IMPACT OF RESOLUTION OF ZONING SYSTEM AND ROAD NETWORK DEFINITION ON ROUTE CHOICE AND ROAD NETWORK PERFORMANCE: A CASE STUDY IN BANDUNG (INDONESIA)

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Abstract: The level of resolution of zoning system and road network definition has been accepted to obviously affect the route choice and hence the link flows. In principle, greater accuracy (in terms of link flows) could be achieved by using a more detailed zoning system and road network definition. The research describes the impact of zone aggregation and road network definition on the accuracy of traffic flows. The objectives are to justify the recommendation for zone aggregation and road network definition. Four levels of resolution, both for zoning system and road network, have been established; and there are 10 combinations have been tested. The research found that the optimum level of zoning aggregation was found in level 2 (Z_2), where zones were Kecamatans and for the road network system was in level 3 (J_3), in which it comprised arterial roads, collector roads, and part of local roads (50%). The optimum level for combination of zone and network definition was found in level 5 (Z_2J_3), where the zones were Kecamatans and the road network consisted of arterial roads, collector roads, and part of the local road (50%). Finally, it is concluded that the impact of aggregating zoning system has greater influence on the average flows rather than lowering the road network system definition.

Key Words: route choice, zoning system, road network, resolution, impact

1. INTRODUCTION

One of the most important early choices facing the transport modeller was that of the level of detail (**resolution**) to be adopted in a study. This problem has many dimensions: it refers to the schemes to be tested, the type of behavioral variables to be included, the treatment of time, etc. Finally, the final choices reflect a compromise between two conflicting objectives: **cost** and **accuracy**. In principle, greater accuracy could be achieved by using a more detailed zoning and network system e.g. the higher number of zones with small size or imply recognizing each individual household. With a large enough sample (100% rate), the representation of the current system could be made very accurate indeed. However, the problem of stability over time weakens this vision of accuracy, as one would need to forecast, at the same level of resolution, changes at the individual household level that would affect transport demand. Therefore, the objective of this paper is to analyze the influences of the level of resolution of the zoning and road network definition system to route choice and to identify the optimum level of resolution for Bandung by analyzing the estimated link flows.

2. LITERATURE REVIEW

In transport modelling, the representation of **zoning system** and **road network definition** is very important. A more detailed zoning system and road network definition would achieve a higher accuracy. However, this accuracy would need more costs and more time; on the other hand, a lower level of detail would need less costs and less time, but with lower accuracy of results.

There has been some research on influence of zone sizes and road network definition. **Jansen and Bovy (1982)** investigated the effect of the level of detail in road network model upon road assignment output quality in Eindhoven, Netherland. Two assignment models have been applied at 3 levels of detail: equilibrium and all-or-nothing assignment model. Their conclusions were:

- the level of detail of the road network model has significant effect on the assignment output quality;
- refining the road network and zone system always improves assignment outcomes. Beyond a certain level, however, further refinement only yields marginal improvements;
- at every level of detail investigated the equilibrium assignment model performs much better than the all-or-nothing model, even though the road network was only slightly congested.

Tamin, Dalimunthe and Irawan (1999) investigated the accuracy of level of resolution of road network definition system in Bandung. The conclusion was that the simplification of road network definition system has resulted in decreasing level of accuracy.

2.1 Zoning System

Our towns and cities are arranges in a very rich and complex way where roads, buildings, and activities are inter-related. It becomes necessary to simplify this relationship highlighting those of greater relevance only. This simplification must relate the elements of the real world rationally. A basic element in this simplification is the zone and its centroid, which is assumed to concentrate all trip-making characteristics of delimited geographical area.

A zoning system is used to aggregate the individual household and premises into manageable chunks for modeling purposes. The two dimensions of a zoning system are the numbers of zones and their sizes. The two are, of course, related. The higher the number of zones, the lower they can be to cover the same study area. It has been common practice in the past to develop a zoning system especially for each study and decision-making context. This is apparently wasteful if one performs several studies in related areas; moreover, the introduction of different zoning systems makes it difficult to use data from previous studies and to make comparisons of modelling results over time.

The first choice in establishing a zoning and road network system were to distinguish the study area itself from the rest of the world. Some ideas may help in making this choice (**Bovy and Jansen, 1983**):

- In choosing the study area, one must consider the decision-making contexts, the schemes to be modelled and the nature of the trips interest: mandatory, optional, long or short distance, etc.
- For strategic studies one would like to define the study area so that the majority of the trips have their origin and destination inside it. However, this may not be possible for the analysis of transport problems in smaller urban areas where the majority of the trips of interest are through-trips and a bypass is to be considered.
- Similar problems arise with traffic management studies in local areas where again, most of the trips will have their origin, destination or both clearly outside the area of interest.
- The study area should be somewhat bigger than the specific area of interest covering the schemes to be considered. Opportunities for rerouting, changes in destination and so on should be allowed for.

Some examples of zone numbers chosen for various studies are represented in **table 1**.

