The Application of Gravity Model in Scenario-based Forecasting for Airport Feasibility Study

Rolan Mauludy Dahlan
Ametis Institute and
School of Business and Management
Institut Teknologi Bandung
rolan.mauludy@sbm-itb.ac.id

Santi Novani
School of Business and Management
Institut Teknologi Bandung
Bandung, Indonesia
snovani@sbm-itb.ac.id

***Abstract*— Airport Industry is very dynamic. It often appears many new plans from the internal and from the environment. To anticipate the various possibilities outcome that may occur in the future we need scenario-based forecasting for the number of passengers. Here the authors use a gravity model which is implemented in the spatial landscape. To get the best results, the parameters are optimized by compare the result with empirical data through numerical analysis approach. The verification process in the Western part of Java Island showed that this model provide a good result when compared with empirical data. After optimizing the parameters, we may create a scenario-based projections by determine airport capacity and growth rates at specific time. Projections of the number of passengers will affect the business feasibility and future development strategies.**

Keywords*— scenario-based forecasting; spatial analysis; gravity model; numerical analysis; feasibility study

I. INTRODUCTION

The western part of Java Island, which consists of the province of West Java, Jakarta and Banten, is the most densely populated areas in Indonesia. In 2014, the area of 45,700 square kilometers is inhabited by 68.15 million people or about 1,491 people per square kilometer [1]. After the Asian crisis in 1998, the number of middle class grew significantly and encourages purchasing power [2]. The combination of the huge number of population and increased purchasing power creates new challenges, including in the air transportation industries.

In this region, the number of passenger increased very rapidly. It rose from 11.88 million passengers per year (2001) to 61.54 million passengers per year (2014), or an average of 13.99% per year [3]. They are only served by three airports, namely Soekarno-Hatta (CGK), Husein Sastranegara (BDO) and Halim Perdanakusuma (HLP). This is very difficult to fulfill the passenger growth. The Indonesian government has been tried to resolve this problem by making a lot of plans that will be run simultaneously. The first plan is to enlarge the existing airport capacity. The second plan is to encourage state-owned enterprises and the private investors to build a new airport, such as Kertajati (XX1) and South Karawang (XX2).

This parallel development plans increase the level of uncertainty for investors. They are faced with a number of questions. What would happen if the rival airports are built? What happens if the rival airport increases its capacity? What happens if the rival airport development delayed for several years? What happens if the development of the rival airport is canceled? To anticipate the various possibilities outcome that may occur in the future we need scenario-based forecasting [4] for the number of passengers. Projections of the number of passengers will affect the business feasibility and future development strategies. If the number of passengers is below the threshold then the business is not feasible to be implemented. The dynamic of passengers will affect the airport development strategy, for example design capacity at early stage, timing, and design capacity in the next stage and the integration between the early stage and the next stage.

The purpose of this research is to create a scenario based passenger projections. This spatial approach is constructed based on the gravity models that mimic gravitational interaction as described in Isaac Newton's law of gravity. Gravity models are used in various social sciences, for example the gravity model of international trade [5], trip distribution [6] and gravity model of migration [7]. In this study the parameter of the gravity model is optimized by using numerical analysis on empirical data.

II. THEORETICAL FOUNDATIONS

A. *GIS for Transportation (GIS-T)*

Geographic information system (GIS) are interconnected hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and communicating particular types of information about the earth. GIS-T is one of the most important applications of GIS [8]. GIS-T application covers much of the broad scope of transportation, from infrastructure planning, public transit operation, traffic analysis and control to hazard mitigation. The format of the spatial data storage varied, from vector data (represent features as discrete points, lines, and polygons) to raster data (represent the landscape as a rectangular matrix of square cells) [9].

B. *Distance*

There are many concepts of distance in mathematics, for examples Euclidean distance, spherical Distance, Manhattan distance, Chessboard distance, Hamming distance and so on. In this study we use spherical distance or the minimum distance between two points on the surface of the spherical object [10]. Euclidean distance or the minimum distance between two points in Euclidean space [11] is not realistic to describe the distance on the earth's surface. We don't use Manhattan distance or the total distance that connect the segments between two points in space [12] because of data limitations.

