Logistic network optimization using balanced allocation multi depot vehicle routing problem

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Abstract. One of the organization’s logistic business models is to deliver the goods from warehouses (depots) to many retail stores in order to fulfil the customer demand and achieve the KPIs of logistic department. The purpose of the paper is to provide an optimum route of delivery routing operations. The problem was a part of Balanced Allocation Multi Depot Vehicle Routing Problem (BAMDVRP) as a multi-objective mixed integer programming, which solution could be determined to provide an optimum logistic delivery routing and the efficient resources to boost the logistic performance and uplift the overall supply chain sustainability.

Keywords: logistic network, network optimization, vehicle routing problem, supply chain management

1. Introduction

Supply chain management is the coordination of logistical processes for the transport of products within the supply chain. Logistics management is a part of the supply chain that designs, executes, and controls the efficient flow and storage of goods, services, and related information between the generation point and the point of consumption to meet customer’s demands [1]. In recent years of globalization, the world’s indicator for international logistic and supply chain management is called the Logistics Performance Index (LPI). The index is an interactive benchmarking tool created to help countries identify challenges and opportunities they face in their performance on trade logistics and what they can do to improve their performance [2].

Japan and Singapore lead the world in logistics performance. The two countries are leading at an 8.1% logistic cost to GDP ratio [3]. Meanwhile, Indonesia Logistic and Forwarders Association suggested that the total logistic cost versus Growth Domestic Product (GDP) is slowly decreased. It was predicted at 21.0% for 2019; meanwhile, the forecast of the Indonesian contract logistic market shows the linear incremental of Compound Annual Growth Rate (CAGR) 11.70% for the forecast period of 2013 to 2017 [3]. The continuous expansion of global logistics networks, however, involves a considerable level of risk because of the associated huge investment and volatile demand patterns [4]. The logistics cost is an important factor that affects the price of products and is the biggest obstacle for the users of the logistics services industry. Material management performance is a crucial factor in determining project delivery success [5]. Poor material management increased the project duration by
50%-130% [6] and was identified as one of the common factors that accounted for lower productivity [7]. It was reported that about 30% of labor productivity could be lost due to a shortage of the materials when they were needed [8]. The research objectives is to provide solutions with better systematic route and distance calculation, and validated by GIS support implementation.

2. Literature review

One way of resolving this dilemma is conducted by balancing the allocation of customers to available depots while also improving customer service by implementing optimal vehicle routing from each depot to its allocated customers. To solve this problem, the Vehicle Routing Problem (VRP) method was invented to minimize the logistic transportation cost. VRP is defined as the task of designing delivery routes to service customers in a company’s supply chain. The problem captures the essence of allocation and routing of vehicles at minimal cost, given transportation demand. Hence, it is crucial to obtain an effective and efficient logistics management [1].

The process of selecting vehicle routes and sequences allows the selection of many combinations of customers in determining the delivery route for each vehicle owned. Therefore, the vehicle routing problem is a combinatorial optimization problem where the number of feasible solutions for the problem increases exponentially with the number of customers to be serviced. Vehicle routing (VR) approach to find solutions to the vehicle routing [9]. VRP is one of the most challenging problems in the field of combinatorial optimization. Dantzig and Ramser first introduced the VRP in 1959, and based on information availability and quality, according to Pillac et al, there are four categories of VRPs, which are [10]:

- static and deterministic where all input is known beforehand and vehicle routes do not change once they are in execution,
- static and stochastic where input is partially known as random variables, realizations of which are only revealed during the execution of the routes,
- dynamic and deterministic where part or all of the input is unknown and revealed dynamically during the design or execution of the routes, and
- dynamic and stochastic where part or all of the input is unknown and revealed dynamically during the execution of the routes, but in contrast with the previous category, exploitable stochastic knowledge is available on the dynamically revealed information.

Meanwhile, Balanced Allocation Vehicle Routing Problem (BAVRP) is primarily concerned with an optimal, balanced allocation for customer demands of warehousing capacity, and an optimal vehicle routing of product deliveries for the depot and its assigned customers. The BAVRP arises when building a seamless logistics network between a manufacturer and a set of customers via multiple distributors. The BAVRP is used in achieving the following three objectives: (i) the logistics network should be cost-efficient such that the maximum transportation cost to each distributor is reduced to a minimum, (ii) the assignment of the product flows within the logistics network should be as equitable as possible such that each depot is neither underutilized nor overburdened, and (iii) customer delivery service in the logistics network should remain at a high and an acceptable level, so the maximum vehicle route distance from each distributor to its customers must be reduced to a minimum.