Table 1: Typical zone number for various studies

Location	Population (millions)	Number of Zones	Comments
London (1972)	7.20	2,252	Fine level sub-zones
		1,000	Normal zones at GLTS
		230	GLTS district
		52	Traffic Boroughs
Montreal (1980)	2.00	1,260	Fine zones
Ottawa (1978)	0.50	120	Normal zones
Santiago (1986)	4.50	260	Zones, strategic study
Washington (1973)	2.50	1,075	Normal zones
		134	District level
West Yorkshire (1977)	1.40	1,500	Fine zones
		463	Coarse zones
Jakarta (1995)	7.50	106	Normal zones
Bandung (1995)	2.40	58	Normal zones
Semarang (1995)	1.30	33	Normal zones
Solo (1995)	0.50	19	Normal zones
Palu (1995	0.17	22	Normal zones
East Java (1995)	34.00	30	Normal zones
Nganjuk (1996)	0.95	23	Normal zones
North Sumatera (1996)	10.20	11	Coarse zones

Source: Tamin (2000)

2.2 Road Network System

The transport network may be represented at different levels of aggregation in a model. The level of aggregation can be increased further when detailed traffic simulation models are used. A key decision in setting up a network is how many levels to include in the road hierarchy to analysis (**arterial**, **collector**, and **local**). There was depended on type and purposed study. If more roads are included, the representation o reality should be better. But, there must be pay additional cost for survey and time. Budget and time restraints that influence the level of aggregation. Moreover, it does not make much sense to include a large number of roads in the network and then make coarse assumptions about turning movements and delay in junctions. It is not sensible to use a very detailed network with a coarse zoning system will reduce the value of the modelling process.

2.3 Trip Assignment Model

The most popular technique called **'the equilibrium assignment'** tries to satisfy **Wardrop's equilibrium principle**. Under congested conditions, trip makers tend to switch the alternative roues in order to minimize their perceived costs of travel. If no trip maker is able to switch route to reduce his travel cost then the system is said to have reached equilibrium. This behavior has been summarized in Wardrop's equilibrium principle **(Wardrop, 1952)**. **Beckman *et al* (1956)** first stated that finding links costs and volumes according to Wardrop's first principle in a network could be solved in terms of non-linear mathematical programming. **Nguyen (1974)** have proposed an efficient algorithm to solve for the non-linear mathematical problem. **Van Vliet and Dow (1979)** also proposed an improved algorithm based on iterative loading assignment.

2.4 Saturn Package Program

Saturn (Simulation & Assignment of Traffic on Urban Road Network) package program has been designed to deal with broad range applications of traffic assignment models. Saturn has **4 (four)** basic functions; they are:

a. as a combined simulation and assignment model for traffic management design;
b. as a conventional assignment model for analysis of network up to 2,500 links;
c. as a simulation model for individual junctions;
d. as the network data base and analysis system.

The model is in essence a two-stage interactive process comprised of assignment and simulation phases carried out iteratively.

3. DATA BASE

3.1 Zoning System Definition

The purpose of this stage was to divide the study area into smaller zones. The zone boundaries were **administrative boundaries** of **kelurahans**, **kecamatans**, and **sub-districts** (wilayah). The study area (Bandung and its surrounding area) was divided into **9 sub-districts** (wilayahs) with **31 Kecamatans** and **279 Kelurahans** as well as another **5 kabupatens** as external zones. The zoning system was divided into **4 (four)** levels of resolution as mentioned in **table 2**. **Figure 1–2** shows the coarsest zoning system definition (**Z_1**) and the densest one (**Z_4**), respectively.

3.2 Road Network Definition

Road network system in Indonesia can be grouped according to their hierarchy of the function, status, and class. Hierarchy of the function can divide the road as arterial, collector, and local roads. By status, the road can be divided into national, provincial, and kabupaten roads. By class, the road can be divided into class I, II, and III. In this paper, the road network is classified by road function such as: **arterial**, **collector**, and **local** roads and divided into **4 (four)** levels of resolutions as mentioned in **table 2**. The description of each level of resolution is given in **table 1**. **Figure 3–4** shows the lowest resolution of road network definition (**J_1**) and the highest one (**J_4**), respectively.

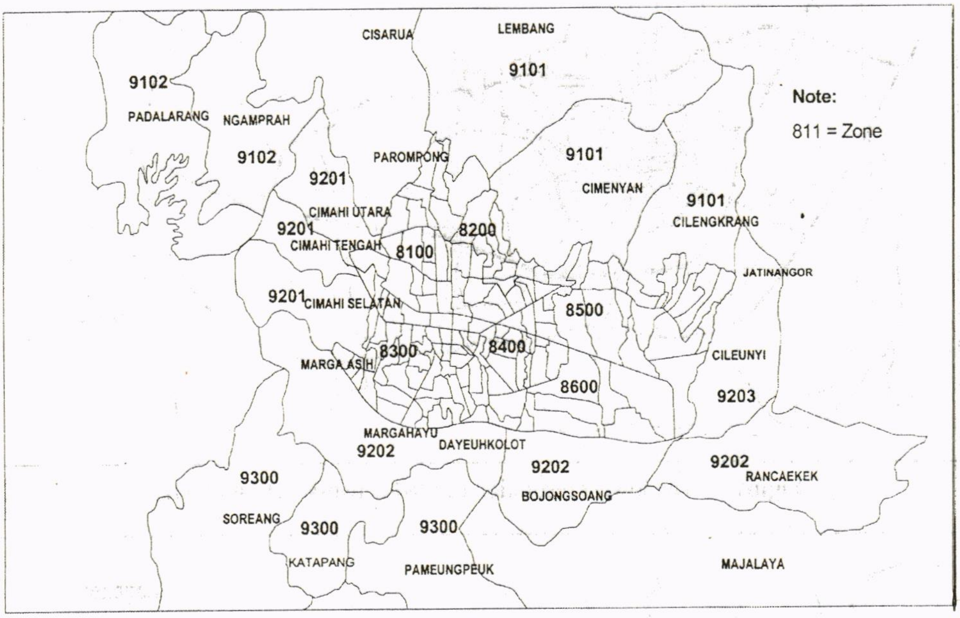


Figure 1: The coarsest zoning system definition (Z_1)