C. Numerical Analysis

Numerical analysis is the branch of mathematics which is used to find approximations to difficult problems such as finding the roots of non–linear equations, integration involving complex expressions and solving differential equations for which analytical solutions do not exist [13]. There are many mathematical problem cannot be solved by analytic methods. Sometimes we have to use numerical analysis or study of algorithms that use numerical approximation for the problems of mathematical analysis. The invention of the computer also influenced the field of numerical analysis, since now longer and more complicated calculations could be done.

D. Gravity Model

Gravity models that mimic gravitational interaction as described in Isaac Newton's law of gravity are used in various social sciences. This approach is used to measure the interaction between two separate things based on economic mass and spatial distance. The gravity model illustrates the macroscopic relationships between places. The Economic mass increase the interaction between the two regions, while the distance reduces the interaction between the regions. There are many application of gravity model in spatial problem, for example the gravity model of international trade [5], trip distribution [6] and gravity model of migration [7].

E. Related Research

Tobias Grosche, Franz Rothlauf and Armin Heinzl [14] used gravity models for the estimation of air passenger volume between city-pairs in European countries. Their models showed a good fit to the observed data and are statistically tested and validated. Fengjun Jin, Fahui Wang and Yu Liu also used gravity models for the estimation of air passenger volume between cities in China [15]. But unfortunately these two models only explore the interaction between cities or airports, not the relationship between the distributions of the population to the airports.

III. METHODOLOGY

In this study we tried to examine the relationship between the distributions of the population to the airport. About 68.15 million people in the western part of the island of Java inhabit 7,735 desa (villages) or kelurahan (urban communities).

Map of villages or urban communities (i) are in polygons format (ρ).To be analyzed further, it needs to be transformed (T) into a point or centroid (p) or geometric center of a plane figure is the arithmetic mean ("average") position of all the points in the shape.

$$T: \rho_i \rightarrow p_i \qquad (1)$$

Where:

$$T: \rho_i(x_0^i, y_0^i; x_1^i, y_1^i; \dots; x_{N-1}^i, y_{N-1}^i) \rightarrow p_i(\bar{x}^i, \bar{y}^i) \qquad (2)$$

The transformation process assumes that the two-dimensional polygon has a uniform density. Centroid can be calculated by [16]:

$$\bar{x}^i = \frac{1}{6L}\sum_{n=0}^{N-1}(x_n^i + x_{n+1}^i)\cdot(x_n^i \cdot y_{n+1}^i - x_{n+1}^i \cdot y_n^i) \qquad (3)$$

And

$$\bar{y}^i = \frac{1}{6L}\sum_{n=0}^{N-1}(y_n^i + y_{n+1}^i)\cdot(x_n^i \cdot y_{n+1}^i - x_{n+1}^i \cdot y_n^i) \qquad (4)$$

L is the area of the polygon, where:

$$L = \frac{1}{2}\sum_{n=0}^{N-1}(x_n^i \cdot y_{n+1}^i - x_{n+1}^i \cdot y_n^i) \qquad (5)$$

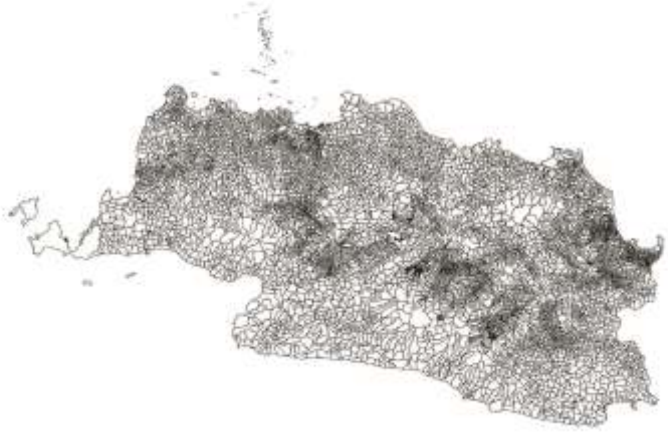

Fig. 1. 7,735 villages or urban communities in the western part of the island.

