Qualitative comparative assessment by fsQCA for Transit Oriented Development (TOD) area comparison

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Abstract. The station development through transit oriented development principles in favor to transit patronage has emphasized the important of design, diversity and density. However, studies were lacking in identification of the level of combination of all these ingredients toward increasing ridership. Using the node-place balance perspective, the design, diversity and density are re-evaluated. Four transit terminals or stations are used as case study in the City of Surabaya. Each of the transit area is divided into several zones/subzones to evaluate the level of density, diversity and design into the value of node and place index. Each transit points would be regarded as having one among the five categories of node-place index. The level of the daily trip demand is identified as the target variable. Qualitative comparative analysis then is used to mapping the position of each station, suggested the level of combination of design, diversity and density in each node-place category, to explore which combinations that are found to be statistically significant to support the increases of trip demand. The research showed that employment density may has more impact than housing density, while node aspect maybe of more important compare to place aspect that explain high or low trip demand.

Keywords: TOD, fsQCA, node-place index, 3D factor

1. Introduction
The problem of congestion in Surabaya City has been among the worst in the world¹. The private transport share was about 73.41% of total passenger transport². Although the Suroboyo Bus is now operated in the City, but its network coverage is still limited. Often, public transport is unable to compete with cars due to: (1). Inability to compete in terms of speed or travel time; (2). Inability of public transport to connect the center of activities (residential, commercial, offices, etc) due to low accessibility.

Transit oriented development or TOD as one implementation of Land use and transport integration (LUTI) has successfully increased the public transport uses ([1], [2]). In Curitiba - Brazil, TOD has been successful in increasing the share of transit from 7% in 1970s to 75% in 2006 [3]. The strength of the TOD is in the implementation of the 3D development, such as: density - to increase the number of

¹ Castrol Magnatec, 2015
² Surabaya in Figure, 2016
residential and jobs in the transit area; the diversity - to mix the various land use types, and the various social economy of residents and buildings in the transit area; the design - to improve the pedestrian and bike services that are integrated with the transit accessibility. Density creates sufficient demand for mass transit, while design creates good accessibility for non-motorized transport (NMT) access and diversity creates activities opportunities.

Many scholars agreed on the idea that TOD encourages mixed use around the transit area [4], improved land potentials to develop activities opportunities [5], and can integrate the transit area with pedestrian, transport feeders, and mass public transport [3]. Nevertheless, these literatures perceived the 3D characteristics should fulfill certain parameters on density, diversity and design. For example [6] pointed out the minimum 10,000 employees or residents in a TOD station precinct. TOD design standard had been proposed by several research institutions, such as ITDP (the Institute for Transportation and Development Policy). In Indonesia, the regulation on TOD is documented in the Permen ATR No. 16/2017 about TOD classification. However, the implementation of 3D parameter standards may not be achieved due to constraints such as low density areas and lack of business attractiveness [7].

A node-place index has been an additional emerging concept in the literature that evaluate the level of integration between land use and transportation in TOD [8]. A balance node and place, according to [5], is a pre-condition to achieve the spatial development with a sustainable infrastructure provision. TOD with a balance node and place will improve the transportation system and land use integration in the area [5]. Using the node-place balance perspective, the design, diversity and density are re-evaluated in this paper.

Four transit terminals and stations in the City of Surabaya are used as a case study. Using a subzone analysis, each of the transit point is divided into several zones to evaluate the level of density, diversity and design into the value of node and place index. Each transit points would be regarded as having one among the five categories of node-place index. The level of the daily trip demand is identified as a target variable. Qualitative comparative analysis then is used to mapping the position of each station, suggested the level of combination of design, diversity and density in each node-place index category.

2. Literature Review
TOD defined as the development of transit area in within ½ mile from a transit point or station, with compact land uses, high density and intensity, mixed uses, designed to maximize pedestrian access to the transit. TOD was differentiated with TAD or Transit Adjacent Development, in which in TAD, the development of activity centers are in proximity or adjacent to the transit points (transit-proximate development), but these development in TOD are integrated or orientated to the transit points.

The 3D principles in TOD area are implemented in a way that density achieved, i.e., a sufficient density of buildings, jobs, and high access to jobs. Closer to stations, the density should be higher, means the building are higher. Diversity, a mixed use development determined by the proportion of land use of commercial or trade and service land uses. The mixed used is high enough in each subzone for direct mobility. Design, a provision of facilities to support the NMT for station access. In pedestrian area, the traffic speed is low, a connectivity between each subzone to the transit facilities and between activities centers to pedestrians are well maintained. An innovative parking should be implemented in the TOD area such as central parking and progressive payment system [9].