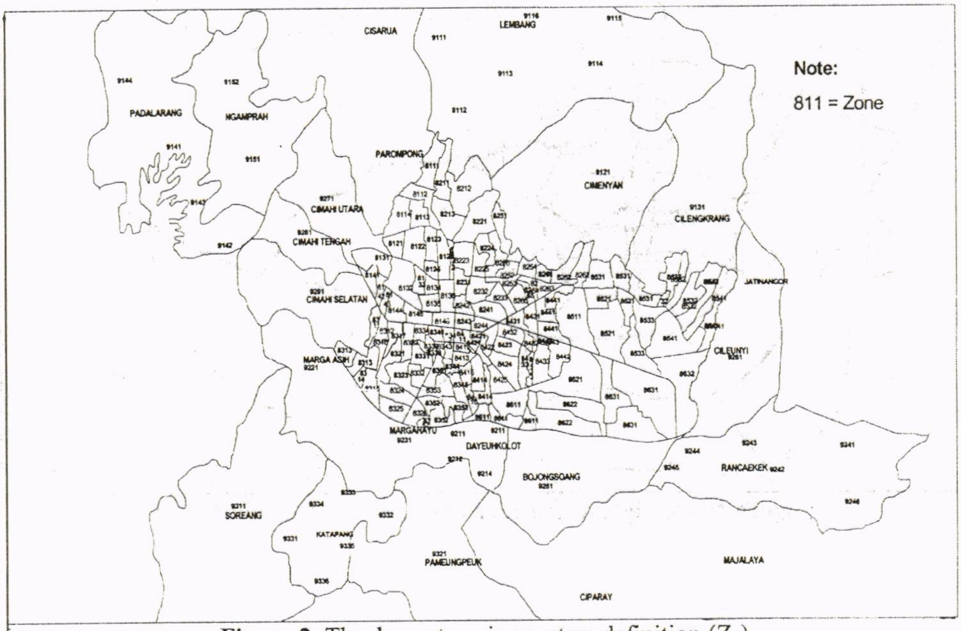


Figure 2: The densest zoning system definition (Z_4)

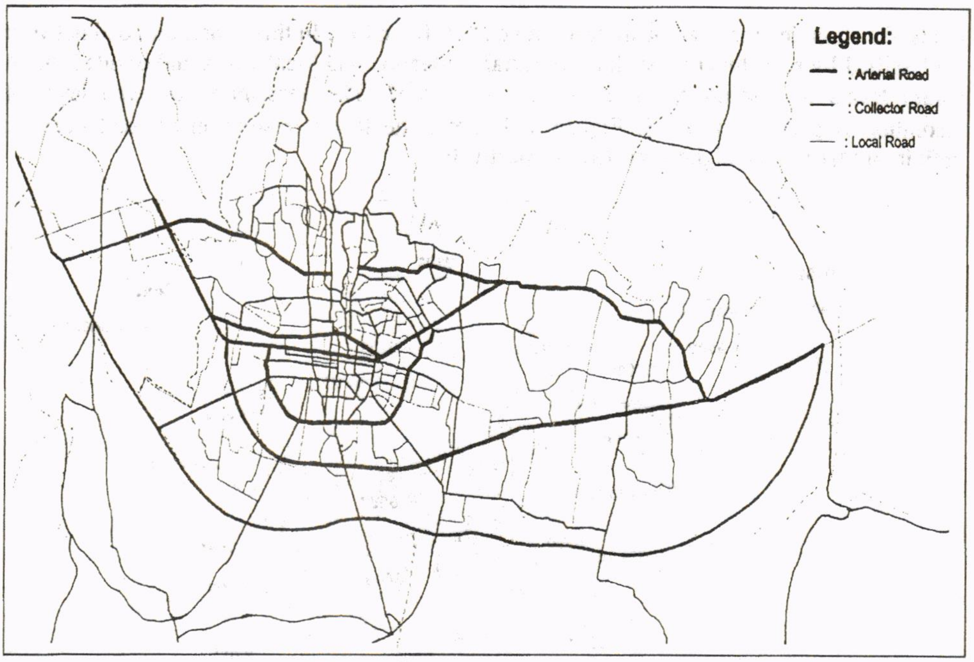


Figure 3: The lowest resolution of road network definition (J_1)

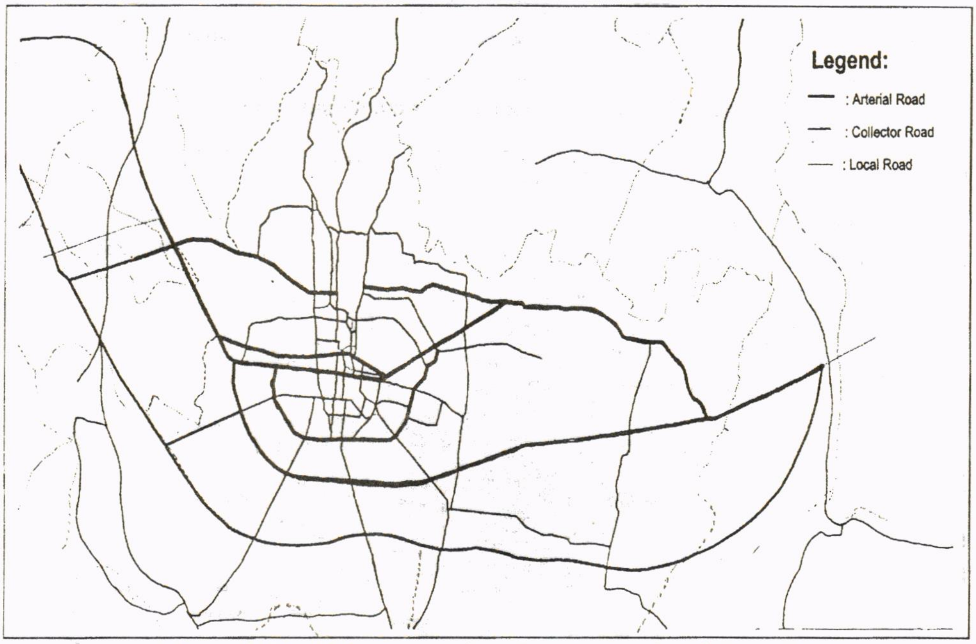


Figure 4: The highest resolution of road network definition (J_4)

