Experiment Design for Determining the Minimum Sample Size for Developing Sample Based Trip Length Distribution

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Abstract. In transportation modelling, the origin and destination matrix is essential. To develop an origin-destination matrix, trip length distribution pattern is needed. Thus, it is important to develop a representative trip length distribution based on data sample. This paper present an attempt to develop experiment design for investigating the behaviour of curve pattern acceptance and error value acceptance due to the sample size variation. The experiment design indicate that, in general, smaller sample size produce higher error value. The experiment also indicate that even if the curve pattern is consider accepted, the error value can be unacceptable. Since the experiment design development is merely based on a particular small sample size, the research result can only give an indication yet the calculation result value can not be taken as a proper dictum. The experiment design can be considered as appropriate to be used for any further assessment.

1. Introduction
Transport modelling is needed for transportation planning. The main role of transport modelling is to calculate the trip desired lines and the trip flow assignment in the network of modelling area. These two products are calculated based on origin destination matrix (OD Matrix). The base OD Matrix can be refined and corrected through validation-and-calibration process in the end. The future prediction model is done by calculating the future OD Matrix. Thus, OD Matrix is an essential part of the transport modelling [1-5].

In conventional modelling method, the OD Matrix is a product of mathematical operation among Trip Generation, Generalized Cost Matrix and Deterrence Function. The Deterrence Function itself is developed based on Trip Length Distribution (TLD). Meanwhile the TLD is gotten from a sample. Hence, collecting a good Sample of TLD is important. A Special Conventional Transport Model for a New BRT Line Passenger Demand Prediction has been developed and it is not incorporate the validation-and-calibration process. Thus, having an accurate Sample Based TLD is absolutely crucial for this modelling. One of the basic sampling requirements is to get a minimum number of samples. However, guidelines on number of samples for developing Sample Based TLD is very weak [1-10].

Sample based TLD Quality Measure has ever been formulated before. The main point is having the same curve pattern as the reference’s with having an acceptable error, both at a certain confidence.
level. It has been mentioned before that deriving formula to express the minimum sample size to get a good Sample Based TLD can not be done. Therefore, the minimum sample size requirement can only be gotten from an extensive experiment [8-9].

This paper presents the result of an attempt to develop an Experimental Design for determining the Minimum Sample Size. If this design can be proved appropriate, then it can be used to execute further extensive experiment.

2. Research Method
The research was conducted by following these steps: research objective definition, recalling the Sample Based TLD Quality measurement method, experiment design, case study determination, calculation and analysis, and finished by a conclusion.

3. Sample Based TLD Quality Measure
Sample based TLD quality measures follows the principle of Maximum Acceptable Error at a Certain Confidence Level (MAE at CCL). For this case, it has two main measures: having a curve pattern which considered the same as the reference’s curve pattern and having an accepted error, both are measure at a certain confidence level. This pairs is similar to the Zonal Regression Trip Production model quality measure which are: accepted coefficient of determination value with accepted span of prediction value. This principle is conform to the statistics basic principle of sample quality : “MAE at CCL” [8-9,11-12].

The Curve Pattern Acceptance (CPA) test is the statistical goodness of fit test based on $\chi^2$ value. The test is as follows [9,11].

$$H_0 : \quad \chi^2 \leq \chi^2_{0,\beta}, \text{curve pattern is considered the same as the reference’s.}$$
$$H_1 : \quad \chi^2 > \chi^2_{0,\beta}, \text{curve is not part of the reference’s curve pattern.}$$

$$\chi^2 = \sum \{(Y_i - Y_0^i)^2 / Y_0^i\}$$
(1)

$$\chi^2_{0,\beta} = \chi^2_{\nu,\beta}$$
(2)

$$\nu = n - k - 1$$
(3)

where :
- $\chi^2$ = sample’s chi square value
- $\chi^2_{\nu,\beta}$ = chi square value at a certain degree freedom and confidence level value
- $Y_i$ = the $i$th sample distribution value, measured in percentage
- $Y_0^i$ = the $i$th reference distribution value, measured in percentage
- $\beta$ = one tail confidence level ($1-\alpha$, where $\alpha$ is one tail significance level)
- $\nu$ = degree of freedom of $\chi^2$
- $n$ = number of distribution points
- $k$ = number of observed parameter

