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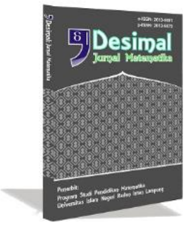

Graph coloring for determining courier frequency

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ABSTRACT

The exponential growth of online transactions in Indonesia has intensified the competition among courier service providers to ensure efficient goods delivery, prompting the need for exceptional performance. However, this surge has also brought forth various challenges, including imbalanced courier allocation, intricate delivery routes, and sprawling coverage areas, resulting in delays and extended working hours for couriers. This research, conducted in Jakarta, centers on a logistics and courier service company grappling with a critical courier shortage, leading to overburdened personnel and extended work hours. To address this issue, we employed graph coloring, rooted in graph theory, as a novel approach to determine the ideal number of couriers based on the route and delivery area. Through graph coloring, delivery routes, and areas can be optimized so that each courier has the same average route length and area and does not exceed the threshold limit set by the company. The number of delivery routes and areas generated from graph coloring shows the number of couriers required for the company. The results of this research obtained 27 routes that show the need for the ideal courier frequency so that the delivery of goods can be on time without extending the courier's working hours.

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INTRODUCTION

The delivery of goods is a crucial aspect of online transaction processes (Morganti, Seidel, Blanquart, Dablanc, & Lenz, 2014). The increase in demand for courier services has a significant impact on the competition among delivery service providers and couriers (Ejdys & Gulc, 2020). Companies that offer excellent courier services will undoubtedly reap the benefits, as customers tend to choose providers with good performance (Yıldız, 2021). Consequently, courier services compete in a perfect competition to deliver the best performance for consumers (YU, Subramanian, Ning, & Edwards, 2015).

Reducing inhibiting factors is a crucial factor in achieving good performance (Gulc, 2017). With the growing number of online orders and couriers, there is a high possibility of bottlenecks that can affect courier performance (Karcz & Ślusarczyk, 2016). Some examples of obstacles that couriers may encounter include exchanging goods, incorrect delivery addresses, damaged goods, and delayed delivery processes. Timely delivery is a significant concern for consumers, as they expect a fast and accurate delivery process (Duarte, Costa e Silva, & Ferreira, 2018).

Companies also consider the timely delivery and condition of goods sent to consumers. They aim to ensure that goods are delivered on time and in good condition. However, the high number of complaints about delivery performance from consumers requires special attention(Duarte et al., 2018).

In Indonesia, the growth of the e-commerce ecosystem is directly linked to the rise of the logistics and courier services industry, which has encouraged new players to enter the market. However, established players still dominate 80% of the market, making it difficult for new entrants to establish themselves (Puspa & Kusumawardhani, 2022).

In practice, many newly established logistics companies exploit their courier personnel by overloading them with deliveries to minimize operational costs. Adding more personnel without a sound delivery strategy can actually increase the company's operational costs. Therefore, companies need to analyze the need for the number of couriers by considering other factors such as the size of the delivery area and the route taken (Ratnawati, 2015).

This research was conducted in Jakarta at one of the logistics and courier service companies, where the main challenge was the shortage of couriers to meet the needs of delivering goods to the supply chain. There are only 15 couriers employed by the company. The couriers were overworked, with an average of 40 – 41 supply chains per courier, whereas ideally, each courier should only handle 15 – 20 supply chains, impacting extended working hours for couriers.

If the area is not too large, then the courier can be burdened with more than 20 supply chains, or if the area is too large, then the courier can be burdened with less than 15 supply chains.

The solution to the above problem is to use graph coloring. With graph coloring, the ideal number of couriers will be obtained by optimizing the area covered and the route taken.

METHOD

The method used is graph coloring, which is an improvement on graph theory. Leonard Euler initially proposed graph theory in 1736, when he wondered if it was possible to cross all the bridges in the city of Königsberg, Russia, only once, starting and terminating in the same location. He suggested a solution to the problem in the form of points and edges, which became known as graph theory. Mathematicians have since examined the issue of this graph (De, 2022).