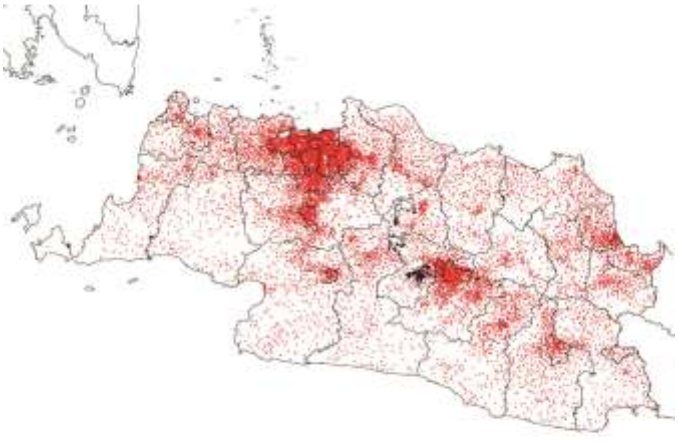

Fig. 2. The spatial distribution of the population in the western part of the island of Java.

Total number of passengers (W) at time t grow at rate r_t.

$$W_t = W_{t-1} \cdot (1 + r_t) \qquad (6)$$

We assume the number of passengers (w) of a villages or urban communities (i) is directly proportional to population (q) and income per capita (π), or:

$$w_{i,t} \sim q_{i,t} \cdot \pi_{i,t} \tag{7}$$

Where:

$$W_t = \sum\nolimits_{\forall i} w_{i,t} \tag{8}$$

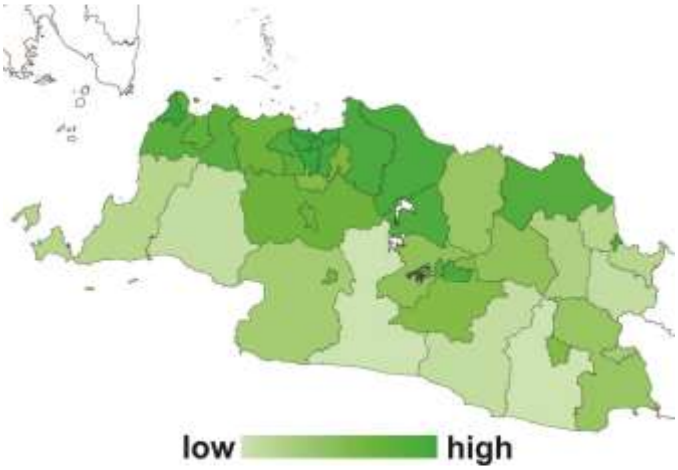

Fig. 3. The spatial distribution of the income per capita in the western part of Java Island.

There are three existing airports, namely Soekarno-Hatta (CGK), Husein Sastranegara (BDO) and Halim Perdanakusuma (HLP). There are also two candidates of new airport, namely Kertajati (XX1) and South Karawang (XX2).

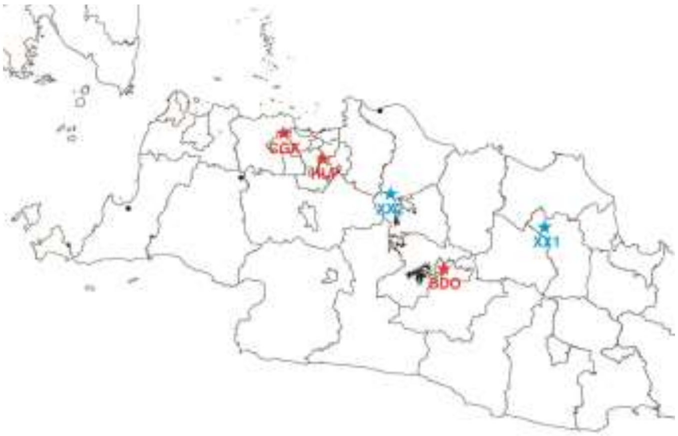

Fig. 4. 3 existing airport and 2 candidates of new airport in the western part of the island of Java.

The interaction force (F) between passengers in a villages or urban communities (i) and airport (j) is calculated through gravity models [5-7], which simply:

$$F_{i,j,t} \sim \frac{c_{j,t}}{{d_{i,j}}^{k}} \tag{9}$$

Where c is capacity of the airport, d is spherical distance between villages or urban communities (i) and airport (j) and k is power coefficient of spherical distance.