The Error Value Acceptance (EVA) test follows the principal of “MAE at CCL”. The error used is the Mean Absolute Error. The Confidence Level value used is the same as for measuring CPA. The test is as follows [11].

$$H_0 : \quad |\bar{e}| \leq E, \text{the case is accepted}$$
$$H_1 : \quad |\bar{e}| > E, \text{the case is rejected}$$

$$|\bar{e}| = \sum |e_i| / n$$
(4)

$$|e_i| = |Y_i - Y_0^i| / Y_0^i$$
(5)

where :
- $E$ = accepted error value, measured in percentage.
- $|e_i|$ = absolute error value at each distribution points, measured in percentage.
- $|\bar{e}|$ = mean of absolute error values, measured in percentage.
n = number of distribution points.

\( Y_i \) = the \( i \)th sample distribution value, measured in percentage

\( Y_0^i \) = the \( i \)th reference distribution value, measured in percentage

4. Analysis and Discussion

4.1. Research Objective
Having a good Sample Based TLD is crucial in Transportation Modelling. The Sample Based TLD Quality Measurement Method does not incorporate Sample Size Formula for ensuring good sample quality. An experiment to determine Sample Size must be done. Thus, the Research Objective is to design an experiment for investigating sample’s \( \chi^2 \) value - Curve Pattern Acceptance variation and Error value - Error Value Acceptance variation due to the Sample Size variation.

4.2. Experiment Design
To execute this experiment, a case must be taken, from which the population or the reference sample data were collected. The reference sample can be considered as ‘population’. If the population is taken, the experiment is a ‘real experiment’, but if a reference sample is used, the experiment is called a ‘simulation experiment’. Then, from the ‘population’ (real population of reference sample) take several Samples Groups of various Reference Sample Percentage. Therefore, the Reference Sample must be big enough, so that the minimum sample size still consists of at least 30 individus. For each Sample Groups construct several Samples with the same sample size but consists of different sample individu composition. Then, the “MAE at CCL” value must be set. It consists of : acceptable error value (%) and confident level value (%). Then for each sample, calculate the TLD. Finally make comparaison between the sample against the ‘population’, in terms of the Curve Pattern Acceptance and Error Value Acceptance.

4.3. Case Study and Reference Sample
The BRI Branch Office Kertajaya was taken as the Case Study. Its total number of staff is 78 persons. The BRI Branch Office is located in Jl. Kertajaya 24 Surabaya, the center area of Surabaya.

A Reference Sample of 50 individus was taken from BRI Kertajaya. As this is designed for Working Trip TLD, so the TLD is developed based on the distance between home to office. The employee addresses were noted. To construct the TLD, the trip length is classified into each 3 km incremental distances.

The developed TLD seems very reasonable, the distribution value is low at short distance, then arrive at peak at second distance category, then gradually decrease. The TLD is presented in Table 1, while the TLD Graph is presented in Figure 1.

| No | Trip Length | Distribution |
|----|-------------|--------------|
| 0-3| 20          | 40           |
| 3-6| 21          | 42           |
| 6-9| 8           | 16           |
| 9-12| 1         | 2            |
| Total | 50    | 100          |
4.4. Analysis of Sample Size Variation

4.4.1. Sample Size Variation. A Reference Sample was taken, this experiment is consider as ‘Population’, consists of 50 individuals. This number can be considered as fair, since this number is close enough to the real population number of 78. Reference Sample is 67.5% of Population and the 60% of the Reference Sample is 30 individuals.

Four Sample Sizes were taken at 90%, 80%, 70% and 60% of the Reference Sample. Three samples of each Sample Size were constructed. For the development of this experiment design, the samplings were not taken yet as random sample. Each three samples were taken from the first n%, the middle n% and the late n% individuals. Each sample parameters were calculated, i.e. each TLD, each Curve Pattern Acceptance and each Mean Absolute Error Acceptance, all in a certain Confidence Level. The “MAE at CCL” value has 10% Error at 90% Confidence Level. Later on, in the real experiment, sampling must be done in random situation.