Graph coloring is a well-known subject in the field of structural and algorithmic graph theory, with numerous versions. The goal of graph coloring is to keep the number of colors used to color a graph to a minimum. This includes not only coloring the vertex so that they do not have the same color as the vertex close to each other. The chromatic number of the graph $G(\chi(G))$ is the smallest number of colors that can be used to color a graph. Symbolically, let $G = (V, E)$ be a simple graph with a finite vertex set. For $k \in \mathbb{N}$, a map α: $V \to \{1, 2, 3, \ldots, k\}$ is called a k −coloring of G, and $\alpha(v)$ is called the color of v. If $\alpha(u) \neq \alpha(v)$ for all $uv \in E$, α is a proper k − coloring of G (Beier, Fierson, Haas, Russell, & Shavo, 2016).

Coloring technique and data analysis using the Welsh Powell Algorithm (Ermanto & Riti, 2022). This algorithm is relatively easy to implement, has a fast execution time (Kralev & Kraleva, 2023), and avoids schedule conflicts (Fransisca & Kurniawan, 2020).

The data used in this research process is qualitative data, which is non-numerical data (Koro, Fairchild, Benozzo, & Löytönen, 2023). The qualitative data was obtained through observations and interviews conducted by the researchers at the company. The data obtained is in the form of words that describe facts and phenomena that occur in the field.

1) Observation
Observation is a data collection technique in which the author directly goes to the research location to observe the behavior or actions taking place (Concato et al., 2010). Therefore, collecting data through observation is highly beneficial for researchers to gain direct insights into the conditions prevailing in the field (Taherdoost, 2021).
2) Interviews
Interviews are one of the technical data collection techniques that can be conducted directly with the informants. In this research, interviews will be carried out directly with the delivery team to gather data that will be used in the research process (Alshenqeeti, 2014).

The source of data used in this research process is primary data, which is data obtained directly through the interaction between the researchers and the informants (Sinha & Gupta, 2021). The primary data was obtained by researchers through interviews with the delivery team.

In addition to primary data, secondary data was also used in this research process. The secondary data was obtained from the results of direct observations conducted by the researchers at the company, such as the number of couriers and retail customer data in the city (Ajayi, 2017).

For programming, use the Python programming language embedded in Google Collab for construction and coloring graphs (Platt, 2019). Here is an example illustration of the use of the Python programming language in the construction and coloring of graphs (Goldenberg, 2021; networkx.org, 2023; Treinish, Carvalho, Tsilimigkounakis, & Sá, 2022):

```
import networkx as nx
network = nx.Graph()
network.add_nodes_from([1,2,3,4]
)
network.add_edge(1,2)
network.add_edge(1,3)
network.add_edge(2,4)
network.add_edge(3,4)
network.add_edge(1,4)
network.add_edge(1,4)
nx.draw_networkx(network,
with_labels=True)
```

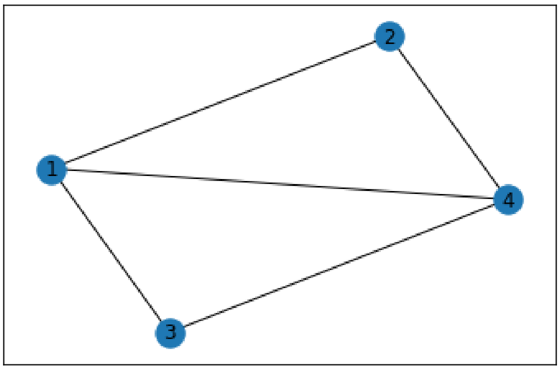

Figure 1. Graphing Output with Google Colab

The next step is to color the graph on Google Colab using the Python programming language. As mentioned earlier, the Welsh Powell Algorithm was used for coloring, and once the vertices to be colored were identified, the writer used Google Colab as the tool. Below is an example of the Python programming language that will be used to carry out the graph coloring (Dierbach, 2014; Hagberg, Schult, & Swart, 2008).

```
color_list = ["white", "yellow",
"yellow", "red",]
nx.draw_networkx(network,node_co
lor=color_list,
with_labels=True)
```

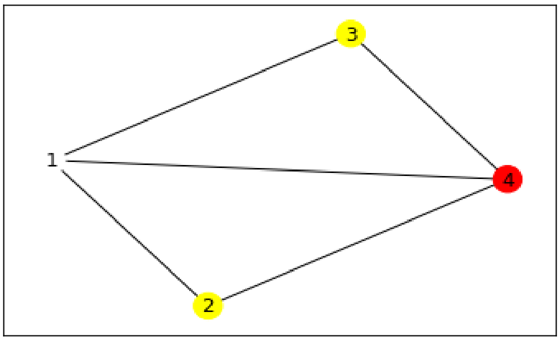

Figure 2. Graph Coloring Output using Google Colab

RESULTS AND DISCUSSION

Observation Data

The obtained customer data will be grouped by region and sub-district to facilitate the author's process of constructing and coloring graphs.