Table 2: The description of each level of resolution of zoning and road network systems

No	Description	Notation	
1.	Kelurahans and Group of Kelurahans (145 zones)	Z_4	zone
2.	Group of Kelurahans + Kecamatans (95 zones)	Z_3	zone
3.	Kecamatans (49 zones)	Z_2	zone
4.	Sub-districts (Wilayahs) + Group of Kecamatans (18 zones)	Z_1	zone
5.	Arterial, Collector, and Local roads	J_4	network
6.	Arterial, Collector, and part of Local roads	J_3	Network
7.	Arterial and Collector roads	J_2	Network
8.	Arterial and part of Collector roads	J_1	Network

3.3 Reduction Method

The road network and zoning system were simplified using the reduction method. The real links of a network model were selected directly from actual road network. The selection was based on the functional class of the real links. The characteristics of the network links such as length and capacity were identical to those of the corresponding real links. The zoning system was based upon the selected networks: they were the **'holes'** delimited by the real links selected. Consequently, zone boundaries generally coincide with the real links selected. Each zone was represented by a centroid that was linked to the real links by a centroid connector. The OD matrix was then compressed by aggregating zones to create **4 (four)** different zoning systems as mentioned in **table 2**. The OD matrix was compressed from **145 zones** to **95 zones**; from **95 zones** to **49 zones**; from **49 zones** to **18 zones**.

4. IMPACT ANALYSIS

To analyse the impact of different levels of resolution of zoning and road network system, there are **3 (three)** defined scenarios to be tested. They are as follows:

- **Scenario I**: the resolution of zoning system was changed (**Z_4, Z_3, Z_2,** and **Z_1**), while the road network system remain the same as **J_4**.
- **Scenario II**: the resolution of road network system was changed (**J_4, J_3, J_2,** and **J_1**), while the zoning system remains the same as **Z_4**.
- **Scenario III**: the resolution of zoning and road network systems was both changed, hence, there are **10 (ten)** combinations of resolutions of zoning and road network system.

The performance of every level of detail was investigated by assigning the OD matrix by using the equilibrium assignment technique on several level detail of zoning and road network system as mentioned in scenario I, II, and III. The road links chosen in which its flows have to be compared were arterial and collector roads since these links were exist in every level of resolution mentioned in scenario I, II, and III. The average link flow was calculated using **equation (1).**

$$Q_{avg} = \frac{\sum_{1}^{N}(Q_i \times L_i)}{\sum_{1}^{N} L_i} \qquad (1)$$

where: Q_{avg} = average link flow
Q_i = flow in link **i**
L_i = length of link **i**

To know the optimum level of detail in each scenario, the average flow in each level of detail on each scenario was plotted on the graph against the quantitative measures of each scenario (see **tables 4, 6,** and **8**).

4.1 Scenario I

In **scenario I**, it is assumed that the level of detail of road network system was remain the same at the **densest level (J_4)**, while the level of detail of zoning system varies from Z_4 to Z_1 as shown in **table 3**. It can be seen that the fineness of the road network definition and the degree of zoning detail were varied in combination. **Table 4** shows the quantitative measures to specify the different level of detail of the zoning system.

Table 3: Different level of detail of zoning system definition for scenario I

Zoning system / Road network system	Z_4	Z_3	Z_2	Z_1
J_4	1	2	3	4
J_3				
J_2				
J_1				

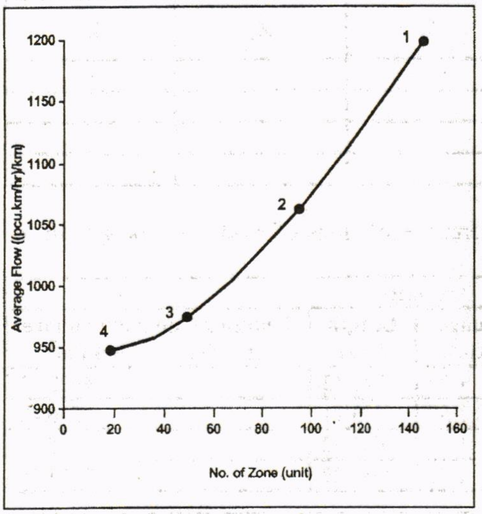
Table 4: Quantitative measures of several different resolutions of zoning system for scenario I

No	Nota-tion	Quantity			
		No. of zone (unit)	No. of centroid connector (unit)	No. of zone x centroid connector (unit)	Intrazonal trip (pcu/hr)
1	Z_4J_4	145	188	27,260	249
2	Z_3J_4	85	152	14,440	497
3	Z_2J_4	49	99	4,851	1,845
4	Z_1J_4	18	41	738	9,897

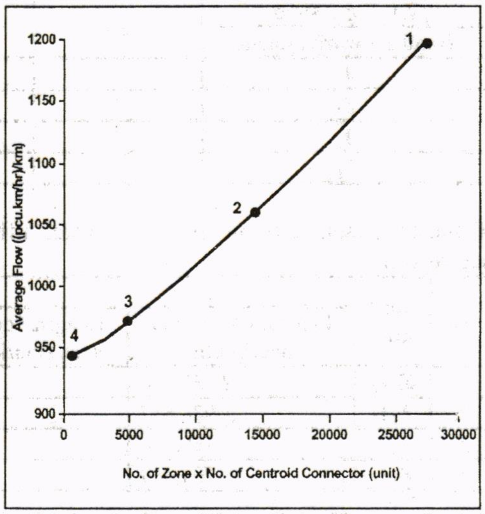
It can be seen from **figures 5abc** that all figures have similar pattern. It shows that the average flows increased with increasing number of zones, number of centroid connectors as well as increasing (no of zones x no of centroid connectors). It can also be seen that from the **level of detail 4 (Z_1J_4)** to **level 3 (Z_2J_4)** the average flows increased quite constantly but from **level 3 (Z_2J_4)** to **level 1 (Z_4J_4)** the average flows increased steeply. There was a significantly change occurred at **level 3**. Therefore, it can be preliminary concluded that the **optimum level of resolution** was found at **level 3 (Z_2J_4** comprises of **49 zones**).