4.4.2. Analysis of 90% Sample.
The 90% TLD Sample are all in normal form. The calculated $\chi^2$ values are 0.031, 0.288 and 0.344. These all are far less than $\chi^2_0 = 5.99$. This means that all curve pattern is the same as the Reference Curve Pattern. The calculated error values are 0.5%, 3.3% and 2.9%. These all are well below the MAE = 10%. It means that the 90% Sample is very good.

The 90% TLD Sample calculation result is presented in Table 2, the TLD Graph is presented in Figure 2, while the Curve Pattern acceptence and the Error Value acceptance calculation is presented in Table 3 below.
Table 2. TLD Calculation of the 90% Samples.

| No | Trip Length | Person Distribution | Percentage Distribution |
|----|-------------|---------------------|-------------------------|
|    | km | 90A | 90B | 90C | % | % | % |
| 1  | 0-3 | 18  | 17  | 17  | 40.0 | 37.8 | 37.8 |
| 2  | 3-6 | 19  | 20  | 19  | 42.2 | 44.4 | 42.2 |
| 3  | 6-9 | 7   | 7   | 8   | 15.6 | 15.6 | 17.8 |
| 4  | 9-12| 1   | 1   | 1   | 2.2  | 2.2  | 2.2  |
|    | Total | 45  | 45  | 45  | 100.0 | 100.0 | 100.0 |

Figure 2. TLD Graphs of 90% Samples.

Table 3. Calculation of Curve Pattern Acceptance and Error Value of 90% Samples.

| No | Trip Length | Percentage Distribution | $\chi^2$ Calculation | $|\bar{e}|$ Calculation |
|----|-------------|-------------------------|---------------------|---------------------|
|    | km | 90A | 90B | 90C | $\chi^2$Ai | $\chi^2$Bi | $\chi^2$Ci | $|\bar{e}|_A$ | $|\bar{e}|_B$ | $|\bar{e}|_C$ |
| 1  | 0-3 | 40  | 40.0 | 37.8 | 37.8 | 0.000 | 0.121 | 0.121 | 0.0 | 5.5 | 5.8 |
| 2  | 3-6 | 42  | 42.2 | 44.4 | 42.2 | 0.001 | 0.137 | 0.001 | 0.5 | 6.0 | 0.5 |
| 3  | 6-9 | 16  | 15.6 | 15.6 | 17.8 | 0.010 | 0.010 | 0.203 | 1.0 | 1.0 | 4.8 |
| 4  | 9-12| 2   | 2.2  | 2.2  | 2.2  | 0.020 | 0.020 | 0.020 | 0.5 | 0.5 | 0.5 |
|    | Total | 100 | 100  | 100  | 100  | 0.031 | 0.288 | 0.344 | 0.5 | 3.3 | 2.9 |

CPA $\nu = 2$ $\chi^2 (2.95\%) = 5.99$ ok ok ok

EVA Maximum Accepted Error Value = 10% ok ok ok
4.4.3. Analysis of 80% Sample.
Calculation of the three Samples gives the following $\chi^2$ value: 3.006, 0.428 and 1.376. All of these $\chi^2$ values are less than $\chi^2_{0.05} = 5.99$. The error calculation give error values of 7.5%, 2.8% and 6.0%. Those are less than MAE of 10%. It can be concluded that the Curve Patterns and the Errors are all accepted. The 80% Sample is acceptable.

The calculation and the calculation result are presented in the following Table 4, Figure 3 and Table 5 below.

**Table 4.** TLD Calculation of 80% Samples.

| No | Trip Length | Person Distribution | Percentage Distribution |
|----|-------------|----------------------|-------------------------|
|    | km          | 80A person 80B person 80C person | 80A % 80B % 80C % |
| 1  | 0-3         | 18 15 15           | 45.0 37.5 37.5         |
| 2  | 3-6         | 17 17 16           | 42.5 42.5 40.0         |
| 3  | 6-9         | 4 7 8              | 10.0 17.5 20.0         |
| 4  | 9-12        | 1 1 1              | 2.5 2.5 2.5            |

|    |          | 40 40 40         | 100.0 100.0 100.0      |

![TLD Graphs of 80% Samples](image)

