthaya	7	Lampang
8	Phichit	8	Yala
9	Nong Bue Lumphu	9	Prachuap Khiri Khan
10	Nakhon Pathom	10	Phayao
		11	Amnat Chareon
		12	Kanchanaburi

Table 2. All road transport distance from suppliers to clients. Source: the Authors

Origin (i)	Destination (j) 1	2	3	4	5	6	7	8	9	10	11	12
1	747	592	1,150	186	672	872	109	1761	982	153	914	685
2	54.1	120	568	787	73.2	598	601	1179	400	693	547	229
3	233	351	689	1018	264	617	832	1300	521	924	582	382
4	1316	1263	701	1931	1191	1806	1745	94.5	868	1837	1755	1155
5	419	467	957	850	477	174	675	1569	789	756	131	593
6	68.6	226	645	893	179	492	707	1256	477	799	457	321
7	141	46.5	529	714	51.1	606	528	1141	361	620	555	152
8	376	221	779	504	301	576	329	1390	611	410	582	318
9	468	457	972	639	492	323	464	1584	804	545	365	608
10	213	137	429	799	90.4	702	610	1040	261	705	651	68.9

Remark: unit in kilometer

As seen in **Table 1**, whole transport route was 120 ways. Subsequently, the distance between each supplier and client was pulled from the Google Map application, and all distances (d_{ij}) for transporting on the road in this research was shown as **Table 2**. Besides, the shortest transport distance was 46.5 kilometers which was the delivery route from Phra Nakhon Si Ayutthaya to Ang Thong while the longest transport distance was 1,931 kilometers which was the delivery route from Narathiwat to Chiang Rai. Moreover, the total transport distance in this demonstrative currier delivery planning was 77,694.3 kilometers.

4.2 The transportation cost based on distance: TPD

In order to find the transportation cost based on distance by ideally fixing the traffic speed of the personal car outside the metropolis v = 100 kilometers per hour, at this stage has the rate of energy consumption e at 0.0708 liter per kilometer. Besides, **Table 2** was superlatively represented $d_{ij}Y_{ij}$ in case of having all delivery orders on every route. Moreover, the transportation cost based on distance by ideally stabilizing transport speed had been formulated into $e\ d_{ij}Y_{ij}$ which was presented as underneath.

Table 3. Transportation cost based on distance by fixing velocity. Source: the Authors

Origin (i)	**Destination (j)** 1	2	3	4	5	6	7	8	9	10	11	12
1	52.9	41.9	81.4	13.2	47.6	61.7	7.7	124.7	69.5	10.8	64.7	48.5
2	3.8	8.5	40.2	55.7	5.2	42.3	42.6	83.5	28.3	49.1	38.7	16.2
3	16.5	24.9	48.8	72.1	18.7	43.7	58.9	92.0	36.9	65.4	41.2	27.0
4	93.2	89.4	49.6	136.7	84.3	127.9	123.5	6.7	61.5	130.1	124.3	81.8
5	29.7	33.1	67.8	60.2	33.8	12.3	47.8	111.1	55.9	53.5	9.3	42.0
6	4.9	16.0	45.7	63.2	12.7	34.8	50.1	88.9	33.8	56.6	32.4	22.7
7	10.0	3.3	37.5	50.6	3.6	42.9	37.4	80.8	25.6	43.9	39.3	10.8
8	26.6	15.6	55.2	35.7	21.3	40.8	23.3	98.4	43.3	29.0	41.2	22.5
9	33.1	32.4	68.8	45.2	34.8	22.9	32.9	112.1	56.9	38.6	25.8	43.0
10	15.1	9.7	30.4	56.6	6.4	49.7	43.2	73.6	18.5	49.9	46.1	4.9

Remark: unit in liter

As shown in **Table 3**, the energy consumption on each delivery route had been investigated. Besides, the lowest fuel consumption was 3.3 liters which was the delivery route from Phra Nakhon Si Ayutthaya to Ang Thong while the highest fuel consumption was 136.7 liters which was the delivery route from Narathiwat to Chiang Rai. At this phase, the whole transportation cost based on distance by fixing velocity in term of the energy consumption, which was $e\sum_{i=1}^{m} . \sum_{j=1}^{n} \left(d_{ij}Y_{ij}\right)$, totally was 5,500.8 liters.