The research combines the Balanced Allocation Problem (BAP) with a Multi Depot Vehicle Routing Problem (MDVRP). In a BAP, the situation of equitably assigning a set of customers to the capacitated depots is considered [4]. Therefore, a BAP is a variation of the classical location problem in that the location of the depots is given and fixed a priori [4]. BAP is, therefore, an NP-complete problem [11]. On the other hand, MDVRP is a variation of the VRP with multiple vehicles.

The MDVRP is a core optimization problem in transportation, logistics, and supply chain management because it minimizes the total travel time or distance (the major factor of total transportation cost) of all vehicles among several given depots [12]. The MDVRP is known to be an NP-
hard problem [12]. As the BAMDVRP is a combination of a BAP with an MDVRP, it belongs to the class of NP-hard problems.

Yamada formulated a mini-max spanning forest problem similar to the BAP and then proved that the problem is NP-complete [11]. They developed a heuristic algorithm to solve this problem approximately. Zhou, Min, & Gen was proposed a genetic algorithm for a model based on a naïve balanced star-spanning forest formulation to design a supply chain network that maintains a balance of transportation cost and customer service [4]. They proposed a mathematical model and an efficient solution procedure for the bi-criteria of an allocation problem involving multiple warehouses with different capacities and they developed a genetic algorithm to find the Pareto optimal solutions for this problem and presented an integer programming model for the Cyclic Bottleneck Assignment Problem (CBAP) considering multiple warehouses of varying capacities in the supply chain network and then proposed a tree-based genetic algorithm to solve it [4].

Researchers presently are using combinations of different heuristics to shorten the time needed for finding the nearly optimal solutions. Recent literature concerning the above-mentioned problem included Geetha et al in which both k-means algorithm and nested particle swarm algorithm are used for solving multi-depot VRP used simulated annealing with variable neighborhood descent, similarly for simultaneous pickup and delivery vehicles routing variant, hybrid heuristic, based on Iterated Local Search (ILS) and GENIUS is used by Marcone et al [13].

In the MDVRP, Wren and Holliday proposed a heuristic to use the initial solution obtained by the saving method in each depot. To establish the exact algorithm for solving an MDVRP, Laporte et al proposed two Branch and Bound (B&B) algorithms: one for symmetric distance cases and one for asymmetric distance cases [14]. Cho, Lee, Cho, & Gen developed a simple initialization heuristic combined with an improvement phase that was more powerful than those proposed in earlier studies [12]. In the improvement phase, the candidate moves consisted of repositioning a single customer in another route, which may or may not, is based on a different depot. Giosa et al considered the design and analysis of algorithms for the MDVRP with time windows. They proposed a two-step approach called ‘cluster first, route second’ for resolving practical-sized problems. Lim and Wang introduced an MDVRP with a fixed distribution of vehicles, which is one important and useful variant of the traditional MDVRP. They then proposed two solution methodologies: two-stage and one-stage approaches [14].

BAVRP problem in the real world is much more complicated and nonlinear. In the corporate operation, the timeliness in the product delivery is still paramount. Particularly, those corporations with multiple logistic services, including warehousing, transportation, cross-docking, inventory management, packaging, and freight forwarding. They have to deal with the actual travel distance in logistic and delivery management with a minimum logistic operating logistic to fulfill the customer’s demand. This article addresses a BAVRP problem in an actual corporate world.

3. Research method

The research focuses on solving a BAMDVRP problem in the real world where the actual data should be aggregated from various sources involving the use of GIS and by considering the actual traffic density. We consider a case involving two depots serving customers of forty stores with the objective of not exceeding the capacities of the vehicles. The research is performed following the procedure described in Figure 1. We start the research by gathering the data of the depots, including their capacities, and stores location from GIS. The locations of stores are tabulated in the appendix. Besides, we also collect the data of the daily order volume of each store in cubic meter (CBM), the number of delivering vehicles, and their capacities. We identify and supply all necessary data and all relevant parameters into a solver integrated with a modern spreadsheet Excel software and perform the analysis of the optimum delivery routes. Based on the vehicle specification and daily store’s order volume, and with the support of maps visualization through GIS, which is supported by Bing Map, we input the parameter to the Excel VRP solver. This approach is of great interest in the business community due to its cost-effectiveness and simplicity. More succinctly, the problem is stated as: we are given the locations of depots and stores, as shown in Figure 2, and their capacities and a fleet of trucks, we should determine
the optimal routes to serve those stores efficiently. We simplify the case by assuming the fleet consisting of vehicles of a similar type, which is Colt Diesel Engkel (CDE), a widely used vehicle type in the market nowadays.