TOD planning principle consisted of the efficient location, rich mix of choices in a neighborhood unit, the value capture socially, economically and environmentally, the place making aspect and the node aspect [2]. TOD in a node and place perspective aims to integrate the role of transit as a transit point, a place for passenger boarding and alighting, and a place in that the transit area can become a center of activity that generating and attracting trips characterize with a sense of place attraction.

The node-place model for TOD was introduced by [9]. There is a relationship between the location as place or as the center of activities and as a node or the transit points for intermodal of public transport. The accessible node and accessible place attract people (trips). The accessible nodes are created by the high daily frequency of train services, the number of stations in within 45 minutes catchment, the number of destination served by the station, the number of connected access by buses, trams, and subway; the
parking capacity, and the accessibility by walk or cycle. The accessible place is characterized by the degree of functional mix, the number of population and the number of employment of four sectors (retail, catering, education/health/culture, administration and services, industry and distribution).

The determinant factor for the node-place index, as summarized from ([10], [5], [11]) is described in the following table.

| The aspect                  | The variable                                      |
|-----------------------------|---------------------------------------------------|
| **Node**                    | The frequency of public transport leaving the station |
|                             | The type of station or terminal                    |
|                             | The length of travel                               |
|                             | The number of destination served by the transit service |
|                             | The level of pedestrian connectivity               |
| **Place**                   | Land area ratio                                    |
|                             | Floor space ratio                                  |
|                             | Household density per hectare                      |
|                             | The number of employment or job per sector per hectare |
|                             | Degree of functional mix                           |

In evaluating TOD according to the Node-Place model, [5] specified five types of possibilities in which the station may appear to have a balance node-place at the most ideal situation or unbalance node-place characteristic as the least to expect, and ranges of variation in between. Figure 1 illustrates these five possible situations.

![Figure 1. Node – Place Model](source: [5])

3. Method
This research used QCA or Qualitative Comparative Analysis to analyze the relationship between the variable 3D TOD and the category in which the station would be included into the five categories of node-place indices. Unit analysis defined into micro scale i.e. the 800 meter radius of transit area are divided into several sub-zones, i.e. 5 zones for each station/terminal, resulted in 20 sub-zones altogether (see figure 2). The zone division was defined by main streets such as primary or secondary arterial and collectors, natural boundaries such as waterbody or rivers, and the distribution of land uses (See [12] for station precincts sub division).
QCA used Boolean Algebra with the application of fsQCA (see www.compasss.org/) or fuzzy set QCA, in which the membership criteria fall as a continuous values between 0 to 1. The y category is the index balance (full membership 1) and unbalance (0) or the negation of balance. The process of analysis in QCA is explained in figure 3 as followed ([13], [14]).

![Figure 2. Study area](image)

The relationship between X and Y in an asymmetric situation. Combination of high values of X is sufficient to generate a high value of Y; but combination of high values of X is not necessary for generating a high value of Y. Woodside, 2013 described the example from 15 cases as in the figure (case a to case p). Each of the case is mapped according to its X values to describe the instance of Y high (or low). (Woodside, 2013).

![Figure 3. The relationship between X and Y according to asymmetric relationship](image)
In this regards, there are two steps of analysis conducting in this research. First, to identify characteristic of 3D TOD, and secondly, to evaluate 3D TOD as a node place index and its relationship with trip demand.

In this paper, the $Y$ values consisted of 5 possible situations [8]:

1. Unbalance node, i.e. a situation in which the node index (the transportation network system) is high but the land use or place is low.
2. Unbalance place, i.e. a situation in which the place index (the land use) is high but the transportation index or node is low.
3. Dependence, both the value of node and place are low. The transportation system is dependence on the external services, there is no competition for developing the vacant land.
4. Stress, is the opposite of dependence, the node and place index are both high.
5. Balanced, is a situation in that both node and place index can support the system, the environment, the need of the community without enforcement to extent the system. Node and place are supporting one another and integrated.

In [10], the range of value as criteria of categorization as above mentioned is explained. The values is presented in the table 2.

**Table 2. Node and Place Index Categorization**

| Class      | Node and Place Index Range | Node Index | Place Index | Category       |
|------------|----------------------------|------------|-------------|----------------|
| Very high  | $\geq 0.8$                 | 0.6 - 1    | 0.6 - 1     | Stress         |
| High       | 0.6 – 0.79                 | 0 – 0.49   | 0 – 0.49    | Dependent      |
| Standard   | 0.5 – 0.59                 | 0.5 – 0.59 | 0.5 – 0.59  | Balance        |
| Low        | 0.2 – 0.49                 | 0.5 - 1    | 0 – 0.59    | Un-sustained node |
| Very Low   | $\leq 0.19$                | 0 – 0.59   | 0.5 - 1     | Un-sustained place |

*Source: Adapted from [10].*

The combination of $X$s configuration that may create a possible $Y$ situation in this research is illustrated in the following table 3.