**Figure 3.** TLD Graphs of 80% Samples.
Table 5. Calculation of Curve Pattern Acceptance and Error Value of 80% Samples.

| No | Trip Length | Percentage Distribution | $\chi^2$ Calculation | $|\bar{e}|$ Calculation |
|----|-------------|-------------------------|----------------------|------------------------|
|    |             | Ref 80A 80B 80C         | $\chi^2_{A_i}$ $\chi^2_{B_i}$ $\chi^2_{C_i}$ | $|\bar{e}|_A$ $|\bar{e}|_B$ $|\bar{e}|_C$ |
| 1  | 0-3         | 40 45.0 37.5 37.5       | 0.625 0.156 0.156   | 12.5 5.6 6.7           |
| 2  | 3-6         | 42 42.5 42.5 40.0       | 0.006 0.006 0.095   | 1.3 1.1 5.3            |
| 3  | 6-9         | 16 10.0 17.5 20.0       | 2.250 0.141 1.000   | 15.0 3.3 10.7          |
| 4  | 9-12        | 2 2.5 2.5 2.5           | 0.125 0.125 0.125   | 1.3 1.1 1.3            |
|    | Total       | 100 100 100             |                      |                        |

$\chi^2 = 3.006$ $|\bar{e}| = 0.428$ $|\bar{e}| = 1.376$

4.4.4. Analysis of 70% Sample.
The analysis of the 70% Sample gives the following $\chi^2$ value : 6.670, 2.053 and 1.170. Two of them are less than $\chi^2_0 = 5.99$, while one value is slightly more than $\chi^2_0$. This mean that 2 samples have curve pattern which can be considered as the reference curve pattern, and one of them is not. The calculation gave these error values : 11.8%, 5.4% and 6.1%. One sample has an error which is slightly bigger than the acceptable value. Not all of them are really good. The 70% Sample is very close to be acceptable.

The calculation and analysis result together with TLD graph are presented in the following Table 6, Figure 4 and Table 7.

Table 6. TLD Calculation of 70% Samples.

| No | Trip Length | Person Distribution | Percentage Distribution |
|----|-------------|---------------------|------------------------|
|    |             | 70A 70B 70C         | 70A 70B 70C            |
|    | km          | % % %               | % % %                  |
| 1  | 0-3         | 15 14 13            | 42.9 40.0 37.1         |
| 2  | 3-6         | 17 16 14            | 48.6 45.7 40.0         |
| 3  | 6-9         | 3 4 7              | 8.5 11.4 20.0          |
| 4  | 9-12        | 0 1 1              | 0.0 2.9 2.9            |
|    | Total       | 35 35 35            | 100.0 100.0 100.0      |
Table 7. Calculation of Curve Pattern Acceptance and Error Value of 70% Samples.

| No | Trip Length | Percentage Distribution | $\chi^2$ Calculation | $|\bar{e}|$ Calculation |
|----|-------------|-------------------------|----------------------|-------------------|
|    |             | Ref 70A 70B 70C         | $\chi^2_A$ $\chi^2_B$ $\chi^2_C$ | $|\bar{e}|_A$ $|\bar{e}|_B$ $|\bar{e}|_C$ |
|    | km          | %  %  %                | %  %  %                | %  %  %            |
| 1  | 0-3         | 40 42.9 40.0           | 37.1 0.210 0.000 0.210 | 7.3 0.0 7.3        |
| 2  | 3-6         | 42 48.6 45.7           | 40.0 1.037 0.326 0.095 | 16.5 8.6 5.0       |
| 3  | 6-9         | 16 8.6 11.4           | 20.0 3.423 1.323 1.000 | 18.5 10.7 10.0     |
| 4  | 9-12        | 2  0.0  2.9            | 2.9 2.000 0.405 0.405 | 5.0 2.1 2.3        |
|    | Total       | 100 100.1 100          | 6.670 2.053 1.710       |                  |

$\nu = 2$  
$\chi^2 (2.95\%) = 5.99$  
$|\bar{e}|_A$ ok ok  
$|\bar{e}|_B$ ok ok  
$|\bar{e}|_C$ ok ok

4.4.5. Analysis of 60% Sample.
The analysis of the 60% Sample gives the following $\chi^2$ value : 5,412, 1,803 and 3.142. It means that all sample’s curve patterns are accepted. On the other hand, error calculation gave error values of : 39.3%, 25.0% and 28.7%. This means that all samples are very bad.