Denote $C$ as the set of nodes representing $n$ customers, $D$ as the set of nodes representing $m$ ($k=1, 2, ..., m$) depots, and $E$ as the set of edges representing the connection from customer $i$ to depot $k$ or from customer $i$ to customer $j$ ($i,j \in \text{CU}D, i \neq j ; k \in D$). Each customer $i$ ($i \in C$), is served by exactly one depot $k$ ($k \in D$). On each edge $(i, k)$ ($i \in C, k \in D$), there is a weight $w_{ik}$ associated with the transportation cost between the customers and the depots. At each customer $i$ ($i \in C$), customer demand is denoted as $d_i$, and at each depot $k$, its capacity is denoted as $q_k$. Each depot $k$ ($k \in D$), owns exactly one vehicle $v_k$. Each vehicle $v_k$ has a route $R_k$ serving several customers assigned to the depot $k$, starting out from its corresponding depot $k$, and returning to the same depot. All $i$ ($i \in C$) customers must be served, and each of them is served by exactly one vehicle. The total demand of the served customers on each route $R_k$ does not exceed the vehicle capacity $g_k$. On the basis of the distance from customer $i$ to customer $j$($i,j \in \text{CU}D, i \neq j$), $d_{ij}$ is calculated from the customers’ locations, the customers’ demands $d_i$, the capacity of the depot $q_k$ ($k \in D$), the capacity of the vehicle $g_k$ ($k \in D$), and the decision variables $x_{ik}$ and $x_{ijk}$ for which $x_{ik}, x_{ijk}=1$ if customer $i, j$ is allocated to depot $k$, and otherwise 0. The BAVRP aims to determine to which depot each customer is assigned based on balancing the customers’ demands among the depots as fairly as possible and determining the detailed routing for each vehicle to minimize the total travel distance.

\[
\min \quad \max_{k=1, ..., m} \sum_{i=1}^{n} d_i w_i x_{ik} \tag{1}
\]

\[
\min \quad \sum_{i \in \text{CU}D} \sum_{j \in \text{CU}D} d_{ij} s_{ij} \sum_{k \in D} x_{ijk} \tag{2}
\]

\[
\text{subject to : } \sum_{i \in C} d_i x_{ik} \leq q_k, \forall k \in D \tag{3}
\]

\[
\sum_{k \in D} x_{ik} = 1, \forall i \in C \tag{4}
\]

\[
\sum_{i \in C} \sum_{k \in D} x_{ijk} = 1, \forall j \in C \tag{5}
\]

\[
\sum_{i \in C} \sum_{j \in D} x_{ijk} \leq 1, \forall k \in D \tag{6}
\]

\[
\sum_{j \in \text{CU}D} x_{ijk} = \sum_{j \in \text{CU}D} x_{ijk}, \forall k \in D, i \in C \cup D \tag{7}
\]

\[
\sum_{j \in C} \sum_{i \in \text{CU}D} x_{ijk} \leq g_k, \forall k \in D \tag{8}
\]
\[
\sum_{i \in S} \sum_{j \in S} x_{ijk} \leq |S| - 1, \quad \forall S \subseteq C, |S| \geq 2, k \in D
\]  
(9)

\[
x_{ik} \sum_{j \in C \cup D} x_{ijk}, \quad \forall i \in C, k \in D
\]  
(10)

\[
x_{ik} = 0 \text{ or } 1, \forall i \in C, k \in D
\]  
(11)

\[
x_{ijk} = 0 \text{ or } 1, \forall i, j \in C \cup D, k \in D
\]  
(12)

In those formulations, objective function (1) minimizes the total transportation costs, while balancing the demand at each depot as equitably as possible and while representing the mini-max objective as the mini-max operator. Objective function (2) minimizes the total travel distances for all vehicles, where each vehicle owned by each depot visits each of its customers exactly once and then returns to its starting point. Constraint (3) ensures that the total demand of the customers does not exceed the given capacity of the depot serving them.