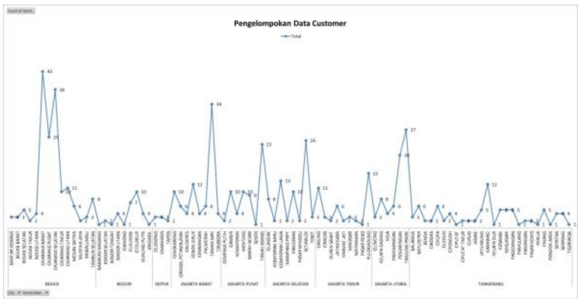

Figure 3. Customer Data Grouping

Construction and Coloring Graphs

After grouping the data by sub-district, the writer will proceed to create a neighbor table for each region and use it in the graph coloring process. If the distance between two sub-districts is not too far, the two vertices can be made non-neighboring (Wang & Huang, 2014).

After obtaining the neighbor table of each vertex, the next step is to create a graph using the Python programming language on Google Colab (Naik, 2023). A graph is considered neighboring if it is denoted by the number 1 in the adjacency table, while the number 0 indicates that the two vertices are not neighboring (Singh & Sharma, 2012). Once the graph is formed, it will be colored using the Welsh-Powell method.

a. Bekasi

The results are the following:

1) Blue : Cikarang Selatan – Cikarang Utara (49 supply chain, area 9.54 km^2)
2) Green : Bantar Gebang – Mustika Jaya – Tambun Selatan (13 supply chain, area 49.17 km^2)
3) Orange : Cikarang Pusat – Cikarang Timur (35 supply chain, area 9.891 km^2)
4) Pink : Bekasi Selatan – Bekasi Timur – Rawalumbu (10 supply chain, area 47.54 km^2)
5) Red : Bekasi Barat – Bekasi Utara – Medan Satria (13 supply chain, area 46.56 km^2)
6) Yellow : Cikarang Barat (43 supply chain, area 5.36 km^2)

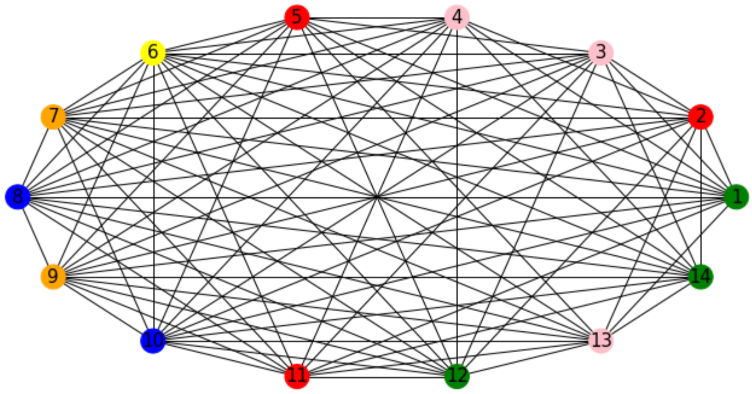

Figure 4. Bekasi Graph Coloring

Symbol : (1) Bantar Gebang, (2) Bekasi Barat, (3) Bekasi Selatan, (4) Bekasi Timur, (5) Bekasi Utara, (6) Cikarang Barat, (7) Cikarang Pusat, (8) Cikarang Selatan, (9) Cikarang Timur, (10) Cikarang Utara, (11) Medan Satria, (12) Mustika Jaya, (13) Rawalumbu, (14) Tambun Selatan

b. Bogor and Depok

The results are the following:

1) Blue : Bogor Selatan – Bogor Tengah – Bogor Utara (7 supply chain, area 56.66 km^2)
2) Green : Cileungsi – Jonggol (8 supply chain, area 292.17 km2)
3) Red : Cibinong – Gunung Putri – Cilodong – Cimanggis – Tapos (13 supply chain, area 178.52 km^2)
4) Yellow : Babakan Madang – Citeureup (11 supply chain, area 112.57 km^2)