4.3 The transportation cost based on distance and time: TPDT

In order to find the transportation cost alternatively based on transport distance and time which both items create the different velocity on each route. Besides this, its subsequence has created the different rate of energy consumption e_{ij} at (0.003968v_{ij}^2 - 0.5826v_{ij} + 25.66)/100 liter per kilometer. As known, **Table 2** was outstandingly signified $d_{ij}Y_{ij}$ in case of taking all delivery orders on every route for shipping on the road lines, but the transportation time between each supply location and usage point had not been determined yet. Afterwards, the transport time (t_{ij}) between each supplier and client was drawn from the Google Map application as in **Table 4**.

Table 4. All transport time on roads from suppliers to clients. Source: the Authors

Origin	Destination (j)											
(i)	1	2	3	4	5	6	7	8	9	10	11	12
1	10.4	7.9	15.2	3.2	8.8	12.1	1.7	23.6	13.0	2.6	13.0	9.6
2	1.0	2.2	7.8	11.3	1.3	8.0	8.3	16.2	5.6	9.8	7.6	3.5
3	3.5	4.7	9.4	13.9	3.6	9.0	10.9	17.8	7.2	12.4	8.6	5.2
4	18.5	17.5	9.9	27.0	16.6	24.0	23.7	1.8	12.1	25.0	23.9	16.3
5	6.0	6.4	12.7	12.5	6.3	2.5	9.7	21.1	10.5	11.0	2.1	8.1
6	1.1	3.7	8.7	12.9	2.9	7.3	9.9	17.1	6.5	11.4	6.8	4.5
7	2.6	0.8	7.2	9.9	0.9	8.1	6.9	15.6	5.1	8.4	7.7	2.4
8	5.6	3.2	10.4	7.4	4.1	8.3	4.6	18.8	8.2	5.9	8.9	4.9
9	7.2	7.0	13.5	10.0	7.1	4.5	7.2	21.9	11.3	8.5	5.4	8.9
10	3.5	2.1	5.8	11.6	1.5	9.3	8.5	14.2	3.7	10.1	8.8	0.9

Remark: unit in hour

As shown in **Table 4**, all transport time for transporting on the road in this research can be exposed. In addition, the shortest period was 0.8 hour which was the delivery route from Phra Nakhon Si Ayutthaya to Ang Thong while the longest period was 27 hours which was the delivery route from Narathiwat to Chiang Rai. At this part, the whole transportation time in this demonstrative currier delivery planning was 1084.9 hours. At this phase, there had the distance (d_{ij}) and transport time (t_{ij}) which had been explained in **Table 2** and **Table 4** respectively. Following this, the transport velocity on each route (v_{ij}) was be able to designed by (d_{ij}/ t_{ij}) as in **Table 5**.

As illustrated in **Table 5**, all different transport velocities upon the traffic condition were presented. Besides this, the slowest velocity was 53.5 kilometers per hours which was the delivery route from Narathiwat to Yala while the fastest velocity was 78 kilometers per hour which was the delivery route from Nakhon Pathom to Kanchanaburi. Entirely, the average transport speed in this demonstrative currier delivery planning was 71.6 kilometers per hour.