Constraint (4) ensures that every customer is served by only one depot. Constraint (5) says that each customer is served exactly once by each vehicle. Constraint (6) imposes the limitation that each route is served by at most one vehicle. Constraint (7) mandates that the same vehicle enters and leaves a given customer (flow conservation constraint). Constraint (8) is the capacity restriction for each vehicle. Constraint (9) is the well-known generalized subtour elimination, which states that each vehicle \(v_k\) is on at least one route that visit then leaves each customer set \(S\).

Constraint (10) means that each customer assigned to one depot is served exactly once by each vehicle. Constraint (11) maintains a binary representation of the decision variables that represent the assignment solution. \(x_{ik} = 1\) if and only if the customer \(i\) is assigned to depot \(k\) (\(i \in C, k \in D\)); it is 0, otherwise. Finally, constraint (12) is the binary requirement on the decision variables that represent the routing solution such that \(x_{ijk} = 1\) if and only if customer \(j\) immediately precedes customer \(i\) on route \(R_k\) (\(i, j \in C \cup D, k \in D\)); it is 0, otherwise.

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Figure 1. Research Method Flowchart
Figure 2. The Locations of Depots and Stores in The Present Study as Obtained by Bing Map

More accurately, the geographical locations of the two depots are presented in Table 1, and Table 2 shows the truck geometry and capacity. Besides, Table 3 shows the depot limitation, capacity, and operating cost.

Table 1. The Geographical Locations of Two Warehouses

| No | Depot   | Longitude (x)   | Latitude (y)   |
|----|---------|----------------|----------------|
| 1  | Depot A| 1.069.681.400  | -64.065.600    |
| 2  | Depot B| 1.066.909.400  | -60.953.200    |

Table 2. Vehicle Specification

| Parameter | Box Size | Vehicle Size | Unit |
|-----------|----------|--------------|------|
| Length    | 350      | 473          | cm   |
| Width     | 173      | 175          | cm   |
| Height    | 200      | 205          | cm   |
| Capacity  | 9        |              | CBM  |
Table 3. Warehouse and Vehicle Information

| Depot | Depot Capacity | Vehicle Type | Depot Daily Operating Hour | Vehicle Owned | Operating Days per Month | Cost per Trip (IDR) |
|-------|----------------|--------------|----------------------------|---------------|-------------------------|-------------------|
| A     | 100 CBM        | CDE          | 8 hours                    | 4             | 22                      | 1,000,000         |
| B     | 100 CBM        | CDE          | 8 hours                    | 4             | 22                      | 1,000,000         |

4. Result and analysis
Solving a BAMDVRP problem on a corporate level is still very challenging. Constructing a unified platform for the data sources, solution algorithms, and visual representation of the results is often rather complicated and requires expensive resources. Some of those resources that need to be integrated are the following. A geocoding system that functions to translate and convert an actual address into the corresponding latitude and longitude coordinate system. A mapping system complete with traffic information that functions to determine distance and actual travel time between two given points and direction under the condition of the actual traffic. Finally, a static mapping system that functions to provide a graphical representation of the location with various viewing levels.

Those capabilities are often available separately and their integration is not completely straightforward. For example, at the current time, the leading public GIS systems are Bing and Google maps. Both offer limited free service and subscriptions are required for extended services.

As for the solution algorithm, we integrate VRP spreadsheet solver in Microsoft Excel, which is designed form small to medium scale quantitative analysis for businesses. This approach is more accessible to the public as most academics developed their solution algorithms in C++, resulting in a system that is accessible to those with a strong technical background. Finally, many solution algorithms present their results, such as total cost and routes, numerically, making them less practical and hard for practitioners to interpret the results. Differently, the current integration allows accessing the results graphically. With the present approach, firstly, we specify the parameters for the VRP problem (see Table 4), involving the number of vehicles in the fleets, the number of depots, their respective locations, and the average speed of the vehicles.