The number of passengers at airports j at time t ($\omega_{j,t}$) is calculated using the following pseudo algorithm:

```
For i=1:I
        Search i*,j* where F_{i*,j*,t} = max(F_t)
        ω_{j*,t} = ω_{j*,t} + w_{i*,t}
        For j=1:J
                F_{i*,j} = 0
        End
        If ω_{j*,t} > c_{j*,t}
                For i=1:I
                        F_{i,j*} = 0
                End
        End
End
```

There are 2 possible outputs: if $\sum_{\forall j} c_{j,t} \geq W_t$ then $\sum_{\forall j} \omega_{j,t} = W_t = \sum_{\forall i} w_{i,t}$ and if $\sum_{\forall j} c_{j,t} < W_t$ then $\sum_{\forall j} \omega_{j,t} = c_{j,t} < W_t = \sum_{\forall i} w_{i,t}$.

The power coefficient of spherical distance (k) in gravity model is optimized by using numerical analysis [13] on empirical data. Figure 5 show the mean absolute percentage error of the power coefficient of spherical distance (k) compared with empirical data of passengers in 2015. The smallest value of mean absolute percentage error (MAPE) is 4.75% when $k = 2.0$.

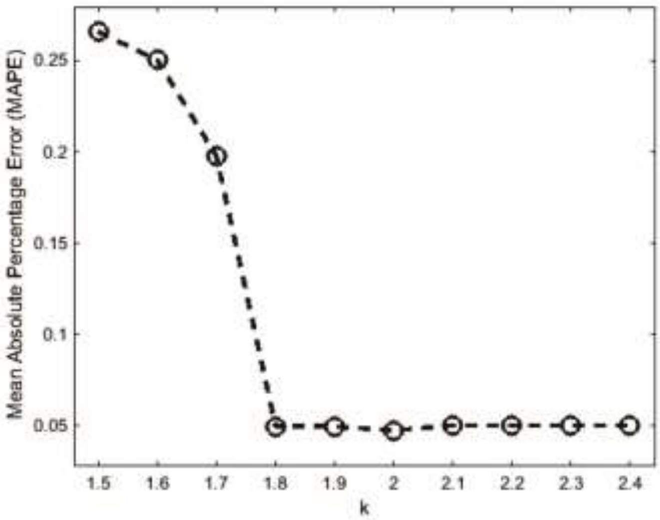

Fig. 5. Mean absolute percentage error of the power coefficient of spherical distance (k) compared with empirical data of passengers in 2015.

IV. RESULT

After optimizing the parameters, we can predict the number of passengers at specific airport in certain scenarios by determine airport capacity ($c_{j,t}$) and growth rates (r_t) at specific time. In this case there are millions possible scenarios.

We tried to implement this model in case of planninf new airport in Kertajati (XX1). XX1 was targeted to serve 5 million passengers per year in 2018, 10 million in 2020 and 20 million in 2026.

Scenario 1:

The XX1 feasibility study was made in 2013 without information about XX2 airport. CGK's capacity will increase 40% after the operation of a third runway in 2022. HLP will be expanded to reach 11.5 million passengers per year in 2020. They assumed that BDO can be closed in 2020. The economic situation is very bright after a very explosive passenger growth from 2001 to 2012. The number of passengers is expected to increase by 7% per year. This situation is called scenario 1.

Scenario 2:

In early 2016 there was new plan of XX2 airport that can serve 20 million passengers per year and will be operational in 2023. The operation plan of the third runway at CGK will be accelerated into 2019. No change of plan in HLP. Because of public resistance BDO will not be closed. After economic slowdown in 2012-2015, passenger growth is corrected at only 6% per year. This new situation is called scenario 2.

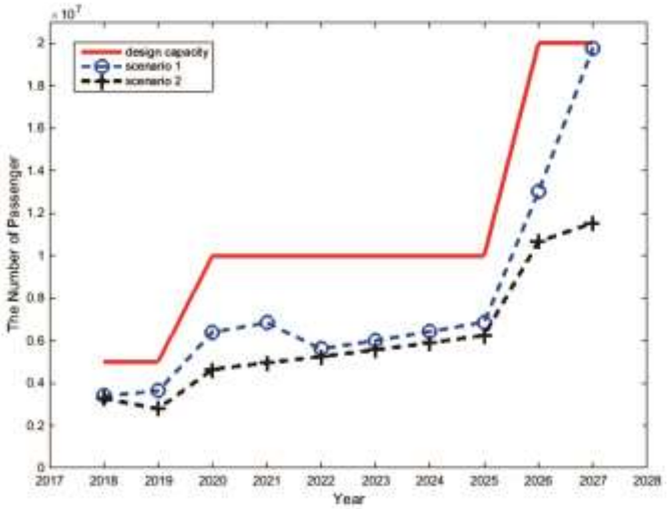

Fig. 6. The calculation results of the number of passenger for scenario 1 and scenario 2 compared to its design capacity.