Table 5. All transport velocities from suppliers to clients. Source: the Authors

Origin (i)	**Destination (j) 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	71.9	74.8	75.8	58.7	76.2	72.2	66.1	74.7	75.5	60.0	70.1	71.7
2	54.1	55.8	72.8	69.5	57.0	74.9	72.1	72.8	71.0	70.6	72.5	66.1
3	67.5	74.7	73.6	73.4	73.0	68.4	76.4	73.1	72.2	74.7	68.1	74.2
4	71.3	72.2	71.2	71.5	72.0	75.3	73.7	53.5	71.6	73.5	73.3	70.9
5	70.2	72.6	75.6	67.8	76.1	70.5	69.5	74.4	75.0	68.5	61.9	72.9
6	64.3	60.8	74.1	69.3	62.8	67.7	71.4	73.5	73.0	70.2	67.2	72.1
7	54.9	60.7	73.5	72.0	60.1	74.5	76.2	73.1	71.5	73.7	72.1	64.7
8	66.9	70.2	74.9	68.4	74.3	69.5	72.3	73.9	74.2	69.7	65.8	64.9
9	65.5	65.1	72.2	63.9	69.6	72.0	64.6	72.4	71.2	64.1	67.2	68.2
10	60.6	64.2	74.0	69.2	62.3	75.8	71.6	73.2	71.5	70.1	73.7	78.0

Remark: unit in kilometers per hour

Table 6. All energy consumption rate from suppliers to clients. Source: the Authors

Origin (i)	**Destination (j) 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	0.043	0.043	0.043	0.051	0.043	0.043	0.045	0.043	0.043	0.050	0.043	0.043
2	0.058	0.055	0.043	0.043	0.053	0.043	0.043	0.043	0.043	0.043	0.043	0.045
3	0.044	0.043	0.043	0.043	0.043	0.044	0.043	0.043	0.043	0.043	0.044	0.043
4	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.058	0.043	0.043	0.043	0.043
5	0.043	0.043	0.043	0.044	0.043	0.043	0.043	0.043	0.043	0.044	0.048	0.043
6	0.046	0.049	0.043	0.043	0.047	0.044	0.043	0.043	0.043	0.043	0.044	0.043
7	0.056	0.049	0.043	0.043	0.050	0.043	0.043	0.043	0.043	0.043	0.043	0.046
8	0.044	0.043	0.043	0.044	0.043	0.043	0.043	0.043	0.043	0.043	0.045	0.046

9	0.045	0.045	0.043	0.046	0.043	0.043	0.046	0.043	0.043	0.046	0.044	0.044
10	0.049	0.046	0.043	0.043	0.048	0.043	0.043	0.043	0.043	0.043	0.043	0.044

Remark: unit in liters per kilometer

Based on the different velocities (v_{ij}) in **Table 5**, there were the input variables for investigating the diverse energy consumption rate. Successively, the fuel consumption on each transport route was identified by (0.003968v_{ij}^2 - 0.5826v_{ij} + 25.66)/100, and the dissimilar energy consumption rate (e_{ij}) on each delivery order was shown as underneath. Moreover, the energy consumption rate (e_{ij}) in **Table 6** multiplied with the data in **Table 2**, which was superlatively represented $d_{ij}Y_{ij}$ in case of devouring entirely supply commands on every itinerary for transferring on the motorway, resulted to the energy consumption along the transportation routes. In addition, the transportation cost in term of energy consumption alternatively on each route based on transport distance and time ($e_{ij}d_{ij}Y_{ij}$) had been presented as **Table 7**.

Table 7. Transportation cost based on distance and time. Source: the Authors

Origin	**Destination (j)**											
(i)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	32.0	25.4	49.4	9.5	28.9	37.3	4.9	75.4	42.2	7.6	39.5	29.4
2	3.1	6.6	24.3	34.1	3.9	25.6	25.7	50.4	17.2	29.8	23.4	10.3
3	10.3	15.0	29.5	43.5	11.3	27.0	35.9	55.6	22.3	39.6	25.5	16.3
4	56.5	54.1	30.1	82.8	51.0	77.4	74.6	5.5	37.2	78.5	75.0	49.7
5	18.1	20.0	41.1	37.4	20.5	7.5	29.3	67.1	33.8	33.0	6.3	25.4
6	3.2	11.1	27.6	38.8	8.5	21.7	30.3	53.7	20.4	34.5	20.2	13.7
7	7.9	2.3	22.6	30.6	2.5	25.9	22.7	48.8	15.5	26.5	23.8	7.0
8	16.7	9.5	33.4	22.0	12.9	25.0	14.1	59.4	26.1	17.8	26.2	14.5
9	21.2	20.8	41.6	29.6	21.3	13.8	21.3	67.8	34.5	25.2	16.2	26.7
10	10.5	6.3	18.3	34.7	4.3	30.2	26.2	44.5	11.2	30.4	27.8	3.0