Table 4. VRP Solver Parameter

| Sequence       | Parameter                          | Value                                      |
|----------------|------------------------------------|--------------------------------------------|
| Optional - GIS License | Bing Maps Key  | [ Bing Maps Key ]                         |
| Locations      | Number of depots                   | 2                                          |
|                 | Number of customers (stores)       | 40                                         |
| Distances      | Distance computation method        | Bing Maps driving distances (km)           |
|                 | Duration computation method        | Average vehicle speed                      |
|                 | Average vehicle speed              | 40 kilometers per hours                    |
| Vehicles       | Number of vehicle types            | 1 type (CDE)                               |

Besides, we provide the worksheet data involving the locations, the service time, the pickup amount, the delivery amount, and the cost of each location and populate latitude and longitude by using the given addresses (see Table 5). With that information, the system develops an estimation of the distance and the travel duration in hours; some instances of those estimations are reproduced in Table 6. Finally, the requirement of each depot is provided in an additional spreadsheet involving the data of the vehicle types, capacity, cost, distance limit, work start time, driving time limit, working time limit,
and fleet size (see Table 7). With those data, the BAVRP solution system establishes the most optimum route selection as shown in Table 8. The solution is presented graphically in Figure 3, suggesting an intuitively acceptable solution.

Table 5. Address and Coordinate Mapping

| Name       | Address                                      | Longitude (x) | Latitude (y) |
|------------|----------------------------------------------|---------------|--------------|
| Depot A    | Jl. Raya Jonggol - Cileungsi No.47, Cileungsi, Kec. Cileungsi, Bogor, Jawa Barat 16820 | 1.069.681.400 | -            |
| Depot B    | Pergudangan Pantai Indah Dadap, JL Raya Perancis No. 2 Blok CD No. 8-9, Tangerang, 15211, Dadap, Kosambi, Tangerang, Banten 15211 | 1.066.909.400 | 60.953.200   |
| Customer 1 | Plaza Indonesia 1st floor # 160 Jln. M.H. Thamrin Kav.28-30 Jakarta 10350 | 1.068.228.400 | -            |

Table 6. Address and Distance-Hour Mapping

| From       | To            | Distance (Km) | Distance Duration (Hour) |
|------------|---------------|---------------|--------------------------|
| Depot A    | Depot A       | 0.00          | 0:00                     |
| Depot A    | Depot B       | 60.67         | 1:31                     |
| Depot A    | Customer 1    | 36.50         | 0:54                     |
| Depot A    | Customer 10   | 35.15         | 0:52                     |

Table 7. Distribution Parameter

| Starting Depot | Vehicle Type | Capacity (CBM) | Work start time | Driving time limit | Working time limit | Vehicle Owned |
|----------------|--------------|----------------|-----------------|--------------------|--------------------|---------------|
| Depot A        | CDE          | 8              | 4:00            | 9:00               | 10:00              | 4             |
| Depot B        | CDE          | 8              | 4:00            | 9:00               | 10:00              | 4             |

Table 8. Distribution Result Parameter

| Stop count | Location name | Distance travelled (Km) | Delivery amount (CBM) | Load |
|------------|---------------|-------------------------|-----------------------|------|
| 0          | Depot A       | 0                       | 0                     | 8    |
| 1          | Customer 39   | 32.006                  | 1                     | 7    |
| 2          | Customer 12   | 36.748                  | 1                     | 6    |
| 3          | Customer 10   | 37.518                  | 1                     | 5    |
| 4          | Customer 11   | 39.704                  | 3                     | 2    |
| 5          | Customer 6    | 39.704                  | 2                     | 0    |
| 6          | Depot A       | 74.901                  | 0                     | 0    |
5. Conclusion
In the paper, we have established a system for solving BAMDVRP problem, unifying several platforms for data sources, solution of optimization algorithms using multi-objectives mixed integer programming, and visual representation of the results. Those aspects are rather complicated and require expensive resources. With this proposal, we suggest an approach to aggregate those platforms into a cohesive system. It captures the essence of allocation and routing of vehicles at minimal cost, given transportation demand, which is crucial to effective and efficient logistics management in order to boost the company performance and excellence and serve the customer better.

The recommendation for further research is to develop the Excel Solver with more scenarios the organization faces nowadays. Some may have problems in one single depot, another may have problems in time-window wise delivery, and another may have problems in multi delivery and or split delivery method. Thus, the usage of different GIS platform such as QGIS could also be considered to give more options and decision analysis support. There are so much more scenarios those are available for further research and development to support and achieve organization's logistic excellence and supply chain sustainability in regards to support business continuity.