This model can be used to make scenario-based projections of passengers. Figure 6 show the calculation results of the number of passenger for scenario 1 and scenario 2 compared to its design capacity. Due to limited capacity of the airports in Greater Jakarta, in scenario 1, the number of passengers in XX1 will increase significantly after 2025 However in scenario 2 the significant increase will not appear because the development of XX2. Utilization of installed capacity will be less than 60% in 2027.

Amendment of airport planning by the government will affect the competitive landscape of business. This method will be beneficial for the government and investors to anticipate the new plans through the revision of the old and irrelevant strategic plan.

V. CONCLUSION

Airport industry is very dynamic especially in the long term. It often appears many new plans from the internal and from the environment. The strategic plan that was created before is become irrelevant. We need the forecasting method that can be adapted easily in many possible scenarios. To anticipate the various possibilities outcome that may occur in the future we need scenario-based forecasting for the number of passengers.

Scenario-based forecasting is needed to anticipate the dynamic airport industry situations. Gravity model can be used to make projections of passenger based on scenarios. To get the best results, the parameters are optimized by compare the result with empirical data through numerical analysis approach. In the case of the western part Java Island, the mean absolute percentage error (MAPE) of this model is only 4.75%, meaning that this model provides a relatively good estimation value.

After optimizing the parameters, we can create a scenario-based projections by determine airport capacity ($c_{j,t}$) and growth rates (r_t) at specific time. The result of this projection is very important for the government and investors to construct a new strategic plan.

REFERENCES

[1] BPS, "Laporan Bulanan Data Sosial Ekonomi," Badan Pusat Statistik, Jakarta, 2014.

[2] A. Budiman, H. Chhor, R. Razdan and A. Sohoni, "The New Indonesian Consumer," McKinsey & Company, Jakarta, 2012.

[3] BPS, "Statistik Transportasi Udara 2014," Badan Pusat Statistik, Jakarta, 2015.

[4] M. G. Nimmo , V. H. Nguyen and Y. Shin, "Using Global VAR Models for Scenario-Based Forecasting and Policy Analysis," in *The GVAR Handbook: Structure and Applications of a Macro Model of the Global Economy for Policy Analysis*, Oxford, Oxford University Press, 2013, pp. 97-112.

[5] S. S. Nello, The European Union: Economics, Policies and History, McGraw Hill Education, 2009.

[6] D. M. Levinson and A. Kumar , "A Multi-modal Trip Distribution Model," *Transportation Research Record*, vol. 1466, p. 124–131, 1995.

[7] J.-P. Rodrigue, C. Comtois and B. Slack, The Geography of Transport Systems, Routledge, 2009.

[8] H. Miller and S. Shih-Lung, Geographic Information Systems for Transportation: Principles and Applications, Oxford University Press, 2001.

[9] D. Peuquet and D. Marble, Introductory Readings In Geographic Information Systems, London: Taylor and Francis, 1990.

[10] T. Rowland, "Spherical Distance," Wolfram MathWorld, [Online]. Available: http://mathworld.wolfram.com/SphericalDistance.html. [Accessed 11 September 2016].

[11] E. Deza and M. Deza, Encyclopedia of Distances, Springer, 2009.

[12] M. Barile, "Taxicab Metric," Wolfram MathWorld, [Online]. Available: http://mathworld.wolfram.com/TaxicabMetric.html. [Accessed 11 September 2016].

[13] S. Karris, Numerical Analysis Using MATLAB and Excel, Orchard Publications, 2007.

[14] T. Grosche, F. Rothlauf and A. Heinzl, "Gravity Models for Airline Passenger Volume Estimation," *Journal of Air Transport Management*, vol. 13, no. 4, p. 175–183, 2007.

[15] F. Jin, F. Wang and Y. Liu, "Geographic Patterns of Air Passenger Transport in China 1980–1998: Imprints of Economic Growth, Regional Inequality, and Network Development," *The Professional Geographer*, vol. 56, no. 4, p. 471–487, 2004.

[16] M. Worboys and M. Duckham , GIS: A Computing Perspective, Second Edition, CRC Press, 2004.