Remark: unit in liters

As shown in **Table 7**, the energy consumption on each delivery route cost based on distance and time had been investigated. Besides, the lowest fuel consumption was 3.1 liters which was the delivery route from Nakhon Nayok to Prachin Buri while the highest fuel consumption was 83.2 liters which was the delivery route from Narathiwat to Chiang Rai. At this point, the whole transportation cost based on cost based on distance and time by differentiating velocity in term of the energy consumption, which is $\sum_{i=1}^{m} . \sum_{j=1}^{n} (e_{ij}d_{ij}Y_{ij})$, totally was 3,364.5 liters.

4.4 Comparison the effectiveness

In this section, the effectiveness of two alternative mathematical models for solving the currier transport problem were explained, and then evaluated in order to indicate the most effective strategy for improving the currier distribution in the future. Besides, the comparative descriptions based on the research findings were illustrated as below.

As presented in **Table 8**, the transportation problem based on distance (TPD) and the transportation problem based on distance and time (TPDT) were compared. Primarily, these both mathematical models had analytically tested at the similar origins and destination, so there had an equivalent transport distance in total. In actually, TPDT concept stands on the unstable speed which is depended on distance and approachable time while TDP paradigm stands on preferably fixing speed. Besides this, TPDT had a longer transport duration than TPD approximately 28.4%, since the actual transport ability had a lessor speed than the planed transport at about 39.6% because of approaching a more actual transport condition. Subsequently, TPDT had a fewer energy consumption rate than TPD roughly 63.5% in average, so it was definitely exhibited that TPDT had a higher effectiveness in the transport cost reduction than TPD.

Table 8. The effectiveness comparison between TPD and TPDT. Source: the Authors

Description	TPD	TPDT	Differentiation	
			TPDT - TPD	Rate (%)
1.Total distance (kilometers)	77,694.3	77,694.3	0.0	0.0
2.Total transport time (hours)	776.9	1,084.9	308.0	28.4
3.Average velocity (kilometers/hour)	100.0	71.6	-28.4	-39.6
4.Average energy consumption rate (liters/kilometer)	0.0708	0.0433	-0.027	-63.5
5.Total transport cost (Total energy, liters)	5,500.8	3,364.5	- 2,136.3	-63.5

5. DISCUSSION

In the context of courier services, this study aimed to introduce alternative mathematical models for addressing the courier transportation problem and to compare their effectiveness. Additionally, energy consumption was employed as a representation of transportation costs, serving as the objective function for the courier transportation problem. The most effective model may provide strategic insights for future decision-making regarding the transport of special orders or small lots. To support this analysis, the study examined the economic challenges faced by Thailand, a middle-income country. Subsequently, a review of relevant literature was conducted to identify research gaps that involved road transportation.

Additionally, innovative mathematical models for transportation issues within the context of courier delivery were created and subsequently represented in flowchart form to facilitate the algorithmic processes prior to numerical testing of secondary transport data sourced from the Google Maps application. Following this, the analytical results and comparisons of the various mathematical models developed in this research were established, yielding new insights for the future enhancement of courier transport planning and operational practices as outlined below.

5.1 Research implications

To address the research question regarding the introduction of a new transportation problem based on distance and time within the context of courier distribution, this study utilized the established framework of traditional transportation problems. This foundational approach facilitated the development of a novel mathematical model designed to address various road transport scenarios in courier operations. Specifically, two mathematical models were formulated: one focusing on distance and the other incorporating both distance and time. Additionally, supply and demand points were randomly selected from administrative data, after which distance and time metrics were obtained from Google Maps for subsequent numerical testing and analysis.