It can be seen from **figure 5d** that the average flows decreased with increasing number of intrazonal trips. It means that the more intrazonal trips we have, the lower the average flows. It is quite logical since the intrazonal trip will never appear in assigned link flows. This is due to the intrazonal trip has its origin and destination at the same zone. Therefore, it can be said that the intrazonal trips were found significantly increased with decreasing number of zones. The larger the zone size, or in other words, the smaller number of zone in the study area will result in significantly increasing number of intrazonal trips.

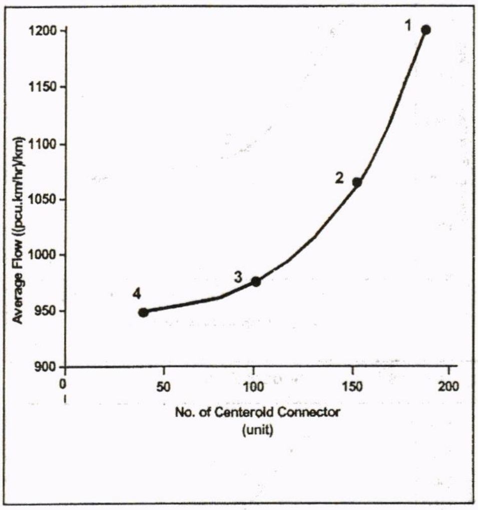
It can also be seen from **figure 5d** that from the **level of detail 4 (Z_1J_4)** to **level 3 (Z_2J_4)** the average flow increased quite constant but from **level 3 (Z_2J_4)** to **level 1 (Z_4J_4)** the average flow increased steeply. Again, there was a significantly change occurred at **level 3**. By analysing the pattern of **figure 5d**, it can be finally concluded that the **optimum level of resolution** was found at **level 3 (Z_2J_4** which comprises of **49 zones**).



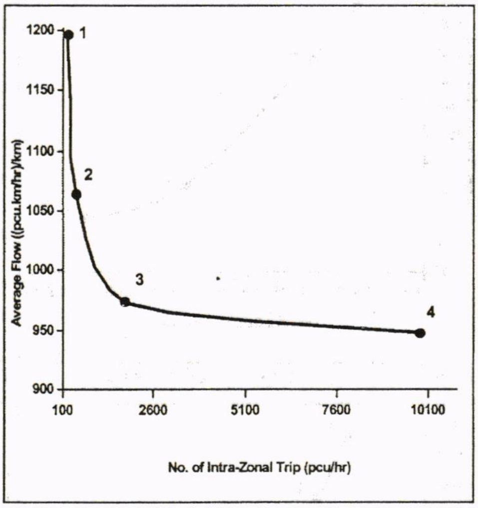
(a) Flow vs no.of zones



(c). Flow vs no. of zones x no. of centroid connectors



(b). Flow vs no. of centroid connector Relationship



(d). Flow vs no. of intrazonal trips Relationship

Figure 5: Average link flows vs quantitative measures of several different resolutions of zoning system for scenario I

4.2 Scenario II

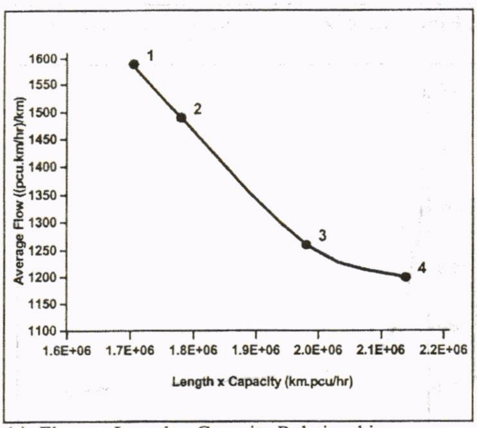
In scenario II, it is assumed that the level of detail of zoning system was remain the same at the most dense level (Z_4), while the level of detail of road network system varies from J_4 to J_1 as shown in **table 5**. It can be seen that the fineness of the zoning system and the degree of road network definition were varied in combination. **Table 6** shows the quantitative measures to specify the different level of detail of the road network system.

Table 5: Different level of detail of road network system definition for scenario II

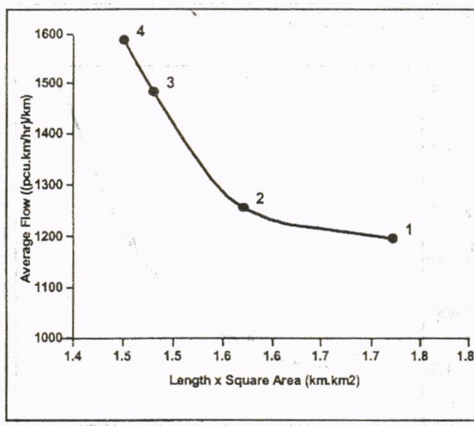
Zoning system / Road network system	Z_4	Z_3	Z_2	Z_1
J_4	1			
J_3	2			
J_2	3			
J_1	4			