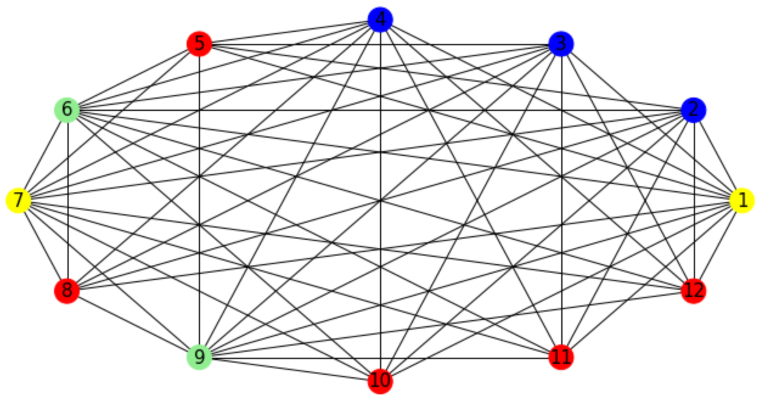

Figure 5. Bogor and Depok Graph Coloring

Symbol : (1) Babakan Madang, (2) Bogor Selatan, (3) Bogor Tengah, (4) Bogor Utara, (5) Cibinong, (6) Cileungsi, (7) Citeureup, (8) Gunung Putri, (9) Jonggol, (10) Cilodong, (11) Cimanggis, (12) Tapos

c. West Jakarta

The results are the following:

1) Yellow : Taman Sari – Tambora (38 supply chain, area 13.13 km^2)
2) Green : Cengkareng – Kalideres – Kembangan (18 supply chain, area 80.93 km^2)
3) Blue : Grogol Petamburan – Kebon Jeruk - Palmerah (24 supply chain, area 35.48 km^2)

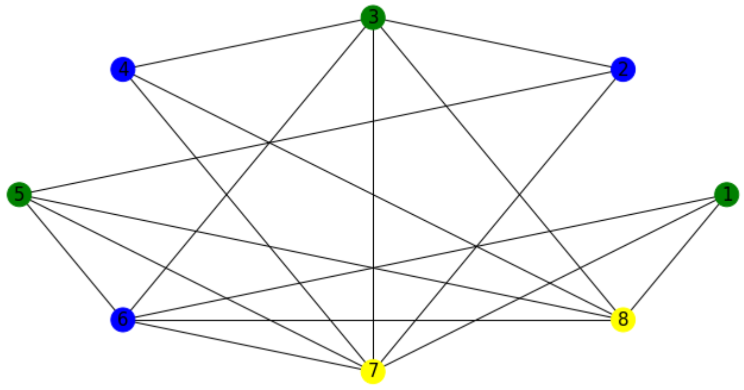

Figure 6. West Jakarta Graph Coloring

Symbol : (1) Cengkareng, (2) Grogol Petamburan, (3) Kalideres, (4) Kebon Jeruk, (5) Kembangan, (6) Palmerah, (7) Taman Sari, (8) Tambora

d. Central Jakarta

The results are the following:

1) Blue : Cempaka Putih – Kemayoran – Menteng – Sawah Besar – Senen (26 supply chain, area 28.8 km^2)
2) Yellow : Gambir – Tanah Abang (33 supply chain, area 16.89 km^2)

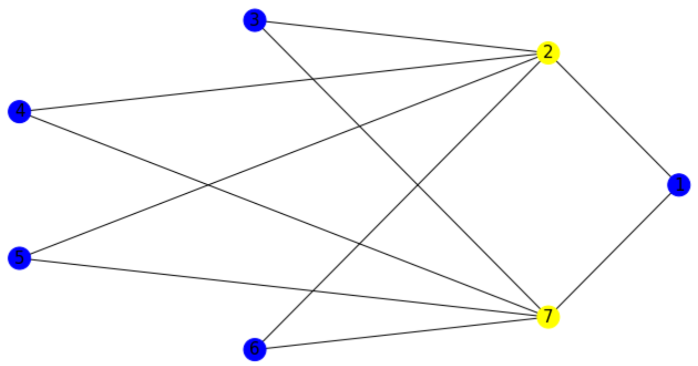

Figure 7. Central Jakarta Graph Coloring

Symbol : (1) Cempaka Putih, (2) Gambir, (3) Kemayoran, (4) Menteng, (5) Sawah Besar, (6) Senen, (7) Tanah Abang

e. South Jakarta

The results are the following:

1) Green : Mampang – Pancoran – Pasar Minggu (14 supply chain, area 37.95 km^2)
2) Light Blue : Setiabudi – Tebet (27 supply chain, area 17.88 km^2)
3) Yellow : Cilandak – Kebayoran Lama – Kebayoran Baru (23 supply chain, area 47.81 km^2)

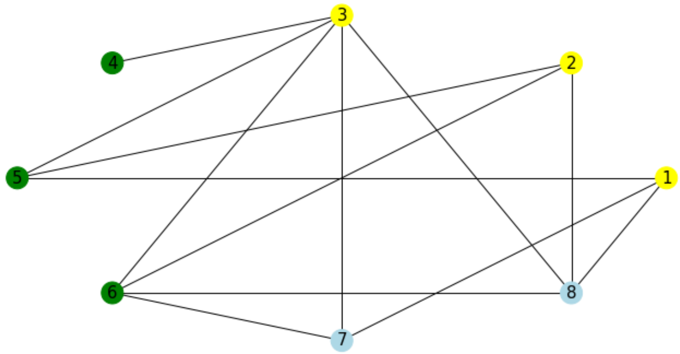

Figure 8. South Jakarta Graph Coloring

Symbol : (1) Cilandak, (2) Kebayoran Baru, (3) Kebayoran Lama, (4) Mampang Prapatan, (5) Pancoran, (6) Pasar Minggu, (7) Setiabudi, (8) Tebet

f. East Jakarta

The results are the following:

1) Blue : Ciracas – Jatinegara – Kramat Jati – Makasar – Matraman – Pasar Rebo (17 supply chain, area 79.04 km^2)
2) Yellow : Cakung – Duren Sawit – Pulogadung (28 supply chain, area 80.54 km^2)

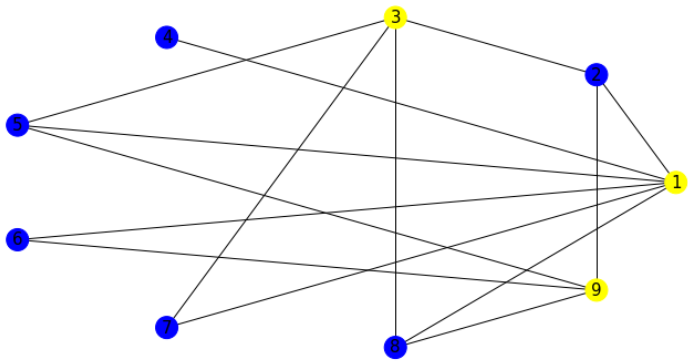

Figure 9. East Jakarta Graph Coloring

Symbol : (1) Cakung, (2) Ciracas, (3) Duren Sawit, (4) Jatinegara, (5) Kramat Jati, (6) Makasar, (7) Matraman, (8) Pasar Rebo, (9) Pulogadung

g. North Jakarta

The results are the following:

1) Green : Cilincing – Kelapa Gading – Koja (15 supply chain, area 67 km^2)
2) Light Blue : Tanjung Priok (27 supply chain, area 23 km^2)
3) Yellow : Pademangan – Penjaringan (26 supply chain, area 57 km^2)

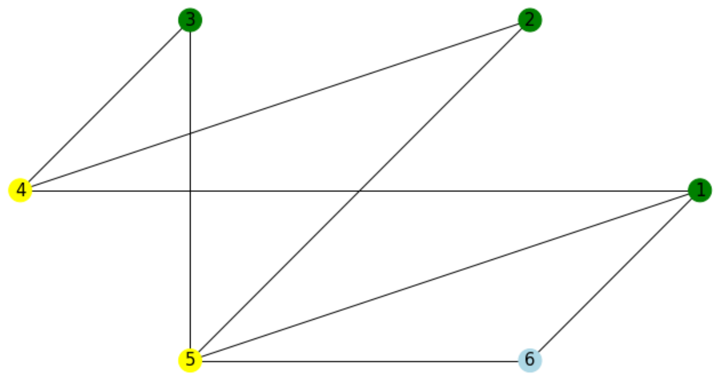

Figure 10. North Jakarta Graph Coloring

Symbol : (1) Cilincing, (2) Kelapa Gading, (3) Koja, (4) Pademangan, (5) Penjaringan, (6) Tanjung Priuk

h. Tangerang

The results are the following:

1) Blue : Ciledug – Ciputat – Ciputat Timur – Pamulang – Pondok Aren – Serpong (18 supply chain, area 123.32 km²)
2) Red : Cikupa – Curug – Jambe – Pagedangan – Panongan – Tigaraksa (14 supply chain, area 225.47 km²)
3) Yellow : Balaraja – Kelapa Dua – Pasar Kemis – Sepatan (8 supply chain, area 90.28 km²)
4) Pink : Batuceper – Benda – Cibodas – Cipondoh – Jatiuwung – Karawaci – Kosambi – Neglasari – Periuk – Pinang (46 supply chain, area 149.88 km²)

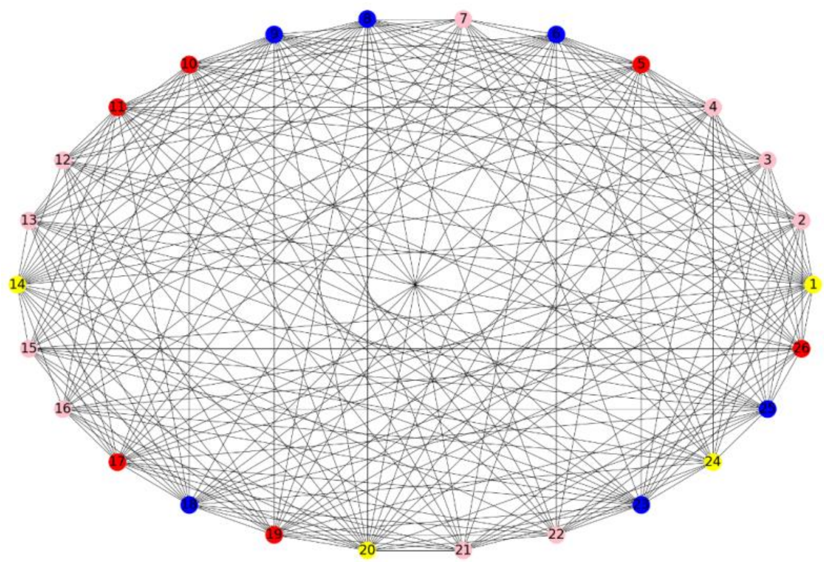

Figure 11. Tangerang Graph Coloring

Symbol : (1) Balaraja, (2) Batuceper, (3) Benda, (4) Cibodas, (5) Cikupa, (6) Ciledug, (7) Cipondoh, (8) Ciputat, (9) Ciputat Timur, (10) Curug, (11) Jambe, (12) Jatiuwung, (13) Karawaci, (14 Kelapa dua, (15 Kosambi, (16 Neglasari, (17) Pagedangan, (18) Pamulang, (19) Panongan, (20) Pasar Kemis, (21) Periuk, (22) Pinang, (23) Pondok Aren, (24) Septatan, (25) Serpong, (26) Tigaraksa

To simplify the process of creating and coloring graphs, customers in each region are first grouped into sub-districts so that stores in the same sub-district can be sent simultaneously, considering that the distance is not too far. This grouping allows the creation of a neighborship table between sub-districts in one area, and sub-districts that are not far from each other will be considered to be able to become one route together. This ensures that the two sub-districts cannot be neighbors when making a graph (Verma, Fu, & S. Panda, 2022). The grouping of data in the formation of a graph also considers the distance and the number of shops that will be covered by the courier, ensuring that the routes made are effective in the field. Consequently, points with the same color can be incorporated into a single route, thereby requiring a single responsible courier for each route. Through this step, the company will need 27 couriers, which is an increase of 12 couriers from the previous 15 couriers.

CONCLUSIONS AND SUGGESTIONS

This research shows that by utilizing graph coloring, logistics and courier services companies can determine the need for the frequency of couriers to deliver goods by taking into account the route and coverage of the delivery area. So that couriers can deliver goods on time without exceeding the load of normal working hours. Determining the number of couriers should pay attention to various aspects because, in today's era, where trade and transactions are conducted online, couriers are at the forefront of the goods distribution process.

In the future, development research can add other factors, such as the level of traffic jams. The level of traffic jams between regions will vary, especially in big cities, so the rate of delivery of goods will also vary between regions. In addition, weather factors can also be included as one of the considerations in determining the number of couriers, especially couriers who deliver by motorcycle.

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