The calculation, trip length distribution curve and analysis result are presented in the following Table 8, Figure 5 and Table 9.
Table 8. TLD Calculation of 60% Samples.

| No | Trip Length | Person Distribution | Percentage Distribution |
|----|-------------|----------------------|-------------------------|
|    |             | 60A  | 60B  | 60C | %  | %  | %  |
|    | km      | person | person | person | 60A | 60B | 60C |
| 1  | 0-3      | 14    | 13    | 10   | 46.7 | 43.3 | 33.3 |
| 2  | 3-6      | 13    | 12    | 13   | 43.3 | 40.0 | 43.3 |
| 3  | 6-9      | 3     | 4     | 6    | 10.0 | 13.3 | 20.0 |
| 4  | 9-12     | 0     | 1     | 1    | 0.0  | 3.3  | 3.3  |
| 30 | 30       | 30    | 100.0 | 100.0 | 100.0 |

Figure 5. TLD Graphs of 60% Samples.

Table 9. Calculation of Curve Pattern Acceptance and Error Value of 60% Samples.

| No | Trip Length | Percentage Distribution | \( \chi^2 \) Calculation | \( |\bar{e}| \) Calculation |
|----|-------------|-------------------------|-------------------|------------------|
|    |             | Ref | 60A | 60B | 60C | \( \chi^2 \) | \( \chi^2 \) | \( \chi^2 \) | \( |\bar{e}| \) | \( |\bar{e}| \) | \( |\bar{e}| \) |
|    | km      | %  | %  | %  | %  | A  | B  | C  | A  | B  | C  |
| 1  | 0-3      | 40.0 | 46.7 | 43.3 | 33.3 | 1.122 | 0.272 | 1.122 | 16.8 | 8.2 | 16.8 |
| 2  | 3-6      | 42.0 | 43.3 | 40.0 | 43.3 | 0.040 | 0.095 | 0.040 | 3.1  | 4.8 | 3.1  |
| 3  | 6-9      | 16.0 | 10.0 | 13.3 | 20.0 | 2.250 | 0.456 | 1.000 | 37.5 | 16.9 | 25.0 |
| 4  | 9-12     | 2.0  | 0.0  | 3.4  | 3.4  | 2.000 | 0.980 | 0.980 | 100.0 | 70.0 | 70.0 |
|    | Total     | 100 | 100 | 100 | 100 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| CPA | \( \nu = 2 \) | \( \chi^2_{(2,95\%)} = 5.99 \) | ok | ok | ok |
| EVA | Maximum Acceptable Error = 10% | 39.3 | 25.0 | 28.7 | x | x | x |
4.5. Analyse of Curve Pattern Acceptance and Error Value Acceptance Variation

Different Sample Size gives different $\chi^2$ and error values, thus different Curve Pattern Acceptance Level and Error Acceptance Level. The experiment also indicates that the higher the Sample Size Percentage give the better Curve Pattern Acceptance level and the smaller Error Value. This experiment indicates that all of the samples Curve Patterns are accepted except the 70% sample. The 90% Samples gave a range of Error Value between 0.5% – 2.9%. The 80% Samples gave a range of Error Value between 2.8% – 7.5%. The 70% Samples have a range of Error Value between 5.4% - 11.8%. While the 60% Samples gave an exceptionally high Error Value of more than 20%. The variation of $\chi^2$ value, the Curve Pattern acceptance and the Error Value across different Sample Sizes is presented in Table 10.