Table 6: Quantitative measures of several different resolutions of road network system for scenario II

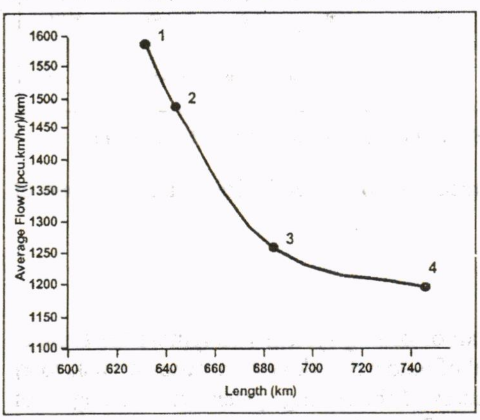
No	Nota -tion	Quantity			
		Length x Capacity (pcu.km/hr)	Length/Square area (km/km^2)	Length (km)	Length x Capacity/ Square area (pcu.km/hr)/km^2
1.	Z_4J_4	2,137,948	1.72	746.13	4922.73
2.	Z_4J_3	1,974,517	1.57	683.71	4546.42
3.	Z_4J_2	1,778,676	1.48	642.62	4095.49
4.	Z_4J_1	1,704,089	1.45	630.87	3923.75



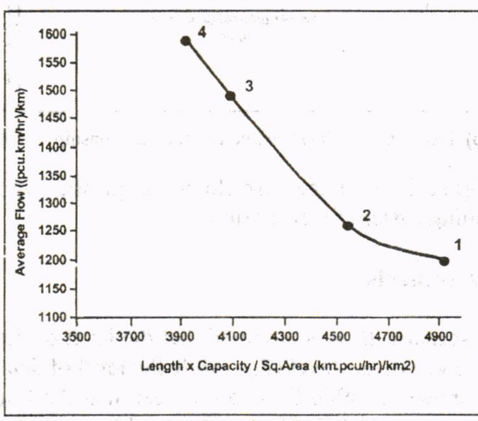
(a). Flow vs Length x Capacity Relationship



(c).Flow vs Length / Square Area



(b). Flow vs Length



(d). Flow vs Length x Capacity / Square Area

Figure 6: Average link flows vs quantitative measures of several different resolutions of road network system for scenario II

It can be seen from **figures 6abcd** that all figures have similar pattern. It shows that the average flows increased with decreasing length x capacity, decreasing length/square area, as well as decreasing length. It can be seen that from the **level of detail 1 (Z_4J_4)** to **level 2 (Z_4J_3)** the average flows increased quite constantly but from **level 2** (Z_4J_3) to **level 4** (Z_4J_1) the average flows increased steeply. There was a significantly change occurred at **level 2**. Therefore, by analysing again the pattern of **figures 6abcd**, it can be finally concluded that the **optimum level of resolution** was found at **level 2** (Z_4J_3).

4.3 Scenario III

In **scenario III**, it is assumed that the level of detail of zoning and road network system varied from Z_4 to Z_1 for zoning system and from J_4 to J_1 for road network system as shown in **table 7**. It can be seen that the degrees of the zoning system and road network definition were varied in combination. **Table 8** shows the quantitative measures to specify the different level of detail of the combined zoning and road network system.

Table 7: Different level of detail of zoning and road network system definition for scenario III

Zoning system / Road network system	Z_4	Z_3	Z_2	Z_1
J_4	1	2		
J_3	3	4	5	
J_2		6	7	8
J_1			9	10

Table 8: Quantitative measures of several different resolutions of combined zoning and road network system for scenario III

No	Nota-tion	No of zone	Length x Capacity (pcu.km/hr)	Quantity: Length x Capacity x No. of zone (pcu.km/hr.unit)	Quantity: (Length x Capacity)/(Square Area x No. of .zone) (pcu.km/hr x unit/km2)
1.	Z_4J_4	145	2,137,948	310,002,388	713,795
2.	Z_3J_4	95	2,137,948	203,105,013	467,659
3.	Z_4J_3	145	1,974,517	286,304,936	659,231
4.	Z_3J_3	95	1,974,517	187,579,096	431,910
5.	Z_2J_3	49	1,974,517	96,751,323	222,775
6.	Z_3J_2	95	1,778,676	168,974,201	389,071
7.	Z_2J_2	49	1,778,676	87,155,114	200,679
8.	Z_1J_2	18	1,778,676	32,016,164	73,719
9.	Z_2J_1	49	1,705,089	83,500,337	192,263
10.	Z_1J_1	18	1,705,089	30,673,593	70,627

It can be seen from **figure 7ab** that both figures have similar pattern. The average flows increased with decreasing either (**length x capacity x no of zones**) and ((**length x capacity)/(square are x no of zones)**) measures. It can be seen from each figure that from **level 1 (Z_4J_4)** to **level 5** (Z_2J_3) the average flows were quite constant (although there were also fluctuations due to different zoning system) but from **level 5 (Z_2J_3)** to **level 10 (Z_1J_1)** the average flows increased steeply. There was a significantly change occurred at **level 5**. By analysing the pattern of each figure, it can be finally concluded that the **optimum level of resolution** was found at **level 5 (Z_2J_3)**.