**Table 3. The configuration of $Y$ and $X$ based on the criteria of 3D TOD**

| Possible situation $Y$ | Negation $Y$ | $X$ configuration for sufficiency condition |
|------------------------|--------------|--------------------------------------------|
| $Y_1 =$ Stress         | $\sim Y_1 =$ Dependence | $\text{dense}^*\text{diversity}^*\text{design} \leq y_1$ |
|                        | $\sim Y_1 =$ Balance       |                                           |
| $Y_2 =$ Un-sustained node | $\sim Y_2 =$ Un - sustained place | $\text{dense}^*\text{diversity}^*\text{design} \leq y_2$ |
|                        | $\sim Y_2 =$ Balance       |                                           |
| $Y_3 =$ Un-sustained place | $\sim Y_3 =$ Un - sustained node | $\sim\text{dense}^*\text{diversity}^*\text{design} \leq y_3$ |
|                        | $\sim Y_3 =$ Balance       |                                           |
| $Y_4 =$ Balance         | $\sim Y_4 =$ All other situations | $\text{dense}^*\text{diversity}^*\text{design} \leq y_4$ |
|                        |                            | $\sim\text{dense}^*\text{diversity}^*\text{design} \leq y_4$ |

*Source: Analysis*

4. Result and discussion

The first finding is formed by analyzing the 3D components as part of node-place index. The method followed a framework offered in [15] (figure 4). The value of variables is measured based on these stages of calculation:
1. Measure the value of variable and compared it against the parameter.
2. Convert these values into the fuzzy index, ranged from 0 to 1.
3. Calculate the node place index from the combined value of variables according to the fuzzy index. The five node-place balance categories valued at 0.59 is the balance index.

![Figure 4. Node-Place Index based on the characteristics of 3D TOD (adapted from [15])](image)

4.1 Node and place indices configuration in fsQCA
The node component according to 3D TOD consisted of design component, covered the variable of the availability of pedestrian (%) or \( \text{inde1} \), pedestrian connectivity level or \( \text{inde2} \), the width of pedestrian path or \( \text{inde3} \), safety and convenience of sidewalk or \( \text{inde4} \). The place component consisted of density component, covered the variable of the ratio of built area to the parcel area (KDB) or \( \text{inden1} \), floor space ratio (KLB) or \( \text{inden2} \), the residential density, i.e. the number of housing per hectare or \( \text{inden3} \), employment density, i.e. the number of employment per hectare or \( \text{inden4} \). The second component of place is diversity, measured by degree of functional mix or \( \text{indiv} \). All of variable was calculated from each subzone and then aggregated for each station/terminal. In fsQCA, all node and place variables are configured to form the combination of variables according to the characteristics of case study and while maintaining the solution with consistency value recorded in fsQCA of at least 0.84. The results are showed in the following table (table 4 and 5) that calculated the calibrated values of node and place indices (symbolized with c) in Boolean algorithm.

| Configuration of variables for node aspect | Raw coverage | Unique coverage | Consistency |
|-------------------------------------------|--------------|----------------|-------------|
| \( \sim \text{inde1}_c \cdot \text{inde2}_c \cdot \text{inde4}_c \) | 0.887         | 0.000          | 0.898       |
| \( \sim \text{inde1}_c \cdot \text{inde3}_c \cdot \text{inde4}_c \) | 0.896         | 0.009          | 0.858       |
| \( \text{inde2}_c \cdot \text{inde3}_c \cdot \text{inde4}_c \) | 0.969         | 0.08           | 0.922       |
According to table 4 and 5, the configuration of node variables with the highest consistency value consisted of configuration among inde2, inde3, and inde4, while for place variables consisted of inden1, inden4, and indiv1. From the model, high value of node index were composed by high value of pedestrian connectivity, the width of pedestrian path, and the convenience of sidewalk measured by lighting and shading. Meanwhile, high value of place index were composed by high value of building density (KDB), employment density, and mixed use.

4.2 Trip demand analysis in fsQCA

This section explained the relationship between the configured node and place index resulted from the first stage analysis and the trip demand for TOD area. Based on the results of analysis in fsQCA, four models were selected as follows:

1. **Model 1a** will include all variables. All configured variables of node and place (inde2, inde3, inde4, inden1, inden4 and indiv) was plugged into the model. This model resulted in random distribution of stations, there was no clustered of subzones of station formed into a meaningful model in which the value of consistency is above 0.84. There was only one meaningful cluster of subzone, however, only covered one subzone, i.e. subzone 2 in Gubeng station.