The analysis revealed that the transportation problem based on fixed transport speed (TPD) resulted in higher transport costs, specifically in terms of energy consumption, compared to the transportation problem that incorporates both distance and time (TPDT). Notably, the velocities used in the TPDT framework were derived from actual delivery speeds, as calculated from data provided by Google Maps based on the experiences of various users and drivers. It is important to recognize that real-world road transport is influenced not only by distance but also by surrounding factors such as vehicle density, infrastructure, and other environmental conditions, which contribute to variations in transport time. Consequently, actual delivery speeds tend to be lower than planned distribution speeds due to the impact of real traffic conditions.

Subsequently, the varying distances and travel times influenced the differences in velocity across the various transport routes. Vehicles consume different amounts of fuel at varying speeds, as noted by Yang *et al.* (2018), resulting in specific energy consumption for each route. These findings corroborate the research hypothesis that distance and time are crucial factors for organizations to consider when analyzing courier transportation costs, as they contribute to differing velocities that impact energy consumption. This outcome reinforces the theoretical framework illustrated in **Figure 1**, suggesting that a focus on multiple transport factors, such as distance and time, rather than a single factor, enhances overall effectiveness. Furthermore, this contribution advances the literature on courier transport planning for future improvements.

5.2 Practical implications

The efficacy of the transportation problem within the context of courier transport is clearly illustrated in **Table 8**. Firstly, courier transport planners must not only consider transport distance but also prioritize transport time, as both factors significantly influence the velocity of transportation, subsequently affecting energy consumption and overall costs. Secondly, planners may opt for the Transportation Problem based on Distance and Time (TPDT) approach when managing the distribution of special orders or small lots from satellite supply plants to various client locations. This method can lead to substantial savings in transport costs for the organization.

5.3 Limitation and future direction

This research article has certain limitations. The secondary data utilized in this study were derived from Geographic Information System (GIS) datasets, along with information collected from the Google Maps application in Thailand, which serves as an example of the developing countries. It is important to note that the GIS conditions in the developed countries and the undeveloped countries may differ significantly, potentially leading to varying traffic outcomes. Furthermore, this research does not assert that the mathematical models employed will yield the same results in different economic contexts. Therefore, further investigation in other regions may be necessary for future educational insights.

6. CONCLUSION

This study sought to propose an alternative mathematical model for addressing the courier transportation problem and to evaluate the effectiveness of these models through an analysis of personal car deliveries in the context of road transport, using specific administrative transport data from Thailand. While there has been growing interest in utilizing transportation models to address quantitative delivery challenges—often referred to as mass product transport—there remains a scarcity of research focused on developing effective strategies to minimize transportation costs when firms need to distribute small orders to various locations. Moreover, many previous studies have primarily concentrated on optimizing transportation costs based on delivery quantities. However, the costs associated with special or small-scale deliveries should be assessed in terms of energy consumption. This study aims to fill this gap by exploring an alternative approach to minimizing overall transportation costs based on energy consumption, which can be viewed as the objective function in the courier transportation problem.

To achieve this, unconventional mathematical models were developed based on existing literature. Subsequently, the transportation problem focused on distance with a fixed transport speed (TPD) and the transportation problem considering both distance and time (TPDT) were mathematically modeled and numerically analyzed using the Solver Add-in in Microsoft Excel 2021, following established procedures. This analysis utilized secondary data from Geographic Information Systems (GIS) obtained through the Google Maps application in Thailand. The results demonstrated the effectiveness of the TPD and TPDT models, and the key findings of this research are detailed in the following summary.

Firstly, the investigation revealed that transport distance is not the only critical variable for addressing the transportation problem in courier delivery; transport time must also be significantly incorporated into the mathematical model. This research demonstrates that variations in distance and time can lead to different velocities, which in turn affect energy consumption and overall transportation costs. Therefore, focusing exclusively on transport distance is inadequate for effectively minimizing the objective function in the context of real-world courier delivery.

Secondly, the most effective method for addressing courier distribution was identified as the transportation problem mathematical model based on distance and time (TPDT). Courier transport planners should consider this mathematical model as an alternative for managing the delivery of special orders or small lots within their operations, as it holds considerable potential for achieving cost savings in courier transport planning.

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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