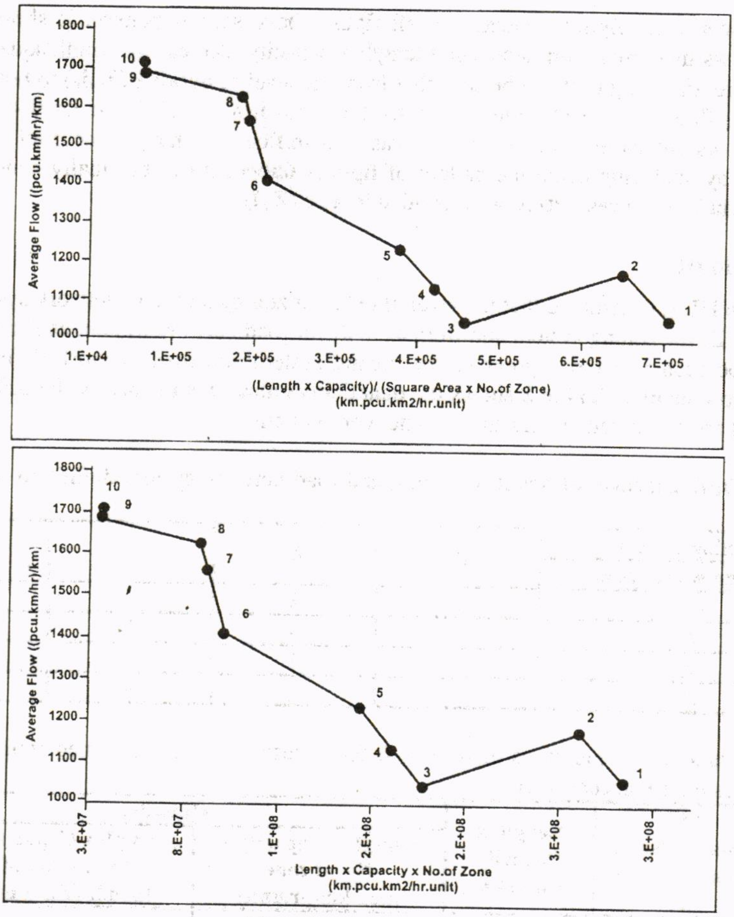


Figure 7: Average link flows vs quantitative measures of several different resolutions of combined zoning and road network system for scenario III

It can be seen that the average flows at **level 1** is somewhat equal with **level 3** but quite different with **level 2** (due to having different zoning system with **level 1**). It can be seen that by changing **level 1** to **level 2** (which have the same road network definition but different zoning system), the average flows changed significantly. Similar effects happened also with other level (see **level 3-4-5**, **level 6-7-8**, and **level 9-10**). Therefore, it can be concluded that the impact of aggregating zoning system has greater influence to the average flows rather than lowering the road network system definition.

4.4 Deviation Degree to Level 1 (Scenario III)

The deviation degree relative to level of detail can be defined as follows:

$$\Delta = \frac{|X_i - X_1|}{X_1} \cdot 100\% \qquad (2)$$

where: Δ = deviation degree (%)
X_i = flows on level i (pcu/hour)
X_1 = flows on level 1 (pcu/hour)

The average deviation degree for scenario III was represented in **figure 8**.

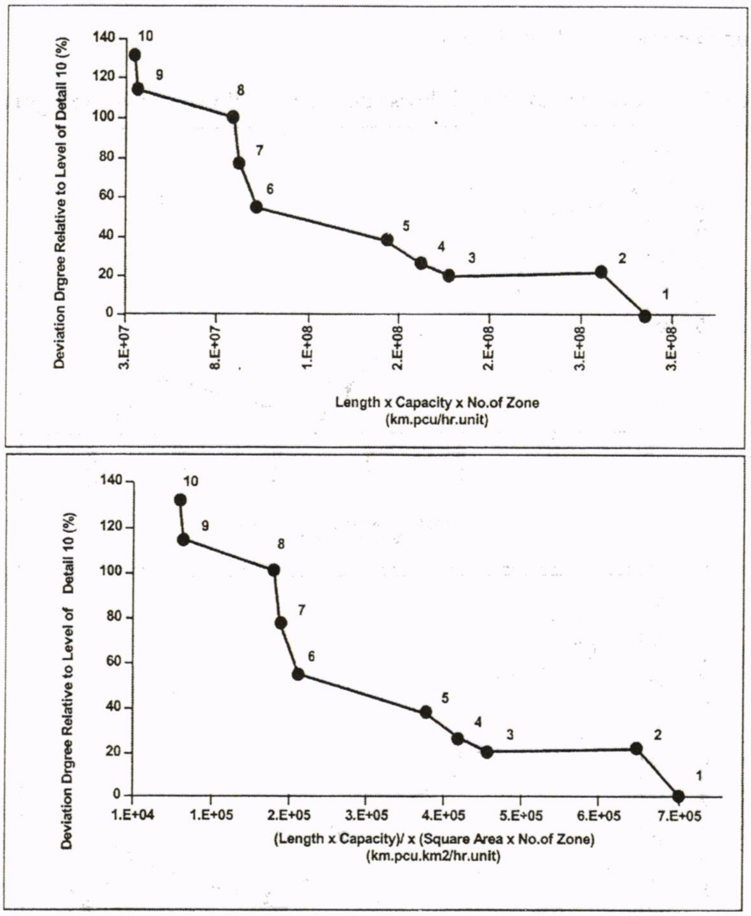


Figure 8: Flow deviation degree relative to level 10 and (length x capacity) / square area x no of zone) relationship

The assignment of every level of detail was compared to level 1 due to the estimated flows in level 1 was assumed to have the highest accuracy. Again, it can be seen from **figure 8ab** that both figures have similar pattern. The flow deviation degree increased with decreasing either **(length x capacity x no of zones)** and **((length x capacity)/(square are x no of zones))** measures. It can be seen from each figure that from the **level of detail 1** (**Z_4J_4**) to **level 5** (**Z_2J_3**) the deviation degrees did not increase significantly but from **level 5** (**Z_2J_3**) to **level 10** (**Z_1J_1**) the deviation degree increased steeply. There was a significantly change occurred at **level 5**. By analysing the pattern of each figure, it can be finally concluded that the **optimum level of resolution** was found at **level 5** (**Z_2J_3**).