   In developing the alternative model, the configured variables were divided into subset and superset of node and place variables to identify which configuration of variables resulted in the highest value of consistency and coverage index. The results are the subset node comprise of inde2 and inde3; while the subset place comprise of inden1, inden3, inden4 or configuration of inden1, inden4 and indiv. Therefore, the alternate models consisted of as follows (model 1b, and model 2a and 2b) using these set of variables.

2. **Model 1b**: Model 1b consisted of configured variables inde2, inde3, negation of inden3, and inden4. This model has the consistency index 0.84 and the coverage value 0.56. The resulted is as follows: a cluster stations consisted of Joyoboyo terminal Subzone 3, Gubeng station Subzone 1, and Bratang terminal Subzone 2. (figure: 5). The model mathematically is written as follows.

   \[ \text{connectivity} \cdot \text{pedestrian width} \sim \text{residential density} \cdot \text{employment density} \leq \text{high trip demand} \]

   The dot “,” indicates the “AND” while the tilde “~” indicates the negation. The model said that high trip demand in the station area is determined by high connectivity of pedestrian, a wide pedestrian width, low residential density, and high employment density.
Figure 5. Model 2 Trip demand analysis based on the configured model: inde2, inde3, ~inden3, inden4 ≤ ttrip

Since “the coverage index in fsQCA assesses the degree to which a causal configuration accounts for instance of an outcome” ([13, p. 223]), the configuration resulted by the model 1b has higher proportion of cases that are consistent with that configuration; and model 1b is more informative than other models since the model has accounted for more cases: 56% out of cases with high outcome membership scores. However, only 3 subzones has appropriately indicated high trip demand, i.e. Stasiun Gubeng subzone 1, Terminal Bratang subzone 2 and Joyoboyo subzone 3. The model showed the combination of good pedestrian connectivity with appropriate pedestrian width and high employment density subzone supported for high trip demand. However, 7 subzones with high trip demand were not accounted for. Considering the density of housing and employment as two separate contested land use resulted in a configuration that has accounted for three subzones with high trip demand occurrence.

3. Model 2a tested the configuration for the low trip demand occurrence. The model consisted of configured variables inde2, negation of inde3, inden1, negation of inden3 and inden4. This model has the consistency index 0.878 and the coverage value 0.294. The resulted is as follows: a cluster consisted of Gubeng station Subzone 3. (figure: 6)

The model mathematically is written as follows.

\[
\text{connectivity} \sim \text{pedestrian width} \cdot KDB \sim \text{housing density} \cdot \text{employment density} \leq \sim \text{high trip demand}
\]

The dot “.” indicates the “AND” while the tilde “~” indicates the negation. The model said that the low trip demand occurrence in the station area is determined by high connectivity of pedestrian with narrow pedestrian width, high KDB or building density, low residential density, and high employment density.

This model indicates more place variables than node variables, even though there is not much an issue of whether the pedestrian has appropriate width (as typically happening in the study area) as the connectivity is more important in determining low trip demand. Similarly to model
the residential and employment density is contested, nevertheless, the building density is accounted for in the configuration, thus in supporting the presence of employment density, this variable is then interpreted as the non-residential building density. This model has much lower coverage value than model 1b. The model only resulted in one subzones Gubeng stasiun subzone 3 but erroneously with high trip demand. However, there are some subzones in clustered such as Pasar Turi subzone 2, Joyoboyo subzone 5, Gubeng subzone 4; all with low trip demand. It may be important to analyze alternative model that explained the low trip demand occurrence and identify a better fitted configuration. This will be discussed in model 2b.

Figure 6. Model 3 Trip demand analysis based on the configured model: inde2, ~inde3, inden1, ~inden3, inden4 ≤ ~ttrip

4. Model 2b consisted of configured variables negation of inde2, inde3, inden1, inden3 and inden4. This model has the consistency index 0.89 and the coverage value 0.439. The resulted is as follows: a cluster consisted of Joyoboyo terminal Subzone 5. (figure: 7).