Table 10. Variation Curve Acceptances and Error Acceptances.

| Sample Size | $\chi^2$ A | $\chi^2$ B | $\chi^2$ C | Curve Accept. | Error A | Error B | Error C | Error Accept. |
|-------------|------------|------------|------------|---------------|---------|---------|---------|---------------|
| 90          | 0.031      | 0.288      | 0.344      | ok            | 0.5     | 3.3     | 2.9     | ok            |
| 80          | 3.006      | 0.428      | 1.376      | ok            | 7.5     | 2.8     | 6.0     | ok            |
| 70          | 6.670      | 2.053      | 1.710      | x             | 11.8    | 5.4     | 6.1     | x             |
| 60          | 5.412      | 1.803      | 3.142      | ok            | 39.3    | 25.0    | 28.7    | x             |

The $\chi^2$ value and curve pattern acceptance for each samples are presented in Figure 6 and Figure 7 below. It can be seen that, in general, the higher sample size give lesser $\chi^2$ value and contrary the less sample size give higher $\chi^2$ value. It means that higher sample value gives higher curve pattern acceptance level. The curve pattern of 70% Sample is rejected.

Figure 6. Range of $\chi^2$ Values across Different Sample Sizes.
The range of Error Value across different sample are presented in Figure 8 below. It can be seen easily that higher sample size give smaller Error Value. The 90% Samples and the 80% Samples produced acceptable Error Values. The 70% Samples produced 2 acceptable error values and 1 slightly more than 10% error value. While the 60% Samples produced very high unacceptable Error Values.

To complete the research, a Correlation between $\chi^2$ value and Error Value is calculated and presented in Figure 9 below. It can be seen easily that higher $\chi^2$ Value produce higher Error Value. For 60% Sample, especially, all Error Values are extra ordinarily very high, more than 25%. Acceptable $\chi^2$ Values do not always give Acceptable Error Values. Meanwhile, if the Error Value is acceptable, the $\chi^2$ Value is also acceptable.

The correlation between $\chi^2$ Value against Error Value can be formulated by a Linear Regression formula as follows. The correlation is not strong as indicated by a very low $R^2$ value.

$$E = 3.702 \chi^2 + 3.505$$

$$R^2 = 0.385$$  \hspace{1cm} (6)
where:

\[ E \] : error value
\[ \chi^2 \] : chi square value

**Figure 9.** Correlation Between \( \chi^2 \) and Error Values.

### 4.6. Remarks
The Experiment Design was succesfully developed. The experiment is capable to indicate acceptable sample size, by indicating sample’s Curve Pattern acceptance and Error Value acceptance.

This experiment calculation result indicates that higher sample size give better result, in terms of Curve Pattern Acceptance level and Error Value Acceptance level. The 90% sample and 80% sample are accurate enough to present the population. The 70% sample and the 60% sample can not be used. This Experiment indicates that accepted curve pattern does not always give acceptable error, but on the other hand accepted error value always gives acceptable curve pattern.

It must be noted that this experiment has very limited number of data. The data was taken not from a whole population rather from one small office. The principal objective of this research is to develop an experiment design for determining appropriate sample size. Hence, this experiment result can not be taken as a dictum, the experiment result can only give an indication of the Curve Pattern Acceptance level variation and Error Value variation across different Sample Size.

### 5. Conclusions
The research objective has been succesfully attained. Several principal conclusions can be written as follows:

- The experiment design has been finished and can be used to define the Minimum Sample Size to develop a Sample Based TLD. The experiment design is capable to produce \( \chi^2 \) Value, Error Value, Curve Pattern Acceptance, Error Value Acceptance and Corelation between \( \chi^2 \) and Error Value.
- In terms of experiment result, indicative conclusions can be presented as follows:
  - In general, higher sample size will give better result: lower \( \chi^2 \) value, higher level of Curve Pattern acceptance, lower Error Value, higher level of Error Value acceptance.
  - In terms of sample size, it can be noted that 90% Sample and 80% Sample are good sample sizes. On the other hand, 70% Samples has a fair quality sample size and 60% Sample is unacceptable sample size.
Accepted Curve Pattern does not automatically gives Accepted Error Value. On the other hand, Accepted Error Value always give Accepted Curve Pattern.

This experiment result can not be taken as a dictum. The experiment result can only give an indication of the $\chi^2$ value, the Error value, the Curve Pattern acceptance level and the Error Value acceptance level variation across different Sample Size.

In order to be easily mentioned, this experiment is called “Experiment for Determining Sample Size for Sample Based Trip Length Distribution Development”.

This research need a further action to investigate different type of morning trips and other related cases.

6. Acknowledgements

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