It can be seen that the deviation degree at **level 1** is somewhat equal with **level 3** but quite different with **level 2** (due to having different zoning system with **level 1**). It can be seen that by changing **level 1** to **level 2** (which have the same road network definition but different zoning system), the deviation degree changed significantly. Similar effects happened also with other level (see **level 3-4-5**, **level 6-7-8**, and **level 9-10**). Therefore, it can be concluded that the impact of aggregating zoning system has greater influence to the average flows rather than lowering the road network system definition.

4.5 Deviation Degree to Observed Flow

The deviation degree between estimated flows and observed flows is given in **figure 9**.

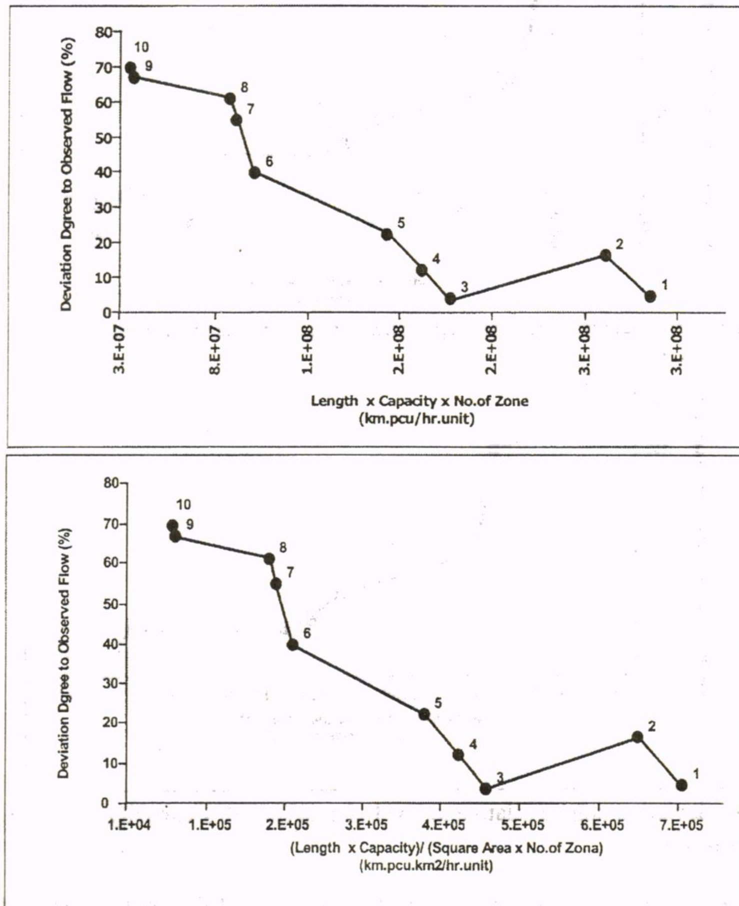


Figure 9: The deviation degree between estimated flow and observed flows vs (length x capacity) / square area x no of zone) relationship

The estimated flows of each level were compared to the observed flows. Again, it can be seen from **figure 9ab** that both figures have similar pattern. The deviation degree increased with decreasing either (**length x capacity x no of zones**) and (**(length x capacity)/(square are x no of zones)**) measures. It can be seen from each figure that from the **level of detail 1** (Z_4J_4) to **level 5** (Z_2J_3) the deviation degrees were quite constant (although there were also fluctuations due to different zoning system) but from **level 5** (Z_2J_3) to **level 10** (Z_1J_1) the deviation degree increased steeply. There was a significantly change occurred at **level 5**. By analysing the pattern of each figure, it can be finally concluded that the **optimum level of resolution** was found at **level 5** (Z_2J_3).

Again, it can be seen that the deviation degree at **level 1** is somewhat equal with **level 3** but quite different with **level 2** (due to having different zoning system with **level 1**). It can be seen that by changing **level 1** to **level 2** (which have the same road network definition but different zoning system), the deviation degree changed significantly. Similar effects happened also with other level (see **level 3-4-5, level 6-7-8**, and **level 9-10**). Therefore, it can be concluded that the impact of aggregating zoning system has greater influence to the average flows rather than lowering the road network system definition.

5. CONCLUSIONS

The paper explains the impact of resolution of zoning system and road network definition on route choice and road network performance. Some conclusions can be drawn from the results obtained:

a. The effect of aggregating the zoning and road network system has resulted in different assigned link flows on the road network. On the zone aggregation, the flow was found decreased on every links. The reason for this is due to the increasing amount of intrazonal trips. The amount of intrazonal trips was found increased by aggregating the zoning system. On the other hands, by simplifying the road network, the flows were found increased on every links. It is caused by the same amount of travel demand being assigned to the lower density of road network resolution.

b. It is concluded that the **impact of aggregating zoning system** has **greater influence on the average flows** rather than **lowering the road network system definition**. The main reason is due to the intrazonal trips since this type of trips is never assigned onto the network. The highest intrazonal trips were found in the coarsest zoning system definition (**Z_1**)

c. The pattern of effect of zone aggregation and road network simplification is similar for several quantity measures.

d. The simplification process of the zoning system and road network definition has resulted in the accuracy of assigned flows to decrease with decreased level of detail.

e. The **optimum level of zone aggregation** was on **Z_2** level (**the smallest area was Kecamatan**). The **optimum level of network aggregation** was on **J_3** level (**combination of arterial, collector, part of local roads**). The **optimum level of combined zone and road network aggregation** was on **Z_2J_3** level.

f. To reduce the network definition system or the zoning system, the simplest starting point was at the higher level of detail.

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