The model mathematically in figure 7 is written as follows.

\[ ~\text{connectivity} \ast \text{pedestrian width} . \text{KDB} . \text{housing density} . \text{employment density} \leq ~\text{high trip demand} \]

The dot “.” indicates the “AND” while the tilde “~” indicates the negation. The model said that the low trip demand occurrence in the station area is determined by low connectivity of pedestrian with good pedestrian width, high KDB or building density, high residential density, and high employment density.
Figure 7. Model 4 Trip demand analysis based on the configured model: ~inde2, inde3, inden1, inden3, inden4 ≤ ~ttrip

Similar to model 2a, this model indicates more place variables than node variables, however, while the pedestrian has appropriate width, its connectivity level is low. In opposite to model 2a, all density variables (the residential and employment density and KDB or building density) has high values. This model has a modest coverage value (better than model 1a but lower than model 1b. Model only resulted in one subzones Joyoboyo terminal subzone 5 that has been identified with low trip demand. Based on the model, high density value is not necessary associate with high trip demand. This model gave a possible explanation that node aspect may be of more important than place aspect in determining the high or low value of trip demand.

4.3 Discussion

The method of qualitative comparative analysis acted as an asymmetric modelling that may able to explain the prevalence of high and low trip demand occurrence according to the most fitted configuration set. In this paper, the high or low trip demand in the station area is tested with several set of configuration variables, accounted for the node and place characteristics. Model 1 and model 2 explained the determinant of trip demand. From model 1a, Gubeng station subzone 2 has been characterized with dominance floor space ratio and the width of the pedestrian. Both variables are high in within the subzone area. Model 1b, covered the area of Gubeng subzone 1, Bratang subzone 2, and Joyoboyo subzone 3. Among the all models developed in this paper, model 1b has the highest coverage value. The variable configured in this model consisted of connectivity and pedestrian path, also low housing density and high employment density. The interesting finding from model 1b, is that, the design variable, i.e. the connectivity of pedestrian and the width of pedestrian path, altogether support trip demand. However, the density variable, i.e. housing density maybe in contested to the number of employment density since low housing density combines with high employment density explain high trip demand. It is interesting to note that while employment and housing may represent different types of activities (residential vs non-residential), it may be true that the static frugal of space is not allowed the two
competitive activities to use of the same limited space. This asymmetric notation may be a contradict to the common believe of mixed use principle of TOD, at least as a preliminary indication that in certain locations, the single most dominated land use may be of more important factor dictate demand for trip. The location mentioned in model 1b mainly the vocal point area of Surabaya City, such as area around the Surabaya Zoo in Joyoboyo, area around the Monumen Kapal Selam and Tunjungan Plaza in the catchment of Gubeng TOD area. These area have become the main generator of transportation that serve not only the neighborhood TOD trip demand, but also for the whole City and regionally.

On the other hand, model 2a and 2b explained factor influence the negation of trip demand or low trip demand. Model 2b has a better coverage and consistency than model 2a. Joyoboyo terminal subzone 5 has the lowest pedestrian connectivity compare to other subzones in all station/terminal. Both Joyoboyo terminal subzone 5 and Gubeng station subzone 3 have the lowest node index value compared to other subzones in its group. It seems the pedestrian facilities to access station/terminal precinct explained low trip demand and maybe of more important than that of the place aspect in explaining low trip demand.

Based on the model, density and design variable have important impact on transit demand in Surabaya City. Unlike the TOD in Western’s cases, it is common that density and pedestrian friendly environment have significant effect on transit ridership in Asian Model of TOD e.g. Singapore and Seoul, Korea. The Singapore TOD experience shows that densely populated transit area and urban design applied to enhance a more transit supportive environment with walkability at micro-scale level have significant impact on increasing MRT ridership from 1990 to 2000 [16]. Density, pedestrian-friendly design and street network at rail station area are also evident as determinant factor of transit demand in Seoul City [17]. In this regard, some area of Gubeng, Joyoboyo and Bratang precinct provide density bonus, especially employment density, to attract more trip demand as emphasized in TOD planning. Pedestrian facility and access can be improved in terminal and station area in Surabaya to promote trip demand, as low quality of pedestrian facility may be regarded as the main factor causing low trip demand.

5. Conclusion
The node and place factor explaining TOD characteristics may be used as determinant of trip demand. The method of qualitative comparative analysis acted as an asymmetric modelling that may able to explain the prevalence of high and low occurrence according to the most fitted configuration set as explained in the subset of node and place variables. The result showed that employment density may has more impact than housing density, while node aspect maybe of more important aspect compare to place aspect that explain high or low trip demand. This findings is limited to the four stations/terminals being researched, as more case studies and more variances in the model may give better explanation about inconclusive findings about why some subzones precinct with high (or low) trip demand cannot be accounted for in the model. Nevertheless development strategy of high-employment density and design factors such as pedestrian connectivity and facility are prior factors to reduce automobile dependency and enhancing pedestrian accessibility to transit center. Improving the street network and a more transit supportive environment should be applied to promote transit users in Surabaya City.

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