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Appendix: The data of the store locations

| No | Stores                               | Longitude  | Latitude  |
|----|--------------------------------------|------------|-----------|
| 1  | Starbucks Plaza Indonesia            | 1.068.228.400 | -61.907.600 |
| 2  | Starbucks Jakarta Stock Exchange     | 1.068.101.349 | -62.258.649 |
| 3  | Starbucks Plaza Senayan              | 1.067.874.146 | -61.760.511 |
| 4  | Starbucks Taman Anggrek              | 1.067.333.200 | -61.878.700 |
| 5  | Starbucks Mall Puri Indah            | 1.068.386.230 | -62.085.390 |
| 6  | Starbucks Skyline Building           | 1.067.982.400 | -62.288.700 |
| 7  | Starbucks Kinokuniya                 | 1.068.051.500 | -62.459.400 |
| 8  | Starbucks Pasaraya Grande            | 1.068.269.119 | -62.129.831 |
| 9  | Starbucks WTC 5                      | 1.067.868.700 | -61.695.800 |
| 10 | Starbucks Mal Ciputra                | 1.067.981.000 | -62.197.200 |
| 11 | Starbucks Senayan City 1             | 1.067.982.400 | -62.288.700 |
| 12 | Starbucks Senayan City 2             | 1.068.022.919 | -62.164.888 |
| 13 | Starbucks FX Sudirman                | 1.068.286.400 | -61.966.500 |
| 14 | Starbucks Plaza Menteng              | 1.068.229.600 | -61.961.960 |
| 15 | Starbucks Grand Indonesia            | 1.068.386.230 | -62.085.390 |
| 16 | Starbucks KM 13.5                    | 1.066.368.500 | -62.297.500 |
| 17 | Starbucks Sumarecon Mall Serpong     | 1.068.101.349 | -62.258.649 |
| 18 | Starbucks Pacific Place              | 1.068.151.200 | -62.174.400 |
| 19 | Starbucks Sampoerna Strategic Sq     | 1.066.380.615 | -61.768.298 |
| 20 | Starbucks Debenhams Karawaci         | 1.068.206.550 | -62.109.150 |
| 21 | Starbucks Graha Niaga Sudirman       | 1.067.923.100 | -61.750.600 |
| 22 | Starbucks Teras Kota                 | 1.066.380.615 | -61.768.298 |
| 23 | Starbucks Central Park               | 1.066.510.300 | -62.441.300 |
| 24 | Starbucks Hayam Wuruk Plaza          | 1.067.949.100 | -61.783.500 |
| 25 | Starbucks Bintaro Plaza              | 1.066.380.615 | -61.768.298 |
| 26 | Starbucks Flavour Bliss              | 1.068.146.800 | -61.754.100 |
| 27 | Starbucks Sogo Central Park          | 1.067.994.200 | -61.774.700 |
| 28 | Starbucks Premier Bintaro            | 1.068.230.500 | -62.002.800 |
| 29 | Starbucks Cideng                     | 1.067.552.500 | -61.882.900 |
| 30 | Starbucks Tomang                     | 1.068.214.400 | -62.224.300 |
| 31 | Starbucks UOB Plaza                  | 1.068.229.600 | -61.961.960 |
| 32 | Starbucks Ranch Pesanggrahan         | 1.067.868.700 | -61.695.800 |
| 33 | Starbucks Kuningan City              | 1.068.269.119 | -62.129.831 |
| 34 | Starbucks Kota Kasablanka            | 1.066.710.510 | -62.152.190 |
| 35 | Starbucks Bintaro Sektor 9           | 1.065.709.300 | -61.554.500 |
| 36 | Starbucks Alam Sutera                | 1.068.193.800 | -62.181.800 |
| 37 | Starbucks Eka Hospital               | 1.068.252.792 | -62.212.400 |
| 38 | Starbucks 1 Park                     | 1.068.140.000 | -61.375.300 |
| 39 | Starbucks Grand Indonesia 3          | 1.068.189.621 | -62.332.020 |
| 40 | Starbucks Central Park 3             | 1.068.228.378 | -61.174.269 |